S.M. JEELANI, S. RANI,
S. KUMAR, S. KUMARI,
R.C. GUPTA

Department of Botany, Punjabi University, Patiala, 147 002 India
E-mail: sandrabi555@gmail.com

CYTOLOGICAL STUDIES OF *BRASSICACEAE* BURN. (*CRUCIFERAE* JUSS.) FROM WESTERN HIMALAYAS

Cytological studies have been carried out on 12 species of Brassicaceae Burn. on population basis from different geographical areas of Kashmir and Himachal Pradesh in the Western Himalayas. Variable chromosome reports for Barbaraea intermedia (n = 16), Cardamine loxostemonoides (n = 8), Nasturtium officinale (n = 8), Sisymbrium orientale (n = 14) on world-wide basis have been added to the previous reports of these species. The chromosome numbers in seven species as Barbaraea intermedia (n = 8), B. vulgaris (n = 8), Capsella bursa-pastoris (n = 8), Descuriania sophia (n = 10), Rorippa islandica (n = 8), Sisymbrium strictum (n = 7) and Thlaspi alpestre (n = 7) have been worked out for the first time from India. The meiotic course in the populations of seven species such as Barbaraea intermedia, Capsella bursa-pastoris, Coronopus didymus, Descuriania sophia, Nasturtium officinale, Sisymbrium orientale and S. strictum varies from normal to abnormal while all the populations of two species Barbaraea vulgaris and Sisymbrium irio show abnormal meiotic course. Meiotic abnormalities are in the form of cytomixis, chromosomal stickiness, unoriented bivalents, inter-bivalent connections, formation of laggards and bridges, all resulting into abnormal microsporogenesis. Heterogenous sized fertile pollen grains and reduced reproductive potentialities have invariably been observed in all the meiotically abnormal populations. However, the meiotic course in all the populations of Cardamine loxostemonoides, Rorippa islandica and Thalspi alpestre is found to be normal with high pollen fertility.

Introduction. The family Brassicaceae includes 332 genera and 3,709 species [1] widely distributed throughout the world but abundant in north temperate zone with Mediterranean as major centre. In Indian subcontinent, 61 genera and 168 species [2] are taxonomically known which are mostly found in temperate and alpine Himalayas. Starting with the first comprehensive cytological studies [3–5], at present more than 9.000 chromosomal counts are known for 232 (68.6 %) genera and 1.558 (42.0 %) species of the family all over the world [1]. The chromosome numbers in the family vary from n = 4 in *Stenoptalum nutans* from Australia to n = 128 in *Cardamine concatenate* and *C. diphylla* from eastern North America [1]. From the Indian subcontinent, the chromosomal counts are known for nearly half the number of species of the family i.e. 90 species belonging to 41 genera. It is noted that cytological evaluation of Brassicaceae has got poor attention from Western Himalayas, in general, and for the present studied areas in particular. As the family is well documented with natural allopolyploidy, dysploid aneuploid series and mixoploidy coupled with economic importance, making it very good collection of plant material to be studied further from cytological perspective. To make additions to the chromosomal database and to study the genetic diversity at intra- and interspecific levels, concerning lesser known angiospermic families, from newer here as areas the present meiotic studies on the aforesaid taxa of Brassicaceae have been carried out.

Materials and methods. For meiotic studies, flower buds were collected from different localities of selected areas of Western Himalayas (Table 1). Smears of appropriate sized flower buds were made after fixing in Carnoy's fixative, using standard acetocarmine technique. Pollen fertility was estimated by mounting mature pollen grains in glycero-acetocarmine (1:1) mixture or 1 % aniline blue. Well-filled pollen grains with stained nuclei were taken as apparently fertile, while shrivelled and unstained pollen grains were counted as sterile. Photomicrographs of pollen mother cells and pollen grains were made from freshly prepared slides using Nikon 80i eclipse Digital Imaging System. Voucher specimens are deposited in the Herba rium, Department of Botany, Punjabi University, Patiala (PUN).

Results. Detailed meiotic studies have been carried out on 29 populations belonging to 12

Table 1

Data showing location, altitude, accession number, present chromosome number, ploidy level, meiotic course and pollen fertility in different taxa of family *Brassicaceae* Burn. from Western Himalayas

