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Pollen morphology of the genus *Fritillaria* L. (Liliaceae) in Turkey

Mehtap TEKŞEN[1,*], Zeki AYTAÇ[2], Nur Münevver PINAR[3]

[1]Aksaray University, Faculty of Arts and Science, Department of Biology, Campus, 68100 Aksaray - TURKEY

[2]Gazi University, Faculty of Arts and Science, Department of Biology, 06500 Teknikokullar, Ankara - TURKEY

[3]Ankara University, Faculty of Science, Department of Biology, 06100 Tandoğan, Ankara, TURKEY

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Abstract: Pollen grains of 39 taxa of the genus *Fritillaria* L. in Turkey were examined by light and scanning electron microscopy. Detailed pollen morphological characteristics are given for these taxa. Our investigation shows that the sculpturing of the exine provides valuable characters for separating species. In particular, sculpturing of the exine at the proximal face turned out to be taxonomically important. Six types of ornamentation were determined: reticulate, reticulate-perforate, suprareticulate, rugulate-reticulate, psilate-perforate, and perforate. On the basis of exine sculpturing, the sulcus membrane, and the apex sulcus, 5 main pollen types are recognised.

Key words: *Fritillaria*, Liliaceae, pollen morphology, SEM, LM

Türkiye *Fritillaria* L. (Liliaceae) cinsinin polen morfolojisi

Özet: Türkiye'deki *Fritillaria* L. cinsine ait 39 taksonun polenleri ışık ve taramalı elektron mikroskobu ile çalışılmıştır. Bu taksonların detaylı polen morfolojik karakterleri verilmiştir. Çalışmamız, ekzin ornamentasyonunun türlerin ayrımında değerli karakterler sağladığını göstermiştir. Proksimal yüzde retikulat, retikulat-perforat, supraretikulat, rugulat-retikulat, psilat-perforat ve perforat olarak 6 ornamentasyon çeşiti saptanmıştır. Ekzin sulkupturu, sulkus membranı ve sulkus apeks özelliklerine göre 5 polen tipi fark edilmiştir.

Anahtar sözcükler: *Fritillaria*, Liliaceae, polen morfolojisi, SEM, LM

Introduction

The species of the genus *Fritillaria* L. occur naturally in most temperate regions of the northern hemisphere from North America, through Europe, the Mediterranean region and Central Asia, to China and Japan in the east (Rix, 2001). *Fritillaria* is represented worldwide by 7 subgenera, 2 sections, and 165 taxa (139 species, 17 subspecies, and 9 varieties; Rix, 2001). It has 39 taxa (33 species and 6 subspecies), 20 taxa of which are endemic in Turkey. The taxa of

* E-mail: mteksen@aksaray.edu.tr

the genus *Fritillaria* are distributed in the Mediterranean and Irano-Turanian regions (Rix, 1984; Özhatay, 2000).

The pollen structure of some species of the genus *Fritillaria* has been subject to previous studies (e.g. Schulze, 1980; Kosenko, 1991a, 1991b, 1992, 1999; Özler & Pehlivan, 2007; Tekşen & Aytaç, 2004, 2008). The aim of the present study was to examine the pollen morphology of almost all Turkish *Fritillaria* taxa recognised and to evaluate the significance of pollen characteristics for the infrageneric taxonomy of the genus.

Materials and methods

The specimens of *Fritillaria* were collected in Turkey during 1999 to 2003. Information about collectors and localities for the specimens investigated is provided below. All specimens are deposited at GAZI.

For LM investigations, pollen slides were prepared as described by Wodehouse (1935). LM studies were performed using a Prior microscope. Measurements were based on 30 or more pollen grains per sample. For SEM investigations, pollen grains were transferred to aluminium stubs and coated with gold plate and examined under a JEOL JSM-5600 scanning electron microscope.

The pollen terminology follows Faegri and Iversen (1975), Erdtman (1969), Kosenko (1991a, 1991b), Punt et al. (2007), and Pınar and Oymak Dönmez (2000).

Specimens Investigated

Fritillaria taxa examined for the present study are listed below:

Fritillaria imperialis L.; C10 Hakkâri, *M.Tekşen* 2120.

Fritillaria persica L.; C4 İçel, *M.Tekşen* 2025.

Fritillaria latifolia Willd.; B7 Erzincan, *M.Tekşen* 2139.

Fritillaria aurea Schott; C6 Kahramanmaraş, *M.Tekşen* 2049.

Fritillaria pontica Wahlenb.; A3 Bolu, *M.Tekşen* 2095.

Fritillaria acmopetala Boiss. subsp. *acmopetala*; C6 Hatay, *M.Tekşen* 2036.

Fritillaria acmopetala Boiss. subsp. *wendelboi* Rix, C4 İçel, *M.Tekşen* 1989.

Fritillaria whittallii Baker; C3 Antalya, *M.Tekşen* 1988.

Fritillaria hermonis Fenzl subsp. *amana* Rix; C6 Kahramanmaraş, *M.Tekşen* 1992.

Fritillaria crassifolia Boiss. & Huet subsp. *crassifolia*; C3 Antalya, *H.Duman* 6623.

Fritillaria crassifolia Boiss. & Huet subsp. *kurdica* (Boiss. & Noe) Rix; B9 Van, *M.Tekşen* 2063.

Fritillaria crassifolia Boiss. & Huet subsp. *hakkarensis* Rix; C10 Hakkari, *M.Tekşen* 2117.

Fritillaria michailovskyi Fomin; B9 Ağrı, *M.Tekşen* 2076.

Fritillaria straussii Bornm.; C10 Hakkâri, *M.Tekşen* 2181.

Fritillaria alburyana Rix; A8 Erzurum/Bayburt, *M.Tekşen* 2084.

Fritillaria alfredae Post subsp. *platyptera* (Samuelsson) Rix; C6 Hatay, *M.Tekşen* 2033.

Fritillaria alfredae Post subsp. *glaucoviridis* (Turrill) Rix; C6 Hatay, *M.Tekşen* 1929.

Fritillaria bithynica Baker; C2 Muğla, *M.Tekşen* 1963.

Fritillaria milasense M.Tekşen & *Aytaç*; C2 Muğla, *M.Tekşen* 1999.

Fritillaria stribrnyi Velen.; A1(E) Edirne, *M.Tekşen* 2114.

Fritillaria fleischeriana Steudel & Hochst ex Schultes & Schultes fil.; A3 Ankara, *M.Tekşen* 2113.

Fritillaria forbesii Baker; C2 Muğla, *M.Tekşen* 1998.

Fritillaria mughlae M.Tekşen & Aytaç; C1 Muğla, *M.Tekşen* 1996.

Fritillaria sibthorpiana (Sm.) Baker subsp. *sibthorpiana*; C2 Muğla, *M.Tekşen* 1960.

Fritillaria sibthorpiana (Sm.) Baker subsp. *enginiana* Byfield & *N.Özhatay*; C2 Muğla, *M.Tekşen* 1972.

Fritillaria carica Rix; C2 Muğla, *M.Tekşen* 2009.

Fritillaria byfieldii N. Özhatay & Rix; C2 Denizli, *M.Tekşen* 2137.

Fritillaria serpenticola (Rix) *M.Tekşen* & Aytaç; C2 Burdur, *M.Tekşen* 1975.

Fritillaria minima Rix; B9 Van, *M.Tekşen* 2061.

Fritillaria minuta Boiss. & Noe; B9 Van, *M.Tekşen* 2062.

Fritillaria caucasica J. F. Adam; B9 Ağrı, *M.Tekşen* 2075.

Fritillaria baskilensis Behçet; B7 Elazığ, *M.Tekşen* 2051.

Fritillaria pinardii Boiss.; C6 Kahramanmaraş, *M.Tekşen* 1930.

Fritillaria kittaniae Sorger; C2 Antalya, *M.Tekşen* 2017.

Fritillaria assyriaca Baker subsp. *assyriaca*; B9 Van, *M.Tekşen* 2150.

Fritillaria assyriaca Baker subsp. *melananthera* Rix; C4 İçel, *M.Tekşen* 2032.

Fritillaria elwesii Boiss.; C3 Antalya, *M.Tekşen* 1978.

Fritillaria latakiensis Rix; C6 Hatay, *M.Tekşen* 2034.

Fritillaria uva-vulpis Rix; C9 Şırnak, *M.Tekşen* 2116.

Results

The main features of the investigated pollen are summarised in Tables 1-3. The general description can be given as follows:

Size and shape

The shape of pollen grains in *Fritillaria* usually isradially symmetrical, heteropolar, prolate, or subprolate (shape classification follows Pınar and Oymak Dönmez (2000) based on the LA/SA ratio in Table 1) with the long axis (LA) 40.1-57.9 µm and short axis (SA) 23.1-40.4 µm based on LM (Table 1, Figure 1).

Aperture

The pollen grains are operculate, usually monosulcate or rarely zonosulcate (*F. whittallii*). Sulcus length is 35.4-54.3 µm, sulcus width is 11.4-6.8 µm based on LM. The sulcus membrane is verrucate (*F. latifolia*, *F. aurea*, *F. pontica*, *F. acmopetala* subsp. *wendelboi*, *F. whittallii*, *F. hermonis* subsp. *amana*, *F. crassifolia* subsp. *crassifolia*, *F. crassifolia* subsp. *kurdica*, *F. crassifolia* subsp. *hakkarensis*, *F. straussii*, *F. alburyana*, *F. alfredae* subsp. *platyptera*, *F. alfredae* subsp. *glaucoviridis*, *F. bithynica*, *F. fleischeriana*, *F. sibthorpiana* subsp. *sibthorpiana*, *F. sibthorpiana* subsp. *enginiana*, *F. forbesii*, *F. mughlae*, *F. carica*, *F. byfieldii*, *F. serpenticola*, *F. minima*, *F. baskilensis*, *F. kittaniae*, *F. assyriaca* subsp. *assyriaca*, *F. assyriaca* subsp. *melanathera*, *F. elwesii*, *F. latakiensis*, *F. uva-vulpis*), psilate (*F. imperialis*, *F. persica*), granulate (*F. michailovskyi*), verrucate-granulate (*F. acmopetala* subsp. *acmopetala*, *F. milasense*, *F. caucasica*), granulate-striate (*F. stribrnyi*), rugulate (*F. minuta*), and gemmate (*F. pinardii*). Sulcus sharp at apex (*F. imperialis*, *F. persica*, *F. crassifolia* subsp. *kurdica*, *F. crassifolia* subsp. *hakkarensis*, *F. straussii*, *F. alburyana*, *F. sibthorpiana* subsp. *sibthorpiana*, *F. sibthorpiana* subsp. *enginiana*, *F. carica*, *F. byfieldii*, *F. serpenticola*, *F. minima*, *F. caucasica*, *F. assyriaca* subsp. *melananthera*, *F. latakiensis*, *F. uva-vulpis*) or round at apex (*F. latifolia*, *F. aurea*, *F. pontica*, *F. acmopetala* subsp. *acmopetala*, *F. acmopetala* subsp. *wendelboi*, *F. whittallii*, *F. hermonis* subsp. *amana*, *F. crassifolia* subsp. *crassifolia*, *F. michailovskyi*, *F. alfredae* subsp. *platyptera*, *F. alfredae* subsp. *glaucoviridis*, *F. bithynica*, *F. milasense*, *F. stribrnyi*, *F. fleischeriana*, *F. forbesii*, *F. mughlae*, *F. minuta*, *F. baskilensis*, *F. pinardii*, *F. kittaniae*, *F. assyriaca* subsp. *assyriaca*, *F. elwesii*), and sometimes sulcus extended to proximal face (*F. aurea*, *F. bithynica*, *F. sibthorpiana* subsp. *sibthorpiana*, *F. sibthorpiana* subsp. *enginiana*, *F. baskilensis*, *F. pinardii*) (Figure 2).

