Research article

Karyotype diversity among twelve varieties of *Brassica* L. (Brassicaceae) from Bangladesh

Susmita Saha, Meghla Saha Pinky, Suma Akter and Kazi Nahida Begum*

Department of Botany, Faculty of Life and Earth Sciences, Jagannath University, Dhaka, Bangladesh

*Corresponding Author: kazinahida@yahoo.com

[Accepted: 15 August 2020]

Abstract: In the present research, karyomorphological characters of twelve varieties of *Brassica*, released by Bangladesh Agricultural Research Institute (BARI) were investigated for appropriate characterization and assuming interrelations among them. Among these, six varieties of *Brassica campestris* (Tori-7, SS-75, BS-6, BS-12, BS-14 and BS-15) showed $2n=20$ chromosomes, whereas $2n=36$ were observed in four varieties of *B. juncea* (Dawlat, Rai-5, BS-10 and BS-11) and $2n=38$ were found in two varieties of *B. napus* (BS-7 and BS-8). Depending on the karyotype symmetry-asymmetry conditions, the AI versus CV_{CI} graph flatly divided these twelve varieties into Group-I as primitive and Group-II as advanced in characteristics. Moreover, notable karyotype diversity was observed in varieties of *Brassica* L. which could be used for their proper characterization.

Keywords: Chromosome - Karyosystematics - Asymmetry indices.

[Cite as: Saha S, Pinky MS, Akter S & Begum KN (2020) Karyotype diversity among twelve varieties of *Brassica* L. (Brassicaceae) from Bangladesh. *Tropical Plant Research* 7(2): 476–483]

INTRODUCTION

Brassica L. is one of the major genus of the Brassicaceae with 37 divergent species (Gómez-Campo 1980). This genus possesses six inter-linked species of which three are diploids (*Brassica oleracea* L., *Brassica rapa* L. and *Brassica nigra* L.) and other three are amphidiploid viz. *Brassica carinata* A.Braun, *Brassica juncea* (L.) Czern. and *Brassica napus* L.; generally derived from adjacent Himalayan territory and collaterally from Asia and European-Mediterranean area (Downey & Robelen 1989). The diversified species of *Brassica* yield vegetables, oil, condiments and dietary fiber (Talalay & Fahey 2001). Moreover, as an oil yielding crop, *Brassica* is the second largest contributor in the world oilseed economy after soybean (Raymer 2002, FAO 2015). While the rapeseed group includes *Brassica campestris* L. and *Brassica napus*, *Brassica juncea* puts in the mustard groups and is commonly known as Indian mustard (Yarnell 1956).

The seed oil of *Brassica* contains a sufficient amount of mono- and poly- unsaturated fatty acids which forms it nutritionally worthier than most other edible oils (Agnihotri *et al.* 2007). The mustard is also an antimicrobial agent against a number of organisms (Luciano & Holley 2009). Nowadays the iso-thiocyanate and brassinosteroids are known as the most significant cancer chemo-preventive phytochemicals which are precursors of *Brassica* seed processing (Zhang *et al.* 2006, Wachsmann *et al.* 2012). Hence, there are vast possibilities to utilize this valuable seed due to the advantageous chemical composition and its relatively low price offer in Bangladesh. Numerous studies have been initiated worldwide in order to characterize and increase different chemical constituents by creating new varieties with optimized bio-productivity. In this type of research, the knowledge of genetic constitution is absolutely necessary. In spite of the through going studies of molecular genetics, the classical cytogenetical investigations are still needed because they provide important proofs concerning numerical and structural traits of chromosome set in view of karyotype construction. To reach their full impact, it is essential that the new exciting molecular findings to be fully integrated with the cytogenetical data (Stace 2000).

Although, several chromosomal and molecular analysis have been carried out within the genus of *Brassica* L. throughout the world (Takamine 1916, Mukherjee 1975, Viinikka & Sovero 1988, Olin-Fatih & Heneen 1992, Du *et al.* 1993, Olin-Fatih 1994, Cheng *et al.* 1995, Fukui *et al.* 1998, Skarzhinskaya *et al.* 1998, Hasterok & Maluszynska 2000, Kulak *et al.* 2002, Snowdon 2007, Fang *et al.* 2014, Sun *et al.* 2018, Liu *et al.* 2019, Sun

et al. 2019) but still there is a lacking of chromosomal information as well as cytological studies in case of BARI (Bangladesh Agricultural Research Institute) varieties of *Brassica* L. Chromosomal information and karyotype through orcein-staining technique furnishes a practical principle for cytogenetic studies. Currently, karyosystematics is one of the most granted guidelines to establish the genetic correlation and degree of diversity among species or populations (Guerra 2008). Thus the current investigation assisted at investigating different cytological characters for accurate identification and characterization of twelve varieties of *Brassica* L. available in Bangladesh.

