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Distribution of Flavonol Glycosides and Their Sugar-free Forms in Subfamily Cereoideae*

By

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岩科　司**・大谷俊二***：柱サボテン亜科におけるフラボノール色素の分布—配糖体およびその遊離型について

The ornamentally important Cereoideae, the biggest one of three subfamilies in Cactaceae, is systematically rather problematic, because it includes large number of "genera" and "species", which are likely to be regarded as subgenera and subspecies or even varieties in other plant families, have been created by many collectors and commercial growers, so that Cereoideae has consisted of about 200 genera with more than 1700 species (Backeberg 1966). As yet, the plants of this family have been studied mostly their alkaloids, phenethylamine and betalain pigments (Brown *et al.* 1968, Smith 1977, Piattelli and Imperato 1969). However, information on flavonoids in Cactaceae, especially Cereoideae, was quite scanty, except that isorhamnetin 3-*O*-galactoside and 3-*O*-rutinoside have been found in the flower of *Cereus grandiflorus* Mill. (Hörhammer *et al.* 1966) and quercetin 3, 7, 3′, 4′-tetramethyl ether (retusine) from the whole plant of *Ariocarpus retusus* Schw. (Dominguez *et al.* 1968).

Recently, we reported that common flavonol glycosides, namely quercetin 3-*O*-galactoside, 3-*O*-rhamnosylglucoside, kaempferol 3-*O*-rhamnosylgalactoside and isorhamnetin 3-*O*-rhamnosylgalactoside were present in the tepals of many Cereoideae species (Iwashina *et al.* 1982), and quercetin 7-*O*-galactoside, kaempferol 3-*O*-rhamnosylglucoside and 3, 7-*O*-diglycoside, isorhamnetin 3-*O*-rhamnosylglucoside, 5-hydroxy-3, 4′-oxygenated flavonol glycoside and free quercetin, kaempferol and isorhamnetin were also found in the tepals of several species (Iwashina *et al.* 1986). Moreover, rare flavonols, quercetin 3-methyl ether and its 7-*O*-glucoside and 4′-*O*-glucoside (neochilenin) were isolated from three *Neochilenia* and seven *Neoporteria* species, and *Parodia sanguiniflora* Fric. ex Backbg. (Iwashina *et al.* 1984).

Until now, much less work has been made on the systematic relationship between the genera in the subfamily Cereoideae. In the course of our chemotaxonomic studies of this subfamily, we have also examined on the distribution of the flavonols mentioned above. The present paper describes the flavonol characterization of cactus species, so

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as to clarify the chemotaxonomic position in cactus genera.

Materials and Methods

Plant materials (48 genera, 269 species, see Table 2) have been cultivated in Itô Branch Station of the Research Institute of Evolutionary Biology for a long time.

Isolation of flavonoids: An appropriate amount of fresh tepals of each cactaceous species was extracted with MeOH overnight, filtered and evaporated *in vacuo* to an aqueous concentrate, which was applied to two-dimensional paper chromatography on Tôyô No. 50 filter paper using two kinds of solvent systems, BAW (n-BuOH/AcOH/H_2O =4 : 1 : 5, upper phase) on the one direction and 15% AcOH (AcOH/H_2O=15 : 85) on the other. The individual crops separated were subjected to mass-paper chromatography using the same solvents or to polyamide column chromatography (4×30 cm) according to

Table 1. Chromatographic data for flavonoids found in the subfamily Cereoideae

Flavonoids	Colors		Rf-values			
	UV	UV/NH_3	BAW	BEW	Forestal	15% AcOH
quercetin	yellow	bright yellow	0.74	0.75	0.42	0.06
quercetin 3-*O*-galactoside	dark purple	dark yellow	0.65	0.61	0.79	0.44
quercetin 3-*O*-rhamnosylglucoside	dark purple	dark yellow	0.59	0.53	0.82	0.64
quercetin 7-*O*-galactoside	yellow	bright yellow	0.35	0.28	0.58	0.05
kaempferol	yellow	yellow	0.89	0.89	0.54	0.03
kaempferol 3-*O*-rhamnosylgalactoside	dark purple	dark yellow	0.67	—	—	0.59
kaempferol 3-*O*-rhamnosylglucoside	dark purple	dark yellow	0.66	0.68	0.86	0.73
kaempferol 3, 7-*O*-diglycoside	dark purple	yellow	0.46	0.47	0.85	0.69
isorhamnetin	yellow	bright yellow	0.78	0.81	0.53	0.01
isorhamnetin 3-*O*-rhamnosylgalactoside	dark purple	yellow	0.58	0.60	0.85	0.68
isorhamnetin 3-*O*-rhamnosylglucoside	dark purple	yellow	0.41	0.47	—	0.57
quercetin 3-methyl ether	dark purple	dark yellow	0.92	0.94	0.73	0.13
quercetin 3-methyl ether 7-*O*-glucoside	dark purple	bright yellow	0.67	—	0.81	0.28
quercetin 3-methyl ether 4′-*O*-glucoside	dark purple	dark purple	0.75	0.78	—	0.29
5-hydroxy-3, 4′-oxygenated flavonol glycoside	dark purple	dark purple	0.38	—	—	0.50

BAW=n-BuOH/AcOH/H_2O (4 : 1 : 5, upper phase), BEW=n-BuOH/EtOH/H_2O (4 : 1 : 2.2), Forestal=AcOH/conc. HCl/H_2O (30 : 3 : 10), 15% AcOH=AcOH/H_2O (15 : 85).

the procedure of Iwashina *et al.* (1984), and were thoroughly purified in solution or obtained as crystals.

Identification of flavonoids: This was made by the standard methods (Mabry *et al.* 1970, Markham 1982, Iwashina *et al.* 1984) such as acid hydrolysis, and direct comparisons with authentic specimens in the UV spectral and chromatographic properties, as usual.

Results

The results of flavonoid survey on the methanol extracts of fresh tepals of 269 species from 48 genera in the subfamily Cereoideae are shown in Tables 2 and 3. The 15 kinds of flavonoids found in this experiment were mostly flavonols, i. e. kaempferol, quercetin, isorhamnetin, quercetin 3-methyl ether and their glycosides (see Table 1 and Fig. 1). However, the flavones, *C*-glycosylflavones, and dihydroflavonols which were present in *Echinocereus triglochidiatus* var. *gurneyi* (Miller and Bohm 1982) seemed to be absent.