Exine, *Intine*

The exine is tectate and 1.4-1.9 µm thick. Intine thickness ranges from 0.4 to 1 µm (Table 2). The sexine is thicker than the nexine. The ornamentation is usually reticulate, rarely suprareticulate, rugulate-reticulate, reticulate-perforate, or perforate (Figures 3-12). Reticulate, suprareticulate, and reticulate-perforate sculpturing are observed in the *Fritillaria*

Table 1. Pollen morphological parameters of *Fritillaria* taxa (values in μm).

Taxa	Long axis (LA)			Short axis (SA)			LA/SA ratio, shape		Exine		Intine	Pollen type
	min	max	mean	min	max	mean			thickness	ornamentation		
F. imperialis	54.7	59.9	57.9	38.2	41.7	40.4	1.43	prolate	1.8	rugulate-reticulate	1.0	I
F. persica	39.1	45.2	42.3	29.5	33.9	31.6	1.34	prolate	1.8	reticulate-perforate	0.9	II
F. latifolia	40.8	47.7	44.1	32.1	36.5	34.4	1.28	subprolate	1.7	reticulate-perforate	0.9	II
F. aurea	39.9	49.5	45.0	26.0	35.6	28.9	1.56	prolate	1.4	reticulate	0.8	III
F. pontica	42.5	48.6	45.2	34.7	39.9	36.2	1.25	subprolate	1.8	suprareticulate	0.9	IV
F. acmopetala subsp. *acmopetala*	42.5	48.6	45.1	23.5	31.3	26.0	1.73	prolate	1.5	reticulate	0.7	III
F. acmopetala subsp. *wendelboi*	40.5	53.0	45.1	23.5	32.1	26.2	1.71	prolate	1.5	reticulate-perforate	0.6	II
F. whittallii	36.5	44.3	40.2	20.0	30.0	23.1	1.74	prolate	1.5	reticulate	0.6	III
F. hermonis subsp. *amana*	37.3	48.6	42.9	21.7	36.5	27.8	1.54	prolate	1.5	suprareticulate	0.7	IV
F. crassifolia subsp. *crassifolia*	38.2	55.6	48.0	23.4	40.8	32.2	1.49	prolate	1.5	reticulate-perforate	0.7	II
F. crassifolia subsp. *kurdica*	39.9	49.5	43.9	29.5	37.3	33.8	1.30	subprolate	1.9	reticulate-perforate	0.9	II
F. crassifolia subsp. *hakkarensis*	39.1	48.6	42.5	30.4	38.2	34.0	1.25	subprolate	1.8	reticulate-perforate	0.9	II
F. michailovskyi	40.8	47.7	43.9	33.0	39.1	35.9	1.22	subprolate	1.8	reticulate-perforate	0.9	II
F. straussii	37.3	49.7	43.8	25.2	34.7	28.0	1.56	prolate	1.7	suprareticulate	1.0	IV
F. alburyana	38.2	49.5	44.3	30.4	39.1	34.9	1.27	subprolate	1.8	reticulate	0.9	III
F. alfredae subsp. *platyptera*	38.2	47.7	42.8	21.3	36.5	32.8	1.30	subprolate	1.7	reticulate-perforate	0.8	II
F. alfredae subsp. *glaucoviridis*	38.2	45.1	40.7	28.6	34.7	31.7	1.28	subprolate	1.7	reticulate-perforate	0.8	II
F. bithynica	38.2	47.7	43.2	26.0	34.7	30.7	1.41	prolate	1.7	rugulate-reticulate	0.8	I
F. milasense	40.8	47.7	43.4	31.3	35.6	33.6	1.29	subprolate	1.8	rugulate-reticulate	0.9	I
F. stribrnyi	36.5	43.4	40.1	21.3	32.9	30.8	1.30	subprolate	1.8	psilate-perforate	0.9	V
F. fleischeriana	39.1	44.3	42.5	30.4	36.5	33.7	1.26	subprolate	1.8	reticulate-perforate	0.9	II
F. sibthorpiana subsp. *sibthorpiana*	41.7	49.8	45.1	30.4	45.6	35.9	1.26	subprolate	1.7	reticulate-perforate	0.9	II
F. sibthorpiana subsp. *enginiana*	42.3	52.1	47.8	33.9	38.2	35.7	1.34	prolate	1.8	reticulate-perforate	0.9	II
F. forbesii	43.4	50.3	46.4	31.3	36.5	33.9	1.37	prolate	1.8	reticulate-perforate	0.9	II
F. mughlae	39.9	48.6	45.4	30.4	39.1	34.6	1.31	subprolate	1.8	reticulate	0.9	II
F. carica	44.3	54.7	49.2	38.6	42.5	34.6	1.42	prolate	1.8	reticulate	1.0	III
F. byfieldii	39.9	45.1	42.5	30.4	35.6	33.5	1.27	subprolate	1.8	reticulate-perforate	0.4	II
F. serpenticola	39.1	46.9	41.6	26.0	33.0	30.0	1.39	prolate	1.7	reticulate-perforate	0.9	II
F. minima	40.8	46.0	43.5	30.4	35.6	33.6	1.29	subprolate	1.8	reticulate	0.9	III
F. minuta	42.6	48.6	45.3	32.1	38.2	34.9	1.30	subprolate	1.8	perforate	0.9	V
F. caucasica	39.9	48.6	44.9	31.3	39.1	34.8	1.29	subprolate	1.8	reticulate-perforate	0.9	II
F. baskilensis	38.2	44.3	41.5	29.5	34.7	32.7	1.27	subprolate	1.8	suprareticulate	0.9	IV
F. pinardii	44.3	52.1	47.8	29.5	36.5	33.3	1.44	prolate	1.8	reticulate-perforate	0.9	II
F. kittaniae	36.5	49.5	41.6	29.5	39.9	32.3	1.29	subprolate	1.5	reticulate-perforate	0.7	II
F. assyriaca subsp. *assyriaca*	39.1	46.0	42.5	29.1	34.7	31.8	1.34	prolate	1.8	rugulate-reticulate	0.9	I
F. assyriaca subsp. *melananthera*	43.4	52.1	45.4	32.1	36.5	34.6	1.31	subprolate	1.7	reticulate-perforate	0.8	II
F. elwesii	39.9	50.3	45.5	30.4	36.5	33.3	1.37	prolate	1.8	rugulate-reticulate	0.9	I
F. latakiensis	39.1	51.2	44.4	32.1	36.5	34.1	1.30	subprolate	1.8	reticulate-perforate	0.9	II
F. uva-vulpis	43.4	47.7	45.9	30.4	34.7	32.9	1.4	prolate	1.8	suprareticulate	0.9	IV

Table 2. The pollen morphological characters of *Fritillaria* taxa on LM and SEM (values in μm).

Taxa	Aperture type	Sulcus length			Sulcus width			Sulcus membrane ornamentation	Apex of sulcus
		min	max	mean	min	max	mean		
F. imperialis	Monosulcate	51.2	56.4	54.3	20.0	28.6	26.8	Psilate	Sharp
F. persica	Monosulcate	35.6	41.7	38.9	15.6	25.2	22.0	Psilate	Sharp
F. latifolia	Monosulcate	37.3	44.3	40.6	17.4	27.8	24.5	Verrucate	Round
F. aurea	Monosulcate	43.4	53.0	48.7	8.7	17.4	11.4	Verrucate	Round
F. pontica	Monosulcate	39.1	45.1	41.7	17.4	27.8	24.8	Verrucate	Round
F. acmopetala subsp. *acmopetala*	Monosulcate	36.4	43.4	39.9	11.0	17.4	11.7	Verrucate - granulate	Round
F. acmopetala subsp. *wendelboi*	Monosulcate	33.0	47.7	40.4	13.0	20.0	12.8	Verrucate	Round
F. whittallii	Zonosulcate	29.5	39.1	35.4	8.7	18.2	12.9	Verrucate	Round
F. hermonis subsp. *amana*	Monosulcate	32.1	45.1	38.8	10.4	26.0	16.2	Verrucate	Round
F. crassifolia subsp. *crassifolia*	Monosulcate	34.7	50.3	43.5	18.7	26.0	16.9	Verrucate	Round
F. crassifolia subsp. *kurdica*	Monosulcate	36.5	46.0	40.4	17.4	26.0	23.0	Verrucate	Sharp
F. crassifolia subsp. *hakkarensis*	Monosulcate	35.6	45.1	39.0	18.2	26.9	23.2	Verrucate	Sharp
F. michailovskyi	Monosulcate	37.3	44.3	40.3	17.4	26.9	24.1	Granulate	Round
F. straussii	Monosulcate	33.0	43.4	39.0	15.6	21.7	19.0	Verrucate	Sharp
F. alburyana	Monosulcate	34.7	45.1	40.9	19.1	28.6	24.2	Verrucate	Sharp
F. alfredae subsp. *platyptera*	Monosulcate	34.7	44.3	39.3	10.4	21.7	16.0	Verrucate	Round
F. alfredae subsp. *glaucoviridis*	Monosulcate	34.3	41.7	37.1	11.3	20.8	15.5	Verrucate	Round
F. bithynica	Monosulcate	41.7	53.8	46.6	11.3	22.6	16.5	Verrucate	Round
F. milasense	Monosulcate	37.3	44.3	40.0	23.4	27.8	25.7	Verrucate - granulate	Round
F. stribrnyi	Monosulcate	33.0	39.9	36.7	20.0	26.0	23.7	Granulate -striate	Round
F. fleischeriana	Monosulcate	35.6	41.7	39.4	21.7	26.9	24.5	Verrucate	Round
F. sibthorpiana subsp. *sibthorpiana*	Monosulcate	45.1	53.0	48.6	17.4	26.0	21.2	Verrucate	Sharp
F. sibthorpiana subsp. *enginiana*	Monosulcate	46.9	55.6	51.4	17.4	16.9	22.1	Verrucate	Sharp
F. forbesii	Monosulcate	39.9	46.9	42.9	17.4	23.4	20.3	Verrucate	Round
F. mughlae	Monosulcate	35.6	44.3	41.6	15.6	28.6	23.5	Verrucate	Round
F. carica	Monosulcate	36.5	50.3	44.1	13.9	26.0	19.7	Verrucate	Sharp
F. byfieldii	Monosulcate	35.6	41.7	39.5	20.8	26.0	23.3	Verrucate	Sharp
F. serpenticola	Monosulcate	35.6	43.4	38.2	14.8	22.6	18.0	Verrucate	Sharp
F. minima	Monosulcate	37.3	42.5	40.0	20.8	26.0	24.2	Verrucate	Sharp
F. minuta	Monosulcate	39.1	45.1	41.8	19.1	26.0	22.9	Rugulate	Round
F. caucasica	Monosulcate	35.6	45.1	41.7	21.7	27.8	24.4	Verrucate - granulate	Sharp
F. baskilensis	Monosulcate	34.7	40.8	37.5	20.6	26.0	23.3	Verrucate	Round
F. pinardii	Monosulcate	46.9	55.6	51.2	14.8	26.0	20.3	Gemmate	Round
F. kittaniae	Monosulcate	33.8	45.1	38.1	10.4	23.4	19.8	Verrucate	Round
F. assyriaca subsp. *assyriaca*	Monosulcate	34.0	45.1	38.1	16.6	21.7	19.1	Verrucate	Round
F. assyriaca subsp. *melananthera*	Monosulcate	39.5	48.6	41.9	15.6	24.3	21.4	Verrucate	Sharp
F. elwesii	Monosulcate	37.3	46.9	42.1	17.4	26.9	22.7	Verrucate	Round
F. latakiensis	Monosulcate	35.6	47.7	41.0	17.4	27.8	22.5	Verrucate	Sharp
F. uva-vulpis	Monosulcate	39.9	44.3	41.5	20.0	26.0	22.4	Verrucate	Sharp

