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Review Article

Advances in Agronomic Management of Indian Mustard (*Brassica juncea* (L.) Czernj. Cosson): An Overview

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India is the fourth largest oilseed economy in the world. Among the seven edible oilseeds cultivated in India, rapeseed-mustard contributes 28.6% in the total oilseeds production and ranks second after groundnut sharing 27.8% in the India's oilseed economy. The mustard growing areas in India are experiencing the vast diversity in the agro climatic conditions and different species of rapeseed-mustard are grown in some or other part of the country. Under marginal resource situation, cultivation of rapeseed-mustard becomes less remunerative to the farmers. This results in a big gap between requirement and production of mustard in India. Therefore site-specific nutrient management through soil-test recommendation based should be adopted to improve upon the existing yield levels obtained at farmers field. Effective management of natural resources, integrated approach to plant-water, nutrient and pest management and extension of rapeseed-mustard cultivation to newer areas under different cropping systems will play a key role in further increasing and stabilizing the productivity and production of rapeseed-mustard. The paper reviews the advances in proper land and seedbed preparation, optimum seed and sowing, planting technique, crop geometry, plant canopy, appropriate cropping system, integrated nutrient management and so forth to meet the ever growing demand of oil in the country and to realize the goal of production of 24 million tonnes of oilseed by 2020 AD through these advanced management techniques.

1. Introduction

Rapeseed-mustard is the third important oilseed crop in the world after soybean (*Glycine max*) and palm (*Elaeis guineensis* Jacq.) oil. Among the seven edible oilseed cultivated in India, rapeseed-mustard (*Brassica spp.*) contributes 28.6% in the total production of oilseeds. In India, it is the second most important edible oilseed after groundnut sharing 27.8% in the India's oilseed economy. The share of oilseeds is 14.1% out of the total cropped area in India, rapeseed-mustard accounts for 3% of it. The global production of rapeseed-mustard and its oil is around 38–42 and 12–14 mt, respectively. India contributes 28.3% and 19.8% in world acreage and production. India produces around 6.7 mt of rapeseed-mustard next to China (11-12 mt) and EU (10–13 mt) with significant contribution in world rapeseed-mustard industry. The rapeseed-mustard group broadly includes Indian mustard, yellow sarson, brown sarson, raya, and toria crops. Indian mustard (*Brassica juncea (L.)* Czernj. & Cosson) is predominantly cultivated in Rajasthan, UP, Haryana, Madhya Pradesh, and Gujarat. It is also grown under some nontraditional areas of South India including Karnataka, Tamil Nadu, and Andhra Pradesh. The crop can be raised well under both irrigated and rainfed conditions. Brown sarson (*B. rapa* ssp *sarson*) has 2 ecotypes lotni and toria. Yellow sarson (B. *rapa* var. *trilocularis*) is cultivated in Assam, Bihar, Orissa, and West Bengal as rabi crop. In Punjab, Haryana, UP, Himachal Pradesh, and Madhya Pradesh, it is grown mainly as a catch crop. Taramira (*Eruca sativa*) is grown in the drier parts of North-West India comprising the states of Rajasthan, Haryana, and UP. Gobhi sarson (*B. napus* L. ssp. *oleferia DC.* var *annua L.*) and karan rai (*Brassica carinata*) are the new emerging oilseed crops having limited area of cultivation. Gobhi sarson is a long duration crop confined to Haryana, Punjab, and Himachal Pradesh. It has good yield potential, wide adaptability and possesses high oil content of good quality. Karan rai yields well and shows better environment adoption and substantial resistance to pests and diseases. The country witnessed yellow revolution through a phenomenal

Table 1: Salient features of cultivated species of rapeseed-mustard (Cruciferous) group of crops.

SN	Common name	Botanical name	Days to maturity (days)	Yield potential, Kg/ha	Oil %
(1)	Indian mustard	*Brassica juncea*	105–160	1500–3000	38–42
(2)	Yellow mustard	*Brassica rapa* var. *yellow sarson*	120–155		41–47
(3)	Brown sarson	*Brassica campestris* syn. *B. rapa* var. *brown sarson*	100–235	900–2000	40–45
(4)	Black mustard	*Brassica nigra*	70–90	1000–1200	40-41
(5)	Karan rai	*Brassica carinata*	150–200		36–43
(6)	Toria	*Brassica rapa* var. *toria*	70–100	600–1800	36–44
(7)	Taramira	*Eruca sativa*	140–150	700–1400	34–38
(8)	Gobhi sarson	*Brassica napus*	145–180	1300–2700	37–45

increase in production and productivity from 2.68 MT and 650 kg/ha in 1985-86 to 6.96 MT and 1022 kg/ha in 1996-1997, respectively. In spite of these achievements, there exists a gap between production potential and actual realization. In India rapeseed-mustard is grown on an area of 5.53 Mha with production and productivity of 6.41 MT and 1157 Kg/ha, respectively [1].

Mustard is cultivated in mostly under temperate climates. It is also grown in certain tropical and subtropical regions as a cold weather crop. Indian mustard is reported to tolerate annual precipitation of 500 to 4200 mm, annual temperature of 6 to 27°C, and pH of 4.3 to 8.3. Rapeseed-mustard follows C_3 pathway for carbon assimilation. Therefore, it has efficient photosynthetic response at 15–20°C temperature. At this temperature the plant achieve maximum CO_2 exchange range which declines thereafter. *Rai* is mostly grown as a rainfed crop, moderately tolerant to soil acidity, preferring a pH from 5.5 to 6.8, thrives in areas with hot days and cool night and can fairly sustain drought. Mustard requires well-drained sandy loam soil. Rapeseed-mustard has a low water requirement (240–400 mm) which fits well in the rainfed cropping systems. Nearly 20% area under these crops is rainfed. A review is prepared on advances on agronomic practices for enhancing the rapeseed-mustard production in India. A review of the work done on the different aspects in India and abroad especially under advance agronomic practices is done in this paper.

2. Crop Adaptation and Distribution

The rapeseed-mustard group includes *brown sarson, raya,* and *toria* crops. Indian mustard (*Brassica juncea* (L.) Czernj. & Cosson) is predominantly cultivated in Rajasthan, UP, Haryana, Madhya Pradesh, and Gujarat. It is also grown under some nontraditional areas of South India including Karnataka, Tamil Nadu, and Andhra Pradesh. The crop can be raised well under both irrigated and rainfed conditions. Being more responsive to fertilizers, it gives better return under irrigated condition. Brown sarson (*B. rapa* ssp. sarson) has 2 ecotypes *lotni* and *toria*. Yellow sarson (*B. rapa* var. *trilocularis*) is cultivated in Assam, Bihar, Orissa, and West Bengal as *rabi* crop. In Punjab, Haryana, UP, Himachal Pradesh, and Madhya Pradesh, it is grown mainly as a catch crop. Taramira (*Eruca sativa*) is grown in the drier parts of North-West India comprising the states of Rajasthan, Haryana and UP. *Gobhi sarson* (*B. napus l.* ssp. *oleferia DC*. Var. *annua* L.) and *karan rai* (*Brassica carinata*) are the new emerging oilseed crops having limited area of cultivation. *Gobhi sarson* is a long duration crop confined to Haryana, Punjab, and Himachal Pradesh. It is photo- and thermosensitive and makes little growth up to middle of February, but in the end of this month, plants make a quick growth. It has good yield potential, wide adaptability, and possesses high oil content of good quality. There are eight cultivated crops in rapeseed-mustard crop; the main characteristics features have been explained in Table 1.

