



Hundred years of rapeseed-mustard breeding in India: accomplishments and future strategies

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ABSTRACT

Oilseeds Brassica crops often called as rapeseed-mustard crops in India comprise traditionally grown indigenous species, namely toria, brown sarson, yellow sarson, Indian mustard, black mustard and taramira along with non-traditional species like gobhi sarson, white mustard and Ethiopian mustard or karan rai. Indigenous species have been grown since about 3500 BC. These crops are grown in diverse agro-climatic conditions ranging from north-eastern / north-western hills to down south under irrigated/rainfed, timely/late-sown, saline soils and mixed cropping. In India the research work on the improvement of rapeseed-mustard started by the turn of the 20th century at Pusa (Bihar), the then Bengal Presidency through the collection of land races and their purification. The scientific work for varietal improvement of Indian *oleiferous* Brassicaceae started at Layallpur (now Faisalabad in Pakistan), then in Punjab of undivided India. This paper reviews the research and development in rapeseed-mustard breeding during the past 100 years in terms of organizational set up as well as major accomplishments in relation to genetic resource management, varietal development, quality improvement, hybrid development, improving tolerance to abiotic / biotic stresses, seed production and convergence of conventional and biotechnological approaches. Accomplishments in oilseeds Brassica improvement have been remarkable with the development of 203 agro-climatic specific varieties till 2010 including four hybrids, five low erucic, five low erucic and low glucosinolate varieties and registration of 42 genetic stocks. The paper also attempts to present future outlook and strategy for rapeseed-mustard research to enhance productivity and quality as well as stabilizing yield gains.

Keywords: Breeder seed, Crop scenario, Germplasm, Rapeseed-mustard, Varietal improvement, Varieties

CROP SCENARIO

Oilseed Brassicas also referred to as rapeseed-mustard, an important group of oilseed crops in the world, comprise eight cultivated crops of tribe Brassicaceae within the family Cruciferae (Brassicaceae). The word ‘rape’ and ‘mustard’ have been derived from the word *rapum* meaning turnip and European practice of mixing the sweet ‘must’ of old wine with crushed seeds of black mustard [*Brassica nigra* (L.) Koch] to form a hot paste, respectively (Hemingway 1976). Rapeseed-mustard crops in India comprise traditionally grown indigenous species, namely toria [*Brassica campestris* syn. *B. rapa* L. var. toria, 2n (AA) = 20], brown sarson [*B. campestris* syn. *Brassica rapa* L. var. brown sarson, 2n (AA) = 20], yellow sarson [*B. campestris* syn. *Brassica rapa* L.

var. yellow sarson, 2n (AA) = 20], Indian mustard [*B. juncea* (L.) Czernj & Cosson, 2n (AABB) = 36], black mustard [*B. nigra* (L.) Koch 2n(BB) = 16] and taramira [*Eruca sativa/vesicaria* Mill., 2n (EE) = 22] which have been grown since about 3,500 BC along with non-traditional species like gobhi sarson [*B. napus* L. ssp *oleifera* DC var. *annua* L., 2n (AACC) = 38], white mustard [*Sinapis alba* L. 2n (SS) = 24] and Ethiopian mustard or karan rai [*B. carinata* A. Braun, 2n (BBCC) = 34]. Toxopeus and Oost (1985) suggested that the name *B. campestris* be changed to *B. rapa* since floral parts of two are indistinguishable and both have the same chromosome number (2n = 20) and are fully inter-fertile. The estimated area, production and yield of rapeseed-mustard in the world was 30.74 million ha, 59.93 million tonnes and 1 950 kg/ha respectively during 2009–10. During the last seven years, there has been a considerable increase in productivity from 1 540 kg/ha in 2003–04 to 1 950 kg/ha in 2009–10 and production has also increased from 39.42 million tonnes in 2003–04 to 59.93 million tonnes in 2009–10. Globally, India account for 21.7% and 10.7% of the total acreage and production (USDA 2010). In India, these crops on an average contributed 23.7% and 26.0%, respectively, to

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the total oilseed acreage and production during the last five years. Nevertheless, during 2009–10, rapeseed-mustard contributed 25.9% and 22.0% to the total oilseeds production and acreage. The yield of rapeseed-mustard was 1 159 kg/ha as compared to 955 kg/ha of total oilseeds (Agricultural Statistics at a Glance 2010. www. dacnet.nic.in).

Rapeseed–mustard crops are grown in diverse agro-climatic conditions ranging from north-eastern/north-western hills to down south under irrigated/rainfed, timely/late-sown, saline soils and mixed cropping. Indian mustard accounts for about 75–80% of the 5.53 million ha under these crops in the country during 2009–10. The cultivation of brown sarson which once dominated the entire rapeseed-mustard growing region, now shadowed by Indian mustard. There are two different ecotypes of brown sarson: lotni (self-incompatible) and tora (self-compatible). The lotni predominantly is cultivated in colder regions of the country, particularly in Kashmir and Himachal valley. The tora, on the other hand is cultivated in limited areas of eastern Uttar Pradesh. Yellow sarson is now mainly grown in Asom, Bihar, north-eastern states, Odisha, eastern Uttar Pradesh and West Bengal. Toria is a short-duration crop cultivated largely in Asom, Bihar, Odisha and West Bengal in the east mainly as winter crop. In Haryana, Himachal Pradesh, Madhya Pradesh, Punjab, Uttarakhand and western Uttar Pradesh, it is grown as a catch crop. Taramira is grown in the drier parts of north-west India comprising Rajasthan, Haryana and Uttar Pradesh. Gobhi sarson and karan rai are the new emerging oilseed crops having limited area of cultivation. Gobhi sarson is a long duration crop confined to Haryana, Himachal Pradesh and Punjab. Rapeseed-mustard crops because of their low water requirement (80–240 mm) fit well in the rainfed cropping system of resource-poor farmers. The rapeseed-mustard production trends represent fluctuating scenario with all time high production of 8.13 million tonnes from 7.28 million ha during 2005–06. The yield levels also have been variable ranging from 854 in 2002–03 to 1 159 kg/ha in 2009–10 (Fig 1).

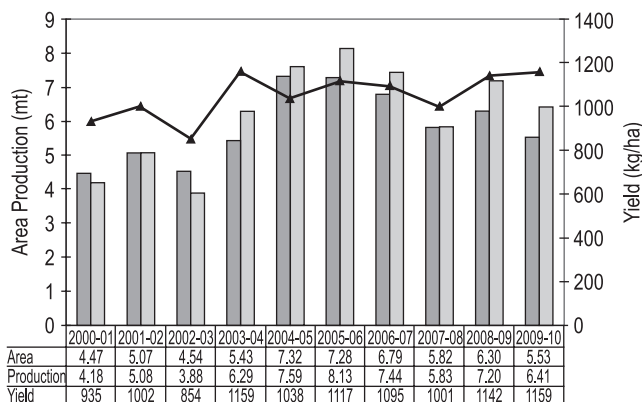


Fig 1 Area, production and yield of rapeseed-mustard in India during the last decade

Rajasthan, Uttar Pradesh and Madhya Pradesh are the major rapeseed-mustard growing states with 45.5%, 13.1% and 11.1% contribution, respectively, to the national acreage during the last five years. The corresponding contribution to production was 48.6%, 13.4% and 9.8%, respectively (Fig 2 a, b). Nevertheless, yield (kg/ha) was in general higher in Gujarat varying from 1 072 to 1 635 kg/ha but during 2008–09 and 2009–10, Haryana recorded the highest yield, 1 738 and 1 656 kg/ha, respectively (Agricultural Statistics at a Glance 2010. www. dacnet.nic.in). The present paper reviews the past and current varietal rapeseed-mustard improvement programme in India and also identifies some thrust areas of future research.

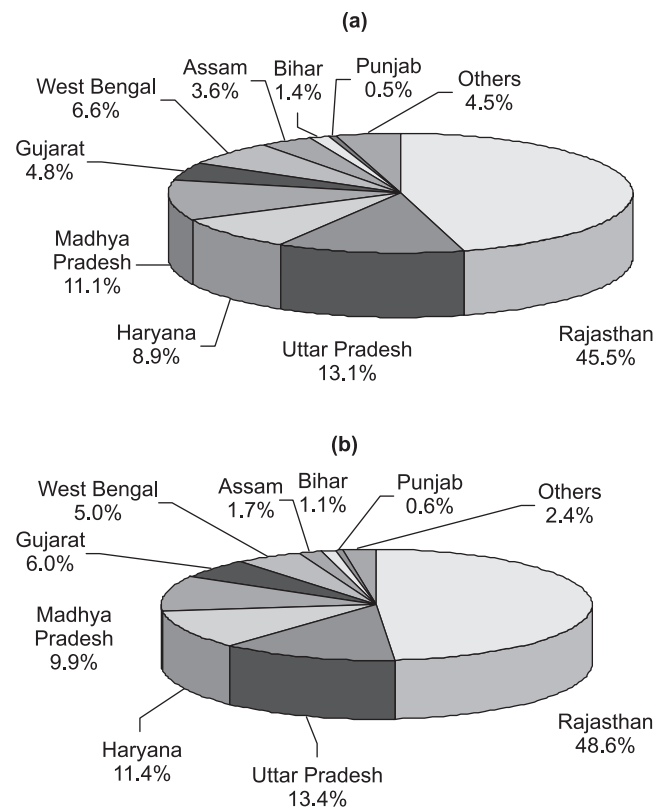


Fig 2 Contribution of different states of India to rapeseed-mustard (a) acreage and (b) production during 2005–06 to 2009–10

HISTORY AND ACCOMPLISHMENTS

Pre-All India Coordinated Research Project on Rapeseed-mustard

The research work on the improvement of rapeseed-mustard started by the turn of the last century at Pusa (Bihar), the then Bengal Presidency through the collection of land races and their purification. The scientific work for varietal improvement of Indian *oleiferous* Brassiceae started at Layallpur (now Faisalabad in Pakistan), then in Punjab of undivided India (NRCRM 2000). The initial efforts led to the

identification and release for cultivation of RL 18 (Raya Layallpur 18), a variety of Indian mustard in 1937 and L1 of yellow sarson through selection. Indian mustard strain RT 11 from Uttar Pradesh was found superior to local varieties and released in 1936. However, systematic research efforts were started after independence. Until mid-forties, barring sporadic and isolated research efforts, the rapeseed-mustard crop commodity did not get attention in terms of research and development. The earliest attempt to organize research in oilseeds was made by constituting the Indian Central Oilseeds Committee (ICOC) in 1947 under the Indian Oilseeds Committee Act IX in 1946. The main objective of the ICOC was to increase production of individual oilseeds through ad hoc-funding of research programmes carried out by the State Department of Agriculture, Universities and Central Institutes. Oilseeds Development Council replaced the ICOC in 1966. During the course of about two decades (1947–67), a number of high-yielding varieties of mustard (Laha 101, Varuna, Durgamani, Patan Mustard), toria (Abohar, BR 23, M 27, T 9, ITSA, T 36, DK 1), brown sarson (BSA, BSG, BSH 1, BS 2, BS 65, BS 70), yellow sarson (T 151, Patan sarson, YSPb 24, T 42) and taramira (ITSA) were developed (NRCRM 2007).