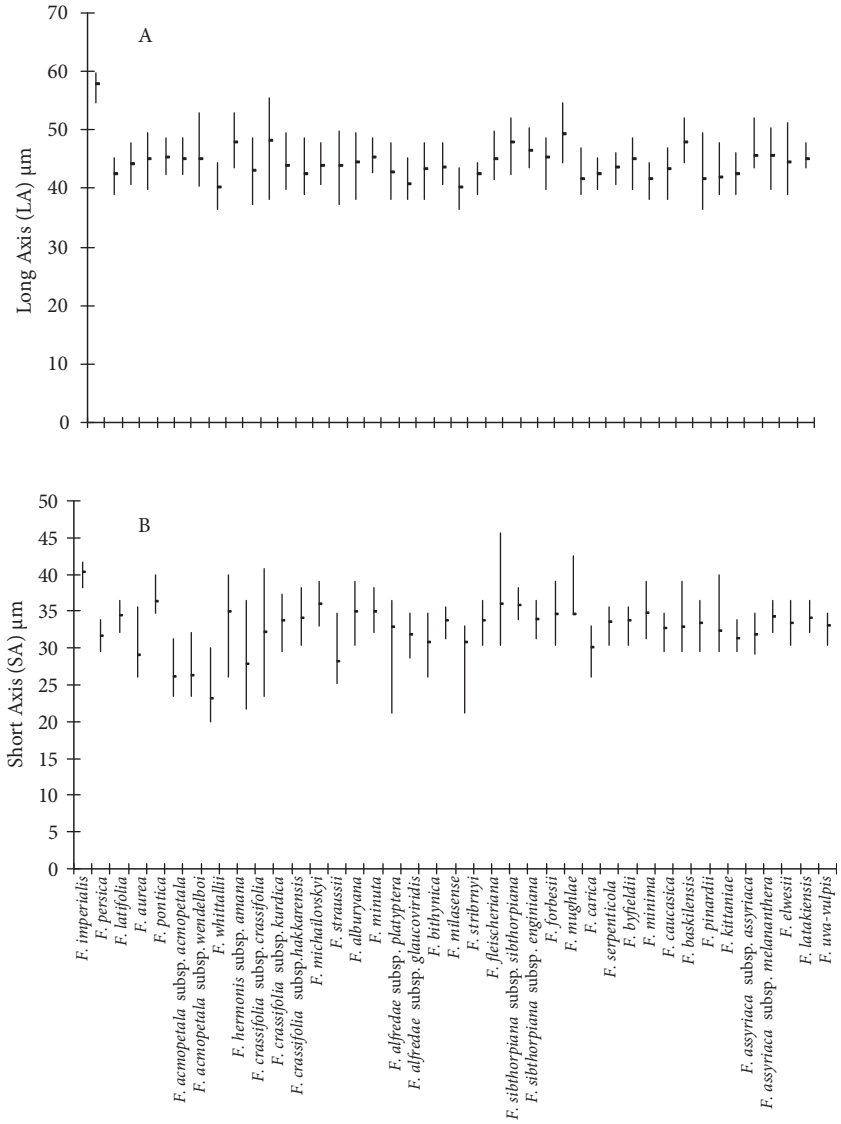

Figure 1. Measurements of pollen grains in *Fritillaria* based on LM. A: Long axis (LA). – B: short axis (SA).

taxa examined, the lumen width being 0.1-2.4 µm. The number of lumina across 4 µm^2 is 4-23 (Table 3). The pollen grains have generally irregular amorphous rarely regular-polygonal shaped lumina. Murus width is 0.1-1.4 µm. *Fritillaria hermonis* subsp. *amana* and *F. straussii* have 4-5 sided and undulate muri, *F. acmopetala* subsp. *acmopetala* and *F. uva-vulpis* have 4-5 sided and smooth muri. *Fritillaria pontica*, *F. whittallii*, *F. serpenticola*, *F. minima*, *F. baskilensis*, and *F. latakiensis* have undulate muri; *F. persica*, *F. latifolia*, *F. aurea*, *F. acmopetala* subsp. *wendelboi*, *F. crassifolia* subsp. *crassifolia*, *F. crassifolia* subsp. *kurdica*, *F. crassifolia* subsp. *hakkarensis*, *F. michailovskyi*, *F. alburyana*, *F. alfredae* subsp. *platyptera*, *F. alfredae* subsp. *glaucoviridis*, *F. fleischeriana*, *F. sibthorpiana* subsp. *sibthorpiana*, *F. sibthorpiana* subsp. *enginiana*, *F. forbesii*, *F. mughlae*, *F. carica*, *F. byfieldii*, *F. pinardii*, *F. kittaniae*, and *F. assyriaca* subsp. *melananthera* have smooth muri (Table 3).

On the basis of exine sculpturing, the sulcus membrane and the apex of the sulcus, 5 main pollen types are recognised in *Fritillaria*.

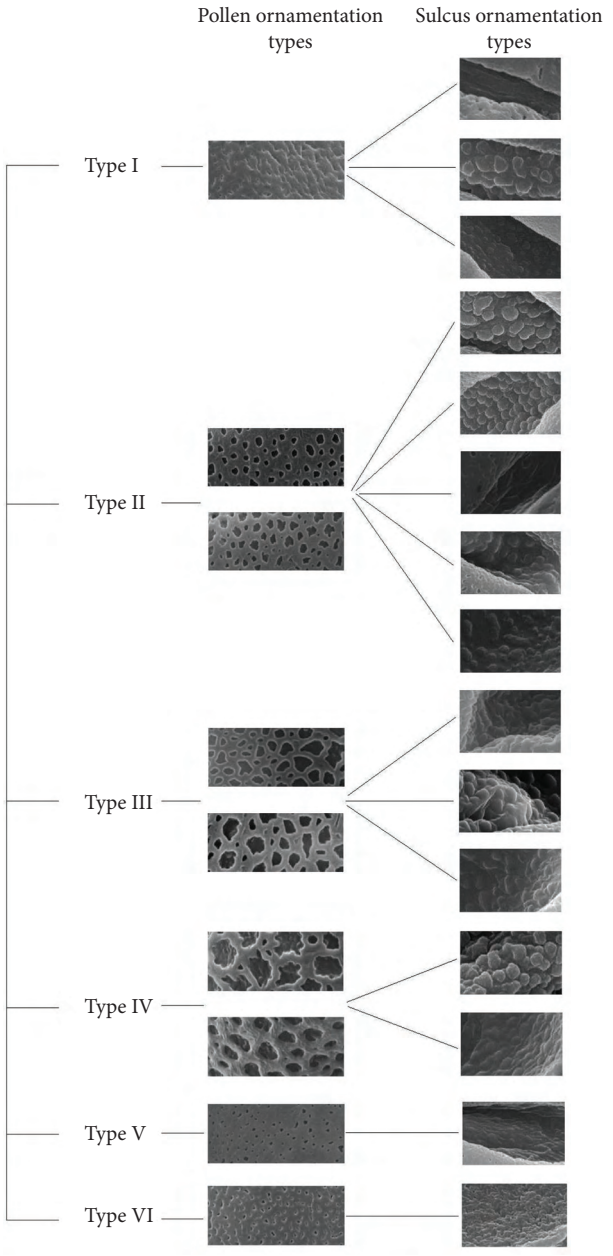

Figure 2. Pollen and sulcus membrane ornamentation types observed in Turkish *Fritillaria*.

Type I: The exine sculpturing is rugulate-reticulate. Sulcus membrane is psilate (*Fritillaria imperialis*), verrucate (*F. bithynica*, *F. assyriaca* subsp. *assyriaca*, and *F. elwesii*), and verrucate-granulate (*F. milasense*). The sulcus apex in *F. imperialis* is sharp, whereas it is round in the remaining taxa (Tables 1-3, Figures 3 and 4).

