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Review

An overview of oilseeds seed industry

R K TRIVEDI[1], R K TRIPATHI[2], DEEPANKER PANDEY[3] AND PRAMOD SHARMA[4]

[1]Executive Director, National Seed Association of India, New Delhi-110 001

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ABSTRACT

The seed industry of the country has played a central role in bringing green revolution in India leading to record growth in production and productivity of different crops. Today, the Indian seed sector with a value of USD 3.0 billion is the fifth-largest seed industry in the world and is growing at a fast pace. The oilseed seed industry market is worth 0.06 Bn USD (Approx.) in India, out of which, the hybrid oilseed seed market is worth 0.027 Bn USD (Approx.). The oilseed sector is faced with several challenges concerning poor SRR as compared to other crops, which is less than 25%-30% leading to low productivity. In the case of mustard, castor, soybean, and linseed, the SRR is higher as compared to other oilseed crops. The other challenges are the inadequacy of seeds of high yielding and climate-resilient varieties, the availability of hybrids only in mustard, sunflower, and castor not with full exploitation of their potential. There is an urgent need to promote research varieties developed by private seed companies which suited to local situations and help in increasing the VRR of oilseed crops. Transfer of new agricultural technology to farmers including new seeds of oilseed crops also needs to be strengthened. Further, it is important to look at the concerns of the seed industry relating to IPR, seed traceability, support to private seed industry R&D, incentivizing the private seed industry for increased production of seeds of targeted crops/varieties, involving the seed industry in implementing government programmes on seed production and distribution and strengthening seed storage infrastructure. These are the suggested initiatives for enhancing the availability of quality seeds of oilseed crops.

Keywords: Current Status, Marketing, Oilseeds, Seed industry

Seed is the basic and most critical input for sustainable agriculture, carrying the technology and serving a link between the present and the future. The growth in Indian agriculture has taken place in parallel with the expansion and growth of seed industry. The government's policy assistance has also aided in the evolution and development of the seed sector. The public and private research system has contributed significantly for development of new and improved varieties and hybrids in various crops including oilseed crops. Crop improvement systems coupled with frontier technologies like genomic research have offered a great opportunity for improving the productivity of Indian Agriculture.

The Indian seed industry is driven by the Seeds Act, 1966 which regulates the quality of seeds sold to farmers. The Seed (Control) Order, 1983 oversees the process of licensing for conducting of seed business. In general, private sector specializes in high value hybrid seeds and varietal seeds and offers them to farmers as Truthfully Labelled (TL) seeds. On the other hand, public sector specializes in high volume OPV seeds and offers them to farmers as Certified Seeds. Quality seeds alone have been found to contribute to nearly 20% increase in the productivity/production of crops as compared to other inputs. Hence, it is imperative to increase the availability of good quality seeds to farmers with the active involvement of both the public and private seed industries to achieve the desired growth in production/productivity of priority crops like oilseeds.

[2]Director (Technical), National Seed Association of India, New Delhi; [3]Assistant Director, National Seed Association of India, New Delhi; 4Research Associate, National Seed Association of India, New Delhi; Corresponding author's E-mail: rk.tripathi@nsai.co.in

1. Current status of the Indian seed sector

The Indian seed industry has grown in size and performance over the past five decades. The Indian seed sector is the 5th largest seed sector globally and is valued at USD 3.0 Bn dollars as per NSAI estimates. The Farm Saved Seeds (FSS), saved and used by farmers and exchanged between them are not included in the market size. However, with respect to exports, India has a miniscule share and has a huge opportunity to become a global seed hub. The Indian Open Pollinated Variety (OPV) seed industry is estimated at USD 1.56 Bn. The commercial OPV seed industry falls under both organized and unorganized sectors. The Indian hybrid seed industry is estimated at ₹ 10000 crores or USD 1.33 Bn. The entire hybrid Cotton seed market is GM Cotton seed and therefore GM seed market is nearly 16% of the total seed market and 35% of the hybrid seed market.

The estimates for unorganized seed sector and FSS are not available but are likely to add at least 20-25% to the organised seed market, which may raise the Indian seed market size to a more realistic value of nearly USD 3.6 - 3.75 Bn. The Oilseed seed industry market is worth 0.06 Bn USD (Approx.) in India, out of which, the hybrid oilseed seed market is worth 0.027 Bn USD (Approx.).

2. Scenario of oilseed crops in India, demand and supply position of seeds of major crops, SRR and VRR status

India has been cultivating almost all oilseed crops. It is the 4th largest oilseed producer in the world. It has 20.8% of the total area under cultivation globally, accounting for 10% of global production. Among the nine oilseed crops grown in India, the highest average contribution to total production of oilseeds in the country is of soybean (38%) followed by Rapeseed-Mustard (27%) and groundnut (27%) (Average of 2016-17 to 2020-21). On an average, total *kharif* oilseed crops contribution to total oilseed production is about 67% and the remaining 33% is of *rabi*/summer oilseed crops.

The two critical parameters for improvement of productivity in seeds of OPVs especially applicable to oilseeds are Seed Replacement Rate (SRR) and Varietal Replacement Rate.

i. Seed replacement rate (SRR): SRR has significantly improved for many agricultural crops in the past decade in a number of States. However, it is still low compared to global standards where SRR is more than 90%-100%. Situation in oilseeds is still not satisfactory as in most of the crops, particularly, the OPVs, the SRR is less than 25%-30% leading to low productivity. In cases of Mustard, Castor, soybean and linseed, the SRR is high as compared to the other oilseed crops. There is a sharp decline in SRR of Sunflower seeds after 2015-16 due to lack of adequate availability of varieties resistant to biotic and abiotic stresses. As a result there is less preference of farmers to grow sunflower leading to reduction in the cropped area as well.

Replacement Rate of major oilseed crops in the country by making available quality seeds to farmers. NSAI data on Seed Industry indent ode of breeder seed of Oilseed crops indicate that indent for only three crops namely Mustard, Soybean and Groundnut indents were placed. In case of Mustard and Sunflower Seed industry varieties are dominating the Indian seed market.

ii. Varietal replacement rate: Similarly in many crops, old varieties released and commercialized in the past 3-5 decades in both private and public sector are still under cultivation in a number of States and the productivity of the most of these old varieties has reached a plateau or stagnated. There is a strong need for Varietal Replacement with new varieties being developed by R&D in both public and private sector. The genetic improvement of new varieties over the existing varieties in line with customer and market requirements, changing climatic conditions and tolerance to various biotic and abiotic stress conditions, reflect in the genetic gains developed through conventional plant breeding supported by advance R&D approaches including biotechnology.

However, due to various socio-economic factors the Varietal Replacement Rate (VRR) of the highly adopted varieties is also low in many States of the country. Data on VRR is also not available in the public domain.

Some prominent varieties and hybrids of Indian seed industry in the major States of India in major oilseed crops are given in table 3.

By improving SRR and VRR the productivity potential of various Plant varieties in different crops can be realized successfully on par with global averages in line with improvement in irrigation potential and improved agronomic practices to optimally utilize natural resources.

3. Oilseed producing regions of India

The cropping patterns in different States of India are also dependent on the agro-climatic suitability of the particular crop in the given region. The total land area in India is 328 million hectare (mha) out of which 156 million hectare (mha) is arable land. For a Gross cultivated area of 167 mha (2018-19), the total seed requirement in India is met by both Public sector, Private sector and Farmer's own saved seed (FSS). While larger private sector companies specialize in hybrids and certain OPV crops, public sector seed companies largely produce and supply OPV/non-hybrid seeds. Based on seed rate, seed replacement rate (SRR), and seed multiplication rate (SMR), the area and seed requirements are calculated.

Almost all the hybrid seed production happens in specialized pockets in States like Karnataka, AP, Telangana, Gujarat, Maharashtra, Uttar Pradesh, Uttarakhand, Madhya Pradesh, Odisha, etc., where in farmers have acquired specialized skillsets over a period of time for performing specialized operations involved in production of hybrid crops. Some districts have also acquired high level competencies in hybrid seed production *viz.*, Nizamabad (Telangana), Sabarkantha (Gujarat), Jalna (Maharashtra) specialize in hybrid mustard production. Madhya Pradesh, Maharashtra, Telangana are hubs for soybean seed production, and Gujarat and Andhra Pradesh are for groundnut seed production.

4. Challenges in oilseeds seed production and marketing

When it comes to crop-wise coverage of irrigated areas (2016-17) almost 70 per cent of cereals are covered under irrigation. But when it comes to oil seeds, the coverage of the irrigated area is only 27.8 percent. From 5.16 million MT in 1950-51 to 33. 42 million MT in 2019-20, oil seed production in India has witnessed growth at a slow pace. The average per hectare yield of major oilseeds is over 50 percent lower than average world yields in case of several oilseed crops. The government data also confirm domestic availability of oilseeds in India is much less than the domestic demand for edible oil, primarily, because of less production. As a result, a large volume of edible oils has to be imported every year. Changes in international prices of edible oil have an impact on its domestic price as well.

The major edible oils consumed in the country are mustard, soybean, groundnut, sunflower, sesame, Niger, and safflower act as primary source and coconut, palm oil, cottonseed, rice bran, solvent extracted oil, tree and forest origin oil form the secondary source of oil. Castor and linseed oils are predominantly of industrial use. There is a need to encourage farmers to take up production of these oilseed crops in larger areas through initiatives or policy support like higher Minimum Support Price (MSP). Industry reports indicate that India's domestic oilseed production needs to go up to about 54 million MT by 2025 to reduce edible oil imports by 10 million MT annually.

A long term policy on increasing oilseed production in the country needs to be drawn taking into consideration following challenges,

i. Dependency on imports: According to the Ministry of Consumer Affairs, Food, and Public Distribution the total domestic demand of edible oils in the country is approximately 250 lakh MT per year. Interestingly, around 60 per cent of the edible oils consumed in the country is met through imports. Palm oils (crude + refined) import constitutes around 60 per cent of the total edible oil imported, out of which 54 per cent is imported from Indonesia and Malaysia.