Post All India Coordinated Research Project on Rapeseed-mustard

The research programme, however, started in an organized way when the Indian Council of Agricultural Research (ICAR) took a step forward in April 1967 by launching a comprehensive multi-disciplinary research project for the improvement of oilseeds in the country under the banner of the All India Coordinated Research Project on Oilseeds (AICORPO) with a full time Project Coordinator and 32 research centres covering five major crops namely, groundnut, rapeseed-mustard, sesame, linseed and castor. The project got a fillip in 1977 (V plan) with the elevation of the then Project Coordinator (Oilseeds) as Project Director with seven Project Coordinators to monitor, coordinate and plan the research programmes of each of the seven individual crops namely, groundnut (Junagadh), rapeseed-mustard (Hisar), sesame and niger (Jabalpur), sunflower (Bangalore), safflower (Solapur), linseed (Kanpur) and castor (Hyderabad). The research programme was further intensified by strengthening the individual oilseed crop projects by setting up separate Project Coordinating Unit in the V plan to meet the necessary needs of individual crops, the unit of the Project Coordinator (Rapeseed-Mustard) was accordingly established on 28 January 1981 at the campus of the Haryana Agricultural University, Hisar. In order to provide a strong leadership to the rapeseed-mustard research activities in the country and for promoting mission-oriented basic, strategic and applied research, the ICAR established National Research Centre on Rapeseed-Mustard on 20 October 1993 at Bharatpur (Rajasthan) bringing under its umbrella, the All India

Coordinated Research Project on Rapeseed-Mustard with 19 research centres across the country. In February 2009, the National Research Centre on Rapeseed-Mustard was re-designated as Directorate of Rapeseed-Mustard Research (DRMR).

GENETIC RESOURCE MANAGEMENT

Acquisition/collection

The success of crop improvement programme depends upon the magnitude of variability available in the genetic resources of that crop. No single country for that matter even region can be self-sufficient in its needs for plant genetic resources (Arora *et al.* 1991). India presents rich diversity of oilseed *Brassicaceae*. *Brassica rapa* var. toria and brown sarson, *B. juncea* and *Eruca vesicaria*, were considered to be of Indian gene centre (Arora 1998). The north-eastern and north-western regions hold promising genetic variability in rapeseed-mustard. A total of 4 095 accessions were collected from different parts of the country during 1986–2005 and the National Gene Bank at National Bureau of Plant Genetic Resources (NBPGR), New Delhi conserved 10 259 accessions till December 2010 (NBPGR 2011). The NRCRM/DRMR and other collaborative centres under the umbrella of the All India Coordinated Research Project on Rapeseed-Mustard held 14,722 germplasm accessions (Kumar 2009, Table 1). Exchange Division of NBPGR introduced 3 401 exotic accessions of rapeseed-mustard during 1985–2006 (Sharma and Singh 2007) and the NRCRM through NBPGR received 853 exotic accessions from Canada, USA, Germany, Sweden, Belgium, Australia and China during 2001–07 and of these, 463 are available at DRMR (NRCRM 2007).

Table 1 Status of working germplasm collections at various centres in India

Crop	DRMR, Bharatpur	AICRPRM Centres
Indian mustard	3641	6079
Karan rai	115	128
Toria	966	952
Yellow sarson	535	529
Brown sarson	231	247
Gobhi sarson	272	323
Taramira	381	197
Others	60	68
Total	6201	8521

Germplasm access and benefit sharing

Sovereign rights of states over their biological resources, reaffirmed in the preamble of the Convention on Biological Diversity (CBD) 1992 and articulated clearly in its Articles 8 and 15 brought the twin issues of access and benefit sharing (ABS) to the centre stage (Rana 2010). With the

emergence of highly restrictive intellectual property rights (IPR) systems, it became imperative to enact national legislation to claim sovereign rights of ownership over bio-resources to ensure realization of fair and equitable sharing of benefits arising from their utilization. Following an extensive consultation process, Government of India enacted the Biological Diversity Act 2002 in response to implement the international treaties to determine the access to genetic resources. The Government of India established a body called the National Biodiversity Authority on 1 October 2003. The National Biodiversity Authority came into existence in 2004 at Chennai, Tamil Nadu, headed by a Chairperson. The act provides for its implementation through a 3-tier system comprising the National Biodiversity Authority (NBA), the State Biodiversity Boards (SBBs) and the Biodiversity Management Committees (BMCs) at the local communities' level.

Evaluation and utilization

Precise evaluation of available gene pool and dissemination of findings is imperative for their utilization. Successful variety development programme needs continuous supply of resource genes for crop yield, quality, various biotic (diseases and insect pests) and abiotic stresses (salinity, drought and high temperature) for utilization. Evaluation of exotic germplasm, in particular, is necessary to broaden the narrow genetic base by identifying and incorporating the desired characters lacking in the existing varieties. Valuable donors for various biotic, abiotic stresses, variability in agromorphological and quality characters have been identified among the indigenous Indian mustard germplasm (Kumar and Chauhan 2005, Misra *et al.* 2007a, b). However, limited variability existed for oil and seed meal quality characters. Exotic germplasm has been utilized in Indian breeding programme to develop 21 varieties, especially for oil and seed meal quality characters (Table 2).

Two varieties of brown sarson and 10 varieties of gobhi sarson were of direct introduction/selection/derivatives of exotics. In Indian mustard, two varieties (JM 1 and JM 2) were derived by utilizing white rust resistant accessions L 4 and L 6 from Canada; all the low erucic acid varieties (Pusa Karishma, LET 17, LET 18, LES 1-27) were derived from ZEM 1 and ZEM 2 from Australia (Kirk and Oram 1981). Furthermore, BJ 1058, the only source of low glucosinolate in *Brassica juncea* having Bronowski block (Love *et al.* 1990), has been vastly utilized in the Indian breeding programme to develop canola *B. juncea*. A total of 5 605 accessions have been evaluated/characterized for agromorphological traits at DRMR, Bharatpur till 2009–10 (Kumar 2009). Fortytwo accessions have been registered with NBPGR (ICAR), New Delhi till December 2010 (Table 3).

Varietal development

Until 1970, pure line and mass selection were the only

Table 2 Varieties of rapeseed-mustard developed utilizing exotic germplasm

Crop	Variety	Source	Method
Brown sarson	KBS 3	Yukina	Hybridization
	Gluechin	Unknown exotic	Mass selection
Gobhi sarson	DGS 1	Unknown exotic	Pure line selection
	GSC 5	Agat	Hybridization
	GSC 6	Tribute, NECN 13	Hybridization
	GSL 2	Triton	Hybridization
	Himsarson 1 (ONK 1)	EC 129127	Pure line selection (Reselection from Sheetal)
	Neelam	Culture 2 (Westar)	Pure line selection
	Sheetal	EC 129127	Pure line selection
	NUDB 26-11	Westar	Mutagenesis
	TERI Unnat	ISN 706	Hybridization
	TER Uttam	Cyclone	Hybridization
Indian mustard	Jawahar		
	PBR 91	CM 1	Hybridization
	Pusa Karishma	ZEM 1	Hybridization
	LES 1-27	ZEM 2	Hybridization
	LET 17	ZEM 2	Hybridization
	LET 18	ZEM 1	Hybridization
	JM 1	L 6	Hybridization
	JM 2	L 4	Hybridization
RGN 145	Tobin	Hybridization	
Karan rai	PC 5	Karan, S 67	Hybridization

breeding methods, followed and 26 varieties were developed with the first release in 1 936. Number of varieties developed through hybridization consistently increased after 1980 and 22 varieties in each of the 8th and 9th decade of 20th century was released. This number further increased to 41 during first decade of the 21st century. Simultaneously, mutation breeding was also pursued and 12 varieties had been developed (Table 4). Chauhan and Singh (2004) opined that most of Indian mustard varieties were the pure line selections derived from a few common ancestors and limited number of donors was utilized in the breeding programme resulting into narrow genetic base. In the present paper analysis of pedigree of all the 203 identified/released rapeseed-mustard varieties till 31 December 2010, revealed that 95 and 86 varieties were developed through hybridization and selection from local germplasm, respectively (Table 4). All the varieties developed before the inception of AICRPO/ AICRP-R&M were the selections from the local germplasm. Also, during 2001–10, this continued to be the major method

Table 3 Rapeseed-mustard germplasm registered in India

National identity	Donor/other identity	Novelty /unique feature(s)
<i>Brassica juncea</i>		
IC 296501	Heera	Low glucosinolate content (16.96 μ moles/g of seed) and low erucic acid in oil (0.1%)
IC 296507	NUDHYJ 5	Low glucosinolate content (9.3 μ moles/g of seed) and low erucic acid (0.1%)
IC 296682	CMS Trachy (Restorer)	Restorer gene for CMS Trachy
IC 296683	CMS Trachy	Cytoplasmic male sterility
IC 296684	Swarna [TERI (0E)M21]	Zero erucic acid, yellow-seeded, early maturing
IC 296689	NDYR 8	Yellow seeded mustard with high oil content (45.7%)
IC 296690	NDYR 10	Yellow seeded mustard with high oil content (45.8%)
IC 296701	CMS	Cytoplasmic male sterile carrying cytoplasm of <i>Brassica oxyrrhina</i>
IC 296702	CMS	Cytoplasmic male sterile
IC 296703	CMS	Fertility restorer for CMS (<i>Moricandia arvensis</i>) <i>B. juncea</i>
IC 296705	CMS	Cytoplasmic male sterile with <i>Raphanus/ ogu-B. juncea</i>
IC 296706	CMS	Chlorosis corrected, green, cytoplasmic male sterile mustard
IC 296741	RB1 (Raya Bawal 1)	Tetralocular siliquae
IC 296746	<i>Diplotaxis eruroides</i>	Cytoplasmic male sterile
IC 296749	<i>Diplotaxis siifolia</i>	Cytoplasmic male sterile
IC 296829	TM1 (YSM 2)	Yellow seeded Indian mustard
IC 401570	RH 8814	Resistance to salinity reaction (up to ECE 10 dS/m)
IC 405233	TERIGZ 05	High oleic and linoleic acid, yellow seed and double low material
IC 443623	BIO YSR	Yellow seeded, high oil, white rust resistant
IC 546946	PAB 9511	Tolerant to blight (<i>Alternaria brassicae</i> and <i>A. brassicola</i>)
IC 546947	PRQ-2005-1	Low erucic acid with yellow seed
IC 553910	Divya (PPMS 1)	Dwarf, early maturity, distinct whorl around the axis
IC 555891	NRCDR 515	White rust resistant
IC 573439	PRB 2006-5	Bold seed
IC 0583386	BPR 541-4	Thermo tolerance at terminal stage and salinity tolerance at juvenile stage and high water use efficiency
IC 0583448	BPR 543-2	Thermo tolerance at juvenile stage and high water-use efficiency
IC 296684	Swarna [TERI (0E) M21]	Zero erucic acid, yellow seeded, early maturing
<i>Brassica napus</i>		
IC 296685	Phaguni [TERI(0E)R 03]	Zero erucic acid and early maturing
IC 296688	Shyamali [TERI(0E)R09]	Zero erucic acid, high oleic acid (70.1%) and high oil content
IC 296704	CMS (<i>B. oxyrrhina</i>)	Cytoplasmic male sterile
IC 296707	CMS	Cytoplasmic male sterile carrying cytoplasm of <i>Brassica oxyrrhina</i>
IC 296731	Teri Gaurav [TERI (00) R 986]	Zero erucic acid, low glucosinolate (15.3 μ m/g oil free mean), early maturing (125 days), dwarf
IC 296732	Teri Garima [TERI (00) R 985]	Zero erucic acid, low glucosinolate (12.2 μ m/g oil free mean), high oleic acid (57%),
IC 296747	<i>Erucastrum gallicum</i>	Early flowering variant (31 – 33 days) carrying the cytoplasm of <i>Erucastrum gallicum</i>
IC 296827	NUDB 38	Early maturing double low gobhi sarson
IC 296828	NUDB 42	Early maturing double low gobhi sarson
IC 405232	TERI (00) R 9903	Double low with early maturity (130-135 days)
IC 0582897	NRC GS-1	Early flowering and dwarf plant
<i>B. carinata</i>		
IC 296748	<i>Erucastrum gallicum</i>	Useful variant of Ethiopian mustard (<i>Brassica carinata</i>) showing <i>B. juncea</i> type branching and assembling <i>B. carinata</i> in other features
IC 0582898	NRCKR 304	Early maturity, long main shoot and bold seed
<i>B. rapa (toria)</i>		
IC 296597	Amphidiploid	Amphidiploid Brassica
IC 552726	PHOP 2-2	High oleic acid (70.1%), low erucic acid (0.2%) and brown seeded
IC 552727	PHOT8 2-11	Low linolenic acid (3.63%) and brown seeded