MATERIALS AND METHODS

Materials

Seeds of investigated twelve varieties of *Brassica* L. were collected from the Oilseeds Research Center (ORC) of Bangladesh Agricultural Research Institute (BARI) and maintained in the Botanical garden, Department of Botany, Jagannath University, Dhaka.

Sample preparation

To investigate somatic chromosomes, Root tips (RTs) were collected from germinated seeds. At first seeds were germinated using wet filter papers in a Petri plate for 36 h and 30 min at room temperature (28–30°C) in dark. The RTs were pretreated with 8-hydroxyquinoline (0.002 M) for 40 min at room temperature (28–30°C) and fixed in Carnoy's fluid (1 Glacial acetic acid: 3 Ethanol) at 4°C for 24 hours and then preserved in 70% alcohol for later use. Afterwards, the pre-treated RTs were heated uniformly with a mixture of 1% Aceto-orcein and 1 N HCl with the help of a spirit burner. Lastly, the prepared Aceto-orcein stained slides were observed under the Optika electric microscope and photographs were captured by the Euromax camera (CMEX 10, DC 10000C) with the magnification of 100XS in Auto mode.

Statistical analysis

The fine spread mitotic metaphase chromosomes were used to determine different karyotypic parameters. Based on the position of centromere and the number of chromosomes, karyotypic formula was determined (Levan *et al.* 1964). A diverse range of karyomorphological parameters estimated with the help of KaryoType software (Altınordu *et al.* 2016).

RESULTS AND DISCUSSION

Somatic chromosome number, ideogram and karyological features of studied twelve varieties of *Brassica* L. were detailed with figures 1–2, table 1.

Tori-7, Sonali Sarisha-75, BARI Sarisha-6, BARI Sarisha-12, BARI Sarisha-14 and BARI Sarisha-15, these six varieties of *Brassica campestris* were found to possess $2n=20$ (Figs. 1A–F, 2A–F, Table 1). On the other hand, the four investigated *B. juncea* varieties (Dawlat, Rai-5, BARI Sarisha-10 and BARI Sarisha-11) showed 36 diploid chromosomes whereas the highest chromosome number ($2n=38$) was found in the two *B. napus* varieties (BARI Sarisha-7 and BARI Sarisha-8) (Figs. 1G–L, 2G–L, Table 1). The recent counts of chromosome numbers were similar with the earlier records in *B. campestris* ($2n=20$, Takamine 1916, Viinikka & Sovero 1988, Olin-Fatih & Heneen 1992, Olin-Fatih 1994, Cheng *et al.* 1995, Fukui *et al.* 1998, Hasterok & Maluszynska 2000, Snowdon 2007), *B. juncea* ($2n=36$, Mukherjee 1975, Du *et al.* 1993, Kulak *et al.* 2002, Fang *et al.* 2014, Sun *et al.* 2019, Liu *et al.* 2019) and *B. napus* ($2n=38$, Olin-Fatih & Heneen 1992, Olin-Fatih 1994, 1996, Skarzhinskaya *et al.* 1998, Hasterok & Maluszynska 2000, Kulak *et al.* 2002, Snowdon 2007, Sun *et al.* 2018). The consistency in the number of diploid chromosome complement specified that the varieties of *Brassica* under consideration are highly stable. The above information points out that polyploidy and inter-specific hybridization lead to origin of series of different chromosome number for *Brassica* L.