Type II: The pollen ornamentation is reticulate-perforate. Lumen shape is irregular- amorphous. A further classification has been made on the basis of murus shape, distinguishing those taxa having smooth muri (*F. persica*, *F. latifolia*, *F. acmopetala* subsp. *wendelboi*, *F. crassifolia* subsp. *crassifolia*, *F. crassifolia* subsp. *kurdica*, *F. crassifolia* subsp. *hakkarensis*, *F. michailovskyi*, *F. alfredae* subsp. *platyptera*, *F. alfredae* subsp. *glaucoviridis*, *F. fleischeriana F. sibthorpiana* subsp. *sibthorpiana*, *F. sibthorpiana* subsp. *enginiana*, *F. forbesii*, *F. byfieldii*, *F. pinardii*, *F. kittaniae*, *F. assyriaca* subsp. *melananthera*, and *F. uva-vulpis*) from those with undulate muri (*F. serpenticola*, *F. caucasica*, and *F. latakiensis*). In the taxa with undulate muri, the sulcus membrane is verrucate, sulcus apex is sharp. In the taxa with smooth muri, sulcus membranes are mostly verrucate, rarely psilate (*F. persica*), granulate (*F. michailovskyi*), and gemmate (*F. pinardii*) and the sulcus apex is round (Tables 1-3, Figures 4-9).

Type III: The pollen grains have reticulate exine sculpturing. Only *F. whittallii* and *F. minima* show undulate muri among the species examined: *F. aurea*, *F. acmopetala* subsp. *acmopetala*, *F. whittallii*, *F. alburyana*, *F. carica*, and *F. minima.* These species are divided into 3 sections according to whether they have verrucate (*F. aurea*, *F. mughlae*, *F. whittallii*, *F. alburyana*, and *F. carica*), verrucate-granulate (*F. acmopetala* subsp. *acmopetala*), or rugulate (*F. minima*) sulcus membrane. In the taxa with verrucate sulcus membrane, sulcus apex is sharp except *F. whittallii* (Tables 1-3, Figures 9 and 10).

Type IV: The ornamentation of this type is suprareticulate (*F. pontica*, *F. hermonis* subsp. *amana*, *F. straussii*, *F. baskilensis*, and *F. uva-vulpis*). Only *F. uva-vulpis* has smooth muri, the other taxa have undulate muri. *Fritillaria straussii* has a verrucate-granulate aperture membrane; the remaining taxa in this group have a verrucate aperture membrane (Tables 1-3, Figures 11 and 12).

Type V: *Fritillaria stribrnyi* has psilate-perforate exine sculpturing. *Fritillaria stribrnyi* has a granulate-striate sulcus membrane. Sulcus apex is consistently round (Tables 1-3, Figure 12).

Type VI: *F. minuta* has perforate exine sculpturing. *F. minuta* has a rugulate sulcus membrane. Sulcus apex is consistently round (Tables 1-3, Figure 12).

Table 3. Microsculpturing features of reticulate pollen ornamentation (values in μm).

Taxa	The number of lumen in 4 μm^2	Lumen			Murus			Lumen shape	Murus shape		
		min	max	mean	min	max	mean		4-5 sided	smooth	undulate
F. persica	12	0.3	1.2	0.8	0.4	1.4	0.8	Irregular amorphous	-	+	-
F. latifolia	11	0.2	0.7	0.4	0.3	1.0	0.6	Irregular amorphous	-	+	-
F. aurea	4	0.6	1.6	1.1	0.5	1.4	0.9	Irregular amorphous	-	+	-
F. pontica	7	0.1	1.9	0.9	0.1	0.9	0.5	Irregular amorphous	-	-	+
F. acmopetala subsp. *acmopetala*	4	0.5	1.8	1.0	0.6	0.8	0.7	Regular polygonal	+	+	-
F. acmopetala subsp. *wendelboi*	8	0.3	1.0	0.7	0.5	1.4	0.9	Irregular amorphous	-	+	-
F. whittallii	11	0.3	0.6	0.4	0.4	0.9	0.7	Irregular amorphous	-	-	+
F. hermonis subsp. *amana*	13	0.3	2.4	1.1	0.3	0.5	0,4	Irregular amorphous	+	-	+
F. crassifolia subsp. *crassifolia*	13	0.3	0.8	0.6	0.3	1.0	0.7	Irregular amorphous	-	+	-
F. crassifolia subsp. *kurdica*	11	0.1	1.1	0.4	0.2	0.9	0.5	Irregular amorphous	-	+	-
F. crassifolia subsp. *hakkarensis*	13	0.1	0.8	0.6	0.2	0.6	0.3	Irregular amorphous	-	+	-
F. michailovskyi	13	0.1	1.0	0.5	0.1	0.9	0.4	Irregular amorphous	-	+	-
F. straussii	4	0.3	2.1	1.3	0.3	1.1	0.7	Irregular amorphous	+	-	+
F. alburyana	12	0.3	0.7	0.5	0.3	0.7	0.7	Regular polygonal	-	+	-
F. alfredae subsp. *platyptera*	10	0.4	1.2	0.7	0.3	1.0	0.6	Irregular amorphous	-	+	-
F. alfredae subsp. *glaucoviridis*	7	0.4	1.0	0.6	0.6	1.4	1.0	Irregular amorphous	-	+	-
F. fleischeriana	15	0.1	0.9	0.3	0.3	0.9	0,6	Irregular amorphous	-	+	-
F. sibthorpiana subsp. *sibthorpiana*	14	0.2	0.8	0.5	0.4	0.8	0.6	Irregular amorphous	-	+	-
F. sibthorpiana subsp. *enginiana*	12	0.2	1.0	0.7	0.5	0.8	0.7	Irregular amorphous	-	+	-
F. forbesii	18	0.2	0.7	0.4	0.4	0.9	0.7	Irregular amorphous	-	+	-
F. mughlae	23	0.2	0.6	0.4	0.3	0.6	0.4	Irregular amorphous	-	+	-
F. carica	4	0.8	2.0	0.7	0.3	0.6	0.4	Irregular amorphous	-	+	-
F. serpenticola	11	0.5	1.4	0.5	0.7	1.0	0.7	Irregular amorphous	-	-	+
F. byfieldii	19	0.1	1.0	0.7	0.3	0.9	0.5	Irregular amorphous	-	+	-
F. minima	9	0.3	1.5	0.9	0.4	0.9	0.7	Irregular amorphous	-	-	+
F. caucasica	19	0.1	0.9	0.6	0.3	0.9	0.6	Irregular amorphous	-	-	+
F. baskilensis	6	0.7	1.5	1.0	0.3	0.6	0.4	Irregular amorphous	-	-	+
F. pinardii	11	0.3	0.8	0.6	0.4	1.2	0.8	Irregular amorphous	-	+	-
F. kittaniae	10	0.1	0.8	0.5	0.3	1.4	0.7	Irregular amorphous	-	+	-
F. assyriaca subsp. *melananthera*	8	0.4	1.2	0.7	0.4	1.1	0.7	Irregular amorphous	-	+	-
F. latakiensis	6	0.4	1.0	0.8	0.4	0.6	0.8	Irregular amorphous	-	-	+
F. uva-vulpis	5	0.1	1.9	0.9	0.4	1.1	0.9	Regular polygonal	+	+	-

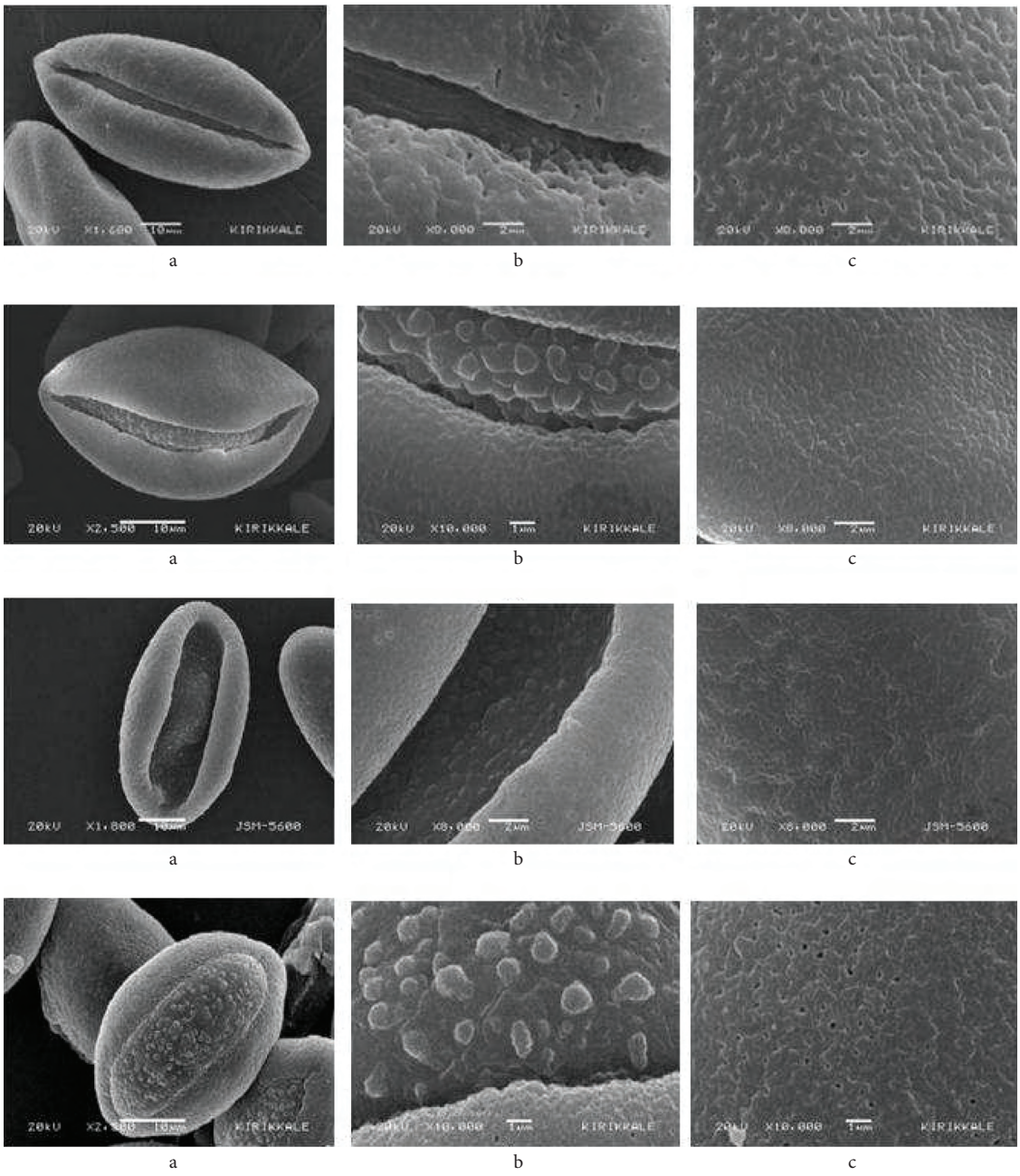

Figure 3. Pollen grains. SEM photos of Type I: – A: *Fritillaria imperialis*. a. equitorial view, b. sulcus membrane, c. exine surface. – B: *Fritillaria bithynica*. a. lateral view, b. sulcus membrane, c. exine surface. – C: *Fritillaria milasense*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria assyriaca* subsp. *assyriaca*. a. equatorial view, b. sulcus membrane, c. exine surface.