Table 4 Number of rapeseed-mustard varieties developed through different breeding methods during 1936–2010

Year	Total number of varieties	Breeding method				Tissue culture
		Selection	Hybridization	Mutation	Hybrids	
1936–66	26	26				
1967–70	03	03				
1971–80	21	15	04	02		
1981–90	41	13	22	03		
	(38+3*)					
1991–2000	40	13	22	02	02	01
2001–10 update	72	16	47	05	03	
	(71+1*)					
Total	203	86	95	12	05	01
	(199+4*)					

*No information on pedigree was available for four mustard (KRV 74, RK 9, RK 14 and Rajendra Suphalam) varieties

predominantly in crop like yellow sarson.

Further, in-depth analysis of varieties those were developed through hybridization revealed that Indian mustard comprised the major portion (68). Only 12 rapeseed-mustard varieties involved more than two strains in their pedigree. The analysis further revealed that a single variety of Indian mustard, Varuna, which itself a pure line selection from Banarasi Rai, a local germplasm, has been extensively used in the development of 46 varieties. Kranti, Krishna and Rohini were the direct selections of Varuna, whereas, Pusa Jaikisan (Bio 902) is a somaclone of Varuna. Further, variety Urvashi was derived from the cross of Varuna × Kranti. In the pedigree of 24 varieties Varuna was directly utilized as one of the parents in hybridization, whereas 18 varieties had Varuna in their pedigree as they were derived from the derivatives of Varuna. Thus the direct and indirect contribution of Varuna to the Indian mustard breeding comes to about 42.6 %. Considering, the rapeseed-mustard programme as a whole, the contribution of Varuna stood out to be 22.5 %.

Since the early 80's, systematic and vigorous recombinant breeding has been perused and large number of varieties have been identified and released. The first notified variety was ITSA of toria (*B. rapa*) in 1973 after the adoption of official notification of varieties in 1969 under the Seed Act 1966 (Section 5). The major objectives of the varietal improvement programme have been genetic enhancement for oil and seed yield through developing varieties for early, timely and late-sown conditions to cater to the need of diverse agro-ecological situations of the country, improvement of oil (low erucic acid) and seed meal (low glucosinolate) quality, introgression of resistance/tolerance against major biotic (white rust, *Alternaria* blight, *Sclerotinia* rot diseases and aphid and painted bug insects) and abiotic stresses (drought, high temperature and salinity) and many trait/

Table 5 Varieties recommended for specific conditions/possessing particular trait

Agro-climatic situation/trait	Name of variety/varieties
<i>Indian mustard</i>	
White rust resistant	Basanti, JM 1, JM 2
Earliness	Kanti, Narendera Ageti Rai 4, Pusa Agrani, Pusa Mahak, Pusa Vijay, Pusa mustard 25 (NPJ 112), Pusa mustard 27 (EJ 17)
High oil content	Narendra Swarna Rai 8, NRCRD 02, Rohini
High temperature tolerant	Kanti, Pusa Agrani, RGN 13, Urvashi, NRCRD 02, Pusa mustard 25 (NPJ 112), Pusa mustard 27 (EJ 17)
Intercropping	RH 30, RH 781, Vardan
Late sown	Ashirwad, RLM 619, Swarnjyoti, Vardan, Navgold (YRN 6), RGN 145, NRCHB 101, CS 56 (CS 234-2), Pusa mustard 26 (NPJ 113)
Non-traditional areas	Pusa Agrani, Pusa Jaikisan, Rajat, Gujarat Mustard 2, TPM 1, Shatabdi (ACN 9)
Rainfed	Aravali, Geeta, GM 1, PBR 97, Pusa Bahar, Pusa Bold, RH 781, RH 819, RGN 48, Shivani, TM 2, TM 4, Vaibhav, RB 50
Salinity tolerant	CS 52, CS 54, Narendra Rai (NDR 8501)
Frost tolerant	RGN 13, RH 819, Swarnjyoti, RH 781, RGN 48
Quality trait (low erucic acid)	Pusa Karishma, Pusa Mustard 21, Pusa Mustard 22, Pusa Mustard 24, ELM 079 (RLC 1)
Hybrid	NRCHB 506, DMH 1, Coral PAC 432
<i>Gobhi sarson</i>	
Quality traits	
Low erucic acid and glucosinolate	GSC 5, Hyola 401, NUDB 26-11, OCN 3 (GSC 6), TERI Uttam Jawahar

situation-specific varieties have been developed (Table 5). Brassica improvement programme in India has witnessed a sea change during past few years.

Concerted efforts over the last four decades led to the development and identification of 177 rapeseed-mustard varieties after the inception of the All India Coordinated Research Project on Oilseeds in 1967 for varied cropping systems and situations. In all 203 rapeseed-mustard varieties have been identified and Central Sub-Committee on Crop Standards, Notification and Release of Varieties for

Table 6 Present status of rapeseed-mustard varietal improvement programme in India

Crop	Varieties recommended /released/notified					
	Before inception (1936–1966)		After inception (1967–2010*)		Total	
	Identified	Notified	Identified	Notified	Released/identified	Notified
<i>Rapeseed</i>						
Brown sarson	4	1	5	3	9	4
Gobhi sarson			13	11	13	11
Taramira	1	1	7	5	8	6
Toria	9	4	26	16	35	20
Yellow sarson	6	4	17	11	23	15
<i>Mustard</i>						
Black mustard			1	1	1	1
Indian mustard	6	2	101	81	107	83
Karan rai			7	4	7	4
Total	26	12	177	132	203	144

*Updated till 58th Meeting of Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops, NBPGR, Delhi, 23 December 2010

Agriculture Crops has notified 144 varieties (Table 6) till December 2010.

Bio 902 of Indian mustard, a somaclone was released in 1993. The recommended varieties recorded 9 to 53% yield increase over national checks under varied situations. The varieties released during the last decade (2001–10) have been given in Table 7.

Hybrid development

Reports on availability of heterosis in rapeseed-mustard in early forties (Sun 1943), raised interest amongst plant breeders to develop the means for harnessing hybrid vigour. Introgression of cytoplasmic male sterility developed in radish (*Raphanus sativus* L.) by Ogura in 1968 to *Brassica juncea* (Banga and Labana 1984a) raised hopes to develop hybrids in rapeseed-mustard. In the later years, several cytoplasmic male sterility systems were reported (Table 8). Development of genetically engineered system of male sterility (*barnase - barstar* system) by Jagannath *et al.* (2002) is another milestone in utilizing the hybrid vigour in rapeseed-mustard. Labana *et al.* (1975), Banga and Labana (1984) and Dhillon *et al.* (1990) in Indian mustard recorded heterosis of high level (>100% on plant basis). Rawat and Anand (1979) reported male sterility in Indian mustard (*B. juncea*) but it could not be utilized due to incomplete fertility restoration. Systematic and coordinated efforts for developing hybrids in Rapeseed-Mustard started in 1989 under the ICAR sponsored project on “Promotion of Research and Development Efforts on Hybrids in Crops” with 2 CMS systems in *B. juncea*, ie *ogu* and *tour* and one in *B. napus*, ie *polima*. Major emphasis was given to the simultaneous development of CMS-fertility restorer systems. The approach led to the development of seven new CMS systems, viz *siifolia*, *oxyrrhina*, *muralis*,

catholica, *nigra*, *moricaudia* and *trachystoma* till 1995. These systems due to several limitations, particularly non-availability of full fertility restoration, could not be utilized for hybrid development. Due to the failure of conventional breeding methods in identifying the restorer gene(s) in *B. juncea*, it was felt to find out restorer gene(s) in the same species from which cytoplasm had been intro-gressed. Concerted efforts were made at National Research Centre for Plant Biotechnology, New Delhi for the development of fertility restorer through protoplast fusion between the wild species and *B. juncea*. These efforts resulted in the development of fertility restorer for *mori* and *trachy* CMS systems. Two more CMS systems, viz *lyratus* and *canariense* have also been reported. *Mori* CMS and fertility restorer were found to be associated with severe chlorosis and retarded growth (Fig 3a). Segregation for fertility/sterility coupled with crooked siliqua formation was observed in *trachy* system. Efforts were then put to rectify the chlorosis and to improve the transmission of fertility restorer gene(s). Considering its potential, efforts were concentrated on *mori* CMS-fertility restorer system. Chlorosis associated with *mori* CMS systems was rectified (Fig 3b) and diversified into the improved background of identified heterotic combination for developing commercial hybrids. *Lyratus*, *erucoides*, *canariense* and *I26-1* and *barthauti* CMS systems were later reported (Table 8).

In yellow sarson (*B. rapa* syn. *campestris* var. yellow sarson), three GMS lines, viz YSMS 2, YSMS 6 and YSMS 8163, provided the base for developing the hybrids. YSMS 8163 has been quite stable. Currently major thrust is on the search of a marker to identify male sterile plants in the initial phase of vegetative growth. In *gobhi sarson* (*B. napus*), CMS development programme has been in progress with three CMS systems, viz *polima*, *tournefortii* and *lyratus*.