In stead, some of the other sorts of flavonols appeared to be distinguished in Cereoideae.

Quercetin and its glycosides: Quercetin glycosides such as 3-*O*-galactoside, 3-*O*-glucoside, 3-*O*-rhamnosylglucoside, 7-*O*-galactoside and 7-*O*-glucoside have already been reported in the tepals of Cereoideae species (Iwashina *et al.* 1982, 1986, Miller and Bohm 1982). In our survey, quercetin glycosides, 3-*O*-galactoside (hyperin) and 3-*O*-rhamnosylglucoside (rutin) were found in many species (182 and 222 spp., respectively, Table 2 and 3). Quercetin 7-*O*-galactoside (coptiside II) appeared in 50 spp. mostly centring in *Echinocereus, Notocactus* and *Parodia* species.

Quercetin in sugar-free state abundantly occurred in four *Astrophytum* species, namely, *A. asterias* (Zucc.) Lem., *A. capricorne* (Dietr.) Br. & R., *A. myriostigma* Lem. and *A. ornatum* (DC.) Web. together with a trace of free kaempferol and isorhamnetin. In *A. ornatum*, for example, about 1 g of crude crystals was obtained from ca. 200 g of fresh tepals (Iwashina *et al.* 1986).

As a rule, quercetin and its glycosides

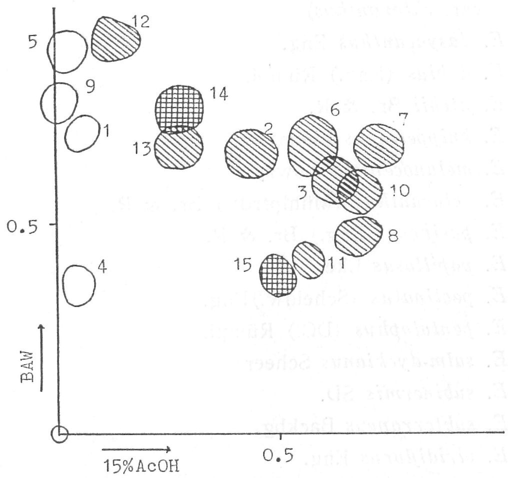


Fig. 1. Two-dimensional chromatogram of tepal extract of Cereoideae showing the flavonoid constituents.
1. quercetin, 2. quercetin 3-*O*-galactoside, 3. quercetin 3-*O*-rhamnosylglucoside, 4. quercetin 7-*O*-galactoside, 5. kaempferol, 6. kaempferol 3-*O*-rhamnosylgalactoside, 7. kaempferol 3-*O*-rhamnosylglucoside, 8. kaempferol 3,7-*O*-diglycoside, 9. isorhamnetin, 10. isorhamnetin 3-*O*-rhamnosylgalactoside, 11. isorhamnetin 3-*O*-rhamnosylglucoside, 12. quercetin 3-methyl ether, 13. quercetin 3-methyl ether 7-*O*-glucoside, 14. quercetin 3-methyl ether 4′-*O*-glucoside, 15. 5-hydroxy-3,4′-oxygenated flavonol glycoside. Colors under UV light: □=yellow, ▨=dark purple, changing to dark yellow—bright yellow with ammonia, ▦=dark purple with and without ammonia.

Table 2. Characterization of flavonols in the 269 species of Cereoideae

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4′gl.	5h34′ox-flgly.
Epiphyllopsis gaertneri (Reg.) Berg.															
Epiphyllum oxypetalum (DC.) Haw.										+					
Chiapasia nelsonii (Br. & R.) Br. & R.						+									
Monvillea phatnosperma (K. Sch.) Br. & R.		+	+			+		+		+					
Thrixanthocereus senilis Ritt.			+			+				+					
Echinocereus baileyi Rose		+	+	+		+									
E. chloranthus (Eng.) Rümpl. (=*E. viridiflorus* var. *chloranthus*)		t	t	+		+									
E. dasyacanthus Eng.		+	+	+											
E. dubius (Eng.) Rümpl.		+	t												
E. fitchii Br. & R.		+	+	+		+									
E. knippelianus Liebn.			+	+											
E. melanocentrus Lowry				t		+									
E. octacanthus (Mühlpfrdt.) Br. & R.		+	+	+											
E. pacificus (Eng.) Br. & R.		+	+	+											
E. papillosus Lke.			+	+											
E. pectinatus (Scheidw.) Eng.		+	+												
E. pentalophus (DC.) Rümpl.		t	+	+											
E. salm-dyckianus Scheer				+											
E. subinermis SD.		+	+												
E. subterraneus Backbg.		+	+	+											
E. viridiflorus Eng.		+	+	+											
Rebutia calliantha Berg.		+	+			+									
R. chrysacantha Backbg. var. *elegans* (Backbg.) Backbg.		+	+			+									
R. fiebrigiana W. Heinr.		+	+			+									
R. grandiflora Backbg.		t	+			+									
R. hyalacantha (Backbg.) Backbg.		t	+			+									
R. krainziana Kesselr.		+	+			+									
R. minuscula K. Sch.		+	+			+									
R. senilis Backbg.		+	+			+									
R. violaciflora Backbg.		+	+			+									
R. wessneriana Berg.		+	+	+		+									

quer.=quercetin (free), qu3ga.=quercetin 3-*O*-galactoside, qu3rgl.=quercetin 3-*O*-rhamnosylglucoside, qu7ga.=quercetin 7-*O*-galactoside, kaem.=kaempferol (free), km3rga.=kaempferol 3-*O*-rhamnosylgalactoside, km3rgl.=kaempferol 3-*O*-rhamnosylglucoside, km37gy=kaempferol 3, 7-*O*-diglycoside, isor.=isorhamnetin (free), is3rga.=isorhamnetin 3-*O*-rhamnosylgalactoside, is3rgl.=isorhamnetin 3-*O*-rhamnosylglucoside, qu3met.=quercetin 3-methyl ether, qm7gl.=quercetin 3-methyl ether 7-*O*-glucoside, qm4′gl.=quercetin 3-methyl ether 4′-*O*-glucoside, 5h34′ox-flgly.=5-hydroxy-3, 4′-oxygenated flavonol glycoside. +=presence, t=trace.