Taxa	Locality/Altitude (m)/ Accession Number	Present Chromosome Number (*n*)/ Figure Number	Ploidy level	Meiotic course**/ Pollen fertility, (%)
Barbaraea intermedia Boreau	Ferozpur Nallah Distt. Baramulla (Kashmir)/2,400 /54270	8 (Fig. 1, *a*)	2*x*	A/64. 42
	Triund, Distt. Kangra N/(H.P*.)/3,000/52744	16 (Fig. 1, *b*)	4*x*	N/96.50
B. vulgaris R.Br.	Chhota-Bhangal, Distt. Kangra (H.P.)/2,300/52796	8 (Fig. 1, *c*)	2*x*	A/60.78
Cardimine loxostemonoides O.E.	Ferozpur Nallah, Distt.Baramullah (Kashmir)/2,200/52473	8 (Fig. 1, *d*)	2*x*	N/97.55
	Ratnipora, Distt. Pulwama (Kashmir)/ 1,750/52472	8	2*x*	N/83.87
Capsella bursa-pastoris (L.) Medik	Lower Munda, Distt. Anantnag (Kashmir)/ 2,300/54193	16 (Fig. 1, *e*)	4*x*	A/69.01
	Ratnipora, Distt. Pulwama (Kashmir)/1,750/54192	16	4*x*	A/62.42
	Chhota-Bhangal, Distt. Kangra (H.P.)/2,300/52722	8 (Fig. 1, *f*)	2*x*	A/60.00
	Salai, Distt. Kangra (H.P.)/1,600/52733	16	4*x*	N/97.98
	Shillai, Distt. Sirmaur (H.P.)/1,800/52653	16	4*x*	N/98.65
Coronopus didymus (L.) Smith	Triund, Distt. Kangra (H.P.)/3,000/52703	16 (Fig.1, *g*)	4*x*	A/65.78
	Dharmkot, Distt. Kangra (H.P.)/2,800/ 52677	16	4*x*	N/94.54
Descuriainia sophia Webb ex Prantl.	Yusmarg, Distt. Budgam (Kashmir)/2,600/54202	10 (Fig. 1, *h*)	2*x*	A/63.45
	Pehalgam, Distt. Anantnag (Kashmir)/ 2,300/54201	10	2*x*	N/88.78
Nasturtium officinale R.Br.	Ferozpur Nallah, Distt. Baramullah (Kashmir)/2,100/54205	8	2*x*	N/92.65
	Ranhear, Distt. Kangra (H.P.)/800/52736	8 (Fig. 1, *i*)	2*x*	A/65.50
	Nahan, Distt. Sirmaur (H.P.)/900/55242	8	2*x*	A/61.45
Rorippa islandica (Oeder) Berbas	Keller, Distt. Shopian (Kashmir)/2,000/ 54827	8 (Fig. 1, *j*)	2*x*	N/92.00
Sisymbrium irio L.	Aharbal, Distt. Kulgam (Kashmir)/2,100/ 54271	14 (Fig. 1, *k*)	4*x*	A/63.47
	Saketi, Distt. Sirmaur (H.P.)/800/55241	7 (Fig. 1, *l*)	2*x*	A/60.87
	Renukaji, Distt. Sirmaur (H.P.)/650/54234	14	4*x*	A/66.94
S. orientale L.	Keller, Distt. Shopian (Kashmir)/2,200/ 54235	14 (Fig 1, *m*)	4*x*	A/65.76
	Chhota-Bhangal, Distt. Kangra (H.P.)/ 2,300/52741	8	2*x*	N/96.45
	Triund, Distt. Kangra (H.P.)/3,000/52740	8	2*x*	A/62.00
	Churdhar, Distt. Sirmaur (H.P.)/3,630/ 54206	8	2*x*	A/60.50

Continuation of table 1

Taxa	Locality/Altitude (m)/ Accession Number	Present Chromosome Number (*n*)/Figure Number	Ploidy level	Meiotic course**/ Pollen fertility, (%)
S. strictum L.	Batnoor Tral, Distt. Pulwama (Kashmir)/2,300/ 52475	7 (Fig 1, *n*)	2*x*	A/69.78
	Chhota-Bangal, Distt. Kangra (H.P.)/2,300/ 52704	7	2*x*	A/65.75
	Nauradhar, Distt. Sirmaur (H.P.)/1,800/54209	7	2*x*	N/96.98
Thlaspi alpestre L.	Baragran Distt. Kangra (H.P.)/3,000/52742	7 (Fig. 1, *o*)	2*x*	N/93.50

* H.P. = Himachal Pradesh, ** N = Normal, ** A = Abnormal.

Data on cytomixis, meiotic course and pollen size in different

Taxa/Accessions	Cytomixis		Meiotic	
	% age of PMCs involved Meiosis-I/Meiosis-II	Number of PMCs involved	Chromosomal stickiness at M-I (%)	
Barbaraea intermedia				
54270	13.86(14/101)/5.71(6/105)	2–3	6.06(6/99)	
52796	–/–	–	1.98(2/101)	
B. vulgaris				
52796	9.73(11/113)/8.04(7.87)	2–3	–	
Capsella bursa-pastoris				
54193	20.83(25/120)/15.38(20/130)	2–6	13.91(16/115)	
54192	7.14(7/98)/4.08(4/98)	2–3	5.55(4/72)	
52722	–/–	–	–	
Coronopus didymus				
52703	5.21(6/115)/6.83(8/117)	2–3	3.38(4/118)	
Descuriainia sophia				
54202	5.21(6/115)/6.42(7/109)	2–3	3.73(4/107)	
Nasturtium officinale				
55736	–/–	–	–	
55242	7.33(8/109)/5.08(6/118)	2–3	1.81(2/110)	
Sisymbrium irio				
54271	–/–	–	4.65(6/129)	
55241	5.94(6/101)	2–3	–	
54234	–/–	–	–	
S. orientale				
54489	6.95(8/115)/5.00(6/120)	2–3	6.15(8/130)	
52740	–/–	–	2.04(2/98)	
S. strictum				
52475	11.53(15/130)/8.00(10/125)	2–3	3.05(4/131)	
52704	12.87(17/132)/12.59(16/127)	2–3	5.45(6/110)	

Figures in parenthesis denote observed number of abnormal PMCs in the numerator and total number of PMCs species of 9 genera of the family Brassicaceae from different localities with altitudinal range of 800–3,000 m from two districts of Himachal Pradesh and 2,000–2,600 m from six districts of Kashmir. The data regarding locality with altitude, accession number, present chromosome numbers with figure numbers, ploidy level, nature of meiotic course and pollen fertility of the presently worked out populations has been presented in Table 1.

Two populations of *Barbaraea intermedia*, one each from Kashmir and Himachal Pradesh shows intraspecific variability in the form of 2x (n = 8) and 4x (n = 16) cytotypes, respectively. Single population of *B. vulgaris* collected from Himachal Pradesh and two populations of *Cardamine loxostemonoides* collected from Kashmir represent 2x cytotypes, all exhibiting n = 8. *Capsella bursa-pastoris* is another species depicting intraspecific variability as one population from Himachal Pradesh shows 2x cytotype (n = 8) whereas two populations from Kashmir and two populations from Himachal Pradesh show 4x cytotype (n = = 16) pointing wide spread occurrence of tetraploids of this species in the Western Himalayas.