Altogether, karyotypes of the studied twelve varieties had a predominance of metacentric (m) chromosomes (Figs. 1–2; Table 1). Five *Brassica* germplasms were found to possess all metacentric chromosomes such as $4M+16m$ in two *B. campestris* varieties (Tori-7 and BARI Sarisha-15), $20\ m$ in *B. campestris* var. BARI Sarisha-14, $2M+34m$ in *B. juncea* var. BARI Sarisha-10 and $1M+37m$ in *B. napus* var. BARI Sarisha-8 [M indicating metacentric chromosome with equal length of long arm and short arm] (Figs. 1A, 1F, 1E, 1I, 1L, 2A, 2F, 2E, 2I, 2L, Table 1). The two varieties of *B. campestris* viz. Sonali Sarisha-75 and BARI Sarisha-6 had $2M+16m+2sm$ (Figs. 1B, 1C, 2B, 2C, Table 1), whereas *B. campestris* var. BARI Sarisha-12 showed $3M+15m+2sm$ (Figs. 1D, 2D, Table 1). On the other hand, two varieties of *B. juncea* viz. Rai-5 and BARI Sarisha-11 were found to possess $34m+2sm$ and $2M+32m+2sm$, respectively (Figs. 1H, 1J, 2H, 2J, Table 1). The highest number of sub-metacentric chromosomes was found in Dawlat with a centromeric formula

32m+4sm (Figs. 1G, 2G, Table 1). Lastly, *B. napus* var. BARI Sarisha-7 was found to possess eighteen pairs of metacentric (m) chromosomes and a pair of sub-metacentric (sm) chromosomes (Figs. 1K, 2K, Table 1). In chromosome pair X of BARI Sarisha-8, two satellites were clearly visible (Figs. 1L and 2L, Table 1). Due to the presence of different karyotypic formula among twelve varieties of *Brassica*, it can be considered that karyotype evolution plays a key role in their individualistic genetic evolution.

Figure 1. Orcein-stained mitotic metaphase of twelve varieties of *Brassica* L.: **A**, Tori-7; **B**, Sonali Sarisha-75; **C**, BARI Sarisha-6; **D**, BARI Sarisha-12; **E**, BARI Sarisha-14; **F**, BARI Sarisha-15; **G**, Dawlat; **H**, Rai-5; **I**, BARI Sarisha-10; **J**, BARI Sarisha-11; **K**, BARI Sarisha-7; **L**, BARI Sarisha-8; Red arrows indicate presence of Satellites. [Scale Bar= 5 μ m]

More or less similar total chromosome length (TCL) was recorded in six variants of *Brassica campestris* in which BARI Sarisha-12 showed the highest TCL value $51.39 \pm 2.04 \mu\text{m}$ and $45.97 \pm 1.20 \mu\text{m}$ for Sonali Sarisha-75 that is the lowest among all. According to this study, the total chromosomal length of studied four varieties of *B. juncea* was reported as $71.48 \pm 5.38 \mu\text{m}$ (lowest) for Rai-5 and $117.93 \pm 3.17 \mu\text{m}$ (highest) for BARI Sarisha-11. For two *B. napus* varieties viz. BARI Sarisha-7 and BARI Sarisha-8, the total length of diploid chromosome complement was reported as $71.11 \pm 3.70 \mu\text{m}$ and $60.50 \pm 3.93 \mu\text{m}$, consecutively. The total chromosome length of *B. juncea* var. BARI Sarisha-11 ($117.93 \pm 3.17 \mu\text{m}$) was about three times larger to that of *B. campestris* var. Sonali Sarisha-75 ($45.97 \pm 1.20 \mu\text{m}$) (Table 1). Regarding the average chromosome length (ACL) of investigated *Brassica campestris* varieties were more or less similar (highest $2.57 \mu\text{m}$ in BARI Sarisah-12 and lowest 2.30

Figure 2. Ideograms prepared from orcein-stained mitotic metaphase stages of twelve varieties of *Brassica L.*: **A**, Tori-7; **B**, Sonali Sarisha-75; **C**, BARI Sarisha-6; **D**, BARI Sarisha-12; **E**, BARI Sarisha-14; **F**, BARI Sarisha-15; **G**, Dawlat; **H**, Rai-5; **I**, BARI Sarisha-10; **J**, BARI Sarisha-11; **K**, BARI Sarisha-7; **L**, BARI Sarisha-8; Red bar indicates presence of Satellite.

Table 1. Karyological features of the studied twelve varieties of *Brassica* L.