Table 2. —(continued)—

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4′gl.	5h34′ox-flgly.
Rebutia xanthocarpa Backbg. var. *coerulescens* Backbg.		+	+			+									
Sulcorebutia canigueralii (Card.) Backbg.		+	+												
S. kruegeri (Card.) Ritt.		+	+			t									
S. tiraquensis (Card.) Backbg.		+	+			+									
S. tunariensis (Card.) Backbg.		+	+												
Aylostera deminuta (Web.) Backbg.		+	+												
A. fiebrigii (Gürke) Backbg.		+	+			t					+				
A. kupperiana (Böd.) Backbg.		+	+			+					+				
A. pseudodeminuta (Backbg.) Backbg.		+	+								+				
A. pseudominuscula (Speg.) Speg.		+	+							+	+				
A. spegazziniana (Backbg.) Backbg.		+	+							+	+				
A. spinosissima (Backbg.) Backbg.		+	+							+	+				
Mediolobivia aureiflora (Backbg.) Backbg. var. *duursmaiana* (Backbg.) Backbg.		+	+	+				+			+				
M. orurensis (Backbg.) Backbg. (=*M. pectinata* var. *orurensis*)		+	+					t			+				
M. pygmaea (R. E. Freies) Backbg.		+	t												
M. steinmanii Hort. (=*M. pectinata* var. *neosteinmanii*)		+	+					+			+				
Acantholobivia tegeleriana (Backbg.) Backbg.			+					+		+					
Acanthocalycium violaceum (Werd.) Backbg.		t	t	t				+		+					
A. spinoflorum (K. Sch.) Backbg.		t	+	t		t		+							
Pseudolobivia aurea (Br. & R.) Backbg.		+	+					+		+					
P. fiebrigii (Gurke) Backbg. (=*P. obrepanda* var. *fiebrigii*)			+			+		+							
P. kermesina Krainz			+			+									
P. kratochviliana (Backbg.) Backbg.		+	+					+							
P. longispina (Br. & R.) Backbg.		+	+					+		+					
Echinopsis bridgesii SD.		+	+			+		+		+					
E. calochlora K. Sch.						+		t		+					
E. eyriesii (Turp.) Zucc.		t				+		+		+					
E. hamatacantha Backbg. (=*Pseudolobivia hamatacantha*)		+	+					+		+					
E. huotii (Cels) Lab.						+	+	+							
E. mamillosa Gürke						+									
E. oxygona (Lk.) Zucc.		t	+			+		t		+					
E. polyancistra Backbg. (=*Pseudolobivia polyancistra*)		t				+		+		+					
E. zuccariniana Pfeiff. (=*E. tubiflora*)		+	+					+							

Table 2. —(continued)—

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4'gl.	5h34'ox-flgly.
Lobivia allegraiana Backbg.								+		+					
L. arachnacantha Buin. & Ritt.		+	+					+		+					
L. argentea Backbg.		+	+					+		+					
L. backebergii (Werd.) Backbg.		+	+					+		+					
L. binghamiana Backbg.		t	+			t		+		+					
L. boliviensis Br. & R.						+		+		+					
L. breviflora Backbg.		+	+			+				+					
L. caespitosa (J. A. Purp.) Br. & R.		+	+	+				+		+	+				
L. carminantha Backbg.		t	+			+		+		+					
L. chrysantha (Werd.) Backbg. var. *hossei* (Werd.) Backbg.		+	+			t		+		+					
L. chrysochete Werd.		+	+			+		t		+					
L. cinnabarina (Hook.) Br. & R.		t	+					t		+					
L. cylindrica Backbg.		+	+			+		+		+					
L. drijveriana Backbg.		+	+	t		+		+		+	t				
L. emmae Backbg.		+	+			t		+		+					
L. famatimensis (Speg.) Br. & R.		+	+			+				+					
L. ferox Br. & R. (=*Pseudolobivia ferox*)		+	+			t		+		+					
L. grandiflora Br. & R. (=*Helianthocereus grandiflorus*)		+	+					+		+					
L. hastifera Werd.			+					+		+					
L. higginsiana Backbg.			+												
L. huilcanota Rauh & Backbg.			+					t							
L. incaica Backbg.		+	+					+		+					
L. leucomalla Wessn. (=*L. famatimensis* var. *leucomalla*)		+	+	t				+		+					
L. leucorhodon Backbg.		t	+					+		+					
L. leucoviolacea Backbg.		+	+			+		+		t					
L. nealeana Backbg.		+	+			+		t		+					
L. pentlandii (Hook.) Br. & R.		+	+			t		+		+	t				
L. planiceps Backbg.		+	+					+		+					
L. pseudocachensis Backbg.		+	+			+				t					
L. rebutioides Backbg.		+	+			t									
L. sanguiniflora Backbg.			+												
L. scoparia Werd.		+	+			+		t		+					
L. vatteri Krainz			+												
L. wegheiana Backbg.			+					+		+					
L. wrightiana Backbg.		+	+					+		+					
Chamaecereus silvestrii (Speg.) Br. & R.		+	+					+							
Soehrensia bruchii (Br. & R.) Backbg.		t	+			+									
Matucana blancii Backbg.		+	+	+											

Table 2. —(continued)—

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4'gl.	5h34'ox-flgly.
Matucana ritteri Buin. (=*Submatucana ritteri*)			+												
Denmoza erythrocephala (K. Sch.) Berg.				+											
Arequipa leucotricha (Phil.) Br. & R.		+	+			t		+							
A. weingartiana Backbg.		+	+			+		+							
Weingartia lanata Ritt.		+	+								+				
W. pulquinensis Card. (=*W. neocumingii*)		+	t								t				
W. riograndensis Ritt.		+	+								+				
Islaya bicolor Akens & Buin.		+	+	+		+									
I. minor Backbg.		+	+			t									
I. mollendensis (Vpl.) Backbg.		+	+	+											
I. paucispina Rauh & Backbg.		+	+	+											
Malacocarpus arechavaletai (K. Sch. ex Speg.) Berg. (=*Wigginsia arechavaletai*)		+	+							+					
M. erinaceus (Haw.) Lem. ex Forst. (=*Wigginsia erinacea*)		+	+												
Gymnocalycium andreae (Böd.) Backbg.			+			+									
G. asterium Y. Ito var. *minimum* (Paz.) Paz.															
G. baldianum (Speg.) Speg.			+												
G. bicolor Schütz			t												
G. bruchii (Speg.) Hoss.		t	+			+									
G. calochlorum (Böd.) Y. Ito		+	+			+									
G. cardenasianum Ritt.			t												
G. castellanosii Backbg.		+	+												
G. chubutense (Speg.) Speg.			+			+									
G. damsii (K. Sch.) Br. & R. var. *centrispinum* Backbg.															
G. deeszianum Dölz			+												
G. denudatum (Lk. & O.) Pfeiff.			+							+					
G. fleischerianum Backbg.		+	+												
G. fricianum Plesnik		t													
G. gibbosum (Haw.) Pfeiff.		t	+												
G. guanchinense Schütz var. *robustius* Ritt.		+	t												
G. hamatum Ritt.		t													
G. hammerschmidii Backbg.															
G. horridispinum Frank		+	+												
G. hybopleurum (K. Sch.) Backbg.															
G. joossensianum (Böd.) Br. & R.			+												
G. kurtzianum (Gürke) Br. & R. (=*G. mostii* var. *kurzianum*)															