Both the populations of *Coronopus didymus*, studied from Himachal Pradesh have the tet-

Table 2

species of *Brassicaceae* Burn. from Western Himalayas

course showing PMCs with			Size (μm) of fertile pollen grains (Range)
Unoriented bivalents at M-I (%)	Bridges at Meiosis-I/Meiosis-II (%)	Laggards at Meiosis-I/ Meiosis-II (%)	
6.45(6/93)	7.23(11/152)/8.92(10/112)	8.86(7/79)/11.22(11/98)	15.08×13.00–15.16×13.08
3.48(4/115)	14.28(15/105)/9.52(10/105)	11.76(12/102)/8.84(10/113)	
–	8.84(10/113)/7.50(9/120)	9.23(12/130)/–	19.96×18.47–16.45×16.20
12.50(15/120)	13.04(15/115)/10.00(12/120)	14.61(19/130)/15.00(18/120)	
–	9.67(6/62)/12.90(8/62)	11.29(7/62)/8.06(5/62)	18.18×17.05–17.24×17.10
5.55(4/72)	10.00(5/50)/8.00(4/50)	11.11(6/54)/9.25(5/54)	
2.63(3/114)	4.80(6/125)/4.13(5/121)	6.25(8/128)/5.88(7/119)	14.17×13.35–16.25×15.45
1.85(2/108)	6.25(7/112)/1.53(2/130)	4.87(6/123)/1.73(2/115)	18.83×17.24–16.95×16.05
–	4,16(4/96)/5/21(6/115)	5.04(6/119)/3.60(4/111)	15.78×14.00–15.17×13.14
1.76(2/113)	4.87(6/123)/–	6.95(8/115)/–	
6.40(8/125)	6.95(8/115)/5.00(6/120)	7.20(9/125)/5/60(7/125)	
–	6.36(7/110)/6.08(7/115)	8.00(10/125)/9/91(12/121)	16.78×14.00–15.26×13.87
–	6.83(8/117)/–	5.21(6/115)/6/66(8/120)	
5.08(6/118)	6.89(8/116)/3.36(4/119)	6.66(8/120)/7.69(9/117)	18.78×16.00–15.05×17.90
4.04(4/99)	7.47(8/107)/5.12(6/117)	13.60(17/125)/12.30(16/130)	
4.65(6/129)	5.98(7/117)/5.21(6/115)	9.30(12/129)/7.63(10/131)	16.75×15.90–14.56×13.26
3.14(4/127)	4.95(6/121)/4.20(5/119)	5.00(6/120)/5.78(7/111)	

observed in denominator.