Karan rai also yields well under a wide range of climate partly because it has a large number of primary and secondary racemes. It shows better environment adoption and substantial resistance to pests and diseases. Mustard is cultivated in most temperate climates. It is also grown in certain tropical and subtropical regions as a cold weather crop. Indian mustard is reported to tolerate annual precipitation of 500 to 4200 mm, annual temperature of 6 to 27°C, and pH of 4.3 to 8.3. Rai is mostly grown as a rainfed crop, moderately tolerant to soil acidity, preferring a pH from 5.5 to 6.8, thrives in areas with hot days and cool night, and fairly resistant to drought. Mustard requires good sandy loamy soil. The agro-climatic conditions of various locations under study have been explained in Table 2.

3. Varietals Development

Since, there is a vast variability in the climatic and edaphic conditions in the mustard growing areas of India, the selection of appropriate cultivars is important as it helps in increasing the productivity. Introduction of relatively short duration cultivar found favor with the environment where effective growing seasonal length is short. Improved varieties of mustard stabilize oil and seed yield through insulation of cultivars against major biotic and abiotic stresses enhance oil (low erucic acid) and seed meal (low glucosinolate) quality. The first Indian mustard hybrid, named "NRCHB-506," has been developed at Directorate of Rapeseed-Mustard Research, Bharatpur which can catapult the output of the country's key oil crop. The new hybrid is meant for cultivation in Rajasthan and Uttar Pradesh. Other high yielding varieties include "JM-1," "JM-3," and "Pusa Bold,"

Table 2: Agroclimatic conditions of various locations during mustard crop season.

Location	Longitude	Latitude	Temp, °C		Rain fall, mm	RH %		Soil texture	Soil fertility, Kg/ha		
			Max	Min		Max	Min		N	P	K
Hisar	75°43′6″ E	29°9′11″ N	3.2	34.2	50–200	38	96	Sany loam	130	12	480
Pantnagar	79°24′36″ E	28°58′12″ N,	4.8	32.3	150–400	47	92	Clay loam	155	15	310
Dholi	85° 35′22″ E	26°0′2.2″ N	6.6	33.3	200–550	52	94	Clay loam	140	12.5	275
Ludhiana	75°18′ E	30°34′ N	3.5	32.0	30–120	45	95	Loamy sand	150	24	220
Bhubneshwar	85°50′ E	20°16′ N	14.8	34.8	180–250	38	94	Clay loam	130	19	175

Table 3: Varieties tolerant to various abiotic and biotic stresses of mustard (*Brassica juncea*).

SN	Specific abiotic/biotic stress	Tolerant verities
(1)	Rainfed	Aravali, Geeta, GM 1, PBR 97, PusaBahar, Pusa Bold, RH 781, RH 819, RGN 48, Shivani, TM 2, TM 4, Vaibhav, RB 50
(2)	Salinity tolerant	CS 52, CS 54, Narendra Rai (NDR8501)
(3)	Frost tolerant	RGN 13, RH 819, Swaranjyoti, RH 781, RGN 48
(4)	High temperature tolerant	Kanti, Pusa Agrani, RGN 13, Urvashi, NRCDR 02, Pusa mustard 25 (NPJ 112), Pusa mustard 27 (EJ 17)
(5)	White rust resistant	Basanti, JM 1, JM 2, NRCDR-2
(6)	*Alternaria* blight tolerant	Jawahar Mustard 3, Him Sarson 1 (ONK 1), Ashirwad (RK-01-03)

"NRCDR-2," "NRCDR 601." Their yield potentials vary from 16 to 25 q/ha. At IARI, an early-maturing and bold seeded mustard variety has been developed called "Mehak" (*B. juncea*). This improved variety is suitable for early sowing to replace *toria (B. rapa* var. *toria)* in Delhi and adjoining areas. *Gobhi sarson* has a good yield potential, wide adaptability and possesses high oil content of good quality. "Hyola" (PAC-401) is canola type hybrid rapeseed, developed in India by Advanta India Ltd, Holland-based multinational company. "Neelam" (HPN-3) and "Sheetal" (HPN-1) are the popular varieties of *gobhi sarson* [2]. Since inception of mustard research programme in India, number of tolerant varieties to various abiotic and biotic stresses of rapeseed-mustard has been developed (Table 3).

"Pusa Jaikisan" of *B. juncea* is the first variety though tissue culture. "TL-15," a toria variety has been recommended as summer crop for high altitude of Himachal Pradesh. In an attempt to incorporate resistance/tolerance to biotic and abiotic stresses in high yielding varieties, aphid tolerant strains like "RH-7846," "RH-7847," "RH-9020" and "RWAR-842," *Alternaria* blight moderately resistant variety "Saurabh"; white rust resistant variety, "Jawahar Mustard-1"; salt tolerant varieties "Narendra Rai" and "CS-52" frost tolerant "RH-781" and "RH-7361" varieties have been identified. "RH-781" is also drought tolerant and suitable for intercropping. For nontraditional areas, Indian mustard varieties "Rajat," "Pusa Jaikisan" and "Sej.2" have been recommended.

4. Land and Seedbed Preparation

A mustard seedbed should be firm, moist, and uniform which allows good seed-to-soil contact, even planting depth and quick moisture absorption leading to a uniform germination. Tillage affects both crop growth and grain yield. The various tillage systems are as follows: conventional tillage includes moldboard ploughing followed by disc harrowing; reduced tillage includes disc ploughing followed by disc harrowing and complete zero tillage in which crop is sown under uncultivated soil. Minimum tillage, with or without straw, enhances soil moisture conservation and moisture availability during crop growth. As a consequence, the root mass, yield components and seed yield increase [3]. Zero tillage is preferred in mustard as it conserves more moisture in the soil profile during early growth period. Subsequent release of conserved soil moisture regulates proper plant water status, soil temperature, lower soil mechanical resistance, leading to better root growth and higher grain yield of mustard [4]. Success with minimum or zero tillage requires even distribution of crop residues, as a well-designed crop rotation and evenly distributing residue will create a firm, moist and uniform seedbed.

Continuous zero tillage results in redistribution of extractable soil nutrients with greater concentration near the soil surface, compared with conventional tillage where mixing of soil, residues, fertilizers, and lime results in a relatively homogeneous soil to the depth of tillage [6]. With zero tillage having greater root density in the surface soil but lesser root density below a depth of 15 cm in the soil profile. Therefore, P and K uptake by crops grown under zero tillage is greater than those grown by conventional methods. But the plant growth and dry matter yields of mustard under zero tillage will be higher only if N fertilizers are applied in appropriate amount [7]. Under AICRP on RM at Dholi, Kanke, Bhubaneshwar, and Behrampur maximum seed yield of *toria* and mustard was obtained in line sowing under zero

Table 4: Seed yield (kg/ha) and oil content (%) of *toria* as influenced by different N levels in *utera* cropping system at Bhubaneshwar.