As the country has to depend heavily on imports to meet the gap between demand and supply, the international prices have an impact on domestic prices of edible oils.

ii. Lack of appropriate technologies: Though these oilseeds are energy rich crops requiring higher inputs with better management practices, more than 75% of the area under oilseed cultivation falls under rainfed cultivation and grown in energy starved conditions with low inputs and poor management practices due to which the total genetic potential of the crop remains unexploited leading to sharp fluctuations in production and giving rise to high risk situations.

iii. Less number of varieties (shortage of HYV seeds): One of the major challenges in spread of oilseeds is the unavailability of adequate quality seeds. Efforts are needed on production of hybrid seed and promotion of hybrids having short stature, higher seed oil content, resistance to stresses and varieties with short durations.

a. Most of the cultivars and hybrids developed are drought susceptible and the high yielding varieties are also not suitable. They are generally long duration and also do not have higher seed oil content. There is scarcity of short, high yielding input responsive biotic and abiotic stress resistant varieties. As compared to cereals there has been failure of hybridization and seed multiplication programs. Similarly, farmers are not able to get sufficient amount of the best quality seeds during sowing period due to very low seed multiplication ratio of the oilseed crops.

iv. Expanding area under hybrids of oilseed crops: Commercial hybrids have been developed in sunflower, castor and Indian mustard, offering huge potential for enhancing oilseed yield. Concerted efforts are needed on production of hybrid seed and promotion of hybrids of oilseed crops.

v. High risk and uncertainty factors in production: There has not been a proper transfer of technology from lab to farm. The supply of technology and desired inputs from farm institutions to farmers is very poor.

vi. Poor infrastructure and lack of cohesive government policy

vii. Variability in the Growth of Area, Production and Yield

viii. Lack of suitable post-harvest technology: This leads to complete failure in preventing post-harvest losses because lack of proper storage, grading and marketing facilities to avoid deterioration of quality.

5. Revival of the oilseeds crop - Need of the hour

Launch of Yellow Revolution by the Government helped in improving productivity of oilseed crop but could not help in increasing oilseeds production significantly owing to lack of awareness and needed change in cropping pattern leading to significant decrease in area under oilseeds production. Technology Mission on Oilseeds II and Yellow Revolution

2.0 with better planning can help India to achieve self-sufficiency in oilseeds and also increase India's agri-export. Yield gap analysis shows that India's oilseeds production can improve by reducing yield gap. Hence, there is a greater scope for increasing the yields of oilseed crops. Few observations which helps revival of the oilseeds crops are:

i. Bringing oilseed revolution in eastern India: The varied natural resources and fertile lands offer possibility to promote oilseed cultivation in eastern India, including eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, Assam, West Bengal and parts of the North East Hill region in different seasons.

a. If there is increase in oil seed prices and the better performance of the crops, the farmers of this region will have greater interest in growing oilseed crops.

ii. Knowledge empowerment of stakeholders: The seed industry is working hard to enhance the production of research varieties, foundation/certified seed and take up hybrid seed production. Increase in adoption of improved cultivars and production technologies are very much needed for enhancing yield of oilseeds. This can be achieved by putting in place a Public-Private-Partnership model. Reassurance for Seed industry through research assistance and participatory research and development activities will be helpful in breaking the yield barrier through improved cultivars and production technologies.

iii. Private companies should also be involved in certified seed production so that the conversion of breeder seed to certified seed is taken up more sincerely.

iv. Sharing of germplasm with Indian seed industry: The available germplasm with the leading research institutes like Indian institute of Oilseeds Research (IIOR) at Hyderabad, National Bureau of Plant Genetic Resources (NBPGR), New Delhi and other institutions may be given immediate access to the private seed companies in the country for taking up fast track breeding activities. The private sector may also be supported by providing germplasm from the countries who enjoy a great diversity in the crop. This enhances the breeding capability of the Indian seed companies thereby leading to higher yield of the crop in the future which can help farmers to take up more additional crops, particularly, in spring season across the country with the availability of enhanced irrigation facilities.

v. Marketing linkage and good transport facilities: Greater attention needs to be given by the government on marketing channel of oilseed and construction of good road connectivity within the rural areas to ensure easy access of the farmers produce to the buyers and to avoid post-harvest losses.

6. Seed Industry feedback on achieving increase in seed production of oilseed crops

a) Since, availability of adequate quantity of quality seeds suited to different regions in the country, it is important to encourage and strengthen the seed industry and seed production in their efforts to increase availability of seeds in oilseed sector. Important initiatives suggested by the industry may be summarized as under:

i. Certain incentives are required to the seed growing farmers for enhancing seed production: Most of the areas in the eastern India after the harvest of paddy are left uncultivated also known as rice-fallow due to the irrigation unavailability. With integrated crop management system like intercropping and sequential cropping as per system suitability these areas can be brought into cultivation of oilseed crops. This practice can offer ample opportunity to promote oilseed cultivation since there is availability of natural resources and fertile land.

ii. Seed crop insurance so that the damage due to vagaries of weather do not affect the farmer's investment in seed crop: Government schemes such as crop insurance with reasonable minimum support prices with added bonus to attract the new oilseed growers or checking the shift of farmers towards other crops or professions.

iii. For the farmers, who have produced the seed successfully, a production linked incentive through Direct Benefit Transfer (DBT) may be provided.

The above can be based on the seed production plot inspection conducted by the officials of the agriculture department / seed certification agency, as the case may be. The seed producing companies shall provide the list of the seed production plots to the department/certification agency. The scheme may be limited to identify production locations which happens to be falling in the major Oilseed seed production areas in India.

b) Suggested initiatives for the seed industry:

i. Protection of Research variety: PPVFR act based IPR regime aligned to the seed quality regulations

ii. Seed traceability: In order to check spurious seed market and illegal players there is a strong need to develop capabilities for Seed traceability utilizing digital technologies and ICTs.

iii. Incentives to the seed industry: For encouraging private seed sector research and development programs for developing the improved varieties, R&D investments for development of improved Plant varieties in all crops including use of biotechnologies for development of transgenic traits, gene edited traits, etc. may be incentivized.

iv. Production linked incentive to the seed companies based on the production of seeds, so that they can pass on this benefit by reducing the sale price to the farmers.

v. In some crops like Sunflower seed off take is irregular and cannot be predicted as the crop is sown during different seasons by the farmers as per the situation (it is sown as a catch crop in August-September if there are no rains in Kharif. Similarly, if there are excess rains, it is sown in January - February to take advantage of residual moisture. Both situations are not regular). The seeds may be procured by the Govt. from the private seed companies and distributed to the farmers whenever the demand arises. In such cases, the seed cost may also become more affordable to the farmers.

vi. The Govt. may also consider 50-100% subsidy on the seeds produced and supplied by private seed companies to the farmers at least for 3 years to encourage farmers to divert to targeted oilseed crops from other crops.

vii. Development of local level cold storage and air conditioned warehouses and processing infrastructure to support domestic seed companies.

For achieving self-sufficiency in the production of oilseeds, the government of India must follow the PPP model and extend needed policy and financial support to the Indian Seed industry because policy and financial risks are the major problems when it comes to increasing seed oil production. For years, farmers produced groundnuts and sunflower but with prevalence of unseasonal rains and pests, they have shifted to soya. Thus, there is a need to have a micro-level plan on development of seeds meeting the required characteristics with technological support.

The Indian seed sector is one of the largest seed sector globally and is valued at USD 3.0 Bn. India has a huge opportunity and potential to become a global seed hub. However looking at the challenges faced in development of seeds of oilseed crops and in achieving desired production/productivity leading to self-sufficiency, the government would need to promote the PPP model and extend needed policy and financial support to the Indian Seed industry as these are the major problems when it comes to increasing oilseed crops production. There is also need to have a micro-level seed plan for the oilseeds, particularly, for the development of climate resilient oilseed crop varieties/hybrids. The private seed sector has to play a key role in this endeavor, as they have demonstrated earlier. It is desired that government support is extended to Indian seed industry through providing research assistance, seed insurance and by making available quality germplasm, as these initiatives will help in improving productivity of oilseed crop and making India self-reliant.

Table 1 Seed replacement rate (SRR) of major oilseed crops in the country from 2004-05 to 2016-17

Crop	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Groundnut	7.11	6.89	9.79	14.29	17.04	22.95	24.50	22.51	24.91	25.38	23.65	23.56	25.24
Rapeseed/Mustard	58.48	55.36	60.71	58.62	52.67	74.80	63.64	78.88	57.31	51.28	54.56	62.20	68.03
Til	13.64	15.91	18.18	25.00	19.49	18.54	20.05	22.82	19.84	23.62	19.48	30.92	42.36
Sunflower	60.15	67.67	66.92	62.88	43.64	51.46	61.20	32.47	35.83	86.29	96.32	86.20	30.67
Soyabean	23.88	25.54	25.11	29.53	29.26	38.95	35.85	52.75	51.63	37.46	30.48	37.74	38.17
Castor	30.60	37.31	26.87	31.34	41.95	31.56	28.32	60.63	61.54	41.06	42.94	54.12	80.80
Safflower	15.69	15.69	13.73	15.69	26.04	23.15	28.63	32.89	14.62	32.91	29.05	29.52	29.32

Figure in %; Source: Seednet portal, GoI; https://seednet.gov.in/cms/home/readyreckoner/Seed3_6/ 18.seed_distribution_and_SRR.xlsxx)

Table 2 Indent of private seed companies for breeder seeds of oilseed crops through NSAI

Crop	Year	Breeder seed allotment (Quintal)	No. of varieties	No. of Companies
	2020-21	4.43	16	17
Mustard	2021-22	11.31	29	29
	2022-23	5.68	24	22
	2020-21	1002.20	16	19
Soybean	2021-22	190.05	15	22
	2022-23	143.47	13	18
	2020-21	106	6	5
Groundnut	2021-22	81.85	12	4
	2022-23	46.05	14	7

Source: Seed net portal (NSAI breeder seed indent)