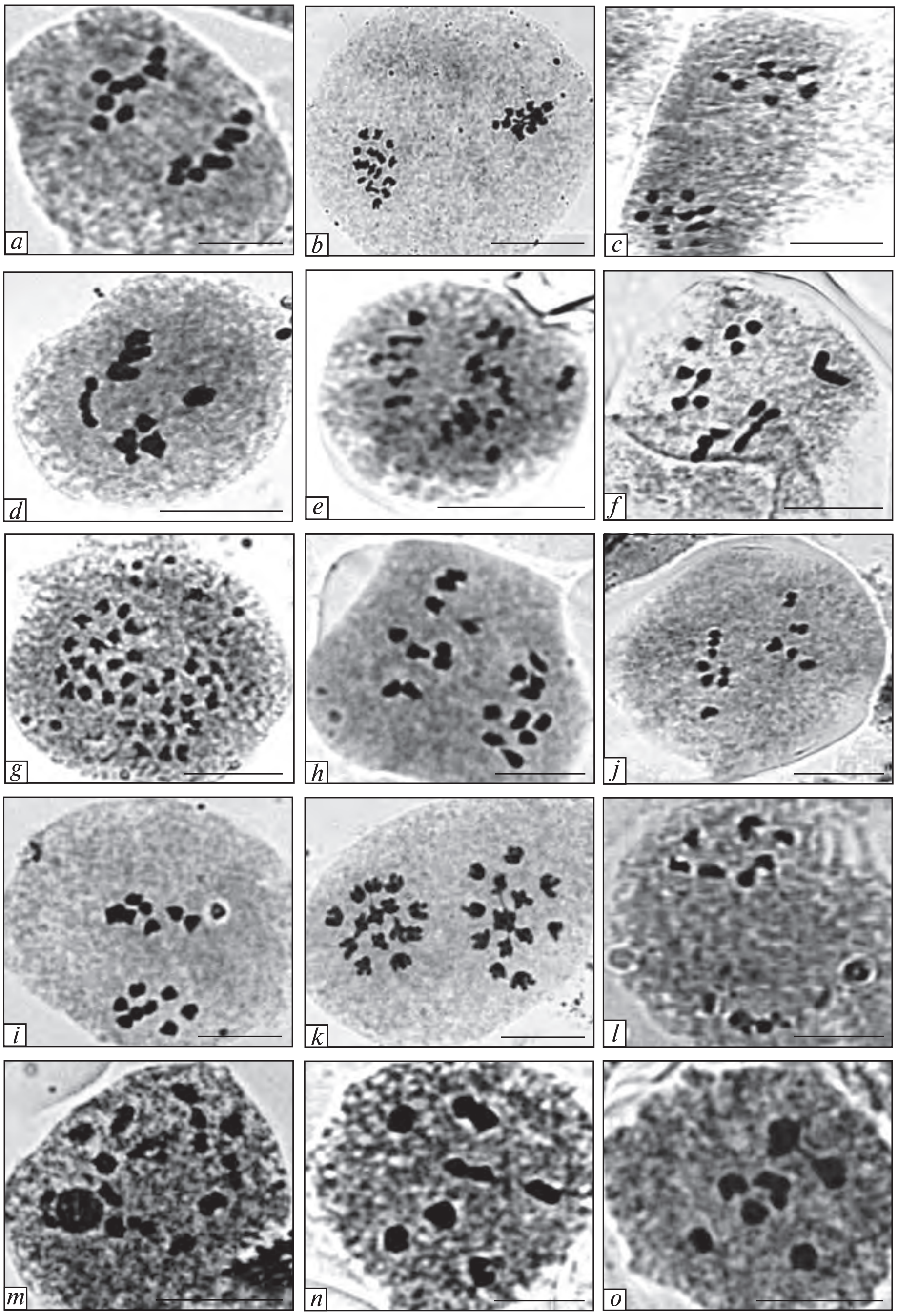

Fig. 1. *Barbaraea intermedia* (*a*) – PMC at A-I (*n* = 8); *B. intermedia* (*b*) – PMC at A-I (*n* = 16); *B. vulgaris* (*c*) – PMC at A-I (*n* = 8); *Cardimine loxostemonoides* (*d*) – PMC at M-I (*n* = 8); *Capsella bursa-pastoris* (*e*) – PMC at M-I (*n* = 16); *Capsella bursa-pastoris* (*f*) – PMC at M-I (*n* = 8); *Coronopus didymus* (*g*) – PMC at M-II (*n* = 16); *Descuriania sophia* (*h*) – PMC at A-I (*n* = 10); *Nasturtium officinale* (*i*) – PMC at A-I (*n* = 8); *Rorippa islandica* (*j*) – PMC at A-I (*n* = 8); *Sisymbrium irio* (*k*) – PMC at M-II (*n* = 14); *S. irio* (*l*) – PMC at A-I (*n* = 7); *S. orientale* (*m*) – PMC at Diakinesis (*n* = 14); *S. strictum* (*n*) – PMC at M-I (*n* = 7), *Thlaspi alpestre* (*o*) – PMC at M-I (*n* = 7). Bar = 10 μm