Variety	2n	RCL (μm)	ACL (μm)	TCL(μm)	Karyotypic formula	SAT
<i>B. campestris</i> var. Tori-7	20	1.64–3.23	2.45	48.99±2.22	4M+16m	-
<i>B. campestris</i> var. Sonali Sarisha-75	20	1.60–3.13	2.30	45.97±1.20	2M+16m+2sm	-
<i>B. campestris</i> var. BARI Sarisha-6	20	1.61–3.22	2.39	47.77±3.70	2M+16m+2sm	-
<i>B. campestris</i> var. BARI Sarisha-12	20	1.80–3.58	2.57	51.39±2.04	3M+15m+2sm	-
<i>B. campestris</i> var. BARI Sarisha-14	20	1.70–3.11	2.36	47.23±2.67	20m	-
<i>B. campestris</i> var. BARI Sarisha-15	20	1.56–3.28	2.44	48.78±3.55	4M+16m	-
<i>B. juncea</i> var. Dawlat	36	1.58–3.30	2.33	83.90±3.99	32m+4sm	-
<i>B. juncea</i> var. Rai-5	36	1.34–2.67	1.99	71.48±5.38	34m+2sm	-
<i>B. juncea</i> var. BARI Sarisha-10	36	1.40–3.19	2.29	82.39±3.75	2M+34m	-
<i>B. juncea</i> var. BARI Sarisha-11	36	2.18–4.73	3.28	117.93±3.17	2M+32m+2sm	-
<i>B. napus</i> var. BARI Sarisha-7	38	1.15–2.82	1.87	71.11±3.70	36m+2sm	-
<i>B. napus</i> var. BARI Sarisha-8	38	1.09–2.37	1.59	60.50±3.93	1M+37m	2

Note: RCL- Range of chromosome length, ACL- Average chromosome length, TCL- Total chromosome length, SAT- Satellite, M- Equal length of long arm and short arm, m- Metacentric chromosome and sm- Sub-metacentric chromosome.

μm in Sonali Sarisha-75). But in case of studied varieties of *B. juncea* and *B. napus*, slight differences were observed. The highest average chromosome length was recorded in *B. juncea* var. BARI Sarisha-11 (3.28 μm), whereas the lowest value of that was reported in *B. napus* var. BARI Sarisha-8 (1.59 μm) (Table 1). Among twelve germplasms, *B. napus* var. BARI Sarisha-8 was found to occupy the lowest range of chromosomal length (RCL) (1.09–2.37 μm), where slight gradual decrease of chromosomal length was observed in their karyotypes. On the other hand, the range of chromosomal length in *B. juncea* var. BARI Sarisha-11 was observed highest (2.18–4.73 μm) which exhibited a clear graduality in the decrease of chromosomal length (Table 1). Based on Stebbins's (1971) classification, Tori-7, Sonali Sarisha-75, BARI Sarisha-12, BARI Sarisha-14 and Rai-5 were positioned in 1A whereas BARI Sarisha-6, BARI Sarisha-15, Dawlat, BARI Sarisha-10, BARI Sarisha-11, BARI Sarisha-7 and BARI Sarisha-8 were belonged to 1B type of karyotype (Table 2).

Karyotype asymmetry can be regarded as a mainspring for speciation where symmetrical karyotypes consider ancestral state in evolution (Stebbins 1971). BARI Sarisha-14 displayed higher chromosomal homogeneity with lowest CV_{CL} and DI value 15.48 and 7.49, respectively since BARI Sarisha-7 indicates lower chromosomal homogeneity in respect to highest value of CV_{CL} (24.76) and DI (12.14). CV_{CL} had a perfect collateral relationship with DI whereas they both showed opposite relationship with chromosomal homogeneity. As regard TF% and AsK% values (Table 2), Tori-7 showed the most symmetrical karyotype with highest TF% (48.71%) value and lowest AsK% (51.29%) and the most asymmetrical one was noticed in *B. campestris* var. BARI Sarisha-6 with lowest TF% (44.85) and highest AsK% (55.15) values. On the contrary, MCA reveals a negative correlation with Syi% (Table 2). All of the germplasms revealed a modest variation level ranging from 0.05 to 0.15 in case of A₁ and 0.15 to 0.25 for A₂ (Table 2).