Table 2. —(continued)—

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4'gl.	5h34'ox-flgly.
Gymnocalycium leeanum (Hook.) Br. & R. var. *netrelianum* (Monv.) Backbg.		+	+										t		+
G. lagunillasense Card.															
G. leptanthum (Speg.) Speg.			t												
G. mazanense Backbg.		t	+												
G. megatae Y. Ito		t													
G. mihanovichii (Fric. & Gürke) Br. & R. var. *stenogonum* Paz.			+												
G. mostii (Gürke) Br. & R.			t			t									
G. multiflorum (Hook.) Br. & R.		+	+												
G. occultum Fric. & Schütz															
G. ochoterenai Backbg. var. *tenuispinum* Backbg.															
G. oenanthemum Backbg.		t	t												
G. parvulum (Speg.) Speg.															
G. pflanzii (Vpl.) Werd.		+													
G. platense (Speg.) Br. & R.		t	+												
G. pungens Fleischer															
G. quehlianum (Hge. jr.) Berg.															
G. ragonesii Cast.															
G. sagrione (Cels) Br. & R.		+													
G. schickendantzii (Web.) Br. & R.			t												
G. sigelianum (Schick) Berg.		t	+												
G. stuckertii (Speg.) Br. & R.		t	+												
G. sutterianum (Schick) Berg.															
G. uruguayense (Ar.) Br. & R.		+	+												
G. valnicekianum Jajo		t	t												
G. vatteri Buin.			+												
G. weissianum Backbg.															
Copiapoa chanaralensis Ritt.			+									+			
C. echinoides (Lem.) Br. & R.		+	+												
C. fiedleriana (K. Sch.) Backbg. (=*C. pepiniana* var. *fiedleriana*)		+	+												
C. grandiflora Ritt.		+	+												
C. malletiana (Lem.) Backbg.		+	+												
C. marginata (SD.) Br. & R. (=*C. lembckei*)			+									+		+	
C. montana Ritt.		+	+												
C. rupestris Ritt.		+	+												
C. taltalensis (Werd.) Loos.		+	+					t							
C. wagenknechtii Ritt. (=*C. coquimbana* var. *wagenknechtii*)		+	+												
Horridocactus copiapensis Ritt. (=*Neochilenia kunzei*)		+	+			+				+					

Table 2. —(continued)—

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4'gl.	5h34'ox-flgly.
Horridocactus curvispinus (Bert.) Backbg.		t	+			t				+					
H. engleri Ritt.		+	+			+				+					
H. kesselringianus Dölz		+								+		+			
H. marksianus (Ritt.) Backbg.		+	+			t									t
H. nigricans (Dietr.) Backbg. & Dölz		+	+	t		+									
H. paucicostatus Ritt. (=*Neochilenia paucicostata*)		+	+			t							+	+	t
H. rupicolus Ritt. (=*Neochilenia rupicola*)			+									+		+	
H. simulans Ritt. (=*Neochilenia setosiflora*)			+									+			
H. trapichensis Ritt.		+	+			t							+	+	+
H. tuberisulcatus (Jac.) Y. Ito		+	+			+									
Neoporteria castanea Ritt.		+	+			+							+	+	t
N. castaneoides (Cels) Werd.		+	+			+							+	+	+
N. chilensis (Hildm.) Br. & R. (=*Neochilenia chilensis*)		+	+	t		+						t	+	+	+
N. clavata (Söhr.) Werd.		+	+	t									+	+	+
N. fusca (Mühlpf.) Br. & R. (=*Neochilenia fusca*)		t	+							+		+			
N. heteracantha (Backbg.) Backbg.		t	+										+	+	
N. litoralis Ritt.			+			t						+	t	+	t
N. mamillarioides (Hook.) Backbg.		+	+	t		+							+	+	+
N. microsperma Ritt.			+			t						+	t	+	+
N. multicolor Ritt.		+	+			t							+	+	+
N. nigrihorrida (Backbg.) Backbg.			+			t							+	+	+
N. polyrhaphis (Pfeiff.) Backbg.			+									+	t	+	t
N. procera Ritt. (=*N. clavata* var. *procera*)			+			t						+		+	
N. rapifera Ritt.			+			t						+	t	+	t
N. senilis (Phil.) Backbg. (=*N. gerocephala*)			+										+	+	
N. serenana Ritt. (=*N. microsperma* var. *serenana*)		t	+			+						+		+	t
N. subgibbosa (Haw.) Br. & R.		+	+			+							+	+	t
N. taltalensis Hutch. (=*Neochilenia taltalensis*)		+	+	t								+		+	+
N. wagenknechtii Ritt.			+			t						+			
Neochilenia aerocarpa (Ritt.) Backbg.		+	+			t							+	+	
N. glabrescens Ritt. (=*N. mitis*)		+	+									t	+	+	t
N. napina (Phil.) Backbg.		+	+			t							+	+	+
Brasilicactus graessneri (K. Sch.) Backbg.		+	+			+									
B. haselbergii (Hge.) Backbg.		+	+	t									+		
Notocactus apricus (Ar.) Berg.		+	+	+		+							+	+	+
N. herteri Werd.		+	+	t											