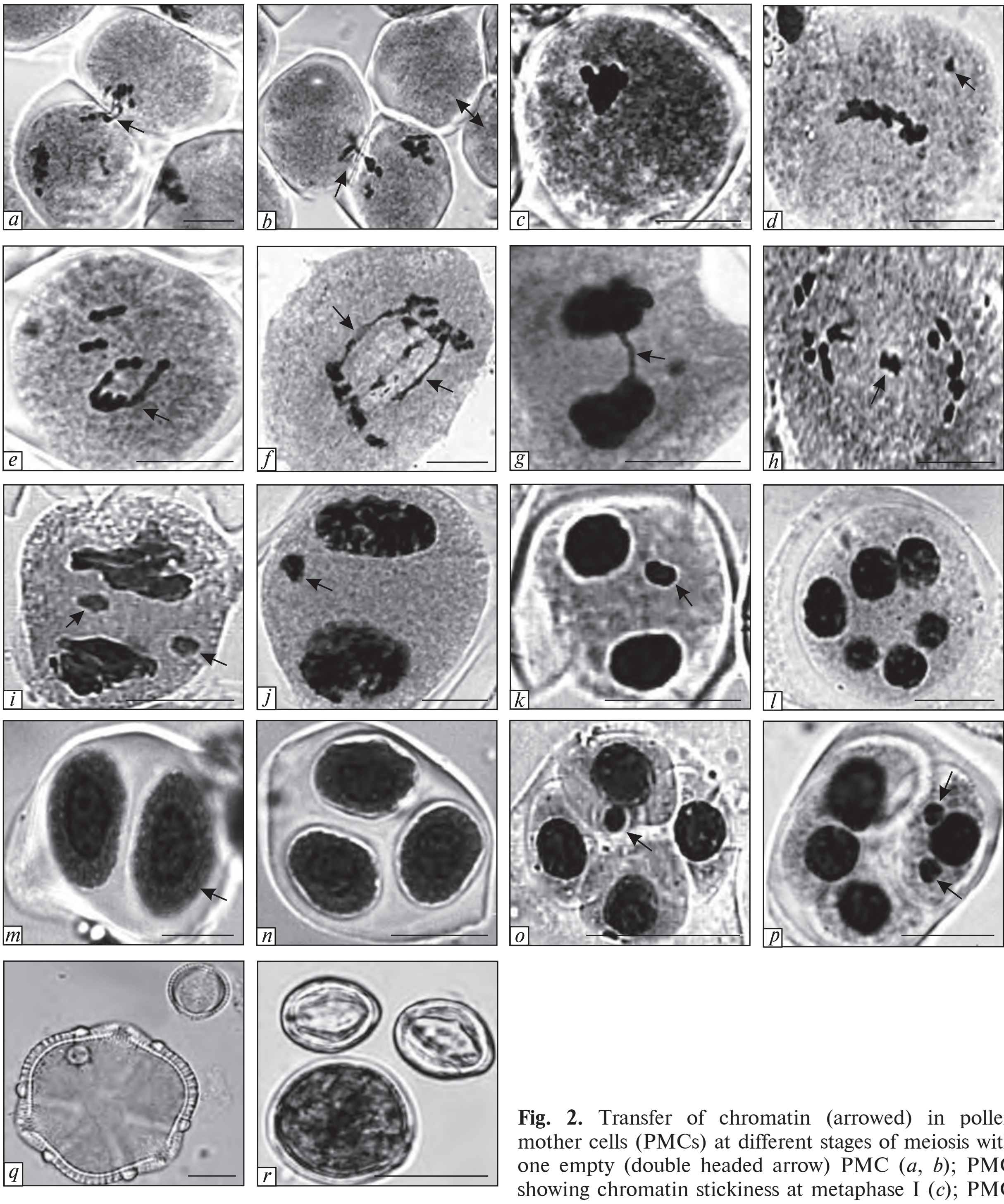

Fig. 2. Transfer of chromatin (arrowed) in pollen mother cells (PMCs) at different stages of meiosis with one empty (double headed arrow) PMC (*a*, *b*); PMC showing chromatin stickiness at metaphase I (*c*); PMC showing unoriented bivalent at M-I (*d*); PMC showing inter-bivalent connections at M-I (*e*); PMC with multiple bridges (arrowed) at anaphase I (*f*); PMC showing bridge (arrowed) at telophase I (*g*); PMC with laggards (arrowed) at anaphase I (*h*); PMCs showing laggards (arrowed) at telophase I (*i–k*); PMC with six poles at telophase II (*l*); Diad (*m*); Triad (*n*); Tetrad with micronuclei (arrowed) (*o, p*); Fertile pollen grains differing in size (*q*); Fertile and sterile pollen grains (*r*). Bar = 10 μm

raploid cytotypes (n = 16). Two populations of *Descuriainia sophia* have been collected from Kashmir exhibiting meiotic chromosome number n = 10 and diploid status based on x = 10. In case of *Nasturtium officinale*, one population from Kashmir and two populations from different parts of Himachal Pradesh, all depict 2x cytotypes with n = 8. Likewise *Rorippa islandica* based on single population studied from Kashmir is also 2x (n = 8). For *Sisymbrium irio* one population form district Kangra of Himachal Pradesh is reported to be 2x (n = 7) whereas two other populations, one from Kashmir and other from district Sirmaur of Himachal Pradesh on the contrary are noted to be 4x (n = 14). *S. orientale* makes interesting case where three populations studied from Himachal Pradesh represent only 2x (n = 8), but a single population studied from Kashmir is found to be 4x based on x = 7. In case of *S. strictum*, one population from Kashmir and two from Himachal Pradesh as well as for *Thalspi alpestre*, a single population from Himachal Pradesh, all unequivocally represent 2x cytotypes strictly with n = 7.

The meiotic abnormalities have been recorded in some populations of *Barbaraea intermedia*, *Capsella bursa-pastoris*, *Coronopus didymus*, *Descuriania sophia*, *Nasturtium officinale*, *Sisymbrium orientale* and *S. strictum* and in all the populations of *Barbaraea vulgaris* and *Sisymbrium irio*. In such populations, the meiotic abnormalities in the form of cytomixis, chromatin stickiness, unoriented bivalents, inter-bivalent connections, bridges, laggards or multipolar spindle have been observed at different stages of meiosis (Table 2; Fig. 2, *g*–*k*). Regarding cytomixis, the chromatin transfer from early prophase to pollen grain formation has been observed in most of these populations, with the highest percentage recorded in one population of *Capsella bursa-pastoris* involving 2–6 PMCs (Table 2). Cytomixis in these species results into the production of hypo- and hyperploid PMCs and even empty PMCs (Fig. 2, *b*). Chromatin stickiness involving few bivalents or whole complement is seen from prophase-I to metaphase-I (Fig. 2, *c*). The unoriented bivalents at metaphase-I (Fig. 2, *d*) have also been observed with highest frequency noted in one population of *Capsella bursa-pastoris* (Table 2). Interbivalent connections have been observed at M-I in one of the populations of *Capsella bursa-pastoris* from Chotta Bhangal (Fig. 2, *e*). These meiotically abnormal populations quite frequently show the presence of chromosomal laggards and bridges at anaphases and telophases (Fig. 2, *f*–*k*). Instead of regular spindle formation, abnormal split spindles and three poles per PMC at T-I and even six poles at T-II (Fig. 2, *l*) have been seen in significant number of PMCs in *Capsella bursa-pastoris*, *Descuriania sophia*, *Nasturtium officinale* and *Sisym-*

Data on abnormal

Taxa/Accessions	Monads	
	WMN	WM
Barbaraea intermedia		
54270	2.06(2/97)	1.03(1/97)
52796	5.60(6/107)	–
Barbaraea vulgaris		
52796	2.00(2/100)	2.00(2/100)
Capsella bursa-pastoris		
54193	1.98(2/101)	0.99(1/101)
54192	4.76(6/126)	2.38(3/126)
52722	4.31(6/139)	0.71(1/139)
Coronopus didymus		
52703	1.96 (2/102)	0.98(1/102)
Descuriainia Sophia		
54202	1.04(1/96)	1.04(1/96)
Nasturtium officinale		
55136	–	–
55242	1.90(2/105)	0.95(1/105)
Sisymbrium irio		
54271	0.86(1/115)	1.73(2/115)
54241	–	–
54234	1.96(2/102)	0.98(1/102)
S. orientale		
54489	0.98(1/102)	–
52740	0.97(1/103)	–
S. strictum		
52475	1.83(2/109)	0.91(1/109)
52704	2.88(3/104)	1.92(2/104)

Indication. WMN = without micronuclei; WM = with ber of PMCs observed in denominator.

brium orientale. This results into abnormal microsporogenesis leading to the formation of monads, diads, triads or polyads, along with micronuclei (Fig. 2, *m*–*p*; Table 3) and leads to the formation of heterogeneous sized fertile pollen grains with reduced pollen fertility (Fig. 2, *q*, *r*). The pollen fertility in the populations with normal meiosis has been recorded to be nearly cent per cent.