Table 7 Recently released rapeseed-mustard varieties (2001–10) in India

Period	Rapeseed				Mustard			
	Brown sarson	Gobhi sarson	Taramira	Toria	Yellow sarson	Indian mustard	Karan rai	Black mustard
2001–05		GSC-5, TERI Uttam Jawahar	Anuradha			Geeta, Kanti, Maya, RGN 13, Swaran jyoti, Vasundhara, PBR 210, Pusa Mahak (JD 6), CS 54, RGN 48, Ashirwad (RK 01-03), JM 2, JM 3, Shivani, Narendra Swarna Rai 8, NavGold (YRN 6), RRN 505, ACN Shatabdi, GM 3, Pusa Karishma (LES 39)	Pusa-Swarnim	Surya
2006–10		GSC 6 (OCN 3), NUDB 26-11, Him Sarson 1 (ONK1)	Narendra Tara(RTM 2002), Vallabh Tara 1 (PUT 93-11), Vallabh Tara 2 (PUT 93-1)	VL Toria 3 Uttara	YSH 0401, NRCYS05-02, Pitambari (RYSK 05-02), Pant Pili Sarson	NRCDR 2, Pusa Mustard 21 (LES 1-27), Pusa Mustard 22 (LET17), RGN 73, Pusa Mustard 24 (LET18), CS 56 (CS 234-2), TPML, RLC 1 (ELM 079), Pusa Vijay (NPJ 93), RB 50, RGN1-45, NRCHB 101, NRCHB 506 (Hybrid), DMHI (Hybrid), Pusa Tarak (EJ 9912-13), Pusa Mustard 25(NPJ 112), NRCDR 601, Coral PAC 432 (Hybrid), Pusa Mustard 26 (NPJ 113), Pusa mustard 27 (EJ 17), Chhattisgarh Sarson, RH 0119	Pusa Aditya	

Table 8 Cytoplasmic male sterility systems available in rapeseed-mustard in India

System	Discovered by	Status of fertility restoration
<i>tour</i>	Rawat and Anand (1979)	Reported in <i>B. napus</i>
<i>oxyrrhina</i>	Prakash and Chopra (1988)	No restoration
<i>siifolia</i>	Rao <i>et al.</i> (1994)	Reported but not in use, no restoration
<i>trachystoma</i>	Kirti <i>et al.</i> (1995 a)	Single dominant gene reported for restoration
<i>moricaudia</i>	Prakash <i>et al.</i> (1995)	Single dominant gene reported for restoration
<i>catholica</i>	Kirti <i>et al.</i> (1995 b)	No restoration
<i>alba</i>	Prakash <i>et al.</i> (1995)	Reported in <i>B. napus</i>
<i>lyratus</i>	Banga and Banga (1997)	Reported but not in use
<i>canariense</i>	Prakash <i>et al.</i> (2001)	Reported but not in use
<i>erucoides</i>	Bhat <i>et al.</i> (2006)	Reported but not in use
<i>126-1</i>	Sodhi <i>et al.</i> (2006)	Reported in <i>B. napus</i>
<i>barthauti</i>	Bhat <i>et al.</i> (2006)	Reported but not in use

The three-line technology has already been perfected with the release of first commercial hybrid PGSH 51 based on *tour* CMS system by PAU, Ludhiana in 1994 and Hyola 401 based on *pol* CMS system was released by Advanta, India in 1997/2000. Recently, experimental hybrids using *ogura* CMS system have been developed by PAU, Ludhiana.

In Indian mustard (*Brassica juncea*), during 1999–2005, efforts concentrated on conversion of normal green *mori* CMS and restorer plants into high-yielding heterotic parents at Bharatpur, Ludhiana and Hisar (Singh 2008). These centres have started the testing of experimental hybrids based on *mori* system by 2003–04. For the first time an initial hybrid trial (IHT) comprising seven hybrid entries and five check varieties was conducted during 2004–05 for multi-location testing under AICRPRM network. Since then, 72 hybrids have been inducted for testing (2004–05 to 2010–11). These include 19 from PAU, 10 from CCS HAU, 15 from DRMR, two from Delhi University, 11 from NRCPB, four from Advanta, one from JK Seeds, seven from Pioneer and two from Bayer Bio Science and one from Nuziveedu Seeds Pvt Ltd. Sustained efforts resulted in the release of three CMS-based hybrids, NRCHB 506 and DMH 1 in 2009 and Coral 432 (PAC 432) in 2010. The present status of hybrid development in rapeseed mustard in India has been summarized in Table 9.

Quality improvement

Oil and seed meal obtained after oil extraction from seed are the two products of economic importance. Rapeseed-mustard oil is an important dietary component in India, especially in eastern and north-western parts. Seed meal is



Fig 3 (a) Chlorotic mori CMS, (b) corrected mori CMS

mainly used as an animal feed. Seed meal has also potential use as manure and also being exported.

Oil quality is determined by the nature and content of fatty acids. Fatty acid is a long chain single carboxyl group containing organic acid compound, mostly of even carbon numbers occurring either as ester or in free form. Fatty acid with the structural formula $\text{CH}_3(\text{CH}_2)_n\text{COOH}$ with no carbon-carbon double bond is termed as saturated fatty acid, as exemplified by palmitic (C 16:0)/stearic (C 18:0) acid and that with double bonds in aliphatic chain is called unsaturated fatty acid. Fatty acids having one double bond or more than one are classified as monounsaturated (oleic acid) and polyunsaturated fatty acids (linoleic and linolenic acids), respectively. Linoleic and linolenic acids are not synthesized by mammals but are important dietary requirements and known as essential fatty acids. Plants are capable of synthesizing these two essential fatty acids and are the original source in our diet. The major fatty acids in rapeseed-mustard oil are oleic (C 18:1^{Δ9}), linoleic (C 18:2^{Δ9, 12}), linolenic (C 18:3^{Δ9, 12, 15}), eicosenoic (C 20:1^{Δ9}) and erucic acid (C 22:1^{Δ13}). Erucic acid in oil of the Indian rapeseed-mustard varieties is quite high (Chauhan *et al.* 2007b). Consumption of higher amount (>20%) of mustard oil having high erucic acid, in the diet, caused myocardial fibrosis, impair myocardial conductance, lipidosis, etc and also increased blood cholesterol (Gopalan *et al.* 1974, Renard and Mc Gregor 1976 and Ackmn *et al.* 1977). The seed meal of rapeseed-mustard mainly comprises proteins (35–40%), carbohydrates (14–15%), fibres (10–12%), moisture (6–8%), ash (4–6%), minerals and vitamins (1.0–1.5%), glucosinoloates (2–3%), tannin (1.6–3.1%), sinapin (1.0–1.5%) and phytic acid (3–6%). Among all the constituents, fibres, tannin, phytic acid,

Table 9 Present status of hybrid development in rapeseed-mustard in India (till 31 December, 2010)

Crop	Present status
<i>Brassica juncea</i>	72 experimental hybrids have been inducted under AICRP-RM multi location testing from 2004-05 to 2010-11. Of these 56, 13, 2 and 1 were based on <i>mori</i> ; <i>ogura</i> , <i>126-1</i> and unknown CMS source, respectively. Three commercial hybrids DMH 1, NRCHB 506 and Coral PAC 432 have been released till 2010.
<i>B. rapa</i>	Three GMS systems are available. GMS-based experimental hybrids have been tested. The programme discontinued due to want of a suitable GMS-linked marker.
<i>B. napus</i>	PGSH 51 a <i>tour</i> and Hyola 401 a <i>pol</i> CMS based commercial hybrid have been released. <i>ogura</i> CMS system hybrids being under testing in AICRP-RM.

glucosinolate and sinapin lower the feed value of seed meal (*cf.* Chauhan *et al.* 2002). Glucosinolates are a group of plant thioglucosides found principally among members of family Cruciferae (Brassicaceae) principally determine the quality of seed meal. The vegetable tissue and seed of Cruciferous plant contain one or more of over 120 known glucosinolates (Fenewick *et al.* 1983). Cleavage products from hydrolysis of glucosinolates are detrimental to animal health as they reduce the feed palatability; affect the iodine uptake by the thyroid glands thus reducing feed efficiency and weight gains (Bell 1984 and Fenewick *et al.* 1983), especially in non-ruminants such as pigs and poultry. Thus, it is imperative

to reduce glucosinolate in Indian mustard cultivars from their present level of very high amount. Glucosinolates and their derived properties have also been reported to have health beneficial effects by reducing the risk of certain cancers in humans (Zhang and Talay 1994, Fahey *et al.* 2001, Shapiro *et al.* 2001, Mithen *et al.* 2003), while other glucosinolates are detrimental for human and animal consumption (Rosa *et al.* 1997). Epidemiological studies indicate that consumption of brassica vegetables is associated with a reduced incidence of cancers at a number of sites including the lung, stomach, colon and rectum (Conaway *et al.* 2001).

Breeding efforts have been underway in India since 1970 to reduce glucosinolate content in the seed of rapeseed-mustard varieties up to 30 micro moles/g defatted seed meal (low or 0) and erucic acid up to 2% (low or 0) as well as combining both to develop double zero or double low varieties to meet the internationally acceptable standard of oil and seed meal. Chauhan *et al.* (2002) reviewed the quality improvement programme of rapeseed-mustard in India. First low erucic acid variety, Pusa Karishma of Indian mustard and first double low variety, GSC 5 of gobhi sarson was released in 2004 and 2005, respectively. Presently, five low erucic varieties have been released in *Brassica juncea*. In gobhi sarson (*B.napus*), 5 double low (low erucic and low glucosinolate) varieties have been released (Table 5). The present status of quality improvement in rapeseed-mustard in India up to December 2010 has been summarized in Table 10. The current efforts are to recombine low erucic acid with low glucosinolate content in Indian mustard and refining the agronomic base to improve yield potential of double low gobhi sarson strains.

Abiotic stresses

Drought, salt, frost and heat are the major abiotic stresses which determine the productivity of rapeseed-mustard. Genetic improvement of these factors is, therefore, imperative to realize the potential of a cultivar.

Drought

About 25 % of the total rapeseed-mustard area is rainfed. These crops, because of their low water requirement fit well in the rainfed cropping system. These are predominantly the crops of marginal, small and resource-poor farmers in rainfed areas. Asom (99.4 %), Bihar (60.2%), and Madhya Pradesh (51.8 %) have substantial area under rainfed production system. In other major rapeseed-mustard growing states like Rajasthan, Uttar Pradesh and Haryana, the rainfed area is 10.6%, 20.8%, 22.1%, respectively (Agricultural Statistics at a Glance 2010. www.dacnet.nic.in). The yield reduction under moisture stress (drought) in Indian mustard ranged from 17 to 94 % (Mohammad Ali *et al.* 1990, Chauhan *et al.* 2007b) due to considerable effects on yield components (Chauhan *et al.* 2007b; Sharma and Pannu 2007). Further the plant growth, a genotypic character is also largely influenced

Table 10 Status of quality improvement programme in India.