Table 3……

State	Mustard including hybrid	Sunflower	Soybean	Groundnut
Andhra Pradesh		Gowri-888, Raja-333, Super Gowri, NSFH-145 Swathi, NSFH-36 Shresta, NSFH-1001 Sunlight		
Telangana		Gowri-888, Raja-333, Super Gowri, NSFH-145 Swathi, NSFH-36 Shresta, NSFH-1001 Sunlight		
Karnataka		Gowri-888, Raja-333, Super Gowri		
Maharashtra	Super Jugni, SBH 118 (Hybrid), SBH-218(Hybrid), Super Hem, Urja, Jawala, Chinnu	Gowri-888, Raja-333, Super Gowri, Gowri-888, Raja-333, Super Gowri, NSFH-145 Swathi, NSFH-36 Shresta, NSFH-1001 Sunlight	E-81, E-61, E-21, Gold-3344, Soybean Prabhakar, Soybean Agresar, KSL-441, KSL-20, Ajeet Shreemanti, Western-101	
Gujarat	45 S 42, 45 S 35, Bayer- 5222, Baioseed-Sonalika, NB-11, Gajani, NB-11, Revathi, Prabhat Gold, Gajani, NMH90M01 (Hybrid), NMS-2017, NMS-2018, NYS-3016 (Yellow), Jambo, Bond, Super Jugni SBH 118 (Hybrid), SBH-218(Hybrid), Super Hem, Urja, Jawala, Chinnu, JKMS 8532, JK 6901		E-81, E-61, E-21, Gold-3344, Soybean Prabhakar, Soybean Agresar, KSL-441, KSL-20, Ajeet Shreemanti, Western-101	Western HB-Shiva, Western Vardan, Western Mahabali,
Chattisgarh			E-81, E-61, E-21, Gold-3344, Soybean Prabhakar, Soybean Agresar, KSL-441, KSL-20, Ajeet Shreemanti, Western-101	
Madhya Pradesh	Kalasona, nathi sona, Talia, PHI-45 S 42, Bayer-5222		E-81, E-61, E-21, Gold-3344, Soybean Prabhakar, Soybean Agresar, KSL-441, KSL-20, Ajeet Shreemanti, Western-101	
Uttar Pradesh	54 S 42, 45 S 46, bayer 5222, Sriram-1666, Savanna- 2042, NB-11, Revathi, Prabhat Gold, Gajani, NMH90M01 (Hybrid), NMS-2017, NMS-2018, NYS-3016 (Yellow), Jambo, Bond, Super Jugni SBH 118 (Hybrid), SBH-218(Hybrid), Super Hem, Urja, Jawala, Chinnu, JKMS 8532, JK 6901			
Punjab	45 s 46, 45 S 42, Advanta 414, Bayer 5222, NB-11, Gajani, Super Jugni, SBH 118 (Hybrid), SBH-218(Hybrid), Super Hem, Urja, Jawala, Chinnu	Gowri-888, Raja-333, Super Gowri, NSFH-145 Swathi, NSFH-36 Shresta, NSFH-1001 Sunlight		
Haryana	45 s 46, 45 S 42, Advanta 414, Bayer 5222, NB-11, Prabhat Gold, Gajani, NMH90M01 (Hybrid), NMS-2017, NMS-2018, NYS-3016 (Yellow), Jambo, Super Jugni, SBH 118 (Hybrid), SBH-218(Hybrid), Super Hem, Urja, Jawala, Chinnu, Bond, JKMS 8532, JK 6901	Gowri-888, Raja-333, Super Gowri, NSFH-145 Swathi, NSFH-36, Shresta, NSFH-1001 Sunlight		
Himachal Pradesh	45 s 46, 45 S 42, Advanta 414, Bayer 5222			
Rajasthan	45 s 46, 45 S 42, Advanta 414, Bayer 5222, MRR-8030, NB-11, Revathi, Prabhat Gold, Super Jugni, SBH 118 (Hybrid), SBH-218(Hybrid), Super Hem Urja, Jawala, Chinnu, JKMS 8532, JK 6901			
Bihar	PHI-45 S 42, 45 S 46, Bayer 5222, Prabhat Gold, Gajani, NMH90M01 (Hybrid) NMS-2017, NMS-2018, NYS-3016, Jambo, Bond	Gowri-888, Raja-333, Super Gowri		
West Bengal	45S 42, 45S 46, Sakata 555 & Bayer 5111	Gowri-888, Raja-333, Super Gowri		
Odisha		Gowri-888, Raja-333, Super Gowri		

Table 4……

Crop	Avg. Seed output	Area (ha)	Seed production regions/Districts
Hybrid Mustard	400 kg/acre	3750	Nizamabad (TS), Sabarkantha (Guj), Jalna (Maha)
Soybean	700 kg	200,000	MP, Maharashtra, Telangana
Groundnut	1000 kg	NA	Gujarat, AP

(Source: NSAI report for NABARD)

Table 5 Total cropped area in India for major oilseed crops (2018-19)

Crops	Seasons	2017-18	2018-19
	Kharif	4.1	4.06
Groundnut	*Rabi*	0.81	0.79
	Total	4.91	4.85
Soybean	*Kharif*	10.47	11.28
	Kharif	0.13	0.12
Sunflower	*Rabi*	0.15	0.17
	Total	0.28	0.29
Sesamum	*Kharif*	1.56	1.56
Nigerseed	*Kharif*	0.22	0.18
Mustard/RM	*Rabi*	5.96	6.24
Safflower	*Rabi*	0.07	0.04
	Kharif	17.32	17.98
Total Oilseeds	*Rabi*	7.33	7.55
	Total	24.65	25.53

(Source: CACP report- https://cacp.dacnet.nic.in/ViewReports.aspx?Input=2&PageId=39&KeyId=669)

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Review

TBO's and alternate sources of oils

DIVAKAR RAO

Member-Executive Committee, Karnataka State Bio-Energy Development Board, Bengaluru-560 020, Karnataka

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ABSTRACT

Oils are triglycerides of glycerol with free fatty acids. The major source of edible oils in agriculture is from the seeds of crops like soya, groundnuts, rapeseed (mustard), sesame, sunflower, safflower etc. Tree-Borne Oilseeds, commonly called TBO`s, are not considered as sources of edible oilseeds, except for oil palm and coconut, and hence do not occupy an important place in the highly commoditized edible oil markets. However, they do have the potential to play major roles in agri-business due to several alternative uses they have, the most important of which is as raw material for production of bio-diesel, an environment-friendly substitute for petro-diesel, which is by far the highest used liquid petroleum fuel in transport and industry sectors. Some of the more potential TBO species are pongamia, simarouba, mahua, neem, *jatropha,* sal etc.

Keywords: Potential TBO species, Pros and cons, Tree-borne oilseeds, Sources of oils

An important oilseed that may not technically fall under the TBO category, but is a highly potential one for bio-diesel is castor (which also has several applications) and India has the potential to significantly jack up its production. There are also other sources of oils like rice bran oil which is slowly gaining in popularity as an edible oil. Oils from algal and microbial sources have proved to have high potential at laboratory or pilot scales, but are yet proven on a commercial basis. There is significant research going on in some labs like CSIR-IICT to convert biomass into FFAs using chemical and biochemical processes. These could well contribute to future sources of oils in the coming decades. In this presentation, I hope to cover some of the prominent and potential TBO species in India, their characteristics, pros and cons, and what needs to be done to make TBO cultivation a mass movement (Table 1). It is also my intention to list out the advantages of TBO oils as raw materials for carbon-neutral bio-diesel and how the deoiled cakes can revolutionize Indian agriculture as bio-fertilizers by improving crop productivity through their judicious application.

Tree borne oil seed crops: Building energy security in rural India

Non-edible tree borne oilseed crops are known to be multipurpose trees in agriculture system. Adoption of multispecies consortia of non-edible oil seed trees in agroforestry systems supports productivity in food crops. The recent trend of using vegetable oil for biofuel production and using it locally in IC engines is of great relevance. The fact is that, these resources are recycled locally without detriment to the carbon sinks. Among the consortia of species, *Pongamia pinnata, Azadirachta indica, Simarouba glauca, Calophyllum inophyllum, Mesua ferrea, Aphanamyxis polystachya, Jatropha curcas* are found to be a good combination of trees in agro-forestry systems with wider adaptation to dry land to semi-wet crop fields. The consortia support the sustainable yield of food crops, improve soil fertility, and help in pest management in the crops. Besides, these species also provide for the production of energy from seed oil on par with petro-diesel. The involvement of community in harnessing this energy locally through biofuel value chain is the model developed. Participation of community in growing selected trees in agro-forestry system as a component and processing of seeds for oil extraction and using it locally for agriculture machineries as energy source, for production of electrical energy for local needs, use of by-products like oil cake as a source of manure, biogas production, and animal feed is interesting. A successful model developed and implemented in the state of Karnataka, India with participation of farming community organised on the lines of the Cooperative milk unions existing in the state is worth trying on a commercial scale.

The developmental work done in Karnataka by the State Bio-Energy Board (KSBDB) between 2010 and 2014 showed great promise. The model being proposed for large-scale growing and aggregating TBO seeds is rather simple. We need to identify potential districts/talukas for planting one or more of these TBO species and plant them on plantation and/or agro-forestry models with full

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involvement of local farmers. The TBO seeds are collected and after drying at farmers` premises are sold at taluk level enterprises which may comprise small de-huskers & oil expellers. The raw oil is further transported to a central place where it would be converted to bio-diesel through the process of trans-esterification. The bio-diesel, and the by-product glycerine will be sold to local farmers or residents at competitive prices. The husk & deoiled cake are sold to farmers as bio-fertilizers. TIFAC in 2018 did a forecast of the TBO Potential in India and their findings are summarised in Table 2.

Despite the large volume of work done on TBOs in India for the past 30 years, the concept of TBOs as raw materials for bio-diesel production has not gained significance. This is largely due to the following major factors:

- TBOs have been grown as agro-forestry crops without significant investments associated with plantation crops
- For the same reason, there is less human access to TBOs as compared to horticultural/plantation crops
- More work needs to be done in stable varietal development in TBO crops
- Because of the isolated growth of TBOs, mostly in forest areas, harvesting of seeds could be a challenge
- Most TBO crops have not been commoditized leading to uncertainties in their marketing and a lack of supply chain development
- Many of the TBO species have multiple commercial uses resulting in a lack of development of supply chains for bio-energy applications
- The yields start 5 to 7 years after planting and hence don`t look lucrative for the investors

Castor oil: It would be appropriate to mention a few words about castor oil as a potential raw material for bio-diesel. India is the world's single largest producer of castor seed accounting for more than 85% followed by China with about 7% and Brazil with about 5% of world castor seed output. There has been a consistent increase in output primarily on account of rise in levels in India. India has natural advantages with castor and has the potential to increase production further which can help in providing an assured supply of raw material to bio-diesel manufacturing units. Considerable work has been done by the DOD, ICAR, and some agri-varsities in the states of Telangana, Gujarat and Karnataka.