Discussion. As evident from the great amount of variation reported in chromosome numbers of Brassicaceae in literature on world-wide basis, it is clear that family Brassicaceae represents range of genera depicting mono-, di- and polybasic nature. Some authors have suggested the base numbers to be considered from $x = 4–13$, considering even some higher numbers as 32, 42, etc. to be taken as base numbers, the later most probably represent single and isolated gametic number report for any species of the genus [1]. On the other hand some authors have reported only $x = 5–8$ as primary base numbers [6]. Both the statements reveal unanimously that $x = 8$ is the most popular base number. Analysis of overall chromosome number data proves that x

Table 3

microsporogenesis in different species of *Brassicaceae* Burn. from different areas of Western Himalayas

	Microsporogenesis, %					
	Diads		Triads		Tetrads	
	WMN	WM	WMN	WM	WMN	WM
	7.21(7/97)	2.06(2/97)	4.12(4/97)	2.06(2/97)	69.07(67/97)	12.37(12/97)
	1.86(2/107)	1.86(2/107)	6.54(7/107)	0.93(1/107)	65.42(70/107)	17.75(19/107)
	4.00(4/100)	2.00(2/100)	5.00(5/100)	2.00(2/100)	62.00(62/100)	21.00(21.00/100)
	1.98(2/101)	0.99(1/101)	0.99(1/101)	3.96(4/101)	67.32(68/101)	21.78(22/101)
	6.34(8/126)	3.17(4/126)	5.55(7/126)	3.17(4/126)	57.14(72/126)	17.46(22/126)
	1.43(2/139)	5.03(7/139)	11.51(16/139)	6.47(9/139)	52.51(73/139)	17.98(25/139)
	1.96(2/102)	2.94(3/102)	1.96(2/102)	0.98(1/102)	67.64(69/102)	21.56(22/102)
	1.04(1/96)	1.04(1/96)	2.08(2/96)	2.08(2/96)	69.79(67/96)	21.87(21/96)
	1.94(2/103)	–	3.88(4/103)	–	75.72(78/103)	18.44(19/103)
	2.85(3/105)	0.95(1/105)	1.90(2/105)	1.90(2/105)	68.57(72/105)	20.95(22/105)
	1.73(2/115)	2.60(3/115)	–	1.73(2/115)	67.82(78/115)	21.73(25/115)
	3.19(3/94)	1.06(1/94)	1.06(1/94)	2.12(2/94)	71.27(67/94)	21.27(20/94)
	2.94(3/102)	1.96(2/102)	1.96(2/102)	0.98(1/102)	67.64(69/102)	21.56(22/102)
	–	0.98(1/102)	3.92(4/102	–	70.58(72/102)	23.52 (24/102)
	0.97(1/103)	–	1.94(2/103)	0.97(1/103)	72.81(75/103)	22.33(23/103)
	1.83(2/109)	1.83(2/109)	3.66(4/109)	2.75(3/109)	64.22(70/109)	22.93(25/109)
	0.96(1/104)	1.92(2/104)	0.96(1/104)	1.92(2/104)	65.38(68/104)	25.00(26/104)

micronuclei. Figures in parenthesis denote observed number of abnormal PMCs in the numerator and total num-

= 8 is represented nearly by 20 % of taxa in the family followed by $x = 7$ being present in 19.13 % taxa [1]. Another frequent base number $x = 10$ is found in 10.24 % taxa and seems to be secondarily derived base number. The same holds true for Indian representatives in general and presently investigated taxa from Western Himalayas in particular.

The meiotic chromosome numbers for *Barbaraea intermedia* ($n = 8$), *B. vulgaris* ($n = 8$), *Descuriania sophia* ($n = 10$), *Rorippa islandica* ($n = 8$), *Sisymbrium strictum* ($n = 7$) and *Thlaspi alpestre* ($n = 7$) have been worked out for first time from India confirming the same chromosome number for these species from outside India. But at the same time other interaspecific cytotypes are also known in literature on world-wide basis for some of these species to be taken into account such as *Barbaraea vulgaris* $2n = 14$ [7], *Descuriania sophia* $2n = 14$, 28, 56 [5, 8, 9], *Rorippa islandica* $2n = 32$ [10]. Out of the four species where new and varied cytotypes have been reported for the first time, *Barbaraea intermedia* ($n = 16$) and *Sisymbrium orientale* ($n = 14$) make an addition of tetraploid cytotypes on world-wide basis. In case of *Cardamine loxostiemonoides present* diploid report ($n = 8$) against tetraploid cytotype $2n = 32$ [11] and for *Nasturtium officinale* also present diploid report ($n = 8$) against another diploid cytotype with $2n = 14$ [12], tetraploid ($2n = 32$) and octaploid ($2n = 64$) cytotypes [5] are recorded on world-wide basis. The diploid cytotype ($n = 8$) in *Capsella bursa-pastoris* is reported for the first time from India and confirms the previous reports of $2n = 32$ [13–15] from outside India. *Sisymbrium irio* is another species with presently worked out diploid and tetraploid cytotypes like those of *Barbaraea intermedia* and *Capsella bursa-pastoris*. Although *Sisymbrium irio* is one species with high amount of intraspecific variability existing in the form of $2n = 14$, 21, 28, 42, 56 numbers showing diploid to octaploid cytotypes collected from the same region of India [16] but in spite of wide screening at present only diploid and tetraploid cytotypes could be found. In *Coronopus didymus* present tetraploid chromosome number count of $n = 16$ is in line with the earlier report of $2n = 32$ from India [17] and from outside India [4, 5, 18]. From this entire account one thing emerges out that there exists a lot of variation of chromosome numbers in the species of the family Brassicaceae. Allopolyploidy coupled with hybridization resulting from different base number seems be major evolutionary factor for generating higher chromosome numbered taxa as postulated earlier [19]. The phenomenon of mixoploidy has also been described for certain members of Brassicaceae [20], and explained that mostly gamete formation in such plants is not affected and show behaviour of normal diploids, but sometimes as an aberration some of the aneuploid and polyploidy cells may enter the germline to give rise to dysploid and polyploidy plants especially in apomicts and spontaneous hybrids.