Crop	Present status
<i>Brassica juncea</i>	124 low erucic acid/glucosinolate content strains were evaluated under AICRP R&M till 2010–11 cropping season. Pusa Karishma (LES 39), first low erucic acid mustard was released for Delhi state during 2004 and five low erucic varieties have been identified for released up to December 2010. four strains (one each of low erucic and low glucosinolate and two low erucic and low glucosinolate) have been registered with National Bureau of Plant Genetic Resources (ICAR), New Delhi.
<i>B. napus</i>	Fortyone low erucic acid and/or low glucosinolate strains evaluated under AICRP R&M till 2010–11 cropping season. Hyola 401, first double low erucic gobhi sarson hybrid was released during 1996; five having low erucic and low glucosinolate have been identified for released up to December, 2010. Six strains (two having low erucic and four having low erucic and low glucosinolate) have been registered with National Bureau of Plant Genetic Resources (ICAR), New Delhi.
<i>B. rapa</i> var. toria	Two strains of toria, viz PHOP 2-2 (INGR 07033) having high oleic (70.1%) and low erucic acid and PHOT 8-2-11 (INGR 07034) with low linolenic acid (3.03%) have been registered with National Bureau of Plant Genetic Resources (ICAR), New Delhi.

by drought. Reduced N₂ assimilatory enzymes activity, plant water relation, root depth, leaf area index, crop growth rate, net assimilation rate, total dry matter, harvest index, partitioning coefficient and translocation of assimilates have been reported as a consequence of drought (Singh *et al.* 2003a, Gunasekara *et al.* 2004, Panda *et al.* 2004, Shiv Ratan *et al.* 2005).

Singh *et al.* (1988) reported that mustard genotypes with drought tolerance trait(s) yielded better than without such trait(s) under water stress condition. Transpiration efficiency (TE), defined as the amount of dry matter produced/unit amount of water transpired is one such trait, which influenced the performance of crop under water-limited condition. Singh *et al.* (2003b) in mustard suggested that genotypes with thicker leaves had greater water-use efficiency. The negative effects of drought during seed development may be mitigated by remobilization of assimilates that is by increasing harvest index. Besides TE, several physiological parameters like, osmotic adjustment (Singh *et al.* 1996) transpirational cooling (Chaudhary *et al.* 1989), epicutlar wax on the leaves (Kumar 1990), difference between canopy and air temperature and loss from the excised leaves (Kumar and Singh 1998), and

drought susceptibility index (Singh and Chaudhary 2003, and Chauhan *et al.* 2007b) have been reported to be associated with drought tolerance. However, exploitation of germplasm for improved TE and other physiological trait(s) has not been possible because of practical difficulties in their measurement. Seed yield *per se* doesn't have genes and largely influenced by components characters such as branches/plant, seeds/siliqua, siliqua length, main shoot length and 1000-seed weight (Meena *et al.* 2006, Singh *et al.* 2006, Brar *et al.* 2007, Misra *et al.* 2007b). Most of these characters are quantitative in nature having complex inheritance and are often affected by environment. The empirical approach has been extensively used to select for high seed yield and other desirable agronomic traits under drought conditions in the target environment that has led to development of many drought tolerant varieties in mustard: Aravali, Geeta, GM 1, PBR 97, Pusa Bahar, Pusa Bold, RH 781, RH 819, RGN 48, RB 50, Shivani, TM 2, TM 4 and Vaibhav (Chauhan *et al.* 2007 b).

High temperature

High temperature is the second most important stress next to drought, which can affect crop plants at any time and impose severe limitation on crop growth and development. Heat stress is often defined as the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and developments. In general, a transient elevation in temperature, usually 10–15°C above ambient, is considered heat stress (Wahid *et al.* 2007). Heat stress is a serious threat to crop production worldwide (Hall 2001). It is a complex function of intensity (temperature in degrees), duration and rate of increase in temperature.

In India prevalence of high temperature (heat) stress at terminal stage of mustard is inevitable in substantial acreage under rapeseed-mustard, especially in eastern and north-eastern parts, as well as central and western Uttar Pradesh due to delayed sowing after rice and mixed/intercropping mustard with wheat (*T. aestivum* L.). Under these situations, the mustard yields have been drastically reduced due to high temperature stress during terminal stage. Therefore, improving seed yield of Indian mustard under late-sown conditions by genetic up scaling of thermo-tolerance at terminal stage would be vital for the sustainability in oilseed production. Seed yield in Indian mustard, as with other crops, is a complex character. Seed yield has been reported to be largely influenced by many yield-contributing characters like days to maturity, branches/plant, seeds/siliqua, siliqua length, main shoot length and 1000-seed weight (Meena *et al.* 2006, Singh *et al.* 2006, Brar *et al.* 2007, Verma *et al.* 2008).

High temperature at the time of crop establishment has been increasingly becoming an important impediment in rapeseed-mustard cultivation in India. The problem is further aggravated in rainfed production system where monsoon

cessation based early sowing is crucial for higher productivity. In the Brassica breeding programme in India, under the All India Coordinated Research Project on Rapeseed-Mustard (AICRPRM), currently, greater emphasis has been laid on screening germplasm for high temperature tolerance during seedling stage to identify appropriate donors for utilization. During 1997–2010, 374 germplasm lines were evaluated under laboratory conditions at PAU, Ludhiana, CCS-HAU-Hisar, CSAUA&T Kanpur and DRMR, Bharatpur. The seedlings were raised in plastic trays/ petridishes under normal temperature ($25 \pm 1^{\circ}\text{C}$) and 3-4 days- old- seedlings were exposed to high temperature ($40 \pm 1^{\circ}\text{C}$) and genotypes showing seedling mortality up to 30% were rated as thermo tolerant. Many useful potential donors, viz., 'NRCDR 02', SKM 9928, RH 0116, RH 8814, SKM 0149 and BPR 543-2 having excellent thermo tolerance at least at three locations for 2 years were identified. Two genetic stocks, BPR 541-4 and BPR 543-2 have been registered with NBPGR for high thermo tolerance at terminal and juvenile stages, respectively. Several varieties of Indian mustard, viz., Kanti, Pusa Agrani, RGN 13, Urvashi, NRCDR 02, Pusa mustard 25, and Pusa mustard 27 showing good thermo tolerance during crop establishment stage have also been developed.

The work on screening Indian mustard genotypes for terminal high temperature tolerance was initiated in 2005. Of the 202 advanced breeding lines evaluated till 2010, NRCDR 02, BPR 541-4, RGN 152, RGN 145 and BPR 549-9 were identified as potential resources having terminal high temperature tolerance rated on the basis of less seed yield reduction (< 30%) under late sowing (AICRPRM 1997-2010). In the national Brassica breeding programme, evaluation and selection under late-sown conditions judges the incorporation of thermo tolerance at terminal stage. The heat stress effects were evaluated by using different sowing dates, optimum (Second fortnight of October) and late (Second fortnight of November) and reduction in seed yield and related characters. No information is available on the level of tolerance (duration, intensity etc.) and it is presumed that varieties developed under late sown condition and showing good yield levels should also possess tolerance to high temperature at terminal stage. Varieties Ashirwad, Swarnjyoti, Vardan, Navgold (YRN 6), RGN 145, NRCHB 101, CS 56 (CS 234-2) and Pusa mustard 26 (NPJ 113) of Indian mustard have been developed for late-sown conditions

Salinity

These crops are also grown in substantial area affected by problem saline soils and poor quality brackish irrigation water. Tolerance to salinity is screened in pots filled with soil of 12–15 dS /m. The tolerance to salinity was characterized on the basis of per cent reduction in seedling emergence and dry weight and BPR 540-6, BPR 541-4, RH 8816 and RH 8814 were identified. RH 8814 and BPR 541-4 have been registered as salinity tolerant genetic stocks. Varieties CS 52,

CS 54 and Narendra Rai 1 tolerant to saline soils have been developed. The breeding work mainly has been carried out at CSSRI, Karnal.

Frost

Rapeseed-mustard crops are susceptible to low temperature leading to freezing injury but occur seldom. In some years a single exposure may cause damages up to 75%. Tolerance to frost is evaluated by number of killed/undeveloped seeds on exposure to low temperature. Screening in freezing cabinets at -30°C for one hour at Hisar revealed Prakash and RH 7868 as tolerant to frost (Dhawan 1985) as both showed low yield reduction ($< 25\%$). Krishna was reported to be tolerant to frost in a six-year study at 36 sites from Pantnagar. Varieties RH 781, RGN 13, RGN 48, RH 819, and Swarnjyoti have been reported to have good frost tolerance.

Biotic stresses

Rapeseed-mustard group of crops are susceptible to a number of biotic stresses. Alternaria blight caused by *Alternaria brassicae* and *A. brassicicola*, white rust (*Albugo candida*), downy mildew (*Peronospora brassicae*) and stem rot (*Sclerotinia sclerotiorum*) are important diseases and aphid (*Lipaphis erysimi*), mustard saw fly (*Athalia proxima*) and painted bug (*Bagrada hilaris*) are major insect pests. One of the economical and environmentally safe ways of protecting the crops from these menaces is development of resistant/tolerant varieties through breeding approaches. Except for white rust genotypic (host) variability for resistance against the other major diseases and insects-pests is limited. Stem rot (*Sclerotinia sclerotiorum*) and *Rhizoctonia* rot which were of minor significance in the past, are now assuming great importance.

Host variability in diseases response exists among various genera and species, wild taxa of this crop could become rich reservoir of genes for disease and insect-pest resistance. Lesion number and size as selection criterion is being generally used in breeding for Alternaria blight resistance. Among cultivated species, *B. carinata* and *B. napus* are tolerant, followed by *B. nigra*, *B. juncea* and *B. campestris* in that order (Skoropad and Tewari 1977) Sharma and Singh (1992) have found *B. hirta* as most resistant. Contrary to these observations, Tewari (1991) reported that there was hardly any variability between resistant and susceptible host at the early stage of infection. Among the related species, *Camelina sativa*, *Capsella bursa-pastoris* and *Neslia paniculata* showed no disease symptoms mainly because of their inhibition capacity of fungal growth on leaf surfaces by producing phytoalexin shortly after infection. *Eruca sativa* (Miller) Thell showed localized flacks and *Armoracia rusticana* Gaertn., showed slow necrosis and chlorosis. Pre- and post-fertilization barriers restrict the transfer of resistant genes from these wild species into *B. juncea* and *B.*

campestris.

Some strains of *B. juncea* such as RC781, PHR 2, EC 399301, PAB 9534, Divya and JMM 915 have been identified as tolerant on the basis of multi-location screening under AICRPRM. These have been extensively used in the breeding programme.

White rust

Two races, AC12 from *B. juncea* and AC13 from *B. rapa* var. toria have been reported. In general *B. napus* and *B. carinata* have been observed as resistant to the pathogen. Utilizing the white rust resistance gene (L 6) from Canadian germplasm, a number of white rust resistant lines have been developed in the genetic background of high-yielding varieties of Indian mustard. The varieties Basanti, JM 1 and JM 2 have been released for general cultivation in white rust prone areas of India.