Cropping system	N levels (kg/ha)		
	0	40	80
Rice: yellow sarson (broadcast) in *utera* cropping (at dough stage of rice)	428 (33.3)	823 (40.3)	810 (37.6)
Rice: yellow sarson (broadcast) in *utera* cropping (sowing before harvest of rice)	530 (30.2)	729 (38.2)	642 (37.1)
Rice: yellow sarson (line sowing) under zero tillage in rice field	506 (34.4)	924 (41.5)	886 (39.6)
Rice: yellow sarson (line sowing) after land preparation in rice fields	388 (32.5)	846 (40.4)	820 (38.4)
Rice: yellow sarson (broadcast) after land preparation in rice fields	301 (28.2)	460 (37.6)	440 (35.5)

CD at 5% cropping system: 79 (0.7), N levels: 32 (0.4), Cropping system × N levels: 98 (1.0). Figures in the parenthesis denotes oil content (%).
Source: AICRP-RM, 2003 [5].

tillage practice which indicated that mustard can be grown well under zero tillage.

At Bhubaneshwar, line sowing of mustard under zero tillage after rice gave the maximum seed yield (933 kg/ha) and oil content (38.4%) (Table 4). The soil under zero tillage system contains higher amount of organic matter having more carbohydrate, amino acid and amino sugar that results in qualitative and quantitative improvement in soil and soil structure due to least soil disturbance. Energy output and input ratio are higher in zero tillage as compared to conventional tillage.

5. Seed and Sowing

Vigorous seedling growth, good root development, early stem elongation, rapid ground covering ability, and early flowering and radiation are important yield determining traits under low temperature and radiation regime. These traits can be successfully exploited in mustard if a good seed is grown at appropriate time along with maintaining an optimum plant population.

5.1. Seed Priming. Seed treatment is a useful practice for healthy plant growth. Seed priming through controlled hydration and dehydration enhances early germination of mustard seed in less time, even in compacted soil [8]. The soaking of mustard seeds in 0.025% aqueous pyridoxine hydrochloride solution for 4 hours improved germination. The combination of pyridoxine + $N_{60}P_{20}$ + $N_{15}P_5$ (top dressing) accelerated the crop performance by enhancing seed yield and oil yield by 15.8 and 13.5%, respectively, over the control [9]. The differential response of varieties for imbibition gives advantage to some of them to germinate early as compared to others. At Hisar, maximum rate of imbibition was reported in "NRCDR-2" (41.7%) and minimum in "NRCDR-509" (7.5%). Such drastic difference in rate of imbibition is important for identification of suitable varieties under abiotic stress conditions namely drought, frost, and temperature abnormalities.

5.2. Sowing Time. Sowing time is the most vital nonmonetary input to achieve target yields in mustard. Production efficiency of different genotypes greatly differs under different planting dates. Soil temperature and moisture influence the sowing time of rapeseed-mustard in various zones of the country. Sowing time influences phenological development of crop plants through temperature and heat unit. Sowing at optimum time gives higher yields due to suitable environment that prevails at all the growth stages. Though different varieties have a differential response to date of sowing, mustard sown on 14 and 21 October took significantly more days to 50% flowering (55 and 57) and maturity (154 and 156) compared to October 7 planting [10]. Delayed sowing resulted in poor growth, low yield, and oil content. The reduction in yield was maximum in "RH-30" and minimum in "Rajat" [11, 12].

Date of sowing influence the incidence of insect-pest and disease also. Sowing on October 21 resulted in least *Sclerotinia* incidence [13]. The maximum (20.5–25.4°C) and minimum (3.9–10.7°C) temperatures at the flowering stage of crops established through sowing on October 21 were negatively correlated with the development of *Sclerotina* stem rot. Mustard aphid (*Lipaphis erysimi (Kaltenbach)*) has been reported as one of the most devastating pests in realizing the potential productivity of Indian mustard. Normal sowing (1st week of November) also helps in reducing the risk of mustard aphid incidence.

5.3. Planting Technique. Sowing technique depends upon land resources, soil condition, and level of management and thus broadcast, line sowing, ridge and furrow method and broad bed and furrow method are common sowing techniques. At higher soil moisture regimes, broadcasting followed by light planking gives early emergence and growth. Under normal and conserved moisture regime, seed placement in moist horizon under line sowing becomes beneficial.

At Shillongani, broadcast method was found to be more successful. Significantly higher seed yield of *toria (Brassica rapa var. toria)* was harvested in broadcast sowing of *toria* over other practices. *Toria* broadcast at dough stage along with 80 kg N/ha gave the highest yield (AICRP-RM, 2006). At Bhubaneshwar, line sowing of yellow sarson after land preparation produced maximum seed yield (870 kg/ha) with 40 kg N/ha [14]. At Behrampore, 40% higher seed yield of *toria* was obtained when sown in line after land preparation in the rice-based cropping system over broadcast (AICRP on RM, 2006). *Paira* or *utera* is a method of *cropping* in which the sowing of next crop is done in the standing previous crop without any tillage operation. Mustard sowing under *paira*/*utera* in the rice field has shown its edge over

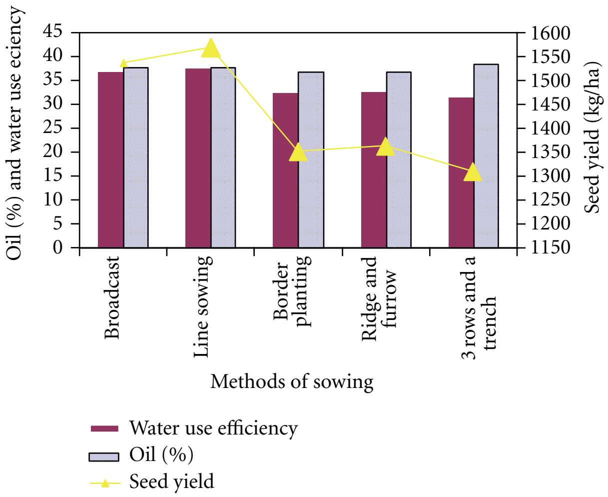

Figure 1: Seed yield, water use efficiency, Kg/ha-mm (WUE), and oil content of mustard (*Brassica juncea*) as influenced by various planting methods.

line sowing and broadcasting (Sowing of seeds by broad casting the seeds in the field) in eastern parts of India. At Dholi, mustard sown with *paira* cropping recorded significantly higher seed yield (1212 kg/ha) over line sown and broadcast method, while these 2 methods yielded at par. At Bhubaneswar, significantly higher yield (887 kg/ha) of mustard was recorded when sown as *utera* crop over line and broadcast sown crop [15].

Ridge and furrow sowing was superior to conventional flat sowing for growth parameters and yield of *Brassica juncea* [16]. Under saline condition, seed yield of canola in ridge sowing was higher by 45, 31, and 28% than broadcast, drill and furrow sowing methods, respectively [17]. The highest yield was associated with less saline environment at the ridges which allowed the seed to germinate and increase the yield. Transplanting of mustard has also been reported thereby saving time, and resources. Transplanting reduces days to maturity and results in higher seed yield. Ridge transplanting reduced water applied by 30% for each furrow as compared to 45 cm row spacing in flat method without any loss in seed yield. The corresponding increase in water use efficiency (WUE) was 27%. In bed planting, there was a 35% saving in water resulting in 32% increase in WUE (Figure 1).