The meiotic abnormalities are considered to be resulting from genetic [21–23] and environmental factors [24] as well as genomic-environmental interaction [25]. Chromatin transfer, production of hypo- and hyperploid PMCs and meiotic irregularities in anaphase segregation of chromosomes may be the possible mechanisms for the formation of large sized pollen grains and low pollen fertility as has been earlier reported in several angiospermic plants [26–29]. All these factors seem to be equally applicable in the presently investigated populations with meiotic irregularities in the form of cytomixis, chromosomal stickiness, unoriented bivalents, interbivalent connections, laggards and bridges. The occurrence of sufficient variation of chromosome numbers as well as change of meiotic behavior at intra- and interspecific level of these 12 species calls for further need of the extensive cytological exploration at population basis of members of Brassicaceae from different phytogeographical areas of India to complete the data bases for Indian Brassicaceae.

The authors are grateful to the University Grants Commission, New Delhi under the DRS SAP II and ASIST programmes and Rajiv Gandhi National Fellowship Scheme for providing financial assistance. We are highly thankful to the Director Botanical Survey of India, DehraDun for their help in the identification of the plant species.

S.M. Jeelani, S. Rani, S. Kumar, S. Kumari, R.C. Gupta

ЦИТОЛОГИЧЕСКОЕ ИЗУЧЕНИЕ СЕМЕЙСТВА *BRASSICACEAE* BURN. (*CRUCIFERAE* JUSS.) ИЗ ЗАПАДНЫХ ГИМАЛАЕВ

Цитологические исследования проведены на 12 видах семейства *Brassicaceae* Burn. из популяций различных географических зон Западных Гималаев. Определены хромосомные числа для *Barbaraea intermedia* (*n* = 16), *Cardamine loxostemonoides* (*n* = 8), *Nasturtium officinale* (*n* = 8), *Sisymbrium orientale* (*n* = 14) и добавлены к известным сведениям об этих видах. Хромосомные числа семи видов, *Barbaraea intermedia* (*n* = 8), *B. vulgaris* (*n* = = 8), *Capsella bursa-pastoris* (*n* = 8), *Descuriania sophia* (*n* = 10), *Rorippa islandica* (*n* = 8), *Sisymbrium strictum* (*n* = 7) и *Thlaspi alpestre* (*n* = 7), были определены впервые в Индии. Течение мейоза в популяциях семи видов (*Barbaraea intermedia*, *Capsella bursa-pastoris*, *Coronopus didymus*, *Descuriania sophia*, *Nasturtium officinale*, *Sisymbrium orientale* и *S. strictum*) изменяется от нормального до аномального, в то время как в популяциях *Barbaraea vulgaris* и *Sisymbrium irio* наблюдается аномальный ход мейоза. Мейотические аномалии проявляются в виде цитомиксиса, слипшихся хромосом, дезориентированных бивалентов, межбивалентных соединений, формировании отставших хромосом и мостов, что в целом приводит к нарушениям микроспорогенеза. Гетерогенные по размеру фертильные пыльцевые зерна и сниженный репродукционный потенциал наблюдались во всех мейотически аномальных популяциях. В то же время ход мейоза во всех популяциях *Cardamine loxostemonoides*, *Rorippa islandica* и *Thalspi alpestre* был нормальным и сопровождался высокой фертильностью пыльцы.

S.M. Jeelani, S. Rani, S. Kumar, S. Kumari, R.C. Gupta

ЦИТОЛОГІЧНЕ ВИВЧЕННЯ СІМЕЙСТВА *BRASSICACEAE* BURN. (*CRUCIFERAE* JUSS.) ІЗ ЗАХІДНИХ ГІМАЛАЇВ

Цитологічні дослідження проведені на 12 видах родини *Brassicaceae* Burn. з популяцій різних географічних зон Західних Гімалаїв. Визначені хромосомні числа для *Barbaraea intermedia* (*n* = 16), *Cardamine loxostemonoides* (*n* = 8), *Nasturtium officinale* (*n* = 8), *Sisymbrium orientale* (*n* = 14) і додані до відомостей про ці види. Хромосомні числа семи видів, *Barbaraea intermedia* (*n* = 8), *B. vulgaris* (*n* = 8), *Capsella bursa-pastoris* (*n* = 8), *Descuriania sophia* (*n* = = 10), *Rorippa islandica* (*n* = 8), *Sisymbrium strictum* (*n*= = 7) та *Thlaspi alpestre* (*n* = 7), були визначені вперше в Індії. Проходження мейозу в популяціях семи видів (*Barbaraea intermedia*, *Capsella bursa-pastoris*, *Coronopus didymus*, *Descuriania sophia*, *Nasturtium officinale*, *Sisymbrium orientale* і *S. strictum*) змінюється від нормального до аномального, тоді як в популяціях *Barbaraea vulgaris* і *Sisymbrium irio* спостерігається аномальний хід мейозу. Мейотичні аномалії проявляються у вигляді цитоміксису, злиплих хромосом, дезорієнтованих бівалентів, міжбівалентних сполук, формуванні відсталих хромосом і мостів, що в цілому призводить до порушень мікроспорогенезу. Гетерогенні за розміром фертильні пилкові зерна та знижений репродукційний потенціал спостерігалися в усіх мейотично аномальних популяціях. В той же час хід мейозу в усіх популяціях *Cardamine loxostemonoides*, *Rorippa islandica* і *Thalspi alpestre* був нормальним і супроводжувався високою фертильністю пилку.