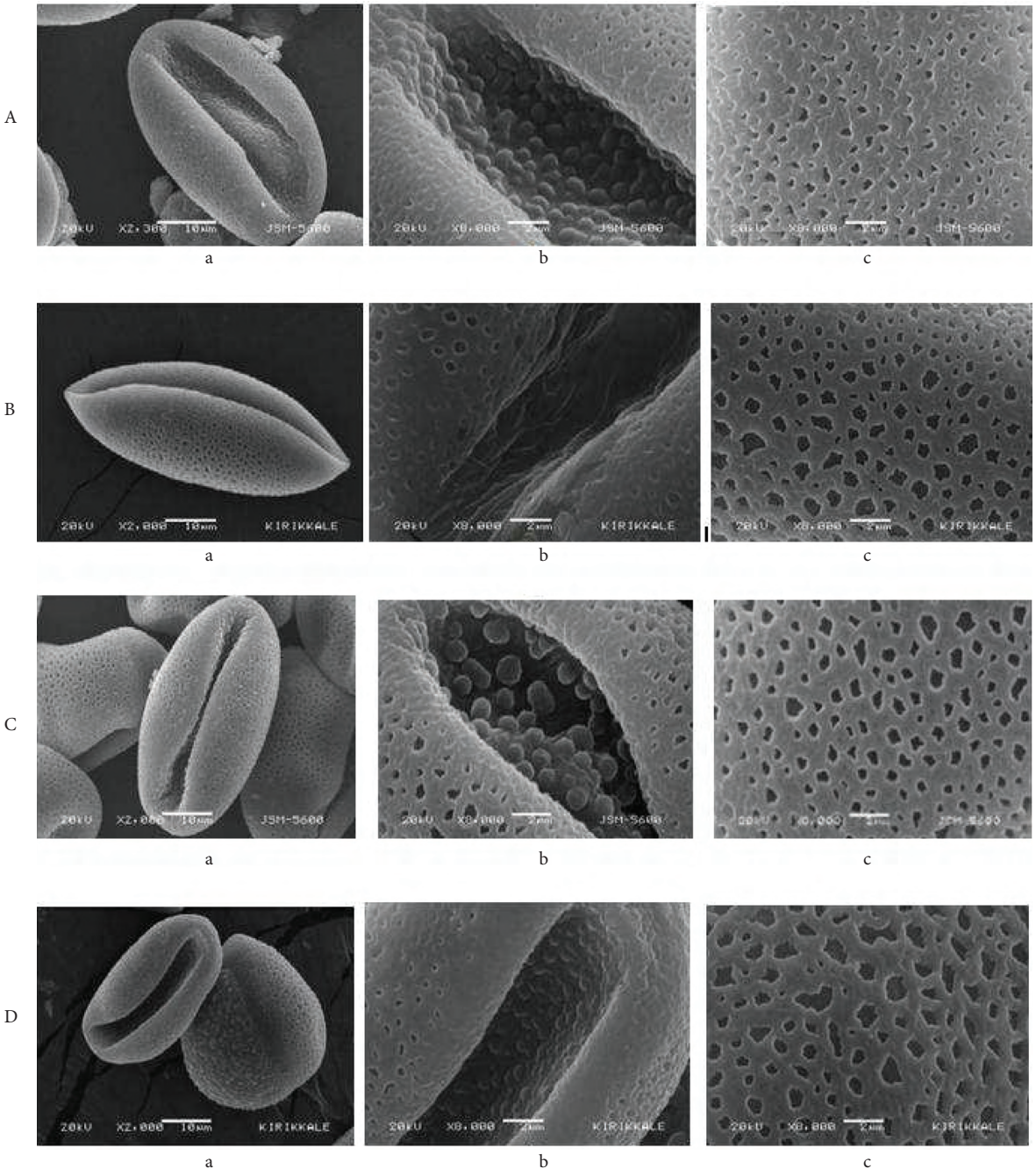

Figure 4. Pollen grains. SEM photos of Type I, Type II: Type I – A: *Fritillaria elwesii*. a. equatorial view, b. sulcus membrane, c. exine surface. – Type II. B: *Fritillaria persica*. a. lateral view, b. sulcus membrane, c. exine surface. – C: *Fritillaria latifolia*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria acmopetala* subsp. *wendelboi*. a. equatorial view, b. sulcus membrane, c. exine surface.

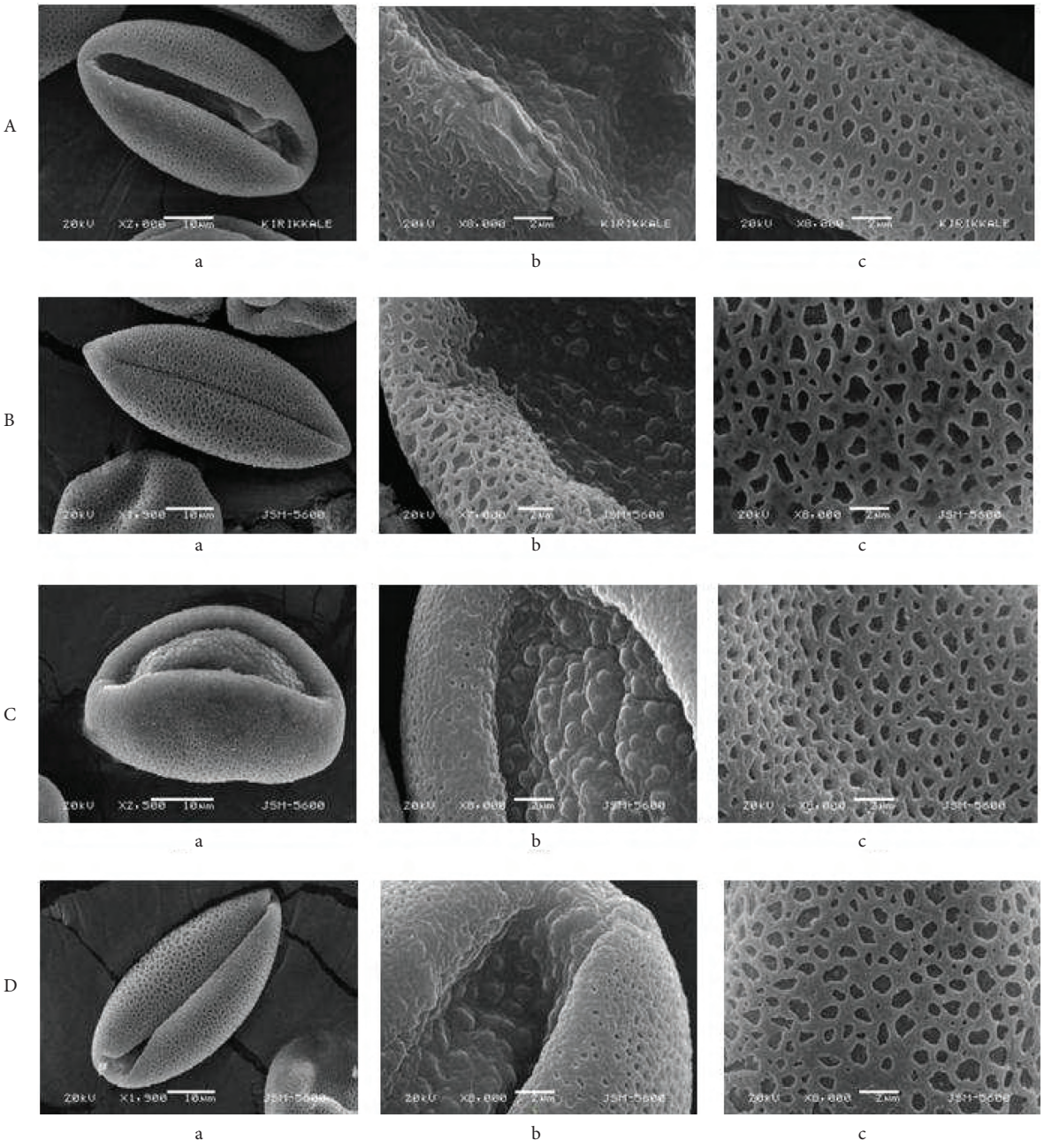

Figure 5. Pollen grains. SEM photos of Type II: – A: *Fritillaria crassifolia* subsp. *crassifolia* a. equatorial view, b. sulcus membrane, c. exine surface, – B: *Fritillaria crassifolia* subsp. *kurdica*. a. equatorial view, b. sulcus membrane, c. exine surface. – C: *Fritillaria crassifolia* subsp. *hakkarensis*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria michailovskyi*. a. equatorial view, b. sulcus membrane, c. exine surface.