Table 2. —(continued)—

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4'gl.	5h34'ox-flgly.
Notocactus mammulosus (Lem.) Berg.		+	+	+								+	+	+	+
N. ottonis (Lem.) Berg.		+	+	+											
N. pampeanus (Speg.) Backbg. (=*N. submammulosus* var. *pampeanus*)		+	+	+								+	+	+	t
N. rutilans Dän. & Krainz		+	+	+									+		t
N. scopa (Spreng.) Berg.		+	+	+		+							+	+	+
Eriocactus leninghausii (Hge. jr.) Backbg.		+	+	+									+		t
E. schmannianus (Nic.) Backbg.			+	+									+		t
Parodia aureispina Backbg.		+	+	+									+	t	+
P. ayopayana Card.		+	+	+		t							+	+	t
P. bueneckeri Buin.		+	+	+		+							+	+	t
P. cardenasii Ritt.		+	+	+								+	+	t	t
P. chrysacanthion (K. Sch.) Backbg.		+	+	+		+							+		+
P. comarapana Card.		+	+							+		+	+	+	
P. gracilis Ritt.		+	+										+	+	
P. maassii (Heese) Berg.		+								+		+			
P. microsperma (Web.) Speg.		+	+	+									+	t	t
P. multicostata Ritt.		+								+			t	+	
P. nivosa Fric. ex Backbg.		+	+	+									+		
P. rigidispina Krainz		+	+	+		t							+		+
P. sanguiniflora Fric. ex Backbg.		+	+	+		t						t	+	t	+
Lophophora lewinii (Henn.) Rusby (=*Epithelantha micromeris* var. *greggii*)			t			+									
L. williamsii (Lem. ex SD.) Coult.			t			+									
Strombocactus disciformis (DC.) Br. & R.		t	+			t				+					
Turbinicarpus pseudomacrochele (Backbg.) F. Buxb. & Backbg.			+			+									
Gymnocactus conothelos (Reg. & Klein) Backbg. (=*Thelocactus conothelos*)						+									
Echinomastus macdowellii (Reb.) Br. & R.			t			+									
Echinofossulocactus coptonogonus (Lem.) Lawr.						+									
E. hastatus (Hopff.) Br. & R.						+									
Hamatocactus hamatacantha (Muhlpfrdt.) Knuth.			+												
Ferocactus acanthodes (Lem.) Br. & R.		+	+			+				t					
F. glaucescens (DC.) Br. & R.		+	+			t									
F. histrix (DC.) Linds.		+	+												
F. peninsulae (Web.) Br. & R.		+	+			+									
F. stainesii (Hook.) Br. & R.			+							+					

Table 2. —(continued)—

Species	quer.	qu3ga.	qu3rgl.	qu7ga.	kaem.	km3rga.	km3rgl.	km37gy.	isor.	is3rga.	is3rgl.	qu3met.	qm7gl.	qm4'gl.	5h34'ox-flgly.
Homalocephala texensis (Hopff.) Br. & R.			+												
Glandulicactus uncinatus (Gal.) Backbg.		t	+												
Thelocactus bicolor (Gal.) Br. & R.		t	+			+									
T. fossulatus (Scheidw.) Br. & R. (=*T. hexaedrophorus* var. *fossulatus*)						+									
T. goldii H. Bravo (=*Gymnocactus horripilus*)			t			+									
T. hexaedrophorus (Lem.) Br. & R.			+			+									
T. nidulans (Quehl) Br. & R.			+			+									
Astrophytum asterias (Zucc.) Lem.	+	+	t		t				t						
A. capricorne (Dietr.) Br. & R.	+	t	+		t				t						
A. myriostigma Lem.	+	+	+		t				t						
A. ornatum (DC.) Web.	+	+	+		t				t						
Coryphantha bumamma (Ehrenbg.) Br. & R.		+	+												
Mamillopsis senilis Web.		+	+												
Mammillaria caupt-medusae O. (=*M. sempervivi* var. *caupt-medusae*)															
M. candida Scheidw. var. *rosea* (SD.) K. Sch.															
M. elongata DC.						+				t					
M. marksiana Krainz		+	+			+									
M. pacifica (Gat.) Böd.															
M. prolifera (Mill.) Haw.										+					
M. sphacelata Mart.															
M. spinosissima Lem.						+									
M. winteriae Böd.															
M. zeilmanniana Böd.			+			+									
Dolichothele longimamma (DC.) Br. & R.		+	+	t											
D. sphaerica (Dietr.) Br. & R.		+	+												

were distributed widely in most genera of Cereoideae (235 spp.), with the exception of *Epiphyllopsis*, *Epiphyllum* and *Chiapasia* (belonging to tribe Pseudohyllocereae), *Echinofossulocactus* and *Gymnocactus* (Table 4).

Kaempferol and its glycosides: Kaempferol glycosides have also been found in some Cereoideae species (Iwashina *et al.* 1982, 1986, Miller and Bohm 1982). In this experiment, three kinds of glycosides, 3-*O*-rhamnosylglucoside (nicotiflorin), 3-*O*-rhamnosylgalactoside and 3,7-*O*-diglycoside were found. Among them, 3-*O*-rhamnosylgalactoside was detected in 110 species and occurred commonly in *Rebutia, Echinopsis, Lobivia* etc. 3,7-*O*-Diglycoside was found in 51 species and centered in *Lobivia, Echinopsis* and *Pseudolobivia* which are native to South America. In contrast, 3-*O*-rhamnosylglucoside was detected

Table 3. Distribution of flavonols in tribes of Cereoideae

Tribes	No.*	quercetin (free)	qu. 3-galactoside	qu. 3-rhamnoglucoside	qu. 7-galactoside	kaempferol (free)	km. 3-rhamnogalactoside	km. 3-rhamnoglucoside	km. 3,7-diglycoside	isorhamnetin (free)	is. 3-rhamnogalactoside	is. 3-rhamnoglucoside	quercetin 3-methyl ether (free)	qm. 7-glucoside	qm. 4′-glucoside	5-hydroxy-3,4′-oxygenated flavonol glycoside
Pseudohyllocereeae	3 (3)	0	0	0	0	0	1 (1)	0	0	0	2 (2)	0	0	0	0	0
Cereeae	18 (3)	0	13 (2)	16 (3)	13 (1)	0	6 (3)	0	1 (1)	0	0	0	0	0	0	0
Echinocacteae	234 (38)	4 (1)	164 (29)	200 (35)	36 (13)	4 (1)	99 (25)	1 (1)	50 (9)	4 (1)	57 (13)	15 (4)	22 (6)	40 (8)	37 (6)	35 (7)
Mamillarieae	14 (4)	0	5 (4)	6 (4)	1 (1)	0	4 (1)	0	0	0	2 (1)	0	0	0	0	0
total	269 (48)	4 (1)	182 (35)	222 (42)	50 (15)	4 (1)	110 (30)	1 (1)	51 (10)	4 (1)	61 (16)	15 (4)	22 (6)	40 (8)	37 (6)	35 (7)

* No. of species examined, ( ) = No. of genera surveyed and distributed.

only in *Echinopsis huotii* (Cels) Lab. (and also Iwashina *et al.* 1986), although this component has been also reported in *Echinocereus triglochidiatus* var. *gurneyi* (Miller and Bohm 1982).