As stated by Zarco (1986) and Peruzzi et al. (2009), bi-dimensional scatter plots is one of the prime schemes to act as karyotype asymmetry interrelations among species, where the two asymmetry computations are placed in the x and y axis and points serve as each sample. A bidirectional scatter plot was established; where the values of AI and CV_{CI} were placed on 'x-axis' and 'y-axis', respectively. The AI of analyzed varieties ranged from 0.26 to 2.23 and the CV_{CI} values of these twelve varieties were ranging from 1.72 to 11.44. Higher AI and CV_{CI} value represent asymmetric karyotype whereas lower values indicate symmetric nature. From the data considering AI and CV_{CI} values, it can be said that four varieties (Tori-7, BARI Sarisha-14, BARI Sarisha-15 and BARI Sarisha-10) were symmetric karyotypes because their AI values ranged from 0.26 to 0.59 and CV_{CI} values ranged from 1.72 to 2.87. The rest eight varieties with asymmetric karyotypes had AI values between 1.17 to 2.23 and CV_{CI} values ranges 5.69 to 11.44. In consonance with these values, the most asymmetric karyotype was observed in BARI Sarisha-6 and the most symmetric one belonged to Tori-7. Based on AI versus CV_{CI} graph (Fig. 3), a systemic appearance and heterogeneity appeared among investigated twelve varieties concerning their asymmetry indices. Considering evolution point of view in relation to karyotypic nature, symmetric karyotypes are usually come up with primitive and asymmetrical as advanced characters (Stebbins 1971). Based on the above concept, varieties those endure in Group I (Tori-7, BARI Sarisha-14, BARI Sarisha-15 and BARI Sarisha-10) were considered as primitive and those remains in Group II (BARI Sarisha-8, BARI Sarisha-7, Rai-5, BARI Sarisha-12, Dawlat, BARI Sarisha-11, Sonali Sarisha-75 and BARI Sarisha-6) were advance in characters (Fig. 3).

Accordingly, the present study emphasizes on chromosomal variation and in particular for improvement of

Table 2. Asymmetry indices of the studied twelve varieties of *Brassica* L.

Variety	CV _{CI}	CV _{CL}	MCA	AsK%	TF%	SyI%	Rec %	A ₁	A ₂	A	AI	DI	Sc
<i>B. campestris</i> var. Tori-7	1.76	16.23	2.69	51.29	48.71	94.98	75.82	0.05	0.16	0.03	0.26	7.86	1A
<i>B. campestris</i> var. Sonali Sarisha-75	9.79	17.90	6.55	53.41	46.59	87.22	73.45	0.11	0.18	0.07	1.75	8.13	1A
<i>B. campestris</i> var. BARI Sarisha-6	11.44	19.49	9.03	55.15	44.85	81.31	74.13	0.15	0.19	0.09	2.23	8.94	1B
<i>B. campestris</i> var. BARI Sarisha-12	8.25	19.35	5.90	53.43	46.57	87.18	71.76	0.10	0.19	0.06	1.60	9.15	1A
<i>B. campestris</i> var. BARI Sarisha-14	1.72	15.48	3.29	51.65	48.35	93.61	75.95	0.06	0.15	0.03	0.27	7.49	1A
<i>B. campestris</i> var. BARI Sarisha-15	2.16	19.05	2.91	51.43	48.57	94.46	74.34	0.06	0.19	0.03	0.41	9.34	1B
<i>B. juncea</i> var. Dawlat	8.83	18.55	8.10	54.22	45.78	84.42	70.86	0.14	0.19	0.08	1.64	8.75	1B
<i>B. juncea</i> var. Rai-5	7.03	18.83	7.54	54.10	45.90	84.43	74.40	0.13	0.19	0.08	1.32	8.68	1A
<i>B. juncea</i> var. BARI Sarisha-10	2.87	20.56	3.94	51.84	48.16	92.90	71.73	0.07	0.21	0.04	0.59	10.08	1B
<i>B. juncea</i> var. BARI Sarisha-11	8.94	21.68	6.27	53.35	46.65	87.43	69.27	0.11	0.22	0.06	1.94	10.41	1B
<i>B. napus</i> var. BARI Sarisha-7	6.74	24.76	6.62	53.56	46.44	86.72	66.39	0.12	0.25	0.07	1.67	12.14	1B
<i>B. napus</i> var. BARI Sarisha-8	5.69	20.56	7.84	53.54	46.46	86.79	67.18	0.14	0.21	0.08	1.17	9.05	1B

Note: CV_{CI}- Coefficient of variation of centromeric index, CV_{CL}- Coefficient of variation of chromosome length, MCA- Mean centromeric asymmetry, AsK%- Karyotype asymmetry index, TF- Total form value, SyI%- Karyotype symmetry index, Rec%- The index of chromosomal size resemblance, A₁- Intrachromosomal asymmetry index, A₂- Interchromosomal asymmetry index, A- Degree of asymmetry of karyotype, AI- The asymmetry index, DI- Dispersion Index and Sc- Stebbins's classification.