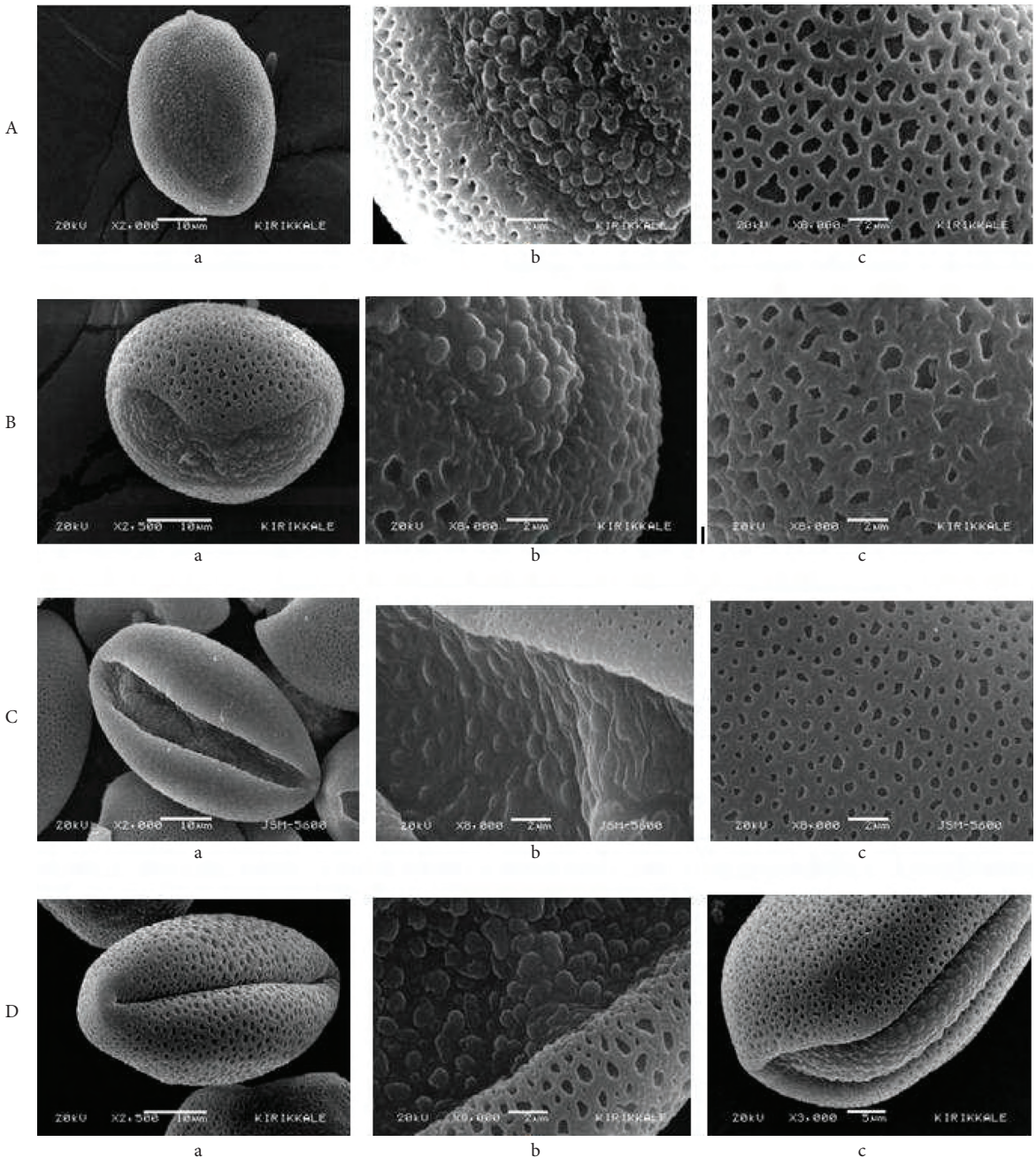

Figure 6. Pollen grains. SEM photos of Type II: – A: *Fritillaria alfredae* subsp. *platyptera*. a. equatorial view, b. sulcus membrane, c. exine surface. – B: *Fritillaria alfredae* subsp. *glaucoviridis*. a. lateral view, b. sulcus membrane, c. exine surface. – C: *Fritillaria fleischeriana*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria sibthorpiana* subsp. *sibthorpiana*. a. equatorial view, b. sulcus membrane, c. exine surface.

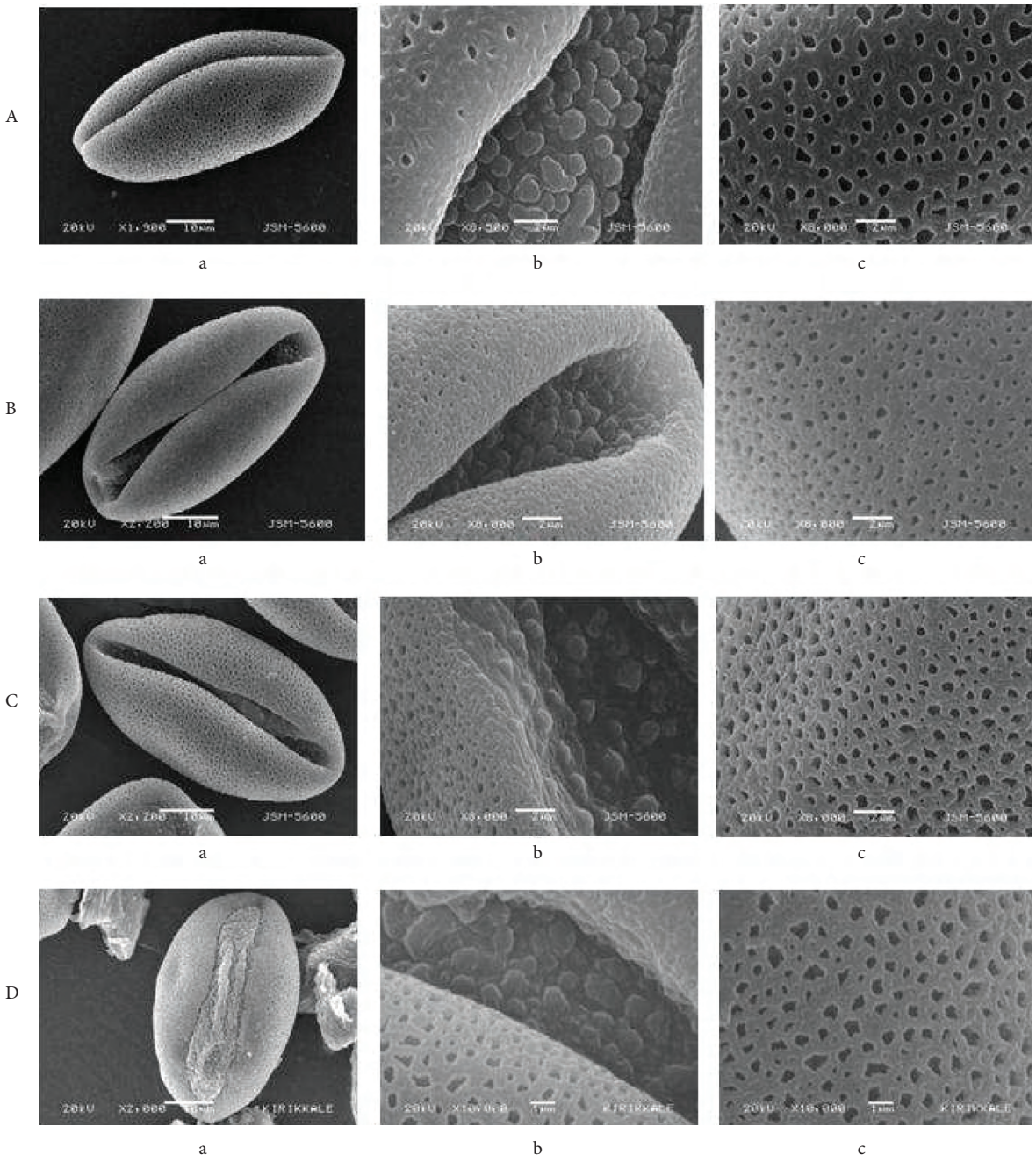

Figure 7. Pollen grains. SEM photos of Type II: – A: *Fritillaria sibthorpiana* subsp. *enginiana*. a. lateral view, b. sulcus membrane, c. exine surface. – B: *Fritillaria forbesii*. a. equatorial view, b. sulcus membrane, c. exine surface. – C: *Fritillaria mughlae*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria byfieldii*. a. equatorial view, b. sulcus membrane, c. exine surface.

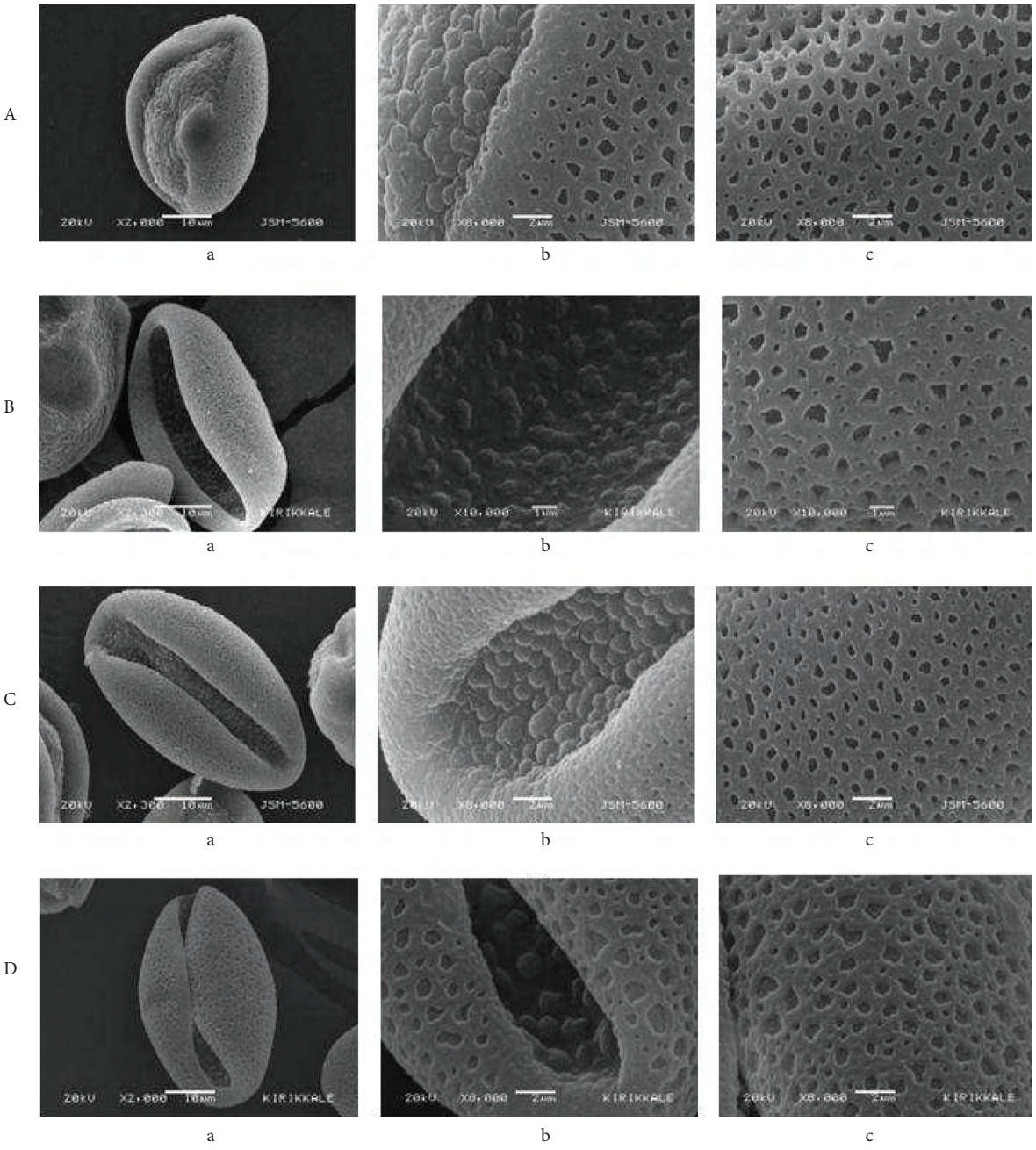

Figure 8. Pollen grains. SEM photos of Type II: – A: *Fritillaria serpenticola*. a. equatorial view, b. sulcus membrane, c. exine surface. – B: *Fritillaria caucasica*. a. equatorial view, b. sulcus membrane, c. exine surface. – C: *Fritillaria pinardii*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria kittaniae*. a. equatorial view, b. sulcus membrane, c. exine surface.