5.4. Crop Geometry. The competitive ability of a rapeseed-mustard plant depends greatly upon the density of plants per unit area and soil fertility status. The optimum plant population density/unit area varies with the environment, the genotype, the seeding time, and the season. Uniform distribution of crop plants over an area results in efficient use of nutrients, moisture, and suppression of weeds leading to high yield. In wider row spacing, solar radiation falling within the rows gets wasted particularly during the early stages of crop growth whereas in closer row spacing upper part of the crop canopy may be well above the light saturation capacity but the lower leaves remain starved of light and contribute negatively towards yield.

Gobhi sarson (*Brassica napus*) being more vigourous, the days to maturity, plant height, branches, pod, seed weight per plant, seed index, seed yield, and oil content were higher at 60 cm row spacing [18]. An increase in rows up to 30 cm correspondingly prolonged maturity days followed by optimum 45 cm and wider rows 60 cm spacing. The plants receiving narrow row spacing increased vegetative growth. Due to shade and competition for nutrients and moisture the crop matures later by increasing developmental phases Taller plants were observed in the plots where crop was planted in rows of 60 cm apart followed by 45 cm and 30 cm row spacing due to sufficient space resulting in plants grown well and showed greater height [19] (Gupta, 1988). The regression coefficient indicated that each increase in row spacing up to 60 cm resulted in increased crop maturity by 0.54 days, plant height by 0.44 cm, number of branches would increase by 0.11, pods per plant by 1.96, seeds per pod by 0.04, seed weight per plant by 0.45, seed index by 0.152 g, oil content by 0.8% and increase in seed yield by 10.32 kg/ha. The recommended spacing for mustard is 30 × 10 and for hybrids it is 45 × 10. At Kumher, plant spacing 45 × 15 recorded significant higher seed yield over other spacing but was on a par with 45 × 10 cm. At Pantnagar, 30 × 15 recorded significantly higher seed yield which remained on a par with 45 × 10 and 45 × 15 cm plant spacing [20].

5.5. Plant Population and Inter-Plant Shading. The dense plant population reduces the yield due to reduction in the photosynthetically active leaf area caused by mutual shading. In an experiment on *Brassica juncea* (*Var. laxmi*) the reduction is more due to shading at 91–110 DAS over 71–90 DAS. The specific leaf weight (SLW), crop growth rate (CGR), and net assimilation rate (NAR) were more adversely affected by 50% shading at 71–90 DAS. Net assimilation ratio remained unaffected by 25% shading, while it reduced significantly by 50% shading at both the stages; the reduction was more with 50% due to shading at 91–110 DAS. On an average 50% shading at 91–110 DAS was more deleterious than 25% shading at 91–110 DAS, that is, at terminal seed development stage (Table 5).

6. Cropping System

Physiography, soils, geological formation, climate, cropping pattern, and development of irrigation and mineral resources greatly influence selection of variety and cropping system. Fallow mustard is popular sequence in major mustard growing areas but studies show that some of the crop result in better resource utilization and high remuneration if included in mustard-based cropping system.

6.1. Mustard Productivity under Various Crop Sequences. Under AICRP trials at Dholi, fallow-mustard sequence gave significantly higher seed yield which was on a par with blackgram-mustard sequence: urdbean-mustard at Morena; greengram-mustard, guar-mustard, and pearl-millet-mustard at S. K. Nagar and Hisar; maize-mustard

Table 5: Effect of shading on yield and growth parameters in Indian mustard at Hisar.

Treatment	Seed yield (kg/ha)	SLW (mg/cm^2)	CGR ($g/m^2/day$)	NAR ($mg/m^2/day$)
Control	571.6	8.3	11.3	0.93
25% shading at 71–90 DAS	546.0	7.0	10.8	0.93
25% shading at 91–110 DAS	490.9	7.9	9.4	0.87
50% shading at 71–90 DAS	527.0	6.4	9.9	0.95
50% shading at 91–110 DAS	380.0	7.0	8.3	0.83
CD at 5%	33.1	1.3	1.0	0.05

Source: AICRP-RM, 2004.

Table 6: Seed yield (kg/ha), mustard equivalent yield (MEY), and gross return (Rs./ha) as influenced by various intercropping combinations under rainfed conditions at Hisar.

Treatment	Main crop	Intercrop	MEY	Gross return (Rs./ha)
Pure mustard	2565	—	2565	29,497
Mustard + chickpea (1 : 5)	966	1035	1956	22,494
Mustard + fieldpea (1 : 5)	1002	189	1230	14,145
Mustard + linseed (1 : 5)	996	642	1721	19,791
Mustard + lentil (1 : 5)	1015	—	1015	11,672
Mustard without intercropping at same distance as in intercropping	1097	—	1092	12,668
CD at 5%	—	—	350	—

Source: AICRP-RM, 1997 [11].

at Kangra and Pantnagar revealed superiority to fallow-mustard. The productivity of the system also depends upon the fertility status and the nutrient supply. When mustard was grown after soybean or bajra, the response to S was observed up to 40 kg S/ha [21]. Productivity measured in terms of land equivalent ratio (LER) was higher for intercropping of chickpea and mustard in the 4 : 1 row ratio than for sowing of chickpea and mustard in sole stands [22].

6.2. Inclusion of Gobhi Sarson (Brassica Napus) under Various Cropping Sequences. *Gobhi sarson* is comparatively recent introduction and hence needs identification of suitable cropping systems. Growing *gobhi sarson* and toria in alternate rows at 22.5 cm spacing is very remunerative. Maize-*gobhi sarson,* blackgram-gobhi sarson, rice-*gobhi sarson,* and soybean-*gobhi sarson* were identified remunerative cropping systems at Kangra [21].

6.3. Mustard-(Brassica Juncea) Based Cropping System under Rainfed Areas. There are possibilities of increasing cropping intensity in monocropping mustard areas under rainfed condition. Green manuring or guar during rainy season enhance seed yield of succeeding mustard [12]. In addition to efficient resource use, intercropping imparts stability to productivity and reduces the risk of crop failure. Under irrigated conditions, at Bharatpur, the seed yield equivalent of mustard (*Brassica juncea*) was significantly higher where mustard was grown in combination with potato (1 : 3), mustard + wheat (1 : 5), mustard + barley (1 : 5) than pure mustard. At Hisar, intercropping *Brassica juncea* (variety RH-30) with rabi crops had revealed highest gross return (Rs. 29,498) when mustard was grown as a pure crop. The mustard seed equivalent was highest in mustard + chickpea (1 : 5). Intercropping of mustard with chickpea, field pea, or linseed proved superior over their cultivation as a pure crop (Table 6).

7. Fertilizer Management

Adequate nutrient supply increases the seed and oil yields by improving the setting pattern of siliquae on branches, number of siliquae/plant, and other yield attributes [23]. Recommended dose of fertilizers (RDF) for different zones changes with climate, soil type, time, and type of cropping system followed.