Isorhamnetin, quercetin 3-methyl ether and their glycosides: Two kinds of quercetin derivatives with a methoxyl group, isorhamnetin (quercetin 3′-methyl ether) and quercetin 3-methyl ether, and their glycosides were detected in a smaller number of Cereoideae species (75 and 51 spp., respectively). However, isorhamnetin glycosides, especially 3-*O*-rhamnosylgalactoside, were rather common to many genera (distribution of 3-*O*-rhamnosylglucoside converged in *Aylostera, Mediolobivia* and *Weingartia*), while quercetin 3-methyl ether and its glycosides, 4′-*O*-glucoside and 7-*O*-glucoside, were found only in nine genera, i. e. *Copiapoa* (2/10 spp.), *Gymnocalycium* (1/47 spp.), *Horridocactus* (5/11 spp.), *Neoporteria* (19/19 spp.), *Brasilicactus* (1/2 spp.), *Notocactus* (5/7 spp.), *Eriocactus* (2/2 spp.), *Parodia* (13/13 spp.) and *Neochilenia* (3/3 spp.) (Table 4). It is noteworthy that all these nine genera belong to subtribe Austroeuechinocactinae in tribe Echinocacteae, which are endemic to South America (Table 3 and 4, Ito 1981). In *Weingartia, Malacocarpus* (=*Wigginsia*) and *Islaya* of the same subtribe, quercetin 3-methyl ether were not detected in this experiment (Table 5). Moreover, five species, *Horridocactus kesselringianus* Dölz, *Neoporteria fusca* (Muhlpf.) Br. & R., *Parodia comarapana* Card., *P. maassii* (Heese) Berg. and *P. multicostata* Ritt., produce isorhamnetin as well as quercetin 3-methyl ether, and other species have either or none of these two compounds.

Table 4. Distribution of flavonol as aglycones in genera of Cereoideae

Tribes and Genera	No.*	Qu	Km	Ir	QM
Tribe Pseudohyllocereeae					
Epiphyllopsis	1				
Epiphyllum	1			1	
Chiapasia	1		1	1	
Tribe Cereeae					
Monvillea	1	1	1	1	
Thrixanthocereus	1	1	1	1	
Echinocereus	16	16	4		
Tribe Echinocacteae					
Rebutia	11	11	11		
Sulcorebutia	4	4	2		
Echinopsis	9	6	9	7	
Pseudolobivia	5	5	5	2	
Lobivia	35	33	32	30	
Soehrensia	1	1	1		
Mediolobivia	4	4	3	3	
Aylostera	7	7	2	6	
Chamaecereus	1	1	1		
Acantholobivia	1	1	1	1	
Acanthocalycium	2	2	2	1	
Matucana	2	2			
Denmoza	1	1			
Arequipa	2	2	2		
Weingartia	3	3		2	
Copiapoa	10	10	1		2
Gymnocalycium	46	34	5	1	1
Horridocactus	11	11	8	4	5
Neoporteria	19	19	13	1	19
Brasilicactus	2	2	1		1
Notocactus	7	7	2		5
Eriocactus	2	2			2
Malacocarpus	2	2		1	
Parodia	13	13	5	3	13
Neochilenia	3	3	2		3
Islaya	4	4	2		
Lophophora	2	2	2		
Strombocactus	1	1	1	1	
Turbinicarpus	1	1	1		
Gymnocactus	1		1		
Echinomastus	1	1	1		
Echinofossulocactus	2		2		
Hamatocactus	1	1			
Ferocactus	5	5	3	2	
Homalocephala	1	1			
Glandulicactus	1	1			
Thelocactus	5	4	5		
Astrophytum	4	4	4	4	
Tribe Mamillarieae					
Coryphantha	1	1			
Mamillopsis	1	1			
Mammillaria	10	2	4	2	
Dolichothele	2	2			
total	269	235	141	75	51

* No. of species examined, Qu=quercetin, Km=kaempferol, Ir=isorhamnetin, QM=quercetin 3-methyl ether.

Free quercetin 3-methyl ether scattered among six genera from which its glycosides were found, excepting *Brasilicactus*, *Gymnocalycium* and *Eriocactus*.

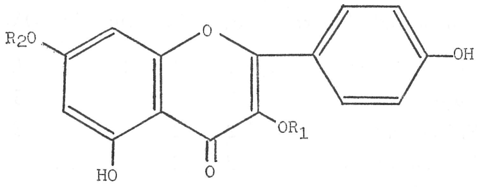
As to the distribution of flavonoid compounds which were found in this experiment, Cereoideae exhibits the following divergencies:

1) Presence of quercetin glycosides only: *Coryphantha, Denmoza, Dolichothele, Glandulicactus, Hamatocactus, Homalocephala, Mamillopsis* and *Matucana*.

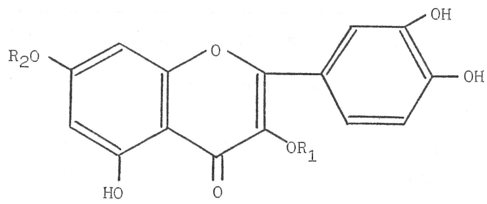
2) Presence of quercetin and kaempferol glycosides: *Echinocereus, Rebutia, Sulcorebutia, Soehrensia, Chamaecereus, Arequipa, Islaya, Lophophora, Turbinicarpus, Echinomastus* and *Thelocactus*.

3) Presence of quercetin with the glycosides of kaempferol and isorhamnetin (sometimes kaempferol glycosides were lacking): *Monvillea, Thrixanthocereus, Echinopsis, Pseudolobivia, Lobivia, Mediolobivia, Aylostera, Acanthocalycium, Weingartia, Malacocarpus, Strombocactus, Ferocatus, Mammillaria* and *Acantholobivia*.