The yields in general are determined by the agroclimatic conditions and management practices. However, average yields of 250 to 500 kg/ha from rainfed crops, 100 to 200 kg/ha from mixed crops and 550 kg to 800 kg from irrigated crops are quite common.

Oils from Algal Biomass: No discourse on oils and fats from biomass can be considered complete without a mention of oils from algal biomass. In a global scenario where land mass for agriculture is rapidly shrinking due to various reasons, it is logical to use natural water bodies including seas for biomass production. Algae are organisms that grow in aquatic environments and use light and carbon dioxide (CO2) to create biomass. There are two classifications of algae: macroalgae and microalgae. Macroalgae, which are measured in inches, are the large, multi-cellular algae often seen growing in ponds. These larger algae can grow in a variety of ways. The largest multicellular algae are called seaweed; an example is the giant kelp plant, which can be more than 100 feet long. Microalgae, on the other hand, are measured in micrometers and are tiny, unicellular algae that normally grow in suspension within a body of water.

Microalgae have long been recognized as potentially good sources for biofuel production because of their relatively high oil content and rapid biomass production. Microalgae grow very quickly compared to terrestrial crops; the practice of algal mass culture can be performed on non-arable lands using non-potable saline water and wastewater. Thus, the use of microalgae as an alternative biodiesel biofuel feedstock is gaining increasing interest from researchers, entrepreneurs, and the general public.

Algal biomass contains three main components: Carbohydrates, proteins, and lipids/natural oils. Because the bulk of the natural oil made by microalgae is in the form of triglycerides (triacylglycerol) which is the right kind of oil for producing biodiesel, microalgae are the exclusive focus in the algae-to-biodiesel arena. In addition to biodiesel, microalgae can also be used to generate energy in several other ways. Some algal species can produce hydrogen gas under specialized growth conditions. Algal biomass is a versatile raw material for biofuels since the biomass from algae can also be burned similar to wood or anaerobically digested to produce methane biogas to generate heat and electricity. Algal biomass can also be treated by pyrolysis to generate crude bio-oil which can then be co-processed in petro-refineries. All these reduce carbon foot print of the bio-fuels.

The following tables give an idea about the potential of algal biomass *vis-à-vis* land-based oil production. The problem seems to be that the yields observed in lab-scale trials are hard to replicate at field/commercial levels. A major breakthrough is required in algal R&D to commercially utilise the full potential of algae as source of biofuel raw materials.

Table 1 Summary of characteristics of important TBO species in India

Crops	Pongamia	Jatropha	Neem	Mahua	Simarouba
Flowering Season	April-May	May-August	March-May	March-April	December-February
Harvesting	January-March	August-October	June-July	June-August	May-April
Uses	Biofuel, Manufacture of Soap, Leather, Tanning, Oil, Cake, Manure, Medicine, Bio-pesticide	Biofuel, Medicine, Bio-Pesticide.	Biofuel, Medicine, Bio-Pesticide. Oil Cake, Manure, Agricultural-Equipment.	Biofuel, Medicine, Oil Cake, Manure, Agricultural-Equipment.	Biofuel, Medicine, Edible Oil, Bio-Pesticide, Oil Cake, Manure,
Starts Yielding	5-6 Years	3 Years	5 Years	10 Years	5-6 Years
Seed-Yield (Kg per tree)	15-40	1-2	10-25	10-40	10-25
Seed Oil Content (%)	30-35	30-35	28-35	30-35	40-50
Cost (₹/kg)	16-30	12-15	10-20	10-20	10-20

Table 2 Forecast of the TBO Potential in India

TBOs	Seed yield (lakh tonnes)	Oil Content (%)	Oil yield potential (lakh tonnes)
Sal; *Shorea robusta*	62	12	7.44
Mahua; *Madhuca indica*	5.2	35	1.82
Neem; *Azadirachta indica*	5	20	1
Rubber; *Hevea brasiliensis*	0.79	45	0.35
Karanja / Pongamia; *Pongamia pinnata*	1.11	27	0.3
Kusum; *Schleichera oleosa*	0.45	33	0.15
Khakan; *Salvadora oleoides*	0.44	33	0.14
Undi; *Calophyllam inophyllum*	0.11	60	0.07
Dhupa; *Vateria indica*	0.13	19	0.02
Others-Maroti (*Hydnocarpus wightiana*), Palash (*Buteamono sperma*), Pisa (*Actinodaphne angustifolia*), Ratanjyot (*Jatropha curcas*), Tumba (*Citrullus colocynthis*), Teak (*Tectona randis*), Simarouba (*Simarouba glauca*)	2.2		
Total	77.54		12.2

Table 3 potential of algal biomass *vis-à-vis* land-based oil production

Oil content of microalgae		Oil yields based on crop type	
Microalga	Oil content (% dry weight	Crop	Oil yield (gallons/acre)
Botryococcus braunii	25-75	Corn	18
Chlorella sp.	28-32	Soybeans	48
Crypthecodinium cohnii	20	Canola	127
Cylindrotheca sp.	16-37	Jatropha	202
Nitzschia sp.	45-47	Coconut	287
Phaeodactylum tricornutum	20-30	Oil Palm	636
Schizochytrium sp.	50-77	Microalgae	6283-14641

Review

Exploring biotic constraints in the biodiesel plant, *Pongamia pinnata* (L.) Pierre cultivation: A comprehensive review

N MUKTA, S HARIHARAN[1], P DURAIMURUGAN[*], AND D NEETHU ROY[2]

ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, Telangana

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ABSTRACT

Pongamia pinnata, a vital non-edible oilseed tree, holds significant potential for various applications including biodiesel production and traditional medicine due to its high seed yield and resilience to harsh conditions. However, it faces substantial challenges from a multitude of pests and diseases throughout its lifecycle, impacting both seedlings and mature trees. Insects such as termites, white grubs, and caterpillars, as well as fungal pathogens like *Ganoderma lucidum* and *Colletotrichum gloeosporioides,* pose substantial threats to *P. pinnata* cultivation. Additionally, nematodes and pod rot fungi contribute to yield losses and storage issues. Despite these challenges, management strategies, including biological control and chemical pesticides, offer avenues for mitigating pest and disease incidence. Collaborative research and innovation are essential for developing sustainable solutions and enhancing the resilience of *P. pinnata* plantations. By addressing these challenges collectively, we can unlock the full potential of *P. pinnata,* supporting biodiversity conservation, ecosystem restoration, and rural livelihoods.

Keywords: Diseases, Insect pests, Nematodes, Pongamia pinnata

Pongamia pinnata, belonging to the family Fabaceae, is a significant non-edible oilseed tree found mainly in semi-arid regions with unique floral architecture. Bisexual, zygomorphic flowers have one large standard petal, two light-purple wing petals and two white keel petals. Anthers and stigma are enclosed but separated in the boat-shaped keel petals (Aronne *et al.,* 2012; Veereshkumar *et al.,* 2019 and Veereshkumar *et al.,* 2020). Its nomenclature can be confusing as it is known by various synonyms such as *Millettia pinnata, Pongamia glabra,* and *Derris indica.* Commonly known as *karanja, ki pahang laut, kacang kayu laut,* or pongam oil tree, it thrives in the Indian subcontinent and Southeast Asia (Akram *et al.,* 2021). With its potential for high seed yield and resilience to harsh conditions, it's cultivated for various purposes including biodiesel production. Each tree can yield 9-90 kg of seed pods, producing oil suitable for biodiesel. Seed propagation is the most commonly known method for producing new plants in large numbers inexpensively (Mukta and Sreevalli, 2010). Vegetative propagation including cuttings and grafting has additional benefits in *P. pinnata* in producing true to type plants with shorter juvenile period leading to early productivity (Raju and Rao, 2006). The oil extracted from Pongamia seeds primarily comprises triglycerides, with oleic acid (C18:1) as the major fatty acid component. The root extract of *P. pinnata* contains compounds with anticancer properties, and the oil from its seeds is used for treating various ailments such as ulcers, piles, leprosy, and liver disorders. The plant's leaves, stems, and roots have also been utilized in traditional medicine for treating a wide range of conditions, including asthma, skin disorders, and joint pain (Al Muqarrabun *et al.,* 2013). Despite historically being used for various purposes, its bitter taste and odor have limited its culinary use. However, advancements in processing techniques have made it possible to extract edible oil from Pongamia seeds, removing bitter compounds and making it suitable for human consumption. This purified oil offers a sustainable and nutritious alternative to traditional cooking oils. With its neutral odor and composition rich in mono-unsaturated fatty acids, it can be used in a variety of food applications, including cooking oil, vegan mayonnaise, plant-based butters, baked goods, and plant-based meats (Marone *et al.,* 2022). Extracts of *Pongamia pinnata* leaves and seeds are also used for pest management in many plant species. *P. pinnata* leaf and seed extracts and seed oil nanoemulsions show concentration-dependent larvicidal activity against 1st and 2nd instar larvae of cabbage webworm, Hellula undalis and 4th instar larvae of *Papilio demoleus,* a serious citrus butterfly pest (Tran *et al.,* 2022; Lingakari *et al.,* 2023). *Pongamia pinnata* is a multipurpose tree with high nutritional value, oil, and cake, making it an excellent fertilizer source for organic agriculture and traditional medicines (Usharani *et al.,* 2019). However, the tree itself attracts many pests and

[1]PG Student, Department of Entomology, College of Agriculture, Rajendranagar, PJTSAU, Hyderabad-500 030, Telangana; [2]Ph.D. Scholar, Department of Agricultural Entomology, UAS, Raichur-584 104, Karnataka; *Corresponding author's E-mail: p.duraimurugan@icar.gov.in

diseases giving it a ragged and tattered appearance. There are about 30 species of insect pests recorded to cause damage to Pongamia raised usually as avenue planting and strip plantations on marginal lands. They include gall inducers, leaf miners, foliage feeders, shoot borers, sap suckers, flower feeders and fruit seed borers. Of these, gall inducers and leaf miners, occupy a predominant position because of their destructive potential and ubiquitous occurrence. Among diseases, the occurrence of nursery diseases is widespread.