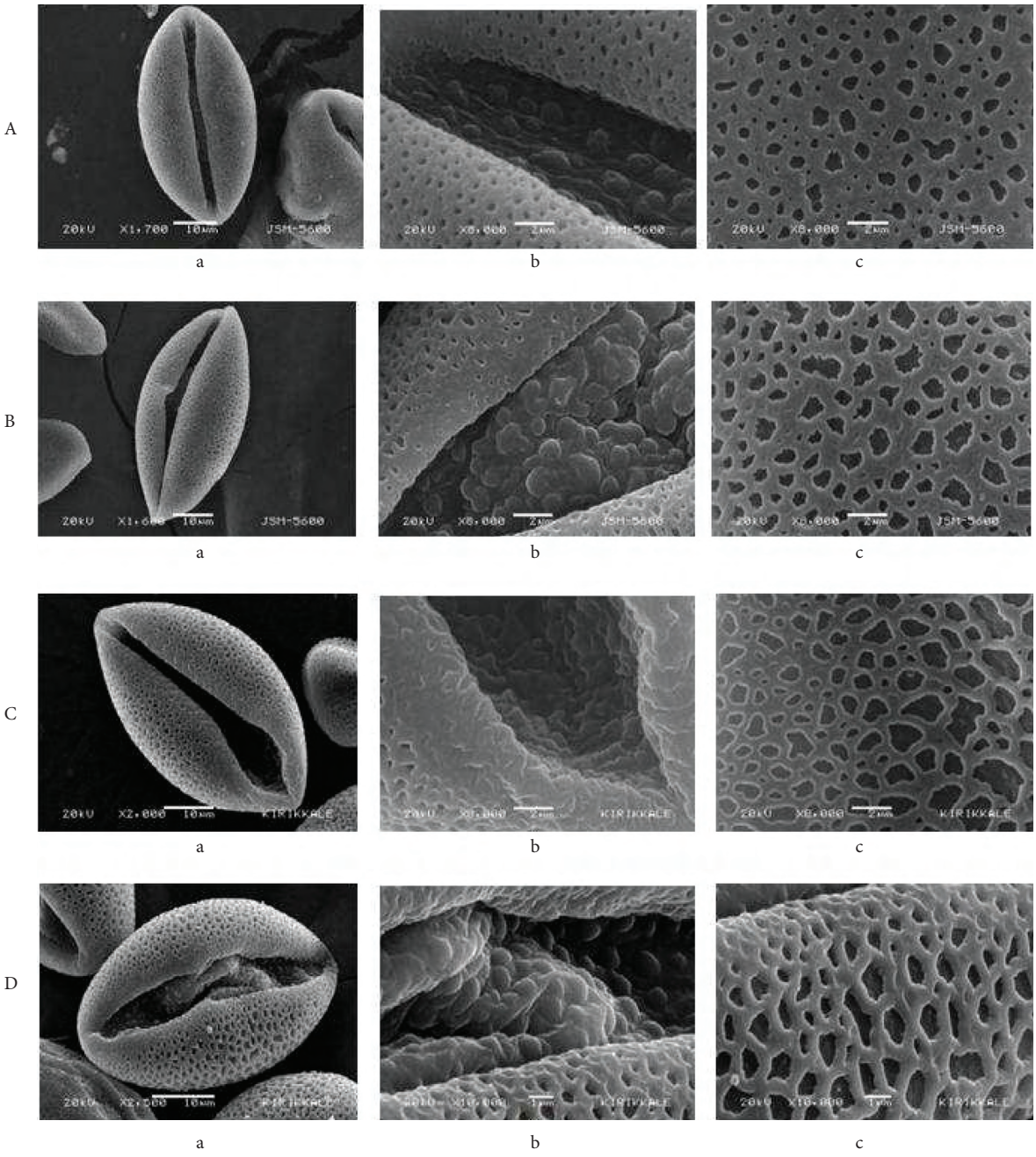

Figure 9. Pollen grains. SEM photos of Type II, Type III: Type II – A: *Fritillaria assyriaca* subsp. *melananthera*. a. equatorial view, b. sulcus membrane, c. exine surface. – B: *Fritillaria latakiensis*. a. equatorial view, b. sulcus membrane, c. exine surface. – Type III. – C: *Fritillaria aurea*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria acmopetala* subsp. *acmopetala*. a. equatorial view, b. sulcus membrane, c. exine surface.

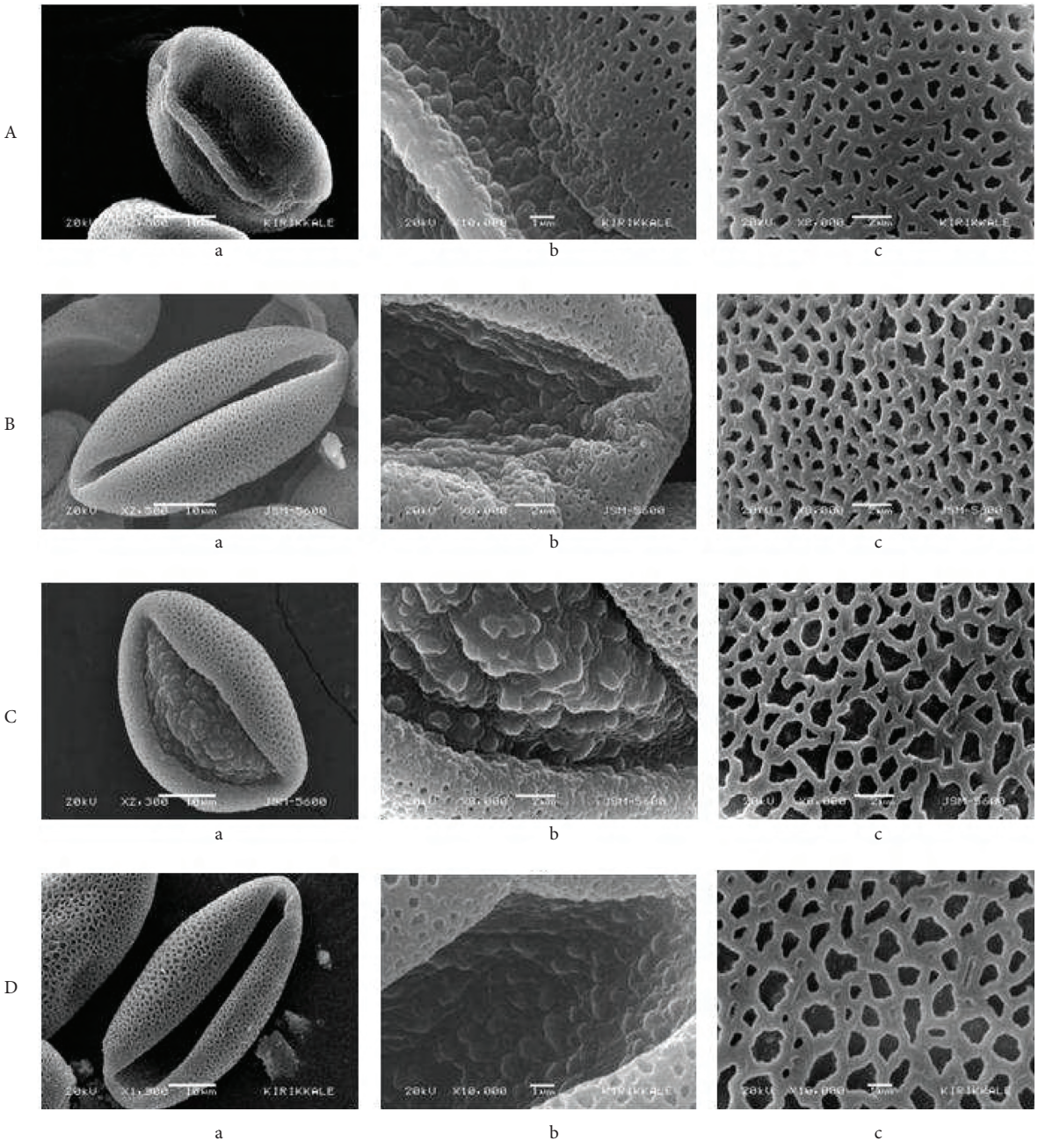

Figure 10. Pollen grains. SEM photos of Type III: – A: *Fritillaria whittallii*. a. equatorial view, b. sulcus membrane, c. exine surface. – B: *Fritillaria alburyana*. a. equatorial view, b. sulcus membrane, c. exine surface. – C: *Fritillaria carica*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria minima*. a. equatorial view, b. sulcus membrane, c. exine surface.