7.1. Nitrogen and Phosphorus Fertilization. Nitrogen use efficiency is greatly influenced by the rate, source, and method of fertilizer application. The rate of nitrogen depends upon the initial soil status, climate, topography, cropping system in practice, and crop. Crop under zero tillage is also more productive (695 kg/ha) with 80 kg N/ha [14]. Increase in the nitrogen level up to 60 kg N/ha consistently and significantly increased the number of primary branches, number of seeds per siliquae and 1000 seed weight [24]; however, increasing the nitrogen level up to 90 kg/ha increased the number of secondary branches per plant, number of siliquae per plant, and seed and straw yield with maximum cost benefit ratio of 3.03 [25]. Split application of total nitrogen in three equal doses one-each as basal, second after first irrigation and remaining one-third after second irrigation resulted in maximum increase in yield attributes and yield of *Brassica juncea* compared to application of total nitrogen in two split doses [26]. Top dressing of N fertilizers should be done immediately after first irrigation. Delaying of first irrigation, results in yield reduction of mustard crop. The application

Table 7: Effect of N and S levels (kg/ha) application on fatty acid composition and glucosinolate content in *Brassica juncea* cv. Varuna at Ludhiana.

N (Kg/ha)	S (Kg/ha)	Glucosinolate content (μmoles/g in defatted meal)	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Eicosenoic acid	Erucic acid
75	0	64	2.61	1.17	11.78	14.99	6.48	50.91	11.80
75	20	72	2.88	1.31	10.15	14.53	5.14	52.75	12.28
100	0	52	2.58	1.58	13.16	15.31	7.01	49.55	10.57
100	20	42	2.91	1.65	11.94	15.06	6.13	49.63	12.18
125	0	52	3.01	1.33	12.19	16.17	5.91	47.71	12.26
125	20	42	4.42	1.31	16.12	16.55	6.57	44.77	9.55

Source: AICRP-RM, 2007 [14].

of nitrogen with presowing irrigation was superior to that of nitrogen application with last preparatory tillage. In case of nitrogen applied with pre-sowing irrigation single application of nitrogen was on a par with split application [27].

Application of phosphorus up to 60 kg/ha significantly enhanced dry matter/plant. Plant height, branches per plant and leaf chlorophyll content increased with up to 40 kg P/ha. The uptake of NPK and sulphur by both seed and stover increased significantly with successive increase in nitrogen levels up to 120 kg N/ha, sulphur levels up to 60 kg S/ha, and P_2O_5 level up to 60 kg P_2O_5/ha. Seed yield and yield attributes increased while oil content decreased with increasing level of nitrogen up to 120 kg/ha. Different levels of phosphorus increased seed yield, maximum being at 80 kg P/ha due to higher number of secondary branches/plant and consequently siliquae/plant. Oil content also increased with increase in levels of N, P_2O_5, and S. Activities of all nitrogen assimilating enzymes, namely; nitrate reductase, nitrite reductase, glutamine synthetase, and glutamate synthetase were found to be maximum at 100 kg N/ha.

7.2. Sulphur Fertilization. Among the oilseed crops, rapeseed-mustard has the highest requirement of sulphur [28]. Sulphur promotes oil synthesis. It is an important constituent of seed protein, amino acid, enzymes, glucosinolate and is needed for chlorophyll formation [29]. Sulphur increased the yield of mustard by 12 to 48% under irrigation, and by 17 to 124% under rainfed conditions [30]. In terms of agronomic efficiency, each kilogram of sulphur increases the yield of mustard by 7.7 kg [31].

Oil content in Canola-4 and Hyola-401 is 3% higher than the hybrid "PGSH-51" due to the effect of various doses of nitrogen and sulphur, while the oleic acid content in these hybrids is double that "PGSH-51." "PGSH-51" had erucic acid ranging from 23.2 in to 29.4%. At higher sulphur level there is 2-3% reduction in erucic acid content. However, lower level of nitrogen reduced erucic acid content by 3% with a concomitant increase in oleic acid (Table 7). Higher doses of sulphur along with low doses of nitrogen affect the chain elongation enzyme system thereby leading to reduction in erucic synthesis.

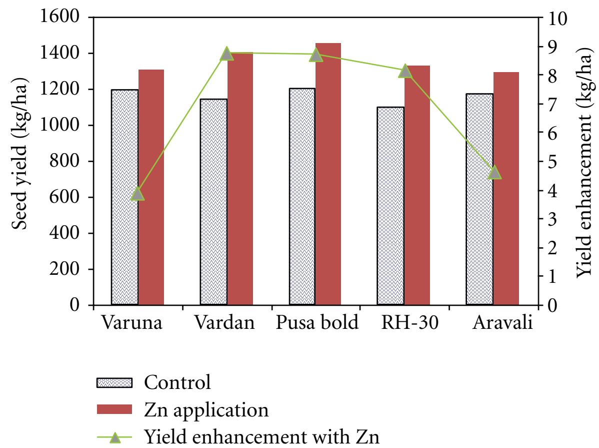

Figure 2: Influence of zinc application on seed yield of different cultivars of mustard.

A significant increase in yield was observed with increase in sulphur levels up to 40 kg S/ha in mustard-based cropping system. At Bawal, the highest seed yield of mustard was recorded in green gram-mustard cropping sequence while the lowest (2686 kg/ha) in pearl millet-mustard sequence. In rice-mustard sequence, the optimum seed yield of mustard was obtained at 40 kg S/ha at Behrampore and for blackgram-mustard at Dholi. Each successive increase in S level increased seed yield up to 20 kg S/ha at Dholi and Ludhiana, 40 kg S/ha at S. K. Nagar, and 60 kg S/ha at Behrampore and Morena conditions [32].

7.3. Micronutrients. Mustard, in general is very sensitive to micronutrient deficiency, specially zinc and boron. The increase in seed yield was 8.5% at 12.5 kg $ZnSO_4$/ha. The harvest index (HI) was significantly affected by Zn application, although seed yield showed diminishing return with additional $ZnSO_4$ doses (Table 8).

The response of various ideotype to the applied micronutrients varies considerably. The response of Indian mustard varieties, *viz.* 'Pusa Bold' and 'Vardan' to applied zinc was found higher (AICRP-RM, 2000) as compared to Varuna, RH- 30 and Aravali (Figure 2).

The concentration of Zn at flowering, pod formation stage, concentration and uptake of Zn in straw and grain

Table 8: Effect of Zn on yield and yield attributes of indian mustard.

$ZnSO_4$ (Kg/ha) levels	Seed yield (kg/ha)	Secondary branches/plant	Oil content (%)	Oil yield (kg/ha)	Protein (%)	Protein yield (kg/ha)	Harvest index (%)
0	1161	6.5	40.2	465.6	22.1	255.2	21.6
12.5	1260	8.1	39.9	501.1	22.5	281.9	22.4
25.0	1336	9.6	39.9	532.4	22.6	301.6	22.9
50	1414	12.4	39.9	570.0	22.5	318.6	22.2
CD at 5%	33	0.7	NS	22.8	NS	18.8	0.8

Source: AICRP-RM, 2000 [33].

at maturity and uptake of Zn in grain and straw at maturity of Indian mustard increased significantly with increase in Zn levels [34]. Similarly, the seed yield increased significantly (16–47%) with the application of boron. The average response to boron application ranged from 21 to 31%. The yield increase was due to 27% and 10% increase, respectively, in seeds/siliqua and 1000 seed weight, indicating the importance role in seed formation [35, 36].