Key insect pests: *P. pinnata* attracts many pests at nursery as well as mature stages. The pests reported and their control measures are listed below.

Seedlings and trees: Insect pests affect seedlings and plantations in early and post growth sequences of forest production systems, saplings and sometimes mature trees. Various insect pests were observed in the field during April to September, with a lull during November to February. Termites (*Microtermes* spp., *Odontotermes* sp.), white grub (*Holotrichia consanguinea* and *H. serrata*), brown field cricket (*Brachytrupes portentosus* [*Tarbinskiellus portentosus*]), mealy bug (*Ferisia virgata*) and Bihar hairy caterpillar (*Spilosoma obliqua* [*Spilarctia obliqua*]) were the major nursery insect pests causing subterranean damage of 4-40 per cent of seedlings (Kumar, 1995; Chandramani Sahu *et al.,* 2016). *Aspongopus* [Coridius] *brunneus* (Thunderg) (Hemiptera: Pentatomidae) was recorded as a pest of *P. pinnata* at the Central Nursery, Katanga, Madhya Pradesh and has been found to cause 20-30 per cent damage to nursery seedlings in India. Both adults as well as nymphs suck the sap from the seedlings. Another Hemipteran, *Dysdercus cingulatus* (Fab.) (Hemiptera: Pyrrhocoridae) has been reported as a pest on plants and seedlings of *P. pinnata* at the same location causing 50-60 per cent damage to nursery seedlings (Meshram *et al.,* 1988, 1990). Brown Grasshopper *Diabolocatantops axillaris,* Katydid *Pterophylla camellifolia,* Short horned grasshopper *Oxya hyla* are minor pests in seedlings, while Long horned grasshopper *Ducetia japonica* is the major pest in the areas of Bhubaneswar, Odisha (Kumari *et al.,* 2020). The lepidopteran pest *Ascotis selenaria* imparata [Ascotis imparata] Walk. (Lepidoptera: Geometridae) has been reported as a minor pest causing defoliation in a plantation at Jabalpur, Madhya Pradesh. Foliar spraying of 0.25% of malathion 50 EC for effective control of this insect has been recommended (Kulkarni *et al.,* 1995).

Myllocerus viridanus (Fab.) (Coleoptera: Curculionidae) is a common defoliator of teak (*Tectona grandis*) in the forests of southern India. It is a potential pest with a distinct polyphagous nature. Regular surveys conducted in forest plantations in Tamil Nadu, Kerala and Karnataka recorded the pest as causing considerable defoliation to many plant species of forestry importance including P. pinnata (Ahmed, 1989). The adult weevils cause considerable damage by defoliating the foliage of plants. The larvae live in soil and feed exclusively on the rootlets. An epidemic outbreak has been reported of lac insect, *Kerria lacca* Kerr on *Santalum album* and its host trees (*P. pinnata* and *Casuarina equisetifolia*) at Gottipura and Nallal in the Hoskote range of Karnataka, during December-January, 1994-95 (Remadevi *et al.,* 1997). P. pinnata was severely attacked at Gottipura. The attacked plants are characterized by the black sooty appearance of the leaves, giving a total blackish colouration to the affected trees. The other symptoms of attack are the presence of dried leafless twigs at the growing crown and the absence of flowers and fruits. Spraying of 250 ml dimethoate 30EC in 250 litres of water as recommended in *Ziziphus mauritiana* (ber) can be tried as a control measure. Alternatively, spraying of 0.5% quinalphos 20 AF solution along with 0.05 % sticker may also be used for drenching the trees thoroughly with fine spray as is recommended for sandal trees. Burning of heavily attacked branches which are lopped out will kill all insects. Treated plants are to be watered on alternative days. Second treatment with 0.1% dimethoate or emulsions of 0.04 % fenvalerate or 0.04 % cypermethrin or 0.2% dimethoate may also be undertaken after 15 days for further prevention and spread of insects, once the plants have sprouted fully. Other insect pests, such as the teak defoliator/skeletonizer (*Hyblaea puera* and *Eutectona machaeralis*), sissoo defoliator (*Plecoptera reflexa*) and Karanj leaf miner (*Lithocolletis virgulata* [Cameraria virgulata]), have also been reported as potential pests causing damage to the saplings and mature trees (Kumar, 1995). Epidemic outbreaks of leaf miner, *Lithocolletis virgulata* [*Cameraria virgulata*] were recorded in Delhi, Hyderabad (Andhra Pradesh) and Jabalpur (Madhya Pradesh) during 1992.

Leaves: Some of the important pests reported from the International Council for Research in Agroforestry (ICRAF) are *Parnara mathias, Gracillaria* spp, *Indarbela quadrinotata, Myllocerus curvicornis,* and *Acrocercops* spp. attacks by these insects cause whitish streaks and the formation of galls on affected leaves. The incidence of galls caused by *Aceria pongamiae* on leaves of *P. glabra* [*P. pinnata*] in and around Delhi, India, was low in May-June on young trees and in April-May on old trees, but was higher in winter in both cases, when temperatures were relatively low. The numbers of eggs and mites were high in October-January and low in March-May (Rani and Naik, 2018). Leaf size had a significant positive correlation with

the number of galls, which was in turn influenced by the number of mites and ultimately the number of eggs within the gall. Maximum, minimum and mean temperatures had significant negative correlations, and relative humidity a significant positive correlation, with numbers of galls and mites (Joshi *et al.,* 1992). The leaf area of galls caused by *Eriophes cheriani* Massee in *P. pinnata* was 12.36 cm^2 compared to 20.91 cm^2 in healthy leaves. *P. pinnata* plants in Mangalore, Karnataka, India, are often infested by the pentatomid (*Cyclopelta siccifolia*). Leaf webber, *Glyphodes negatalis* neonates feed on the leaf and skeletonizes the leaves, while the older larvae folded and webbed the leaves and fed within. Red ant, *Oecophylla smaregdina* were observed infesting leaves of *P. pinnata* by making nests by joining on an average 4-5 leaves (Chandramani Sahu *et al.,* 2016). Pongamia leaf miner, *Lithocolletis virgulata,* mines the leaves and results in formation of white circular blotches on the leaves (Kumari *et al.,* 2020). Although the insects are active throughout the day, the foraging activity was rapid only during the cool hours of the day. As the food supply became exhausted, all the pentatomids metamorphosed into adults and stopped feeding. Only the nymphal stages were phytophagous, sucking leaf sap (Hosetti *et al.,* 1998). During rainy season, common banded awl, *Hasora chromus* was observed as a major defoliator as the larvae folds the leaves and feeds within it, particularly on young and tender leaves. Apart from these, Hairy caterpillar *Euproctis* sp, Indian sunbeam *Curetis thetis,* Common cerulean Jamides celeno, Karanj defoliator *Maruca ambionalis,* Leaf feeding beetle *Diabrotica* sp. are the common defoliators observed in karanj at Bhubaneswar, Odisha (Kumari *et al.,* 2020). Spiraling whitefly (*Aleurodicus dispersus*) infestation on *Pongamia glabra* [*P. pinnata*] has been reported around Coimbatore and Bangalore, during September-October 1996. The predator, *Chilocorus nigritus* was found feeding on leaves infested with spiraling whitefly. In the laboratory, larvae of *C. nigritus* were able to feed and complete their development exclusively on *A. dispersus* (Mani and Krishnamoorthy, 1999).

Stem: Bark borer (*Indarbela quadrinotata*), have also been reported as a potential pest causing damage to the saplings and mature trees (Kumar, 1995). The stem gall caused by an unidentified agromyzid has also been reported during March-April in Tamil Nadu (Joshi and Venugopal, 1985). Bagworm (*Pteroma plagiophleps*) infestation was recorded during the *rabi* season as attached to the stem and hanging from the leaves. Longicorn beetle *Leiopus nebulosus,* grubs and adults are seen feeding on Pongamia stems by boring holes on the stem. (Kumari *et al.,* 2020).

Seeds: The attack of fruit and seed borers begins when the pods/fruits or seeds are on the tree and the infestation continues when they are stored in godowns. Very low incidence of *Calandra linearis* (Herbst) (<1%) as a seed borer in *P. pinnata* has been reported. The bruchid *Caryedon serratus* (Olivier) and Pulse beetle *Callosobruchus* sp. (Coleoptera: Bruchidae) has also been reported on stored seeds of *P. pinnata* (Singal and Toky, 1989; Kumari *et al.,* 2020) Larvae of pod borer, *Ephestia* sp. recorded maximum pod damage in the provenance Nainpur, Raipur at green immature stage of pod (Chandramani Sahu *et al.,* 2016).

Flower: Blister beetle often aggregates in masses on flowers and leaves causing serious damage to crop. They feed on petals, anthers and pollen. The frequency and distribution of *Mylabris pustulata* activity is relatively high before August in Rajasthan. *M. pustulata* utilizes flower colour effectively in their host selection process. Flavonoid pigments are known to act as feeding stimulants/ determinants (Murugesan *et al.,* 1997). Controlling of adult beetles is very difficult because of their quick mobility. Mechanical control, hand picking or collecting in nets and destroying them is very effective in the evening times because of its aggregation behaviour. The damage of flower thrips, *Megalurothrips distalis* as a pest on plants of Pongamia glabra has also been reported.

Nematodes: During forest disease surveys conducted in nurseries in and around Dehra Dun, Uttar Pradesh, in 1990-91, root knot nematodes were identified causing galling and poor growth in 4 important tree species: *Acacia catechu, Albizia procera, Pongamia pinnata* and *Tectona grandis.* Three species of Meloidogyne were identified: *M. arenaria, M. javanica* and *M. incognita.* Different patterns of infection (between species, and incidence) were found at different nurseries (Mehrotra and Sharma, 1990).