Sclerotinia rot

Sclerotinia rot caused by *Sclerotinia sclerotiorum* is also an important disease of rapeseed mustard. This causes premature ripening of diseased plants. This pathogen has a very wide host range therefore breeding for resistant cultivar is rather difficult. However, efforts are being made at different research centres of AICRPRM to identify resistant sources against this disease.

Insects

Mustard aphid is one of the serious pests. They also transmit plant viral diseases, eg turnip mosaic virus. Seedling survival, estimated aphid injury, aphid infestation index, aphid fecundity and field evaluation of genotypes are some of the parameters used for identification of aphid tolerant sources. Some genotypes in *B. juncea* such as T 6342, Glossy B 85, RH 7846, RH 7847 and *S. alba* have been reported to show less infestation. *B. juncea* and *B. carinata* are comparatively less susceptible than *B. campestris*. Lack of reliable and stable source of resistance is the major impediment to breed tolerant varieties.

Non-traditional areas

Horizontal expansion of the crop to new niches (non-traditional areas, rice-fallows, etc.) needs to be vigorously pursued as declining per capita availability of land for cultivation, competing crops and priorities will pose a problem for area expansion in the existing arable lands. Growing scarcity of water also favours rapeseed-mustard expansion owing to their low water requirement. It is estimated that 11.65 million ha lands remained fallow in *rabi* season after rice harvest and 10 % of this lies in eastern India which should be targeted for rapeseed-mustard cultivation. Work in this direction was initiated in 1983-84 under AICRPRM. Experiments were conducted in Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra and north-eastern hill region.

The results clearly demonstrated the potential of rapeseed-mustard in these regions. Subsequently, under collaborative programme with UK concerted efforts were made to identify suitable varieties for rice fallow lands in parts of Jharkhand and West Bengal and non-traditional areas in North Karnataka (Bijapur), Eastern Gujarat (Dahod and Panchmahal) and Southern Rajasthan (Banswara and Dungarpur) through farmer participatory approach involving both variety selections as well as breeding during 2000–07 (Anonymous 2007). In Karnataka, 24 varieties of Indian mustard (*Brassica juncea*), one of toria (*B. rapa* var. toria), one of yellow sarson (*B. rapa* var. yellow sarson) and one of *Karan Rai* (*B. carinata*) were evaluated in 196 farmers' participatory trials in 20 villages during 2000–07. The varieties Sej 2 (378–2738 kg/ha), JM 1 (347–2243 kg/ha) and GM 2 (340–2277 kg/ha) of Indian mustard were identified as promising for Karnataka, especially Bijapur district. The suitable varieties for Eastern Gujarat and Southern Rajasthan were Varuna (347–2333 kg/ha), Sej 2 (310–1994 kg/ha) and GM 2 (333–2333 kg/ha). In Ranchi district of Jharkhand and Purulia district of West Bengal, Pusa bold (251–2500 kg/ha), Sej 2 (380–2143 kg/ha) and GM 2 (389–2500 kg/ha) performed exceedingly well (Anonymous 2007). Furthermore, 240 advanced breeding lines of mustard for drought tolerance (F_6 onwards) were also tested and appropriate location-specific selections were made over three successive cropping seasons (2003–06). Therefore, there is a need for strengthening the programme in Karnataka by integrating research, development and marketing.

Breeder seed production

Singh and Chaudhary (2004) and later on Chauhan *et al.* (2006) have reviewed the breeder seed production scenario and reported a non-consistent pattern of indented amount over the years, though the breeder seed production has been much more, often more than double of the indented quantity 242.5 tonnes breeder seed was produced under the AICRP RM during the last 25 (1985–86 to 2009–10) years against the indent of 100.05 tonnes. An analysis of trends in recent breeder seed indent of different rapeseed mustard (2005–06 to 2009–10) revealed that Indian mustard followed by toria and yellow sarson are the major crops representing 78.5 %, 13.1 % and 6.8 % of the total breeder seed indent, while the other crops like brown sarson (0.05 %), taramira (0.9%), gobhi sarson (0.35 %) and karan rai (0.36 %) had marginal share to the total indent. Karan rai (*B. carinata*) is a new introduction and indent for this crop was received for the first time during 2000–01. The number of varieties indented has consistently increased from 26 in 2000–01 to 65 in 2008–09. However, 63 were in the seed chain during 2009–10. The leading varieties based on demand for breeder seed were Pusa Bold, Varuna, Pusa Jaikisan and RH 30 of Indian mustard, Benoy of yellow sarson and M 27 of toria.

Biotechnological interventions

Brassica improvement programme witnessed a sea change world wide during past few years. Plant breeders are in position to address new problems by incorporating biotechnological tools and techniques in their breeding programmes. In India also, new methodologies have been added in breeding programme. Generally, biotechnology encompasses tissue culture techniques to create somaclonal variation, anther culture to produce haploids and homozygous lines, protoplast culture and somatic hybridization, marker-assisted selection, development of transgenics for biotic and abiotic stresses. Regeneration protocols have been optimized for most of the Brassica species using different explants such as cotyledons (Narasimhulu and Chopra 1987), hypocotyls, leaf segments and protoplasts (Kirti and Chopra 1989), Cotyledon petiole and shoot apex (Verma and Singh 2007). *In vitro* culture techniques offer a unique opportunity to explore somaclonal variation for desirable attributes. BIO-902, a somaclone of Varuna which possess shattering resistance along with high yield was selected and commercially released (Katiyar and Chopra 1995). Studies have also been conducted on standardization of conditions conducive to regeneration of plantlets from microspores. Prakash *et al.* (2004) reviewed the efforts made towards anther/ microspore culture in different Brassica species and reported that normal plants can also be regenerated by culturing anthers of CMS line of *B. juncea* carrying *Diplotaxis erucoides* cytoplasm.

Production of somatic hybrids through somatic cell fusion of sexually incompatible species, have been utilized for transfer of various desirable traits from parents to hybrids. Kirti *et al.* (1991b) produced inter-specific hybrids by fusing mesophyll protoplast of *B. juncea* and *B. spinescens*. Scientists at National Research Centre on Plant Biotechnology, New Delhi developed many cytoplasmic male sterile lines (mentioned in the earlier section on hybrid development) through protoplast fusion technology. Prakash *et al.* (1998) applied this technology in *B. juncea* by protoplast fusion of *Moricandia arvensis* with the fertility restoration function of this male sterile *B. juncea* by introgression. These CMS lines were found to be chlorotic. Protoplast fusion of chlorotic male sterile *B. juncea* with green male sterile *B. juncea* resulted in green male sterile plants (Kirti *et al.* 1998). The *mori*-based cytoplasmic genetic male sterility system has successfully been utilized in hybrid development.

Various markers such as RAPD, RFLP, AFLP and SSR have been used in marker-assisted selection of plant genotypes with the desired combinations of traits. Among them markers linked with resistance to white rust (Prabhu *et al.* 1997), fatty acids, oil content, yellow seed colour and fertility restoration have been reported. Transgenic approaches have been followed to develop the transgenic for aphid resistance, male sterility, herbicide resistance and drought tolerance. Bar, Barnase and Barstar based herbicide resistance and genetic

male sterility have been used in the development of experimental hybrids (Jagannath *et al.* 2002). Transgenics expressing Cod A (from *A. glabiformis*) gene for tolerance against abiotic stresses (salt and drought) have also been produced at IARI, New Delhi (Singh 2003). At present efforts are on the development of transgenics using lectin gene for aphid resistance and DREB gene construct for drought tolerance under Network Project on Transgenics in Crops (ICAR). The other transgenes being used in rapeseed-mustard include osmotin (from tobacco) for drought and salt tolerance annexin gene for stress tolerance, Chitinase, Glucanase (from *Arabidopsis*) for tolerance to Alternaria blight disease (Hegde 2008) and FAE1 gene for low erucic acid mustard cultivars.

DUS testing

In pursuance of implementation of plant variety protection under Protection of Plant Varieties and Farmers' Rights Act 2001, various activities including preparation of database of extant varieties, formulation of crop-specific guidelines for conduct of DUS Test, were initiated during 2002 under the scheme Implementation of Plant Variety Legislation, funded by Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. The genetically pure seed of all available varieties were procured from the respective institutes to prepare a database of extant varieties. Simultaneously, species wise guidelines for the conduct of DUS testing in rapeseed mustard were prepared (Singh *et al.* 2006). Later on these guidelines were adopted by Protection of Plant Varieties and Farmers, Rights Authority after due modifications and notified during 2009. These guidelines mention all the relevant method for conduct of DUS testing based on 24 morphological traits for each species including *Brassica juncea*, *Brassica carinata*, *B. rapa* and *B. napus*. A morphological descriptor of 104 rapeseed mustard varieties based upon DUS characteristics was published (Singh and Chauhan 2010). The registration of varieties for protection under PPV FRA was initiated by the Protection of Plant Varieties and Farmers' Rights Authority since May 2010.

International collaborations

International collaborations in rapeseed-mustard research were initiated during late seventies. Major thrust areas of first Indo-Canada collaborative project (1979–94) were quality, disease resistance, hybrid development and toria improvement. Indo-Swedish project (1981–90) mainly focused on abiotic stresses (drought, frost) and crop management. During late nineties two projects, ie Indo-UNDP collaboration (1997–99) on quality improvement and Indo-UK project (1999–2007) on disease and drought tolerance, were initiated. Indo-Australia project (2004–10) between ICAR (India) and ACIAR (Australia) aimed at developing double low quality genotypes, tolerance to diseases and abiotic stresses, particularly thermo and drought

tolerance. The major programmes executed under IDRC funded projects in phase-I were germplasm collection and maintenance, development of dwarf and early varieties of toria with bold seed and high yield, transfer of tetralocular character in toria, transfer of bold seed size from brown sarson /toria, transfer of yellow seed character from yellow sarson to toria, development and maintenance of composite, development of male sterile lines and population improvement through recurrent selection in toria. During phase II management of Alternaria blight and white rust, heterosis and quality breeding in rapeseed mustard, human resource development and consultancies were main executed programmes. In phase I of Indo-UK project, methodology for research on downy mildew disease was developed and standardized. In phase II multiple disease and drought tolerant varieties of rapeseed mustard were identified and genotypes were developed along with development of sustainable cropping system in DFID collaborating projects area. Genetic base of rapeseed-mustard was improved with the identification of sources of resistance. Two of the *B. napus* accessions, EC 338986-2 and EC 338996-1 maintained high resistance to downy mildew and white rust as well as tolerance to Alternaria blight and Sclerotinia rot. Four of the *Brassica juncea* accessions EC 399296, EC 399299, EC 399301 and EC 399313 expressed some tolerance to Alternaria blight with no visible symptoms of infection with downy mildew, white rust and sclerotinia; two more accessions, EC414308 (NRCR 837) and EC 414319 (NRCR 319) were found to be tolerant to downy mildew, white rust and Sclerotinia stem rot (Anonymous 2007) .