7.4. Organic Sources of Nutrients. Bulky organic manures are applied to improve overall soil health and reduce evaporation losses of soil moisture. Depending upon the availability of raw material and land use conditions various organic sources, *namely,* clusterbean (green manure), *Sesbania* (green manure), mustard straw @ 3 t/ha and Vermicompost (2.5–7.5 t/ha) have been evaluated at Bharatpur. Green manure with *Sesbania* gave significantly higher mustard seed yield at Bharatpur and Bawal. *Sesbania* green manuring has shown higher mustard yield and improved soil environment (AICRP-RM, 2006).

Many biostimulants also encourage higher production. At Hisar, foliar spray of Bioforce (an organic formulation) 2 mL/L at the flowering and siliqua formation stage enhanced mustard seed yield (2059 kg/ha) [14].

7.5. Integrated Nutrient Management (INM). It is important to exploit the potential of organic manures, composts, crop residues, agricultural wastes, biofertilizers and their synergistic effect with chemical fertilizers for increasing balanced nutrient supply and their use efficiency for increasing productivity, sustainability of agriculture, and improving soil health and environmental safety. Balanced fertilization at right time by proper method increases nutrient use efficiency in mustard. Experiments have been conducted at different AICRP centres with the integrated use of organic manure, green manure, crop residue, and biofertilizers along with inorganic fertilizers. INM not only reduces the demand of inorganic fertilizers but also increases the efficiency of applied nutrients due to their favourable effect on physical, chemical and biological properties of soil. The introduction of leguminous crops in the rotational and intercropping sequence and use of bacterial and algal cultures play an important role in increasing the nutrient use efficiency [37].

7.5.1. Growth Promoter, BioFertiliser as a Component of INM. Biofertilizers are inoculants or preparation containing micro-organims that apply nutrients especially N and P. Two types of N-fixing microorganisms namely free living (*Azotobacter*) and associative symbiosis (*Azospirillum*) and two P supplying microorganisms, namely, phosphate solubilizing bacteria and vesicular arbuscular mycorrhiza (VAM) were extensively tested at various AICRP-RM centers. Inoculation of mustard seeds with efficient strains of *Azotobacter* and *Azospirillum* enhanced the seed yield up to 389 and 305 kg respectively with 40 Kg N/ha. The total NPK uptake was also higher with *Azotobacter* inoculation. The combined application of 10 t FYM + 90 : 45 : 45 NPK kg/ha with *Azotobacter* inoculation gave the highest B : C ratio of 1.51. At lower N levels, without inoculation, the seed yield decline was more as compared to inoculated treatment. Growth promoter's formulations like bioforce and biopower contain bio-amino acid, plant growth promoting terpenoid, siderophores, and attenuated bacteria fortified with BGA helped to increase water and nutrient absorption from the soil. Similarly, bioforce contains natural free amino acid, phytohormones, macro- and microelements and plant growth promoting terpenoid activated the cell division and stimulates plant growth, development, and photosynthate translocation. RDF (80 : 40 : 0) along with 25 kg Biopower/ha + spray of Bioforce (1l in 500 litres of water) at 50% flowering and pod filling stage gave significant higher yield of mustard over other combinations [35, 36].

7.5.2. Effect of INM on Quality of Mustard Oil. At Kanpur, INM studies were evaluated in maize-mustard, bajra-mustard, and fallow mustard sequence. In maize-mustard sequence, 100/75% of RDF + 2 t FYM gave highest seed yield and quality of the oil (Table 9).

7.5.3. Integrated Nutrient Management (INM) and Nutrient Use Efficiency. INM improves the nutrient uptake by mustard and hence enhances the use efficiency of various nutrients from the soil. The incorporation of 25% nitrogen through FYM + 75% by chemical fertilizer + 100% sulphur significantly enhanced the uptake use efficiency and of nitrogen and sulphur in both seed and stover of crop followed by 100% NS and 50% N through FYM + 50% by chemical fertilizer + 100% S [38]. The highest mustard-equivalent yield, which includes converted yield of other crops in to mustard seed yield based on market price of the crops (24.88 q/ha), net monetary returns (Rs. 15,537/ha), B : C ratio (2.07), and agronomic efficiency (16.1) were

Table 9: Effect of INM on quality of mustard (Kanti-RK 9807) under maize-mustard sequence.

Treatment	Legends	Oil content (%)	Fatty Acid composition (%)					
			16 : 1 Palmtic acid	18 : 1 Oleic acid	18 : 2 Linoleic acid	18 : 3 Linolenic acid	20 : 1 Eicosenoic acid	22 : 1 Erucic acid
RDF (120-40-40)	T1	40.4	2.8	18.4	10.1	10.6	4.3	52.7
T_1 + 10 t FYM/ha	T2	40.9	2.8	16.3	13.3	10.4	4.1	52.2
T_2 + 40 Kg S/ha	T3	40.4	2.9	18.0	14.4	12.2	3.2	48.6
T_3 + Zn SO4 25 kg/ha	T4	40.3	2.8	17.8	14.9	10.1	6.1	47.3
T_4 + B 1 kg/ha	T5	40.7	2.7	23.0	16.2	9.0	5.2	43.3
T_1 + Crop residue (Maize)	T6	40.1	2.7	20.0	14.3	9.2	4.4	48.6
75% RDF		40.4	2.6	17.8	15.1	7.9	6.3	49.7

Source: Modified from AICRP-RM, 2002 [21].

recorded with the application of 100% recommended N in the rainy season through FYM and 100% recommended NP in the winter season through inorganic fertilizers [39]. Agronomic efficiency is the response in terms of increase in mustard seed yield per unit use of nitrogen.

At Bharatpur and Jobner, 17.8 and 8.6% increase in seed yield was recorded with 50% RDF + 50% N through FYM and vermin-compost. Sole organic treated plot recorded 29.9% lesser seed yield over RDF at Jobner [32]. Amount of available phosphorus increased over initial value when organic manures and crop residues were incorporated. Organic carbon status builds up in organic source incorporated plots. The application of 10 t FYM/ha in addition to recommended dose of fertilizer (RDF) improved soil physical condition by improving aggregation, increased saturated hydraulic conductivity, and reducing bulk density and penetration resistance of the surface soil [40].

8. Water Management

Rapeseed-mustard crop is sensitive to water shortage. A substantial rapeseed-mustard area in Rajasthan (82.3%), Gujrat (98%), Haryana (75.6%), and Punjab (92.4%) is covered under irrigation. A positive effect of irrigating rapeseed-mustard at critical stages is observed. Water use efficiency was highest when irrigation was applied at 0.8 IW : CPE ratio and increased with increasing N rate [41, 42]. Number of irrigations is important for working out the most efficient water use by mustard. For mustard, two irrigations, one at flowering stage and at siliqua formation stage increased seed yield by 28% over the rainfed plots [43]. Increase in the amount of water increased leaf water potential, stomatal conductance, light absorption, leaf area index, seed yield, and evapotranspiration and decreased canopy temperature [44]. In similar study by Panda et al. [45], an average increase in seed yield with irrigation at the flowering and pod development stages and irrigation at the flowering stage over the control was 62.9% and 41.7%, respectively. However, for number of seeds per siliqua and oil content, single irrigation at 45 DAS remained parallel with two irrigations [46]. The water use efficiency was highest with one irrigation at 45 DAS. Crop receiving two irrigations at preflowering and pod-filling stages produce about 33 percent more seed than unirrigated crops [47]. Single irrigation given at vegetative stage is found to be most critical, as irrigation at this stage produces the highest yield. When two irrigations are given, the irrigation at vegetative and pod formation stages is of maximum benefit. The irrigation at vegetative, flowering, and pod formation stages resulted in the highest yield, where three irrigations were given. Oil and protein yield were also significantly affected by number and stages of irrigation (Table 10).