Key fungal diseases

Seedlings and trees: Several fungi attack the seedlings and the trees of *P. pinnata. Ganoderma lucidum* causes root rot and *Fomes merilli* (Murrill) Sacc. and Trott attack the tender shoots and leaves and cause early defoliation in the seedlings and trees. During the five years period from 1989-1993, disease surveys were conducted in forest nurseries established under social forestry, farm forestry and agroforestry in western Uttar Pradesh and Haryana states to detect new disease outbreaks, quantify damage caused to the seedling crops and evolve suitable control measures of economically important diseases. *Pongamia pinnata* was one among the 23 species covered. Chemotherapy was

found to be helpful in controlling most of the serious diseases and minimizing the damage to the nursery stock (Mehrotra *et al.,* 1998). A dieback disease caused by *Haplosporella beaumontiana* in *P. pinnata* has been reported in the young plantations (1-5 years old) in the Jabalpur region of Madhya Pradesh, based on surveys made in 1991-93. The disease appeared after the early rain fall in late July and continued upto September and caused 11.3% damage (Verma *et al.,* 1997). Infected plants started dying from top downward, plants became partially to completely dried. After the rains, lateral shoots arise from the living stump.

Leaves: Leaf spot caused by *Trichotheceum* (Coniothecium) roseum (Per.) Link ex Fries during rainy season in Kerala was found to affect young as well as mature leaves (Harsh *et al.,* 1989). Teliospores of *Ravenelia hobsonii* (Uredinales) infecting leaves of *P. pinnata* have been reported (Nair, 1971). A severe leaf blight of *P. pinnata* incited by *Fusicladium pongamiae* appeared in the nursery beds in Madhya Pradesh during the month of August when there was sufficient moisture in the atmosphere. The disease progressed after subsequent rainfalls. The seedlings in moist and shady places were severely affected due to infection. Disease was less severe in exposed environments. The frequency of the disease was highest during the month of November and December. Mostly the younger leaves of the plants were found to be heavily infected. The few scattered lesions were also present in the leaves of middle age. The infection usually started from the margin of tips of the leaves. Occasionally scattered lesions on the lower surface of the lamina were also observed. There was formation of the larger areas due to coalescing of the two or more lesions. The pustules produced heavy conidiation on the lower surface of the leaves. The lesions appeared light brown to dark in colour due to large number of conidia of the fungus. The midrib and secondary veins were also severely attacked by pathogen. The upper surface of the leaves became chlorotic with yellowish to light brown colour. In severe cases curling of the leaves also may occur. Bavistin [carbendazim] at 0.1 % and 0.2 % completely checked the infection of *Fusicladium pongamiae.* Comparatively Benlate [benomyl] at 0.2 % exhibited significant decrease in the disease development (Jamaluddin *et al.,* 1981).

Colletotrichum gloeosporioides (Penz.) Sacc. [*Glomerella cingulata*] was identified as the cause of blight of 10 to 12-month-old seedlings (Bhat *et al.,* 1988). Foliar infection of 1 to 2-yr-old seedlings of *P. pinnata* was recorded in an experimental plot at Vazhachal (Chalakudy Forest Division) and Medicinal Plant Garden of Kerala Forest Research Institute during September-October 1983. The leaf blight was caused by *Asperisporium pongamiae* and the leaf spot by *Urohendersopnia pongamiae.* Both diseases are first reports for Kerala State. This was also reported as black leaf spot occurring during December to April in 1978-88 in Andhra Pradesh., caused by *Asperisporium pongamiae.* Symptoms are characterized by the production of black velvety spots of variable shape and size on the under surface of the leaves. The small spots gradually coalesced and form a bigger spot. Upper surface of the infected portion of the leaves become necrotic and grayish-brown. The disease is more damaging on older leaves resulting in defoliation. Leaf blight of *P. pinnata* caused by *Cladosporium tenuissimum* in June-September has been reported from many forest nurseries in Dharwad and Dandeli, Karnataka. This is a new record of the fungus on *P. pinnata* (Bhat *et al.,* 1989). A new species of hyphomycetes, *Pseudospiropes indica* was collected on *P. pinnata* in Uttar Pradesh during continuing surveys of *Foliicolous microfungi* in Indian forests (Rai and Rai, 1995).

Studies on forest diseases in Assam state have resulted in reports of 2 fungal pathogens recorded on *P. pinnata* in North East India. The incidence of *Ravenelia hobsonii* (rust) and *Phyllachora pongamiae* (tar spot) on *P. pinnata* leaves has been reported (Borah *et al.,* 1998; Nair, 1971). Host-pathogen interaction was studied for leaf spot causing cercosporaceous pathogen *Pseudocercospora pongamia*-pinnata on *Pongamia pinnata.* The disease was found in Andhra Pradesh. Observations of disease ratings made over 3 years (1989-92) are reported from the Nagarjuna University campus, showing the seasonal patterns of disease development. The leaf spot disease first appeared during 1990-91 but much early in August during 1991-92. Disease severity rapidly increased and the peak was recorded by the beginning of February. Plants appear without foliage by the end of February due to cumulative effect of natural defoliation and drooping off the severely infected leaves. The disease peaked in severity in January or February, just before natural defoliation, however, the start of the disease was more variable and had a duration of 3 months. As infection progressed, chlorophyll decreased, aminoacids and phenols increased while sugars showed no regular trend (Ram and Mallaiah, 1996).

Pods and seeds: Pod rot caused by a complex of *Dothiorella* sp., the Colletotrichum state of *Glomerella cingulata* and a *Phoma* sp. has been reported. It affects pods on the tree and in storage. Sprays of Dithane M-45 [mancozeb] and Difolatan [captafol] bring about effective control, neither treatment was phytotoxic or caused any changes in the oil content of the seeds (Dadwal and Soni, 1983). Because of the long delays in transfer and poor storage conditions,

there is a serious fungal infection of stored seeds by at least a dozen species - *Aspergillus* spp, *Penicillium* spp, *Chaetomium* spp, and *Dothiorella* spp predominating the year round.

Conclusion

In conclusion, the challenges posed by pests and diseases to *P. pinnata* underscore the importance of proactive management strategies to ensure the health and productivity of plantations. From the nursery stage to mature trees, *P. pinnata* faces a diverse array of adversaries, including insect pests, fungal pathogens, and nematodes, each capable of inflicting significant damage. However, through biological control agents, chemical pesticides and timely interventions, farmers can mitigate the impact of pests and diseases on *P. pinnata* cultivation. Furthermore, ongoing research and collaboration are essential for developing innovative solutions and adapting management practices to evolving pest and disease pressures. By harnessing scientific knowledge and leveraging traditional wisdom, we can enhance the resilience and sustainability of *P. pinnata* plantations, supporting biodiversity conservation, ecosystem restoration, and rural livelihoods. Ultimately, the journey of *P. pinnata* serves as a testament to the resilience of nature and the ingenuity of human endeavor. By working together to address the challenges posed by pests and diseases, we can unlock the full potential of this remarkable tree species and harness its myriad benefits for generations to come.

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Estimation of heterosis for yield and its contributing traits in *Brassica juncea* L.

AJAY PAL YADAV* AND M GAIBRIYAL LAL

Dept. of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj-211 007, Uttar Pradesh

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ABSTRACT

Brassica is an economically important genus consisting of oilseeds, vegetables, and forage crops. *Brassica juncea* L. is commonly known as Indian mustard. The current investigation was carried out with ten diverse parents, and 45 crosses in a half-diallel mating design. A total of 55 genotypes (45 F_1 + 10 parents) were investigated for 14 traits, yield, yield characters, and oil content during *rabi* 2021-22 and 2022-23. All crosses along with their parents were assessed in RBD with three replications. Analysis of variance for combining ability showed that significant variation was present among 45 crosses and their parents. The cross DRMRIJ-31× BRIJRAJ showed positive significant mid-parent heterosis (30.76%) and better parent heterosis (30.20%), while the cross DRMR150-35 × RH-406 showed positive significant economic heterosis over both the checks (44.68% and 35.25%) respectively. The best crosses for yield/plant NRCDR-02 x PUSABOLD, NRCDR-02 x RH-761, NRCDR-02 x JM-2 and NRCDR-02 x BRIJRAJ exhibited positive and significant heterosis. Hence, these identified hybrids could be used for exploitation of heterosis after evaluating and testing with large multilocations.

Keywords: *Brassica juncea,* Economic heterosis, F_1 hybrid, Half Diallel, Yield

Oilseeds hold a premier position in India's agricultural economy and are important next to food grains in terms of area and production. India is the fifth largest vegetable oils economy in the world next to USA, China, Brazil and Argentina, but contributes only 10 % of the world's oilseeds production (Gupta *et al.,* 2011). With the increase in world population, demand for high quality oilseeds continues to increase.

In India, rapeseed-mustard is the second most important oilseed crop, second to groundnut, contributing nearly 26 per cent of the total oilseed production (Jat et al., 2019). This crop is solely grown as a potential source of vegetable oil. Vegetable oils are one of the high value agricultural commodities. Rapeseed-mustard is the third most important oilseed crop in the world, occupying an area of 33.64 million hectares with a total production of 67.85 million tons. Canada is the leading country in terms of area and production of rapeseed-mustard (ICAR-DRMR, Bharatpur, Rajasthan, 2019). The demand for edible oils is increasing very rapidly with the increasing population and has been estimated to be 28.40 million tonnes for the year 2030 and 41.6 million tonnes for the year 2050 (Chauhan *et al.,* 2021) Rapeseed-mustard is categorized into two subgroups based on the nature of the pollination mode *viz.,* self-pollinated ones that includeIndian mustard (accounts for about 75-80% of the area beneath rapeseed-mustard), yellow and raya sarson and cross pollinated ones namely brown sarson, taramira and toria. Among self-pollinated types, *Brassica juncea* (2n=4x=36, AABB), an amphidiploid derived from two different Brassica species having low chromosome number, i.e. Brassica nigra (2n = 2x=16, BB) and *Brassica rapa* (2n=2x=20, AA) are the important ones (Chand *et al.,* 2021). *Brassica juncea* is a prevailing self-pollinated crop with some frequent cross-pollination of 4 to 16.6% , depending on the environmental circumstances and the pollinating vector, especially the population of pollinator insects (Vaghela *et al.,* 2011).