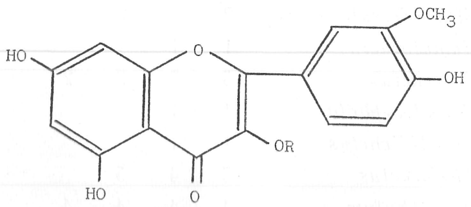
4) Presence of quercetin 3-methyl ether: *Copiapoa, Gymnocalycium, Horridocactus,*



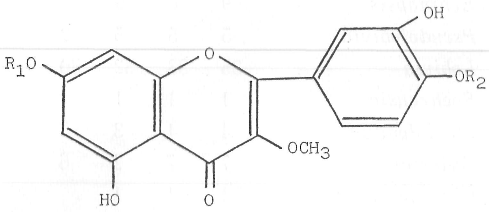
a)
$R_1=R_2=H$; kaempferol,
R_1=rhamnogalactosyl, $R_2=H$;
kaempferol 3-*O*-rhamnosylgalactoside,
R_1=rhamnoglucosyl, $R_2=H$;
kaempferol 3-*O*-rhamnosylglucoside,
$R_1=R_2$=glycosyl; kaempferol 3,7-*O*-diglycoside.



b)
$R_1=R_2=H$; quercetin,
R_1=galactosyl, $R_2=H$;
quercetin 3-*O*-galactoside,
R_1=rhamnoglucosyl, $R_2=H$;
quercetin 3-*O*-rhamnosylglucoside,
$R_1=H$, R_2=galactosyl;
quercetin 7-*O*-galactoside.



c)
R=H; isorhamnetin,
R=rhamnogalactosyl; isorhamnetin
3-*O*-rhamnosylgalactoside,
R=rhamnoglucosyl; isorhamnetin
3-*O*-rhamnosylglucoside.



d)
$R_1=R_2=H$; quercetin 3-methyl ether,
R_1=glucosyl, $R_2=H$;
quercetin 3-methyl ether 7-*O*-glucoside,
$R_1=H$, R_2=glucosyl;
quercetin 3-methyl ether
4′-*O*-glucoside.

Fig. 2. Structures of flavonols from Cereoideae species.

Table 5. Occurrence of quercetin 3-methyl ether in the tribe Echinocacteae

Subtribes	quercetin 3-methyl ether	
	presence	absence
Austropseudocereinae		*Rebutia, Sulcorebutia, Echinopsis, Pseudolobivia,* Lobivia, Soehrensia, Mediolobivia, Aylostera, Chamaecereus, Acantholobivia,** Acanthocalycium*
Austromediechinocactinae		*Matucana, Denmoza, Arequipa*
Austroeuechinocactinae	*Copiapoa, Gymnocalycium, Horridocactus, Neoporteria, Notocactus, Brasilicactus, Parodia, Eriocactus, Neochilenia*	*Weingartia, Malacocarpus,*** Islaya*

* This genus was divided into *Echinopsis, Salpingolobivia, Mesechinopsis, Furiolobivia* and so on according to the system of Ito (1981).
** *Acantholobivia* was newly named as *Acanthanthus* by Ito (1981).
*** *Malacocarpus*=*Wigginsia*

Neoporteria, Brasilicactus, Notocactus, Eriocactus, Parodia and *Neochilenia.*

5) Presence of free quercetin as a major component: *Astrophytum.*

6) Absence of quercetin and its glycosides: *Epiphyllopsis, Epiphyllum, Chiapasia, Echinofossulocactus* and *Gymnocactus.*

Discussion

A number of flavonols which were detected in this survey occurred as glycosides, e. g. 3-*O*-galactoside, 3-*O*-rhamnosylglucoside and 3-*O*-rhamnosylgalactoside, and it has been shown that individual flavonoids in cacti were characterized by the substitution on 3-OH group which may be occupied by the glycosyl residues (Iwashina *et al.* 1982, 1986). And, it is also confirmed that three genera in tribe Pseudohyllocereeae (Ito 1981, corresponding to the tribe Hylocereeae by Backeberg 1966), i. e. *Epiphyllopsis, Epiphyllum* and *Chiapasia,* did not possess quercetin and its glycosides (but, quercetin glycoside was detected in a whole plant of *Epiphyllum anguliger* (Lem.) Br. & R., belonging to Pseudohyllocereeae, Richardson 1978). Among two kinds of methylated quercetins, isorhamnetin and quercetin 3-methyl ether, the former has been found in relatively many other families (Harborne and Williams 1975). On the other hand, quercetin 3-methyl ether which is quite rare in nature, and has been found only in Zingiberaceae, Compositae, Zygophyllaceae and quite recently in Cactaceae (Wollenweber 1982, Iwashina *et al.* 1984). From a chemotaxonomical view point, quercetin 3-methyl ether and its glycosides seem to be quite significant in that the nine genera having these flavonols belong to the subtribe Austroeuechinocactinae (Table 5). However, *Weingartia, Malacocarpus* (=*Wigginsia*) and *Islaya* in the same subtribe do not have their flavonols, and the other nine genera (*Oroya, Mila, Blossfeldia, Frailea,* etc., Ito 1981) are still open to such a survey. Moreover, co-occurrence of isorhamnetin and quercetin 3-methyl ether are extremely rare, and only five species, *Horridocactus kesselringianus, Neoporteria fusca, Parodia comarapana, P. maassii* and *P. multicostata,* possessed both of these components, among 269 species examined. This fact seems to indicate that methoxyl group on 3- and 3′-position may be alternative in Cereoideae.

Although the subfamily Cereoideae is morphologically very diverse (Buxbaum 1953a, b, c), the present survey have shown that the flavonoid structures seem to be rather uniform. For example, the flavonoids which have been reported in Cereoideae were kaempferol, quercetin and its monomethyl derivatives (isorhamnetin and quercetin 3-methyl ether), and their 3- and/or 7-, or 4′-*O*-glycosides (Hörhammer *et al.* 1966, Iwashina *et al.* 1982, 1984, 1986), and exceptionally dihydroflavonols in *Echinocereus triglochidiatus* var. *gurneyi* (Miller and Bohm 1982). With an exception of quercetin 3-methyl ether and its glycosides, many kinds of flavonol glycosides which were present in Cereoideae, were found also in subfamily Opuntioideae (Clark and Parfitt 1980, Clark *et al.* 1980, Rösler *et al.* 1966, Shabbir and Zaman 1968). Moreover, glycosides of quercetin and kaempferol were found in the leaves of *Peireskia bleo* DC. and *P. grandifolia* Haw. in the subfamily Peireskioideae (Richardson 1978). Such a fact suggests that physiological characters are not so much differenciated in contrast to a large diversity of outword morphology, such as flowers, areoles and fruits (Buxbaum 1953b, c) as seen in the subfamily Cereoideae or even in the family Cactaceae.