Irrigation is very important for getting the optimum productivity potential of mustard, but equally important is the quality of irrigation water. If the quality of irrigation water is poor, it needs certain treatment and management before being utilized for crop production. The increasing levels of salinity of the irrigation water applied at presowing and flower initiation reduces the plant height, the branching pattern, and the pod formation [48]. Irrigation with saline water (12 and 16 dS/m) decreased the dry matter yield significantly when applied at pre-sowing or later. The saline irrigation at the pre-flowering stage or later reduced the grain yield by 50% and 70%, respectively.

As a result of saline water irrigation, the soil water infiltration was reduced up to 7%. The EC and exchangeable sodium percentage (ESP) were increased by 2.2 dSm^{-1} and 9.0, respectively. The yield of mustard crop could be further increased by better leveling the plots, reducing the level difference to less than 10 cm [49]. The ill effects of saline water can be overcome with proper N management. Nonsaline water can be substituted by applying N and saline water [50].

9. Weed Management

Weeds cause alarming decline in crop production ranging from 15–30% to a total failure in rapeseed-mustard yield. The critical period is 15–40 days. Weeds compete with crop plants for water, light, space, and nutrients. Therefore, timely and appropriate weed control greatly increases the crop yield and thus nutrient use efficiency. The common weeds of mustard are *Chenopodium album, C. murale, Cyperus rotundas, Cynodon dactylon, Melilotus alba, Asphodelus tenuifolius, Orobanche* spp. *and Anagallis arvensis*.

Farmers have adopted herbicides for weed control because the chemicals can increase the profit, weed control efficiency, production flexibility and reduce time and

Table 10: Influence of irrigation levels and stages on seed yield, oil yield and protein yield of Indian mustard.

Treatment	Seed yield (Kg/ha)	Oil yield (kg/ha)	Protein yield (kg/ha)
4 irrigations at V + F + P + S	2260	909	454
3 irrigations at V + F + P	2250	901	454
3 irrigations at V + F + S	2200	886	442
2 irrigations at V + P	2150	879	436
2 irrigations at V + F	2090	841	422
2 irrigations at F + P	2020	803	417
2 irrigations at P + S	1520	574	316
1 irrigation at V	1920	773	386
1 irrigation at F	1790	727	371
CD at 5%	480	144	94

Note: V: vegetative stage; F: flowering stage; P: pod formation; S: seed development.
Source: AICRP-RM, 1999 [15].

labour requirement for weed management. Hand weeding at 20DAS, fluchloralin preplant incorporation @ 0.75 kg/ha, wooden hand plough between the lines at 35 DAS on Indian mustard was found effective [51]. Polythene mulch was also found effective in controlling the weeds in mustard [52]. At Bawal, reductions in weed population and dry matter were obtained with fluchloralin supplemented with hand weeding at 30 and 60 DAS, which remained on a par with isoproturon and pendimethalin supplemented with hand weeding at 30 and 60 DAS. Weed-free plot recorded 39.9% higher seed yield over weedy check [32].

Broomrape (*Orobanche*) is a major devastating parasitic weed of mustard. Broomrape weed infestation caused 28.2% average reduction in Indian mustard yield. Among *Orobanche* spp., *O. aegyptiaca* is one of the most important parasitic weed causing severe yield and quality reducing factor in rapeseed-mustard. It is endemic in semiarid region and may reach epidemic proportions depending upon soil moisture and temperature. Preceding crop of cowpea, black gram, moth bean, sunn hemp, cluster bean, and sesame significantly reduced *Orobanche* menace in succeeding mustard crop while sorghum, pearl millet, chilies, and green gram did not influence broomrape infestation in mustard [53]. At Bharatpur, S. K. Nagar and Bawal directed spray of glyphoste (0.25–1.0%) and 2 drops of soybean oil per young shoot of *Orobanche* showed effective control and recorded 91.9% higher seed yield over infected sick plot.

Some cultural practices like mulching and hoeing are also helpful to curb some of the major weeds in mustard by providing a shield against sunlight, reducing the soil temperature and acting as a physical barrier for emergence of weeds. Maximum seed yield (2540 kg/ha) was obtained in the treatments where plots were kept weed-free followed by the treatment where mulching was done after hoeing (Table 11).

Table 11: Seed yield (kg/ha) and weed population/m^2 as influenced by different weed control practices.

Treatment	Seed yield	Weed population/m^2
Control	1620	57.0
Weed free (Khurpi)	2520	0.0
Hoeing at 25 DAS	2300	19.3
Mulching with bajra florets	1960	23.0
Fluchloralin @ 1 kg a.i./ha PPI	2000	23.0
Pendimethalin @ 1 kg a.i./ha PE	2050	22.1
Isoproturon @ 1 kg a.i./ha PE	1740	26.3
Hoeing at 25 DAS + mulching	2400	17.9
Fluchloralin @ 1 kg a.i./ha PPI + Hoeing	2210	20.3
Fluchloralin @ 1 kg a.i./ha PPI + Mulching	2100	22.5
Pendimethalin @ 1 kg a.i./ha PE + hoeing	2300	18.9
Pendimethalin @ 1 kg a.i./ha PE + mulching	1860	19.5
Isoproturon @ 1 kg a.i./ha PE + hoeing	1950	22.5
Isoproturon @ 1 kg a.i./ha PE + mulching	1910	22.9

Source: AICRP-RM, 2002 [21].

10. Response to Plant Growth Regulators

Plant growth regulators (PGR) involved in manipulating plant developments, enhancing yield and quality have been actualized in recent years. Indeterminate plant growth habit, shattering, or dehiscence of fruits and lodging are the most significant and consistent limitations to maximum seed yields in *Brassica* spp. Considerable seed loss takes place, before or during harvest, due to shattering of fruits, which is correlated with hormonal imbalances and poorly developed lignified cells in the fruit wall. Further, lodging of the crop canopy adversely affects seed quality and yield due to decreased photosynthesis, increased disease severity, impaired rate of drying, and reduced harvest efficiency. Chemical plant growth regulators are being increasingly used as an aid to yield enhancement [54].

Brassinolide is the most bioactive form of the growth-promoting plant steroid termed as Brassinosteroids. Biologically active brassinosteroids show high growth-promoting as well as antistress activity besides other multiple effects on

Table 12: Seed yield (kg/ha) and net returns (Rs./ha) of mustard as influenced by foliar application of agrochemicals at different locations.