Future outlook and strategy

Ever-increasing population and improved living standard demand higher edible oil, resulting into wide gap between demand and supply despite increases in production. There is a continuous surge in demand for edible oil even at the present level of consumption and it is expected to grow by 3–4% over the next two decades, which translates into an additional requirements of 0.5 million tonnes/annum, reaching a total of 23.8 million tonnes by 2025. Considering about 20% contribution from sources like rice bran, cottonseed, palm oil, coconut and other tree-borne oilseeds, the vegetable oil requirement from nine annual oilseeds to meet the domestic demand works out to be an equivalent of 64.0 million tonnes of oilseeds. Rapeseed- mustard on an average contributed about 24.1% and 27.4% to the total oilseeds acreage and production in the country from 2001–02 to 2005–06 thus expected contribution of these crops could be around 16–18 million tonnes. An all time high of 8.13 million tonnes of rapeseed-mustard production was achieved during 2005–06 (NRCRM 2007).

In the backdrop of this future scenario, foremost and viable option to enhance production is genetic up scaling of the crop. Since rapeseed-mustard crop is quite vulnerable to

many diseases and insect pests, as a first approach, potential of the existing cultivars can be sustained/stabilized by insulating the crop by incorporating gene(s) for resistance to biotic (diseases and insect pests) and abiotic (drought, high temperature and salinity) stresses. In the second approach, *per se* ceiling to the genetic potential of the crop could be raised either by restructuring plant type or heterosis breeding. Of all the 203 identified/released rapeseed-mustard varieties till 2010, 86 varieties were developed through selection from local germplasm. Varuna, a pure line selection from Banarasi rai, a local germplasm was utilized directly or indirectly in the pedigree of 46 varieties. The contribution of Varuna to the Indian mustard breeding comes to about 42.6%. Therefore, there is a need to diversify the genetic base of varieties by extensive and vigorous utilization of exotic germplasm as well as other related species/genera. Hybrid development is a continuous process. The future thrust will be on enhancing the level of heterosis. Development of double low *B. juncea* will continue to be focus in coming years. Greater need for integration of biotechnological tools like microspore culture, isolation of trait specific gene(s), especially for aphid and alternaria resistance, identification of parental lines on the basis of genetic diversity and marker-assisted selection. Functional genomics of drought and heat tolerance deserve priority and accordingly the breeding programme should be reoriented. Breeding programme should also aim at enhancing resource-use efficiency, especially nutrients and water as well as adaptation to the aberrant environmental changes, especially for high temperature.

REFERENCES

- Ackman R G, Eaton C A, Sipes J C, Loew F M and Hancock D. 1977. Comparison of fatty acids from high levels of erucic acid of RSO and partially hydrogenated fish oil in non-human primate species in a short-term exploratory study. *Nutrition Diet* **25**: 170–85.
- AICRPRM. 1997-2010. All India Coordinated Research Project on Rapeseed-Mustard. *Annual Report* (1997–2010). Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan.
- Anonymous. 2007. Indo-UK Collaboration on Oilseed Crops. *Annual Report* for 2006–2007. National Research Centre on Rapeseed-Mustard, Bharatpur (Rajasthan). p. 59.
- Arora R K. 1998. The Indian gene center – priorities and prospects for collection. (in) *Plant Genetic Resources: Indian Perspective*, pp 66–75. Paroda R S, Arora R K and Chandel- K P S (Eds), Indian Society of Plant Genetic Resources, National Bureau of Plant Genetic Resources, New Delhi.
- Arora R K, Paroda R S and Engels M M. 1991. Plant genetic resources activities: International perspective. (in) *Plant Genetic Resource, Conservation and Management—Concepts and Approaches*, pp 351–85. Paroda R S and Arora R K. (Eds), Indian Society of Plant Genetic Resources, National Bureau of Plant Genetic Resources, New Delhi.
- Banga S S and Banga S K. 1997. *Enarthrocarpus lyratus* cytoplasm causes male sterility in oilseed rape, pp 120–1. (in) *Abstracts. International Symposium on Heterosis in Crops*, Mexico.
- Banga S S and Labana K S. 1984. Heterosis in Indian mustard [*Brassica juncea* (L.) Coss.]. *Plant Breeding* **92**: 61–70.
- Bhat S R, Kumar P and Prakash S. 2008. An improved cytoplasmic male sterile (*Diplotaxis berthautii*) *Brassica juncea* – identification of restorer and molecular characterization. *Euphytica* **159**: 145–52.
- Bell J M. 1984. Nutrients and toxicants in rapeseed meal: a review. *Journal of Animal Science* **58**: 996–1010.
- Bhat S R, Vijayan P, Ashutosh K, Dwivedi K and Prakash S. 2006. *Diplotaxis erucoides* induced cytoplasmic male sterility in *Brassica juncea* is rescued by the *Moricandia arvensis* restorer-genetic and molecular analysis. *Plant Breeding* **125**: 150–5.
- Brar K S, Mittal V P and Singh P. 2007. Estimation of genetic parameters, character association and path analysis for seed yield and its components in Indian mustard [*Brassica juncea* (L.) Czern and Coss.]. pp 42–3. (in) *Extended Summaries. National Seminar on Changing Global Vegetable Oils Scenario: Issues and Challenges Before India*. Indian Society of Oilseeds Research, DOR, Hyderabad.
- Chaudhary B D, Singh P, Singh P and Kumar P. 1989. Inheritance studies of plant water relations in *Brassica juncea*. *Biologia Plantarum*, **31**: 202–6.
- Chauhan J S and Singh N B. 2004. Breeding approaches in rapeseed-mustard varietal improvement pp. 51–64. (in) *Rapeseed- Mustard Research in India*. N B Singh and Arvind Kumar (Eds). National Research Center on Rapeseed-Mustard, Sewar, Bharatpur (Rajasthan).
- Chauhan J S, Singh K H and Kumar A. 2006. *Breeder Seed Production Scenario of Rapeseed-Mustard Varieties in India*, 20 pp. NRCRM, Bharatpur.
- Chauhan J S, Tyagi M K, Kumar P R, Tyagi P, Singh M and Kumar S. 2002. Breeding for oil and seed meal quality in rapeseed-mustard in India – A review. *Agricultural Reviews* **23** (2): 71–92.
- Chauhan J S, Tyagi M K, Kumar A, Nashaat N I, Singh M, Singh N B, Jakhar M L and Welham SJ. 2007b. Drought effects on seed yield and its components in Indian mustard (*Brassica juncea* L.). *Plant Breeding* **126**: 399–402.
- Chauhan J S, Bhadauria V P S, Singh M, Singh K H and Kumar A. 2007a. Quality characteristics and their interrelationships in Indian rapeseed-mustard (*Brassica sp.*) varieties. *Indian Journal of Agricultural Sciences* **77** (9): 616–20.
- Conaway C C, Getachun S M, Liebes L L, Pusateri D J, Tophan D K W, Botero-Omary M, Chung F L. 2001. Disposition of glucosinolates and sulphoraphane in humans after ingestion of steam and fresh broccoli. *Nutr. Cancer* **38**: 168–78.
- Dhawan A K. 1985. Freezing in oilseed Brassica species some factors affecting injury. *Journal of Agricultural Sciences (Camb.)* **104**: 513–8.
- Dhillon S S, Labana K S and Banga S K. 1990. Studies on heterosis and combining ability in Indian mustard (*Brassica juncea* [L.] Coss.). *Journal of Research Punjab Agricultural University*. **27**: 1–8.
- Fahy J W, Zalcmann A T, Talalay P. 2001. The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry* **56** : 5–51
- Fenewick G R, Heaney R K, Mullin J. 1983. Glucosinolates and their breakdown products in food and food plants. *CRC Critical Review's in Food Science and Nutrition* **18**: 123–201.