Figure 3. AI versus CV_{CI} parameter of twelve varieties of *Brassica* L.: CV_{CI} = Coefficient of variation of centromeric index; AI = Asymmetry index.

new offspring's or genotypes. The findings coming from these twelve varieties of *Brassica* species indicated the presence of slightly differences among their karyotypes, in terms of chromosome formula, total chromosomal length and asymmetry indices. Finally, the present investigation revealed its karyotypic characteristics from the cytogenetic aspects which also provide the essential information about genetical relationship among *Brassica* L. varieties in Bangladesh.

ACKNOWLEDGEMENTS

The authors are thankful to Bangladesh Agricultural Research Institute (BARI) to provide the seeds of twelve germplasms of *Brassica* L. as well as Ministry of Science and Technology, Government of the People's Republic of Bangladesh for funding to conduct the present investigation.

REFERENCES

- Agnihotri A, Prem D & Gupta K (2007) The Chronicles of Oil and Meal Quality Improvement in Rapeseed. In: Gupta SK (ed) *Advances in Botanical Research - Rapeseed Breeding*. Academic Press, pp. 50–99.
- Altınordu F, Peruzzi L, Yu Y & He X (2016) A Tool for the Analysis of Chromosomes: KaryoType. *Taxon* 65(3): 586–592.
- Cheng BF, Heneen WK & Chen BY (1995) Mitotic Karyotypes of *Brassica campestris* and *Brassica alboglabra* and Identification of the *B. alboglabra* in Addition Line. *Genome* 38: 313–319.
- Downey RK & Robbelen G (1989) *Brassica Species: Oil Crops of the World, Their Breeding and Utilization*. McGraw Hill Publishing Co., New York, USA, pp. 339–374.
- Du W, Chen QX & Mo H (1993) Study on Somatic Chromosome Karyotypes of Xinjiang Wild Rape, *B. campestris*, *B. nigra* and *B. juncea*. *Journal of August 1st Agricultural College* 16(4): 26–31.
- Fang P, Chen FB & Yao QL (2014) Karyotype Analysis On Three Types of Leaf Mustard (*Brassica juncea*). *Journal of Changjiang Vegetables* 12: 13–17.
- FAO (2015) *FAO Agricultural Outlook 2010-2019*. Food and Agriculture Organization, United Nations.
- Fukui K, Nagayama S, Ohmido N, Yoshiaki H & Yamabi M (1998) Quantitative Karyotyping of Three Diploid *Brassica* Species by Imaging Methods and Localization of 45S rDNA Loci on the Identified Chromosomes. *Theoretical and Applied Genetics* 96: 325–330.
- Gómez-Campo C (1980) Studies on Cruciferae: VI. Geographical Distribution and Conservation Status of *Boleum* Desv., *Guiraoa* Coss. and *Euzomodendron* Coss. *Anales del Instituto Botanica A.J. Cavanilles* 35: 165–176.
- Guerra M (2008) Chromosome Number in Plant Cytotaxonomy: Concepts and Implications. *Cytogenetic & Genome Research* 120: 339–350.
- Hasterok R & Maluszynska J (2000) Cytogenetics Analysis of Diploid 322 *Brassica* Species. *Acta Biologica*