Treatment	S. K. Nagar		Sriganganagar	Ludhiana		
	Seed yield (kg/ha)	Net returns over control	Seed yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)	Glucosinolate (μ mole/g defatted meal)
Control	1707	—	1604	34.7	375	130
Thiourea (0.1%)	2087	3226	1696	35.9	429	142
S @ 40 kg/ha	2249	6712	1799	35.2	405	149
S @ 40 kg/ha + Thiourea (0.1%)	2039	4070	1883	33.4	411	134
Urea (2%)	2019	5409	1845	34.7	396	124
$ZnSO_4$ (0.5%)	1921	4622	1667	33.2	372	126
Boric acid (0.1%)	1928	3418	1650	34.3	387	115
CD at 5%	150	—	158	—	—	—

Source: AICRP-RM, 2003 [5].

Table 13: Effect of low monetary agrotechniques on seed yield and oil content of mustard at Bharatpur during 1997-1998.

Treatments	Seed yield (kg/ha)	% increase over local practice	Oil content (%)	Oil yield (kg/ha)
Local Practice (T1)	1200	—	40.3	463
RP (No thinning and gypsum) (T2)	1371	14.2	40.3	525
RP + thinning at 15 & 25 DAS (T3)	1407	17.3	40.5	560
T_3 + N-S sowing (T4)	1376	14.7	40.7	560
T_3 + Removal of 4th row and 4th plant (T5)	1156	3.7	40.4	467
T_5 + 56.75% N as top dressing (T6)	1073	10.6	40.3	432
T_3 + I irrigation at 40–50 DAS (T7)	1232	2.7	40.6	500
T_1 + 200 kg gypsum/ha (T8)	1217	1.4	40.9	500
T_3 + removal of 4 older leaves (T9)	1343	11.9	40.5	544
RP + de-topping at bud-initiation stage (T10)	1464	22	40.7	596

Source: AICRP-RM, 1998 [12].

growth and development. As botanical juvenile hormones, they enhance the growth of young plant tissue and stimulate in submicromolar concentrations metabolic, differentiation and growth processes. Brassinosteroid caused accumulation of maximum total dry matter as compared to rest of the treatment at physiological maturity.

NPK accumulation and yield were maximal when spraying of GA_3 was done at 40 DAS [55]. An increase in secondary and tertiary branching with consequent enhancement in seed yield through increased number of infloresence and siliquae per plant was observed with the application of Mixatalol (a mixture of long aliphatic alcohols varying in chain length from C_{24} to C_{32}) to *Brassica* plants as foliar spray [56]. The percentage of immature siliquae and shattering of siliquae decreased with this treatment. Mixtalol increased total dry matter of plants, partitioning coefficient, and harvest index. The contents of starch, protein, and oil were also higher in seeds from mixtalol treated plants.

The maximum plant height (169.1 cm), number of primary branches per plant (8.2), seed yield (2031 kg/ha), stover yield (5752 kg/ha), harvest index (26.1%), oil content (42%), and net returns (Rs. 20,471/ha) were recorded with thiourea (Shrama and Jain, 2003). At Bawal and Morena, highest seed yield (2060 kg/ha) was obtained with 40 kg S/ha + thiourea (0.1%). At Sriganganagar, significantly higher seed yield (1883 kg/ha) was recorded on a par with 40 kg S/ha + thiourea (0.05%), urea (2%), H_2SO_4 (0.1%), and 40 kg S/ha. 40 kg S/ha + thiourea (0.1%) resulted into 17.67% higher seed yield over no spray. The highest oil content (35.9%) was recorded with thiourea 0.1% spray. Glucosinolate content ranged from 115 to 154 (μmole/g defatted meal) in different treatment (Table 12).

11. Impact of Low Monetary Agrotechniques on Mustard Productivity

Agricultural inputs like fertilizer, irrigation, insecticides, pesticides, and herbicides, and so forth, are very expensive. Some nonmonetary or low monetary inputs can enhance the yield considerably with a slight increase in the cost of cultivation. There are a number of low monetary agro techniques which enhance the mustard yield considerably (Table 13). For harvesting the maximum yield of rapeseed-mustard at a given situation, all the production technologies, like, soil amendments, thinning, nutrient supply, sowing direction, irrigation, plant protection, and so forth should be planned well in advance. At Bharatpur, highest seed yield (1464 kg/ha) was recorded with the application of recommended practice (RP) + thinning at 15 and 25 DAS + detopping at bud-initiation stage followed by RP + thinning at 15 and 25 DAS.

12. Future Line of Research

Rapeseed-mustard will continue to contribute considerably to the oilseed bowl of the country. A streamlined research programme for rapeseed-mustard should be focused on the below-mentioned points.

(i) Horizontal and vertical intensification in rapeseed-mustard production needs to be done for self-sufficiency in oilseed production. It is possible through varietal improvement and introduction of mustard in nontraditional areas.

(ii) An optimum agronomic package of practices for high yielding and insect, pest, and disease resistant varieties, along with the upcoming hybrids needs to be worked out.

(iii) Adoption of site-specific nutrient management (SSNM), precision agriculture, and conservation agriculture can bring more profits to the mustard growers.

(iv) An integrated weed management approach needs to be developed for problematic and parasitic weeds in mustard. *Orobanche* is becoming a serious constraint and for its management a holistic approach which includes GM techniques needs to be explored.

(v) Suitable crop models and simulation for various inputs like water and nutrients will be helpful to target the most productive and most potential mustard growing zones of India.

13. Conclusion

The tremendous increase in oilseed production is attributed to the development of high yielding varieties coupled with improved production technology, their widespread adoption and good support price. To meet the ever-growing demand of oil in the country, the gap is to be bridged through management techniques. The vertical growth in mustard production can be brought by exploiting the available genetic resources with breeding and biotechnological tools which will break the yield barriers. Horizontal growth in rapeseed-mustard can be brought in those rapeseed-mustard growing areas/districts of the country, wherever, the yield is lower than the national average. Production technologies for different agroecological cropping systems, crop growing situations like intercropping, salinity, rainfall, and so forth, under unutilized farm situations like rice-fallows, mustard to be followed after cotton, sugarcane, soyabean, and so forth, and mustard as a *paira* crop in rice with lathyrus, lentil or any other competing *rabi* crop in traditional and nontraditional areas, need to be worked out. It is estimated that at least 1 million hectares can be brought under cultivation, through adoption of such cropping systems.

Proper land preparation, proper time of sowing, selection of better quality seeds, and so forth are always neglected. Fertilizer application is little or nonexistent leading to poor productivity. Whether little is spent on fertilizer input goes entirely on nitrogenous fertilizers. This results in a big gap between requirement and production of mustard in India. Therefore site-specific nutrient management through soil-test recommendation based should be adopted to improve upon the existing yield levels obtained at farmers field. Optimum crop geometry, balanced NPK fertilizers, intercultural operations, and inclusion of farmyard manure are the building blocks for achieving the utmost yield targets of rapeseed-mustard. Effective management of natural resources, integrated approach to plant-water, nutrient and pest management and extension of rapeseed-mustard cultivation to newer areas under different cropping systems will play a key role in further increasing and stabilizing the productivity and production of rapeseed-mustard to realize 24 million tonnes of oilseed by 2020 AD.

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