- Gopalan C D, Krishnamurthy D, Shenolikar I S and Krishnamurthy K A V R. 1974. Myocardial changes in monkey fed on mustard oil. *Nutrition Metabolism* **16**: 352–65.
- Gunasekera C P, Martin L D, French R J and Siddique K H M. 2004. Response of mustard and canola genotypes to soil moisture stress during the post-flowering period, pp 133. *Handbook and Abstracts. 4th International Crop Science Congress*. Brisbane Queensland, Australia. September 26–October 1, 2004.
- Hall A.E. 2001. *Crop Responses to Environment*. CRC Press LLC, Boca Raton, Florida.
- Hegde D M. 2000. Oilseed scenario in India-past, present and future with special reference to rapeseed-mustard. pp. 1–15 (in) *Advances in Rapeseed-Mustard Research Technology for Sustainable Production of Oilseeds. Compendium of Winter School Lecture Notes*, 384pp+vii. NRCRM.
- Hemingway J S. 1976. Mustard: *Brassica* spp. and *Sinapis alba* (Cruciferae). pp 56–9. (in) *Evolution of Crop Plants*. Simmonds (Ed.). Longmans, London.
- Jagannath A, Arumugam N, Gupta V, Pradhan A, Verma P K and Pentel D. 2002. Development of transgenic *barstar* lines and identification of a male sterile (*bar*) restorer (*barstar*) combination for heterosis breeding in Indian oilseed mustard (*Brassica juncea*). *Current Science* **82**: 46–52.
- Katiyar R K and Chopra V L. 1995. A somaclone of *Brassica juncea* is processed in to a variety and is released for commercial cultivation in India. *Cruciferae Newsletter* **17**: 92–7.
- Kirti P B and Chopra V L. 1989. Rapid plant regeneration from organogenesis and embryogenesis from protoplasts of *B. juncea*. *Plant Cell, Tissue and Organ Culture* **20** (1): 65–7
- Kirti P B, Mohapatra T, Prakash S and Chopra V L. 1995a. Development of a stable cytoplasmic male sterile line of *Brassica juncea* from the somatic hybrid *Trachystoma ballii* + *B. juncea*. *Plant Breeding* **113**: 21–4.
- Kirti P B, Mohapatra T, Khanna H, Prakash S, and Chopra V L. 1995b. *Diplotaxis catholica* plus *Brassica juncea* somatic hybrids: molecular and cytogenetic characterization. *Plant Cell Reporter* **14**: 593–7.
- Kirti P B, Prakash S and Chopra V L. 1991b. Interspecific hybridization between *B. juncea* and *B. spinescens* through protoplast fusion. *Plant Cell Report* **9**: 639–42.
- Kirti P B, Prakash S, Gaikwad K, Dinesh Kumar V, Bhat S R and Chopra V L. 1998. Chloroplast substitution overcomes leaf chlorosis in a *Moricandia arvensis*- based cytoplasmic male sterile *B. juncea*. *Theoretical and Applied Genetics* **97**: 1179–82.
- Krik J T O and Oram R N. 1981. Isolation of erucic acid-free lines of *Brassica juncea* Indian mustard, now a potential oilseed crop in Australia. *Journal Australia Institute of Agricultural Sciences* **47**: 51–2.
- Kumar A. 2009. Project Coordinator's Report 2008-09. All India Coordinated Research Project. *Annual Group Meeting of Rapeseed-Mustard Research Workers*, College of Agriculture, Nagpur (MS), August 6–8, 2009.
- Kumar C. 1990. Drought management: Research on rapeseed and mustard, pp 44–8. (in) *Proceedings of an Indo-Swedish Symposium*. Swedish University of Agricultural Sciences, Uppsala, Sweden. September 4–6, 1989.
- Kumar A and Singh D P. 1998. Use of physiological indices as a screening technique for drought tolerance in oil seeds *Brassica* species. *Annals of Botany* **81**: 413–20.
- Kumar A and Chauhan J S. 2005. Status and future thrust areas of rapeseed-mustard Research in India. *Indian Journal of Agricultural Sciences* **75**: 621–35.
- Labana K S, Badwal S S, Chaurasia B D. 1975. Heterosis and combining ability analysis in *Brassica juncea* (L) Czern & Coss. *Crop Improvement* **2**: 46–51.
- Love H K, Rakow G, Raney J P and Downey R K. 1990. Development of low glucosinolate mustard. *Canadian Journal of Plant Sciences* **70**: 419–24.
- Meena M L, Singh M, Chauhan J S and Kumar A. 2006.. Genetic variability and character association of yield and related traits in advance breeding lines of Indian mustard (*Brassica juncea* L.). *Indian Journal of Plant Genetic Resources* **19**: 61–5.
- Misra A K, Kumar A, Kumar P R and Manohar S S. 2007a. Evaluation and characterization of elite germplasm of Indian mustard, *Brassica juncea* (L.) Czern and Coss. *Indian Journal of Oilseeds Research* **24**: 27–30.
- Misra A K, Manohar S S, Singh K and Kumar A. 2007b. Characterization of germplasm for some economic traits in Indian mustard [*Brassica juncea* (L) Czern and Coss]. pp 84–5. (in) *Extended Summaries, National Seminar on Changing Global Vegetable Oils Scenario : Issues and Challenges Before India*. Indian Society of Oilseeds Research, DOR, Hyderabad 29–31 January 2007
- Mithen R, Faulkner K, Magrath R, Rose P, Williamson G and Marquez J. 2003. Development of isothiocyanate enriched broccoli and its enhanced ability to induce phase 2 detoxification enzymes in mammalian cells. *Theoretical and Applied Genetics* **106**: 727–34.
- Mohamed A, Olsson A I and Sevensk H. 1990. Drought management. pp. 49–67. (in) *Research on Rapeseed and Mustard, Proceedings of an Indo-Swedish Symposium*, Olsson I and Kumar P R (Eds), Swedish University of Agricultural Sciences, Uppsala, Sweden. 4–6 September 1989.
- Narsimhulu B S and Chopra V L. 1989. Shoot regeneration from cotyledons of three diploid species of Brassica. *Plant Breeding* **99**: 49–55.
- NBPGR. 2011. *Annual Report 2010–11*. 109 pp. National Bureau of Plant Genetic Resources, Pusa, New Delhi.
- NRCRM. 2000. *Rapeseed-mustard Varieties of India*, 115pp + V.
- NRCRM. 2007. *Vision 2025*, pp 1–46. Perspective Plan National Research Centre on Rapeseed-Mustard, Bharatpur.
- Ogura H. 1968. Studies on the new male sterility in Japanese radish with special reference to the utilization of this sterility towards the practical raising of hybrid seed. *Memoirs Faculty Agriculture Kagoshima University* **6**: 39–78.
- Panda B B, Shivay Y S and Bandyopadhyay S K. 2004. Growth and development of Indian mustard (*Brassica juncea*) under different levels of irrigation and date of sowing. *Indian Journal of Plant Physiology* **9** (NS) : 419–25.
- Prabhu K V, Somens D J, Rakow G and Gugel R K. 1997. Molecular markers linked to white rust resistance. *Theoretical and Applied Genetics* **97**: 865–70.
- Prakash S and Chopra V L. 1988. Synthesis of alloplasmic *Brassica campestris* as a new source of cytoplasmic male sterility. *Plant Breeding* **101**: 253–5.
- Prakash S, Ahuja I, Upreti H C, Kumar D V, Bhat S R, Kirti P B and Chopra V L. 2001. Expression of male sterility in alloplasmic

- Brassica juncea* with *Erucastrum canariense* cytoplasm and development of a fertility restoration system. *Plant Breeding* **120**: 479–82.
- Prakash S, Bhat S R, Kirti P B, Banga S K, Banga S S and Chopra V L. 2004. Oilseed brassica crops in India: history and improvement. *Brassica* **6** (3–4): 1–54.
- Prakash S, Kirti P B and Bhat S R. 1998. A *Moricandia arvensis* based cytoplasmic male sterility and fertility restoration system in *B. juncea*. *Theoretical Applied Genetics* **97**: 488–92.
- Prakash S, Kirti P B and Chopra V L. 1995. Cytoplasmic male sterility systems other than *ogu* and *polima*-current status. *Proceeding, 9th International Rapeseed Congress Cambridge I*: 44–8.
- Rao G U, Sarup U B, Prakash S, Shivanna K R. 1994. Development of a new cytoplasmic male sterility system in *B. juncea* through wide hybridization. *Plant Breeding* **112**: 171–4.
- Rawat D S, Anand I J. 1979. Male sterility in Indian mustard. *Indian Journal of Genetics and Plant Breeding* **39**: 412–5.
- Renard S and Mc Gregor L. 1976. Antithorbo genetic effects of erucic acid poor rapeseed oils in the rats. *Rev. Fr. Cross* **25**: 339–96.
- Rosa E A S, Heaney R K, Fenewick G R, Portas C A M. 1997. Glucosinolates in crop plants. *Horticultural Reviews* **19**: 99–215.
- Shapiro T A, Fahey J W, Wada K L, Stephenson K K and Talay P. 2001. Chemopreventive glucosinolates and isothiocyanates of broccoli sprouts: metabolism and excretion in humans. *Cancer Epidemiol Biomarkers Prev* **10**: 501–8.
- Sharma K D and Pannu R K. 2007. Biomass accumulation and its mobilization in Indian mustard, *Brassica juncea* (L.) Czern & Coss. under moisture stress. *Journal of Oilseeds Research* **24**: 267–70.
- Sharma S K and Singh R. 2007. Genetic resources of oil seed crops in India. pp. 1–16 (in) *Changing Global Vegetable Oils Scenario: Issues and Challenges before India*. Hegde D M (Ed.). Indian Society of Oilseeds Research, DOR, Hyderabad.
- Sharma T R and Singh B M. 1992. Parameters of resistance to *Alternaria brassicae* in some *Brassica* species. *Indian Phytopathology* **45**(Suppl.) P. LIX (Abst.)
- Shivratan, Chaudhary B D, and Singh D. 2005. Partitioning coefficients of plant parts under different growth stages and environments in Indian mustard [*Brassica juncea* (L.) Czern and Cossi.]. *Journal of Oilseeds Research* **22**: 259–62.
- Singh N B. 2003. Accomplishment and challenges in rapeseed. mustard research *Brassica* **3** (3,4): 1–11.
- Singh K H. 2008. Hybrid development in mustard (*Brassica juncea* L.) – A success story. *Sarson News* **12** (2): 2–3.
- Singh K H and Chauhan J S. 2010. *Morphological Descriptor of Rapeseed Mustard Varieties*, 61 pp. Directorate of Rapeseed Mustard Research, Sewar, Bharatpur.
- Singh K H and Chowdhury R K. 2004. Seed production and DUS testing –issues and strategies. (in) *Rapeseed-Mustard Research in India*, pp. 232–47. Singh N B and Kumar A (Eds). National Research Centre on Rapeseed-Mustard, Sewar, Bharatpur.
- Singh S P and Chaudhary A K. 2003. Selection criteria for drought tolerance in Indian mustard [*Brassica juncea* (L.) Czern and Coss]. *Indian Journal of Genetics and Plant Breeding*, **63**: 263–4.
- Singh D P, Sangwan V P, Pannu R K and Chaudhary B D. 1996. Comparison of osmotic adjustment in leaves and siliquae of oilseed *Brassicae*. *Indian Journal of Plant Physiology*, **1** (NS): 284–5.
- Singh K H, Misra A K and Kumar A. 2006. *Draft Guidelines to Conduct the Tests for Distinctness, Uniformity and Stability-Rapeseed and Mustard (Brassica)*, 40 pp. National Research Centre on Rapeseed Mustard, Sewar, Bharatpur.
- Singh K H, Srivastava K K, Chauhan J S and Kumar A. 2006. Genetic divergence and stability analysis in Indian mustard [*Brassica Juncea* (L.) Czern & Coss] *Journal of Oilseeds Research* **23**: 151–5.
- Singh M, Chauhan J S, Kumar A. and Singh N B. 2003a. Nitrogen assimilatory enzymes, chlorophyll content, and yield as influenced by drought stress in Indian mustard (*B. juncea*). *Brassica* **5** : 42–7.
- Singh M, Chauhan J S, and Kumar P R. 2003b. Response of different rapeseed-mustard varieties for growth, yield and yield component under irrigated and rainfed condition. *Indian Journal of Plant Physiology* **8** (NS): 53–9.
- Singh R P, Singh D P and Singh P. 1988. Variation for plant water relations and yield structure in *Brassica juncea* L. under drought conditions. *Narendra Deva Journal of Agricultural Research* **3**: 91–8.
- Skoropad W P and Tewari J P. 1977. Field evaluation of the epicuticular wax in Rapeseed and mustard in resistance to *Alternaria brassicae* *Can Journal Plant Science* **57** : 1001–3.
- Sodhi Y S, Chauhan A, Verma J K, Arumugam N, Mukhopadhyay A, Gupta V, Pental D and Pradhan A K. 2006. A new cytoplasmic male sterility system for hybrid seed production in Indian oilseed mustard (*Brassica juncea*). *Theoretical and Applied Genetics* **114**: 93–9.
- Sun F J. 1943 Hybrid vigor in *Brassica*. *Journal of Agricultural Association, China* **175**: 35–58.
- Tewari J P. 1991. Resistance to *Alternaria brassicae* in crucifers. *IOBC/ WPRS Bulletin* **14**: 154–61.
- Toxopeus H and Oost E H. 1985. A cultivar classification of *Brassica rapa* L. *Cruciferae Newsletter* **10**: 6–10.
- USDA. 2010. United States Department of Agriculture-Rapeseed area, yield and production Table No. 15. <http://www.fas.usda.gov/psd/online/psd/report>. Asps.
- Verma R and Singh R R. 2007. Multiple shoot formation and *in vitro* flowering in *B. juncea* Var. Bhavani. *Our Nature* **5**: 21–4.
- Verma R, Sharma R. and Sharma S K. 2008. Association studies among yield and its component characters in Indian mustard [*Brassica juncea* (L.) Czern and Coss]. *Indian Journal of Genetics and Plant Breeding* **68** (1): 87–9.
- Wahid A, Gelani S, Ashraf M and Foolad M R. 2007. Heat tolerance in plants: An overview. *Environmental and Experimental Botany* **61**: 199–223.
- Zhang Y and Talalay, P. 1994. Anti carcinogenic activities of organic isothiocyanate : chemistry and mechanisms. *Cancer Research* **54** (Suppl.) 1976s–1981s.