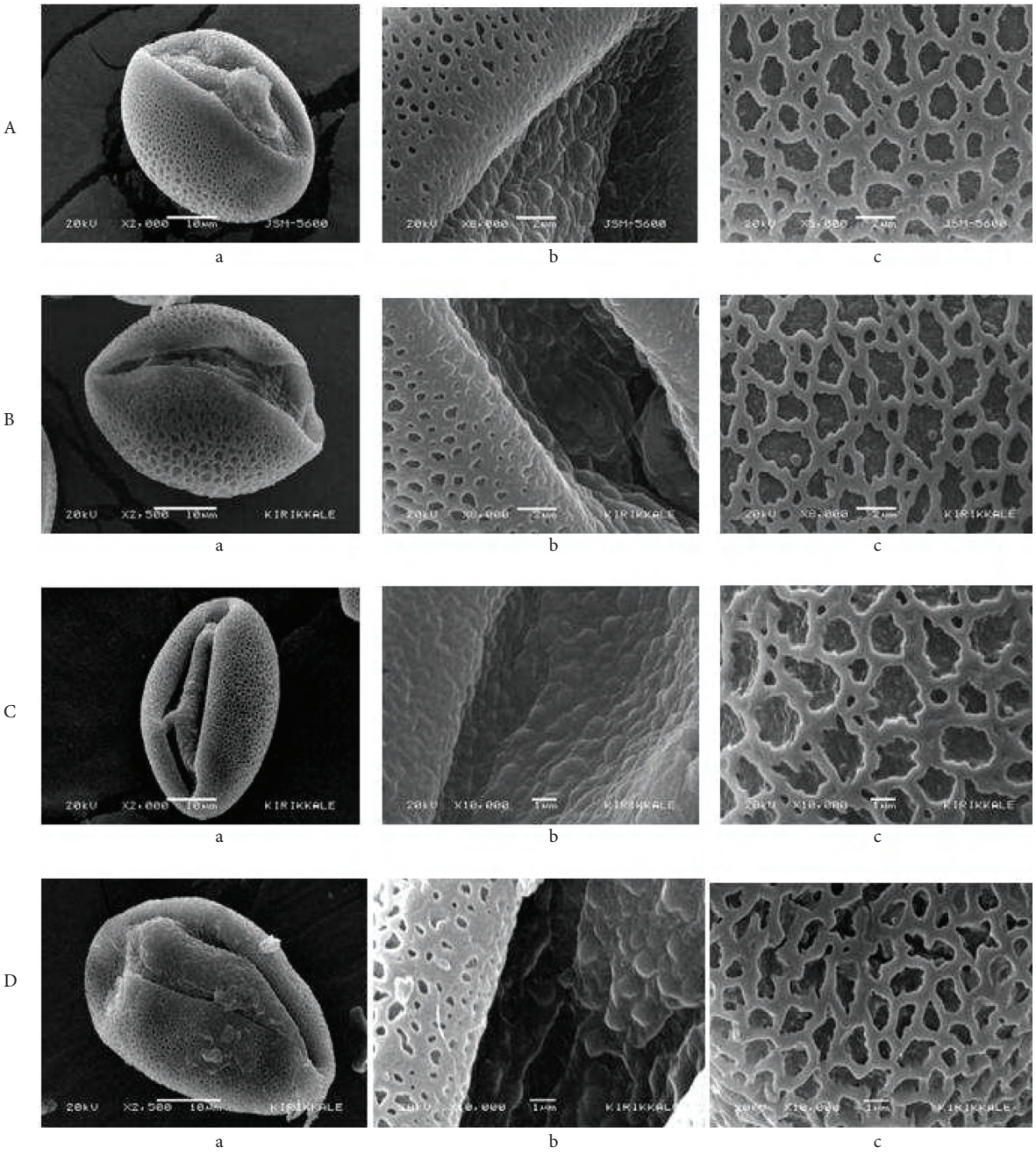

Figure 11. Pollen grains. SEM photos of Type IV: – A: *Fritillaria pontica*. a. equatorial view, b. sulcus membrane, c. exine surface. – B: *Fritillaria hermonis* subsp. *amana*. a. lateral view, b. sulcus membrane, c. exine surface. – C: *Fritillaria straussii*. a. equatorial view, b. sulcus membrane, c. exine surface. – D: *Fritillaria baskilensis*. a. equatorial view, b. sulcus membrane, c. exine surface.

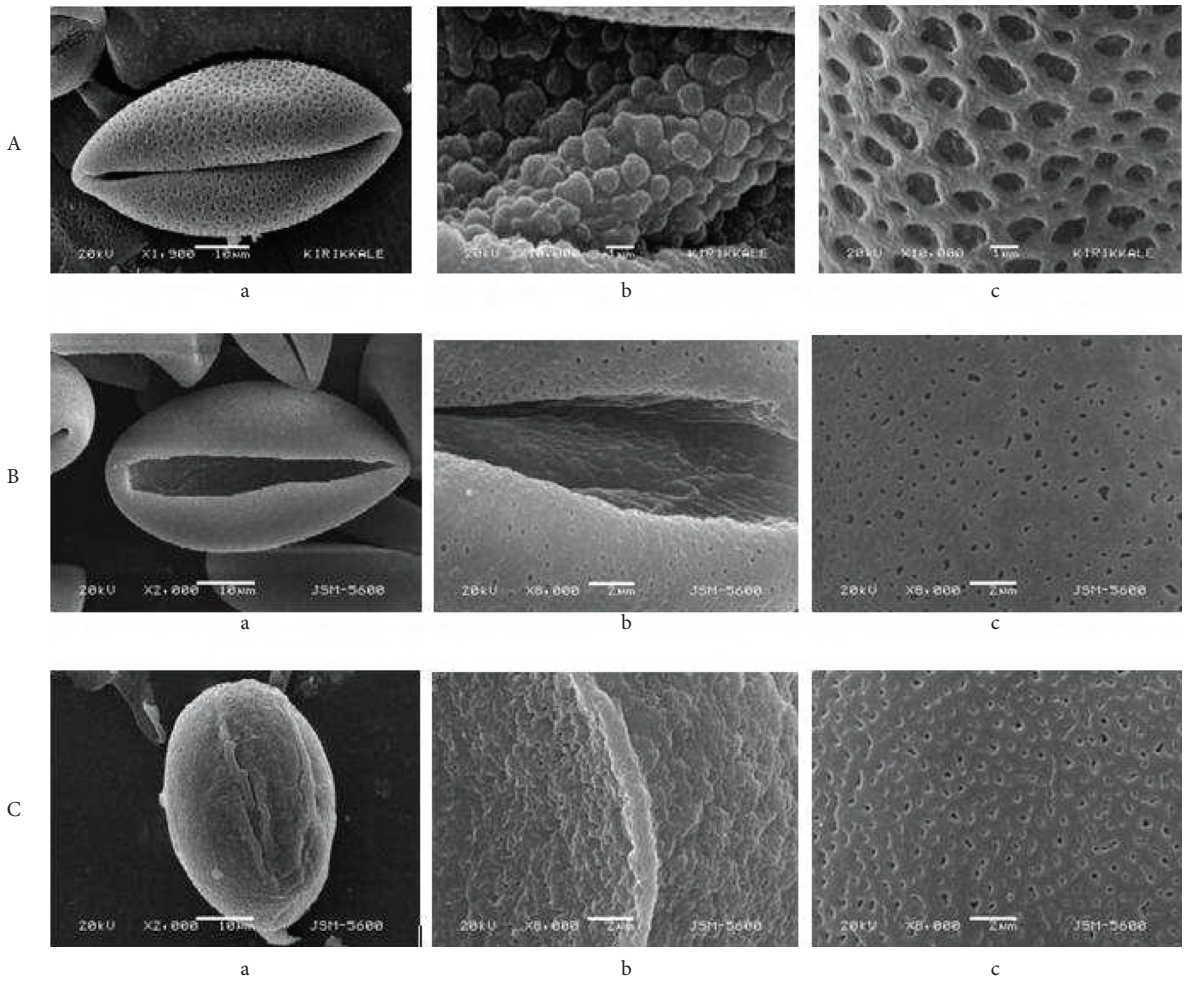

Figure 12. Pollen grains. SEM photos of Type IV, Type V, Type VI: Type IV – A: *Fritillaria uva-vulpis*. a. equatorial view, b. sulcus membrane, c. exine surface. – Type V – B: *Fritillaria stribrnyi*. a. equatorial view, b. sulcus membrane, c. exine surface. – Type VI – C: *Fritillaria minuta*. a. equatorial view, b. sulcus membrane, c. exine surface.

Discussion

This study shows that several pollen characters in *Fritillaria* are of taxonomic significance. *F. milasense* and *F. mughlae* are evaluated as new species by using pollen morphology (Tekşen & Aytaç, 2004, 2008). Differences are encountered in pollen shape, size, ornamentation, sulcus membrane ornamentation, and apex of sulcus. We recognised 5 main types, defined by pollen sculpturing, sulcus membrane ornamentation, and apex of sulcus. *Fritillaria* are proposed to be divided into 4 types by Özler and Pehlivan (2007). All of these characteristics are important for the infrageneric classification of *Fritillaria* (Schulze, 1980; Kosenko, 1991a, 1991b, 1992, 1999; Özler & Pehlivan, 2007) (Tables 1-3, Figures 3-12).

The sculpturing of the pollen exine is useful for establishing relationships among species. We recognised several types of exine sculpturing. In the species belonging to type I, the sculpturing is rugulate-reticulate. The sculpturing is reticulate-perforate in type II. In type III, it is reticulate. The sculpturing is suprareticulate in type IV. In type V, it

is perforate and type VI is psilate-perforate (Table 1, Figure 2). Özler and Pehlivan (2007) and Kosenko (1999) have stated that the most heterogeneous genus in Liliaceae is *Fritillaria* where several types of exine ornamentations (reticulate, suprareticulate, rugulate-reticulate, striate-reticulate, microreticulate, scabrate, and macroreticulate). The taxonomy of some species, such as *F. baskilensis* and *F. pinardii*, is problematic. Because the vegetative characters are very variable, species identification is difficult. The sculpturing of the pollen exine is a valuable character for separating between *F. baskilensis* (suprareticulate) and *F. pinardii* (reticulate-perforate).

Fritillaria have usually monosulcate or rarely zonosulcate (*F. whittallii*) aperture types. Sulcus long, reaching the ends of the grain or extending to the proximal side, broad. Kosenko (1991a, 1991b, 1992) and Özler and Pehlivan (2007) have shown that sulcus features may be taxonomic characteristics in *Fritillaria* pollens. Sulcus apex was rounded or sharp (Table 2). Özler and Pehlivan (2007) stated that the sulcus apex is rounded in *Fritillaria* pollen grains except for in *F. aurea* and *F. bithynica.* In this study the sulcus apex of *F. aurea* and *F. bithynica* was found to be round. Sulcus membrane surface was a good characteristic for classification of *Fritillaria* and its subspecies (Kosenko, 1991a, 1991b, 1992; Özler and Pehlivan, 2007). In species of the genus *Fritillaria* a plicate-granulate, gemmate, and granulate sulcus membrane is typical. We found that *Fritillaria* species can be divided into 7 pollen types according to sulcus membrane: psilate, verrucate, verrucate-granulate, granulate, granulate-striate, rugulate, and gemmate (Table 2, Figure 2-12).

In the taxa with reticulate ornamentation, lumen shape is regular-polygonal or irregular-amorphous. Muri are undulate or smooth. Schulze (1980), Kosenko (1991a, 1991b), and Pınar et al. (2009) have indicated that muri and lumen shapes of the pollen are taxonomically significant characters.

In the analysis of the mean long axis (LA) and short axis (SA) values, the largest grains were found in *F. imperialis* (57.9-40.4 μm) and the smallest LA values in *F. stribrnyi* (40.1 μm), while the smallest SA value was found in *F. whittallii* (23.1 μm). *Fritillaria* taxa have subprolate or prolate pollen shape (Table 1, Figure 1).

Palynological data (type of sulcus apex, membrane, and exine ornamentation) indicate the heterogeneous character of this genus. We have determined that there are intraspecific variations in this genus. Kosenko (1999) and Özler and Pehlivan (2007) have stated that the most heterogeneous genus in Liliaceae is *Fritillaria.*

Acknowledgement

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