- Cracoviensia Series Botanica* 42(1): 145–153.
- Kulak S, Hasterok R & Maluszynska J (2002) Karyotyping of *Brassica* Amphidiploids Using 5S and 25S rDNA as Chromosome Markers. *Hereditas* 136: 144–150.
- Levan A, Fredga K & Sandberg AA (1964) Nomenclature for Centromeric Position on Chromosomes. *Hereditas* 52: 201–220.
- Liu Z, Lia Z, Jin, Z, He Y, Wu R, Zhang F & Sun B (2019) Chromosomal Karyotype Analysis of ‘Four Seasons Shuidong Sweet Crisp’ Mustard. In: *International Conference on Frontiers of Biological Sciences and Engineering (FBSE 2018)*. AIP Conf. Proc. 2058, 020052-1–0200524; [DOI: 10.1063/1.5085565]
- Luciano FB & Holley RA (2009) Enzymatic Inhibition by Allyl-isothiocyanate and Factors Affecting Its Antimicrobial Action against *Escherichia coli* O157:H7. *International Journal of Food Microbiology* 131(2–3): 240–245.
- Mukherjee P (1975) Karyomorphological Studies of Ten Strains of Indian mustard (*Brassica juncea* Coss.). *Euphytica* 24: 483–486.
- Olin-Fatih M & Heneen WK (1992) C- banded Karyotypes of *Brassica campestris*, *B. oleracea* and *B. napus*. *Genome* 35: 583–589.
- Olin-Fatih M (1994) A New Method for Differential Staining of *Brassica* Metaphase Chromosomes and Karyotypes of *B. campestris*, *B. oleracea* and *B. napus*. *Hereditas* 120: 253–259.
- Olin-Fatih M (1996) Morphology, Cytology and C- banded Karyotypes of *Brassica campestris*, *B. oleracea* and *B. napus* Plants Regenerated from Protoplast. *Theoretical and Applied Genetics* 94: 583–591.
- Peruzzi L, Leitch IJ & Caparelli KF (2009) Chromosome Diversity and Evolution in Liliaceae. *Annals of Botany* 103(3): 459–475.
- Raymer PL (2002) Canola: an emerging oilseed crop. In: Janick J & Whipkey A (eds) *Trends in New Crops and New Uses, Vol. 1*. American Society for Horticultural Science Press, Alexandria, USA, pp. 122–126.
- Skarzhinskaya M, Fahleson J, Glimelius K & Mouras A (1998) Genome Organization of *Brassica napus* and *Lesquerella fendleri* and Analysis of Their Somatic Hybrids Using Genomic in Situ Hybridization. *Genome* 41: 691–701.
- Snowdon RJ (2007) Cytogenetics and Genome Analysis in *Brassica* crops. *Chromosome Research* 15: 85–95.
- Stace CA (2000) Cytology and cytogenetics as a fundamental taxonomic resource for the 20th and 21st century. *Taxon* 49(3): 451–477.
- Stebbins GL (1971) *Chromosomal Evolution in Higher Plants*. Edward Arnold Pvt. Ltd., London, 89 p.
- Sun B, Xia X, Tian Y, Zhang F & Tang H (2018) Karyotype Analysis of *Brassica napus* cv. Huayou no. 2. *Advances in Biological Sciences Research* 5: 78–81.
- Sun B, Xia X, Tian Y, Zhang F & Tang H (2019) Karyotype Analysis of *Brassica Juncea* cv. Hong Kong Hakka Mustard. In: *International Conference on Frontiers of Biological Sciences and Engineering (FBSE 2018)*. AIP Conf. Proc. 2058, 020025-1–020025-4. [DOI: 10.1063/1.5085538]
- Takamine N (1916) Über die ruhenden und die präsynaptischen. Phasen der Reduktionsteilung. *Botanical Magazine* 30: 293–303.
- Talalay P & Fahey JW (2001) Phytochemicals from Cruciferous Plants Protect against Cancer by Modulating Carcinogen Metabolism. *Journal of Nutrition* 131: 3027–3033.
- Viinikka Y & Sovero M (1988) Karyotypes and Meiotic Behavior of Chromosomes in Two Male Sterile Strains of *Brassica campestris* L. *Hereditas* 109: 93–97.
- Wachsman MB, Ramirez JA & Galagovsky LR (2012) Antiviral Activity of Brassionsteroids Derivatives against Measles Virus in Cell Cultures. *Antiviral Chemical and Chemotherapy* 13(1): 61–66.
- Yarnell SH (1956) Cytogenetics of the Vegetable Crops. *Botanical Review* 22: 81–166.
- Zarco CR (1986) A New Method for Estimating Karyotype Asymmetry. *Taxon* 35(3): 526–530.
- Zhang S, Chiang CY, Xie YF, Park SJ, Lu Y, Hu JW, Dostrovsky JO & Sessle BJ (2006) Central Sensitization in Thalamic Nociceptive Neurons Included by Mustard Oil Application to Rat Molar Tooth Pulp. *Neuroscience* 142(3): 833–842.