In the current scenario of changing agro-climatic circumstances, where underground water is scarce and a rising terminal temperature, plant breeders face two challenges regarding the production of oilseeds: initially, the yield potential should be further increased within conventional mustard cultivation areas, and secondly, short-duration and drought-tolerant oilseed varieties ought to be developed for sustaining production (Raza *et al.,* 2019; Chaurasiya *et al.,* 2022; Bajya *et al.,* 2023).

The yield peak in oilseed productivity might be broken by identifying a suitable high-yielding hybrid showing high economic heterosis. Consequently, it is essential to assess a large number of available genotypes. The degree of heterosis is used to select suitable parents for creating superior F1 hybrids and further allowing the use of hybrid vigour or the development of an improved gene pool in the following generations, thereby exploiting heterosis (Ahmed *et al.,* 2021). The principal objective of this study was therefore to screen superior cross combination(s) by estimating heterobeltiosis (better parent heterosis) and standard heterosis (economic heterosis) in F_1 crosses of Indian mustard (*Brassica juncea*).

Corresponding author's E-mail: shineajay007@gmail.com

MATERIALS AND METHODS

The experiment was carried out at the Field Experiment Centre of the Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, Uttar Prsdesh. The 10 parents (DRMR IJ-31, DRMR 150-35, DRMR 1165-40, NRCDR-02, PUSA BOLD, RH-749, 7 RH-761, JM-2, BRIJRAJ, RH-406) (Table 1) were selected based on their *per se* performance and crossing was done as per half diallel mating design given by Jinks and Hayman (1954) to generate 45 F_1 hybrids during *rabi* 2021-22. The crosses, along with their parents and checks, were planted in randomized complete block design in three replications during *rabi* 2022-23. Each genotype was grown with a spacing of 45 x 10 cm row to row and plant to plant, respectively. Standard agronomic practices were followed to raise a good crop. Observations were recorded on 14 quantitative traits, *viz.,* days to 50% flowering, days to maturity, plant height (cm), primary branches/plant, secondary branches/plant, siliqua length (cm), siliquae/ plant, main shoot length (cm), harvest index (%), biological yield, seeds/siliqua, 1000-seed weight (g), seed yield/plant (g) and oil content (%).

Heterosis is expressed as per cent increase or decrease of F_1 over the mid-parent (MP), better parent (BP), and standard check (SC), referred to as relative heterosis, heterobeltosis and standard/economic heterosis, respectively. Heterosis, heterobeltiosis and economic heterosis were calculated according to the method suggested by Shull (1908); Fonseca and Patterson (1968); Meredith and Bridge (1972), respectively, for all the traits recorded.

$$\text{Heterosis} = \frac{F1-MP}{MP} \times 100$$

$$\text{Heterobelitiosis} = \frac{F1-BP}{BP} \times 100$$

$$\text{Economic heterosis} = \frac{F1-SC}{SC} \times 100$$

Where, F_1= Mean performance of the F_1 hybrid; MP= Mean value of the parents (P_1 and P_2); BP= Mean value of better parent and SC= mean value of standard check

RESULTS AND DISCUSSION

The analysis of variance (Table 2) for the experimental design revealed significant differences among all genotypes, parents and hybrids for all the characters studied. Thus, it could be seen that abundant variability was present among genotypes, parents as well as their F_1s for almost all the characters, providing an opportunity for improvement through appropriate breeding approaches.

In heterosis breeding, the main objective is to attain a quantum improvement in the performance of certain characters over and above the average performance of otherwise straight-bred parents. Heterosis has been gradually applied in crop improvement and breeding programmes for nearly a century, with the goal of developing higher-yielding, more vigorous and better-performing cross combinations (Fu *et al.,* 2014). The magnitude of mid-parent heterosis, heterobeltiosis and standard heterosis is discussed herefor different yield, yield attributing and quality traits. One of the most important breeding objectives for Indian mustard is to breed early maturing, high seed yield, and high oil content varieties. The lower values (-ve) of days to flowering and the higher values (+ve) of high seed yield and oil content are desirable (Kumar *et al*., 2022).

In the present study, the heterosis for primary branches/plant ranged from -20.91 to 30.76% and -25.27 to 30.2% mid-parent and better parent, respectively, while for economic heterosis ranged from 0.3 to 44.68% and -6.24 to 35.25% over both the checks. The cross DRMRIJ-31× BRIJRAJ showed positive significant mid-parent heterosis (30.76%) and better parent (30.20%), while the cross DRMR150-35 × RH-406 showed positive significant economic heterosis over both the checks (44.68% and 35.25%) respectively (Table 3). The heterosis for secondary branches/plant ranged from -38.1 to 39.51% and -40.44 to 24.52% mid-parent and better parent respectively, while for economic heterosis ranged from -7.13 to 76.57% and 3.65 to 97.07% over both the checks. The cross DRMRIJ-31 × PUSABOLD showed positive significant heterosis over mid parent (39.51%) and DRMR150-35 × BRIJRAJ over better parent (24.52%), while the cross DRMR1165-40 × BRIJRAJ showed positive significant economic heterosis over both the checks (76.57% and 97.07%) respectively (Table 3). The heterosis for main raceme length ranged from -31.21 to 15.88% and -31.84 to 15.35% mid-parent and better parent, respectively, while the economic heterosis ranged from -0.64 to 55.84% and 26.46 to 15.35% over both the checks. The cross DRMRIJ-31 × DRMR150-35 showed positive significant heterosis over mid parent (15.88%) and over better parent (15.35%), while the cross DRMRIJ-31 × DRMR150-35 showed positive significant economic heterosis over both the checks (55.84% and 15.35%) respectively (Table 3). Similar results were reported by Katiyar *et al.* (2000), Kumar *et al.,* 2021 and Kumar *et al.,* 2022.

The heterosis for siliqua on the main raceme ranged from -15.79 to 21.44% and -19.13 to 14.28% over mid parent and better parent respectively, while economic heterosis ranged from -7.67 to 32.58% and -13.78 to 23.80% over both the checks. The cross DRMR150-35 x RH-761 exhibited positive significant heterosis over mid parent (21.44%) and DRMR1165-40 x JM-2 over better parent (14.28%), while the cross DRMR150-35 x RH-761 exhibited positive significant economic heterosis over both the checks (32.58% and 23.80%) respectively (Table 3). The heterosis for siliquae/plant ranged from -19.29 to 57.30% and -27.18 to 54.40% mid parent and better parent respectively, while economic heterosis ranged from -15.95 to 58.12% and -14.25 to 61.31% over both the checks. The cross DRMRIJ-31 x BRIJRAJ exhibited a positive significant heterosis over mid parent (57.30%) and better parent (54.40%), while the cross NRCDR-02 x PUSABOLD exhibited positive significant economic heterosis over both the checks (58.12% and 61.31%) respectively. The heterosis for siliqua length ranged from -6.77 to 40.23% and -9.55 to 25.74% over the mid parent and better parent respectively, while economic heterosis ranged from -15.16 to 24.32% and -7.18 to 36.01% over both the checks. The cross PUSABOLD × RH-406 showed positive significant heterosis mid parent (40.23%) and NRCDR-02 × BRIJRAJ for better parent (30.20%), while the cross PUSABOLD × RH-406 showed positive significant economic heterosis both the checks (24.32% and 36.01%) respectively. Similar results were reported by Gami and Chauhan (2013), Singh *et al.* (2015) and Kumar *et al.* (2022).

The heterosis for seed/ siliqua ranged from -10.72 to 29.94% and -20.30 to 26.07% over mid parent and better parent respectively, while for economic heterosis it ranged from -15.85 to 10.39% and -13.83 to 13.03% over both the checks. The cross DRMR150-35 x PUSABOLD showed positive significant heterosis over mid parent (29.94%) and better parent (26.07%), while the cross DRMRIJ-31 x RH-749 showed positive significant economic heterosis over both the checks (10.39% and 13.03%) respectively (Table 4), Similar results were reported by Divya *et al.* (2023). The heterosis for seed yield/plant ranged from -16.08 to 59.37% and -23.01 to 51.65% over mid parent and better parent respectively, while economic heterosis ranged from -27.22 to 29.23% and -20.4 to 41.34% over both the checks. The cross DRMR150-35 x BRIJRAJ showed positive significant heterosis over mid parent (59.37%) and better parent (51.65%), while the cross NRCDR-02 x RH-761showed positive significant economic heterosis over both the checks (29.23% and 41.34%) respectively (Table 4). The heterosis for oil content ranged from -5.48 to 6.71% and -5.85 to 5.53% over mid parent and better parent respectively, while economic heterosis ranged from -2.48 to 6.05% and -5.59 to 2.67% over both the checks. The cross RH-749 x JM-02 showed positive significant heterosis over mid parent (6.71%) and better parent (5.53%), while the cross RH-749 x JM-02 showed positive significant economic heterosis over both the checks (6.05% and 2.67%) respectively (Table 4). Similar results have been reported by Gami and Chauhan (2013); Kumar *et al.* (2021) and Srivastava *et al.* (2023).