REFERENCES

1. *Warwick S.I., Al-Shehbaz I.A.* Brassicaceae, Chromosome number index and database on CD-Rom. *Plant Syst. Evol.,* 2006, **259**, p. 237–248.
2. *Kumar V., Subramaniam B.* Chromosome Atlas of Flowering Plants of The Indian Subcontinent Vol.I. Dicotyledones. – Calcutta, 1986.
3. *Jaretzky R.* Untersuchungen uber Chromosomen und Phylogenie bei einigen Cruciferen. *Jahrb Wiss Botanik,* 1928, **68**, p. 1–45.
4. *Jaretzky R.* Beziehungen zwischen Chromosomenzahl und Systematik bei den Cruciferen. *Jahrb Wiss Botanik*, 1932, **76**, p. 485–527.
5. *Manton I.* Introduction to the general cytology of Cruciferae. *Ann. Bot.,* 1932, **46**, p. 509–556.
6. *Mandakova T., Lysak A.M.* Chromosomal Phylogeny and Karyotype Evolution in $x = 7$ Crucifer Species (Brassicaceae) *Plant Cell,* 2008, **20**, p. 2559–2570.
7. *Tischler G.* Pflanzliche Chromosomen-Zahlen. 4. *Tabulae Biol.,* 1934, **16**, p. 162–218.
8. *Lan Y.Z., Cheo T.Y.* Cytotaxonomical studies on Chinese species of Cruciferae. D. Hong (editor), *Plant Chromosome Res.* 1987, 1989, p. 283.
9. *Baldwin J.T., Cambell J.M.* Chromosomes of Cruciferae. I. Descurainia. *Amer. J. Bot.,* 1940, **27**, № 10, p. 915–918.
10. *Tomsovic P.* The diploid *Rorippa islandica* discovered in southern Europe. *Folia Geobotanica et Phytotax.,* 1974, **9**, p. 209–212.
11. *Rashid A., Ohba H.* A revision of *Cardamine loxostemonoides* O.E. Schulz (Cruciferae). *J. Japanese Bot.,* 1993, **68**, p.199–208.
12. *Easterly N.W.* Chromosome numbers of some northwestern Ohio Cruciferae. *Castanea,* 1963, **28**, p. 39–42.
13. *Aksoy A., Hale W.H.G., Dixon J.M.* Towards a simp-

lified taxonomy of *Capsella bursa pastoris* (L.) Medik (Brassicaceae). *Watsonia,* 1999, **22**, p. 243–250.
14. *Neuffer B., Eschner S.* Life-history traits and ploidy levels in the genus *Capsella*. *Canadian J. Bot.,* 1995, **73**, p. 1354–1365.
15. *Runemark H.* Mediterranean chromosome number reports 10 (1110–1188). *Flora Mediterranea,* 2000, **10**, p. 386–402.
16. *Khoshoo T.N.* Biosystematics of *Sisymbrium irio* Complex. *Nature* (London), 1955, **176**, p. 608.
17. *Sidhu M., Bir S.S.* Karyological studies on weeds on cultivable lands in Punjab, India. *Tropical Plant Science Research*, 1983, **1**, p. 1–13.
18. *Heiser C.B., Whitaker T.W.* Chromosome number, polyploidy and growth habit in Californian weeds. *Amer. J. Bot.*, 1948, **35**, p.179–186.
19. *Stebbins G.L.* Chromosomal Evolution in Higher plants. Edward Arnold Ltd., London, 1971.
20. *Kunakh V.A., Adonin V.I., Ozheredov S.P., Blyum Ya.B.* Mixoploidy in wild and cultivated species of Cruciferae capable of hybridizing with rapeseed *Brassica napus*. *Cytology and Genet.*, 2008, **42**, № 3, p. 204–209.
21. *Ghaffari S.M.* Occurrence of diploid and polyploid microspores in *Sorghum bicolor* (Poaceae) is the result of cytomixis. *Afr. J. Biotech.,* 2006, **5**, p. 1450–1453.
22. *Kumar P., Singhal V.K., Kaur D., Kaur S.* Cytomixis and associated meiotic abnormalities affecting pollen fertility in *Clematis orientalis*. *Biol. Plant.,* 2010, **54**, № 1, p. 181–184.
23. *Fadaei F., Sheidai M., Asadi M.* Cytological study of the genus *Arenaria* L. (Caryophyllaceae). *Caryologia*, 2010, **63**, № 2, p. 149–156.
24. *Nirmala A., Rao P.N.* Genetics of chromosome numerical mosaism in higher plants. *Nucleus,* 1996, **39**, p. 151–175.
25. *Baptista-Giacomelli F.R., Pagliarini M.S., Almeida J.L.* Meiotic behavior in several Brazilian oat cultivars (*Avena sativa* L.). *Cytologia,* 2000, **65**, p. 371–378.
26. *Villeux R.* Diploid and polyploidy gametes in Crop Plants, Mechanisms of formation and utilization in plant breeding / Ed. J. Janick Plant Breed. Rev. 3, p. 442. AVI Publishing Co. Wesport, Connecticut, 1985.
27. *Sheidai M., Nikoo M., Gholipour A.* Cytogenetic variability and new chromosome number reports in *Silene* L. species (Sect. Lasiostemones, Caryophyllaceae). *Acta Biol. Szegediens.*, 2008, **52**, p. 313–319.
28. *Kumar P., Singhal V.K., Kaur D.* Cytomixis induced meiotic abnormalities in pollen mother cells of *Clematis flammula* L. (Ranunculaceae). *Cytololgia,* 2008, **73**, № 4, p. 381–385.
29. *Gupta R.C., Himshikha Kumar P., Dhaliwal R.S.* Cytological studies in some plants from cold deserts of India, Lahul and Spiti (Himachal Pradesh). *Chromosome Bot.,* 2009, **4**, p. 5–11.

Received 26.10.11I