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The authors offer their sincere thanks to Prof. Dr. Norio Kondo and Dr. Kôzô Hayashi of the Research Institute of Evolutionary Biology for their deep interest and continuous support in this works. Authors' thanks are also due to Messrs. Toshiaki Gotoh and Yukihiro Takahashi (Izu Natural History Park) for the supply of plant materials.

Summary

The tepals of 269 species from 48 genera of subfamily Cereoideae (Cactaceae) were surveyed for flavonoids, and the fifteen kinds of flavonoids, quercetin and its 3-*O*-galactoside, 3-*O*-rhamnosylglucoside, 7-*O*-galactoside, kaempferol and its 3-*O*-rhamnosylgalactoside, 3-*O*-rhamnosylglucoside, 3, 7-*O*-diglycoside, isorhamnetin and its 3-*O*-rhamnosylgalactoside, 3-*O*-rhamnosylglucoside, quercetin 3-methyl ether and its 7-*O*-glucoside, 4′-*O*-glucoside, and 5-hydroxy-3,4′-oxygenated flavonol glycoside were found.

Among these flavonol components, quercetin glycosides were detected in the majority of species excepting *Epiphyllopsis*, *Epiphyllum* belonging to the tribe Pseudohyllocereeae, *Echinofossulocactus* and *Gymnocactus*. Kaempferol glycosides were also found in many species.

The two kinds of *O*-monomethylquercetin, isorhamnetin and quercetin 3-methyl ether were found in small number of Cereoideae species; especially, the latter and its glycosides were only distributed in the nine genera, *Copiapoa, Gymnocalycium, Horridocactus, Neoporteria, Brasilicactus, Notocactus, Eriocactus, Parodia* and *Neochilenia,* all belonging to the subtribe Austroeuechinocactinae and are native to South America.

Among four kinds of flavonols which were found as sugar-free state, quercetin occurred only in four *Astrophytum* species with the trace of kaempferol and isorhamnetin.

In the case of cactus flavonoids, it was shown that the structural diversity of flavonoid components seems to be only slight, although the morphological varieties may be observed in cacti to a greater extent. This is an indication of the fact that internal biochemical characters are not so much differentiated as compared with a higher specialization of external characteristics in cactus plants.

要　　約

サボテン科の３亜科のうち，柱サボテン亜科 (subfamily Cereoideae) は最も大きく，観賞植物としても多くの重要な種類を含んでおり，園芸家などがおびただしい数の種や属を命名してきた。また形態的にも著しく特殊化している関係から，分類学的に非常に複雑，かつ混乱している植物群の一つである。植物化学的には，アルカロイドやベタレイン色素などが比較的よく研究されているが，フェノール化合物についての報告は極めて少ない。

著者らは数年来，サボテンの花に含まれるフラボノイド化合物の分析を進めて，現在までにその15種類を分離して構造解析を行った。すなわち，遊離の quercetin，その 3-*O*-galactoside, 3-*O*-rhamnosylglucoside, 7-*O*-galactoside, 遊離の kaempferol, その 3-*O*-rhamnosylgalactoside, 3-*O*-rhamnosylglucoside, 3,7-*O*-diglycoside, 遊離の isorhamnetin, その 3-*O*-rhamnosylgalactoside, 3-*O*-rhamnosylglucoside, quercetin 3-methyl ether, その 7-*O*-glucoside, 4′-*O*-glucoside および部分的に定性できた 5-hydroxy-3, 4′-oxygenated flavonol glycoside である (Iwashina ら 1982, 1984 および 1986)。

本論文では，柱サボテン亜科の48属 269 種の花被片について，上記のフラボノイド化合物の構成を解明し，従来の分類体系との相関について考察した。

分析方法としては，各植物の花被片のメタノール抽出物を二次元ペーパークロマトグラフィーで含有成分の組成を調査した後，マス-ペーパークロマト法，またはカラムクロマト法によって個々の成分を単離または結晶化し，基準標品との比較や紫外可視吸収スペクトルなどによってそれらの構造を決定した。

フラボノイド化合物の中で最も高頻度に出現するのは quercetin の配糖体で，*Echinofossulocactus, Gymnocactus* および Pseudohyllocereeae 族 (tribe) の 3 属を除くすべての属 (43属, Table 2 参照) に含まれていた。kaempferol の配糖体も多くの植物から見い出されたが，quercetin のモノメトキシ誘導体である isorhamnetin および quercetin 3-methyl ether は quercetin や kaempferol と比較するとその分布は狭く，とくに quercetin 3-methyl ether とその配糖体についてはわずかに南米大陸原産の Austroeuechinocactinae 亜族 (subtribe) に属する 9 属，すなわち *Copiapoa, Gymnocalycium, Horridocactus, Neoporteria, Brasilicactus, Notocactus, Eriocactus, Parodia* および *Neochilenia* の51種の花被片から見い出されたに過ぎなかった。さらに，isorhamnetin と quercetin 3-methyl ether を共有する植物はわずかに 5 種だけであり，メトキシル基を 3′-位に結合するか，3-位に結合するかは柱サボテン亜科の場合では二者択一的である傾向が強い。

これらのフラボノール配糖体とは別に，*Astrophytum* 属 4 種だけから糖を結合していない quercetin そのもの（アグリコン）が，少量の isorhamnetin と kaempferol のアグリコンを伴なって，多量に結晶として得られた。

上記のような特徴的な分布をしているフラボノイド化合物がある一方，全体としては柱サボテン亜科植物に含まれているフラボノイドの分子構造は水酸基，メトキシル基，糖分子などの違いにより若干異なっているだけである。さらに，他のウチワサボテン亜科 (Opuntioideae) と木の葉サボテン亜科 (Peireskioideae) からも quercetin 3-methyl ether とその配糖体以外はほとんど同様の構造がみられ，結合糖の種類だけに差異のあることが知られている (Clark and Parfitt 1980, Clark ら 1980, Rösler ら 1966, Shabbir and Zaman 1968 および Richardson 1978)。この事実から，柱サボテン亜科はもとより，サボテン科全体についても，その特殊化した外部形態的変化に比べて，内部形質の分化はまだほとんど進んでいないことがフラボノイドの分子構造から推定できる。

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