Table 1 List of 10 parents and genotypes along with origin/source and pedigree

Name of genotype	Origin/Source	Pedigree
DRMR IJ-31	ICAR- DRMR, Bharatpur, Rajasthan	HB-9908 X HB-9916
DRMR 150-35	ICAR- DRMR, Bharatpur, Rajasthan	RH 819 x Pusa Bold
DRMR 1165-40	ICAR- DRMR, Bharatpur, Rajasthan	EC552583 x BPR897-4-3
NRCDR-02	ICAR- DRMR, Bharatpur, Rajasthan	MDOC-43 x NBPGR-36
PUSA BOLD	IARI, New Delhi	Varuna x BIC 1780
RH-749	CCS HAU, Hisar, Haryana	RH-781 X RH-7617
RH-761	CCS HAU, Hisar, Haryana	JMR 9738 x RH 30
JM-2	ZARS, JNKVV, Morena, Madhya Pradesh	Varuna x L-4
BRIJRAJ	ICAR- DRMR, Bharatpur, Rajasthan	NRCHB 101 X Pusa Swarnim
RH-406	CCS HAU, Hisar, Haryana	RH-6908 x RH-8812

Table 2 Analysis of variance (ANOVA) for experimental design for yield and yield attributing traits in Indian mustard

Source of variance	Mean sum of squares									
	d.f.	PBPP	SBPP	MRL	SMR	SPP	SL	SPS	SYPP	OC
Replicates	2	1.76	0.96	47.67	16.16	838.49	0.23	6.39	3.44	0.14
Treatments	54	0.63*	9.72**	109.67**	32.54**	7545.40**	0.75**	3.98**	23.01**	2.76**
Parents	9	0.527	17.90**	182.09**	25.60**	9013.34**	0.69**	4.99**	22.82**	3.73**
Hybrids	44	0.66**	8.15**	97.33**	34.64**	7367.64**	0.78**	3.83**	23.48**	2.63**
Parent Vs.Hybrids	1	0.042	5.11	0.41	3.00	2155.185*	0.12	2.28	3.90	0.13
Error	108	0.37	3.08	27.68	7.05	315.33	0.16	1.25	2.15	0.76
Total	164	0.47	5.24	54.92	15.55	2702.34	0.35	2.22	9.03	1.41

PBPP: Primary branches per plant, SBPP: Secondary branches per plant, MRL: Main raceme length, SMR: Siliqua on main raceme, SPP: Siliqua per plant, SL: Siliqua length, SPS: Seeds per siliqua, SYPP: Seed yield per plant, OC: Oil content

Table 3 Estimates of relative heterosis (Ha), heterobeltiosis (Hb) and economic hetetrosis (Hc) for yield and yield attributing traits

Traits	Primary branches per plant				Secondary branches per plant				Main raceme length			
HYBRID	Mid	Better	SH1	SH2	Mid	Better	SH1	SH2	Mid	Better	SH1	SH2
DRMRIJ-31XDRMR150-35	-9.80	-13.11	0.30	-6.24	-3.35	-9.47	-7.13	3.65	15.88**	15.35**	55.84**	15.35**
DRMRIJ-31XDRMR1165-40	-5.29	-12.81	10.87	3.65	-14.90	-31.24**	0.01	11.63	7.09	4.09	48.98**	10.27
DRMRIJ-31XNRCDR-02	-9.38	-16.94	6.65	-0.30	-12.95	-30.04**	3.23	15.22	3.18	-2.66	31.51**	-2.66
DRMRIJ-31XPUSABOLD	2.25	-6.65	20.92	13.03	39.51**	15.41	57.98**	76.33**	-0.80	-4.43	39.31**	3.12
DRMRIJ-31XRH-749	-8.60	-17.10*	8.94	1.84	-21.19	-36.53**	-6.89	3.93	3.45	2.32	38.24**	2.32
DRMRIJ-31XRH-761	3.08	-4.41	19.65	11.85	29.99*	8.70	44.83**	61.65**	7.16	6.97	44.52**	6.97
DRMRIJ-31XJM-2	-9.28	-16.13	5.68	-1.21	-22.85*	-40.26**	-2.44	8.89	-9.15	-10.40	24.49**	-7.86
DRMRIJ-31XBRIJRAJ	30.76**	30.20**	39.27**	30.20**	32.63**	11.91	45.83**	62.76**	-6.38	-8.62	29.67**	-4.02
DRMRIJ-31XRH-406	-6.84	-18.23*	15.77	8.23	-14.12	-32.96**	7.02	19.45	-1.93	-3.01	31.04**	-3.01
DRMR150-35XDRMR-1165-40	3.22	-1.55	25.20*	17.04	25.63*	7.12	55.80**	73.89**	-8.43	-11.39*	26.83**	-6.13
DRMR150-35XNRCDR-02	5.39	0.06	28.48*	20.11	21.32*	2.82	51.73**	69.35**	0.38	-4.89	27.32**	-5.76
DRMR150-35XPUSABOLD	0.31	-5.15	22.85*	14.85	23.25*	7.80	47.56**	64.70**	-3.01	-6.97	35.61**	0.37
DRMR150-35XRH-749	10.29	3.58	36.12**	27.25*	32.12**	12.26	64.68**	83.80**	4.04	3.37	38.39**	2.43
DRMR150-35XRH-761	7.07	2.90	28.80*	20.41	32.85**	17.56	56.64**	74.83**	10.71*	10.40	48.62**	10.00
DRMR150-35XJM-2	11.43	6.75	34.51**	25.74*	24.21*	1.12	65.13**	84.31**	4.54	2.63	42.60**	5.55
DRMR150-35XBRIJRAJ	5.44	1.17	16.77	9.16	39.34**	24.52*	62.25**	81.09**	5.47	2.49	45.43**	7.64
DRMR150-35XRH-406	12.59	2.19	44.68**	35.25**	28.99**	5.94	69.12**	88.76**	-1.66	-2.30	30.80**	-3.19
DRMR1165-40XNRCDR-02	-13.12	-13.54	11.01	3.77	-17.79	-18.37	20.45	34.44*	11.47*	2.39	46.54**	8.47
DRMR1165-40XPUSABOLD	5.58	4.61	35.50**	26.67*	-1.35	-4.26	39.26*	55.43**	-31.21**	-31.84**	-0.64	-26.46**
DRMR1165-40XRH-749	-4.06	-5.61	24.04*	15.95	-16.88	-17.23	21.42	35.52*	-16.34**	-19.55**	15.15	-14.77*
DRMR1165-40XRH-761	6.44	5.61	34.29**	25.54*	-0.54	-4.71	38.60*	54.69**	8.54	5.31	50.73**	11.56*
DRMR1165-40XJM-2	-2.82	-3.26	23.01*	15.00	-2.50	-7.83	50.52**	68.00**	-14.22**	-15.48**	20.97**	-10.46
DRMR1165-40XBRIJRAJ	12.12	2.82	30.74**	22.22*	28.06**	21.39*	76.57**	97.07**	3.56	3.11	47.59**	9.24
DRMR1165-40XRH-406	-9.50	-14.11	21.62	13.69	-10.65	-14.62	36.30*	52.13**	-12.69**	-16.04**	20.17**	-11.05
NRCDR-02XPUSABOLD	-4.26	-4.68	23.47*	15.43	23.75*	19.27	76.00**	96.44**	0.67	-8.29	33.68**	-1.06
NRCDR-02XRH-749	-4.46	-5.55	24.12*	16.03	-5.92	-6.20	38.42*	54.49**	12.56*	7.31	41.80**	4.96
NRCDR-02XRH-761	-5.61	-6.79	19.68	11.88	-0.58	-5.40	39.59*	55.80**	11.03*	4.93	41.25**	4.55
NRCDR-02XJM-2	-5.32	-6.21	20.43	12.58	-35.95**	-39.04**	-0.44	11.12	-8.13	-14.46*	18.85*	-12.03*
NRCDR-02XBRIJRAJ	7.58	-1.78	26.11*	17.89	-3.67	-9.30	33.83*	49.38**	9.19	0.69	42.88**	5.75
NRCDR-02XRH-406	-5.92	-10.30	27.00*	18.72	-38.10**	-40.44**	-4.93	6.11	-3.40	-7.91	21.68**	-9.93
PUSABOLDXRH-749	4.79	4.04	36.72**	27.81**	10.80	7.09	57.10**	75.34**	-9.30	-13.53*	26.04**	-6.71
PUSABOLDXRH-761	-4.78	-6.38	21.27	13.36	-0.40	-1.72	34.52*	50.15**	-3.29	-6.99	35.58**	0.35
PUSABOLDXJM-2	1.95	0.56	30.26**	21.77*	-8.16	-15.59	37.85*	53.86**	-10.17*	-12.27*	27.88**	-5.35
PUSABOLDXBRIJRAJ	1.44	-7.75	19.49	11.70	-5.59	-7.86	26.12	40.77*	-18.47**	-19.55**	17.27*	-13.20*
PUSABOLDXRH-406	-9.49	-13.35	22.69*	14.70	-2.26	-9.22	44.92**	61.74**	-11.96*	-16.07**	22.33**	-9.45
RH-749XRH-761	-10.64	-12.76	14.64	7.17	13.40	8.20	58.73**	77.16**	-20.12**	-20.85**	6.55	-21.13**
RH-749XJM-02	0.35	-1.72	29.15*	20.73	3.62	-1.65	60.62**	79.27**	7.02	4.41	45.06**	7.37
RH-749XBRIJRAJ	4.76	-5.35	24.39*	16.28	-4.67	-10.00	32.03*	47.36**	-9.18	-12.30*	24.44**	-7.89
RH-749XRH-406	-5.21	-8.61	29.39*	20.96	2.67	-1.50	57.25**	75.51**	-1.64	-1.65	29.97**	-3.80
RH-761XJM-2	10.92	10.55	39.30**	30.22**	-18.99*	-26.45**	20.12	34.07	-5.38	-6.85	29.42**	-4.20
RH-761XBRIJRAJ	5.54	-2.52	22.02	14.07	-19.04	-19.94	6.68	19.07	-2.72	-5.22	34.49**	-0.45
RH-761XRH-406	-12.51	-17.59*	16.69	9.08	-16.07	-23.01*	22.91	37.18*	-0.12	-1.05	33.21**	-1.40
JM-02XBRIJRAJ	-0.34	-8.22	15.64	8.10	-20.21*	-28.27**	17.14	30.74	-16.73**	-17.60**	16.92*	-13.46*
JM-02XRH-406	-20.91**	-25.27**	5.81	-1.08	-32.65**	-33.41**	8.75	21.38	-0.90	-3.32	34.32**	-0.58
BRIJRAJXRH-406	-3.39	-15.51	19.62	11.83	-4.44	-13.22	38.54*	54.63**	3.23	-0.32	41.44**	4.69
S.E.Diff.	0.408	0.471	0.471	0.471	1.086	1.254	1.254	1.254	3.527	4.073	4.073	4.073
CD 95%	0.802	0.926	0.926	0.926	2.137	2.468	2.468	2.468	6.939	8.013	8.013	8.013

Table 3 Estimates of relative heterosis (Ha), heterobeltiosis (Hb) and economic hetetrosis (Hc) for yield and yield attributing traits (contd..)

Traits	Siliqua on main raceme				Siliqua per plant				Siliqua length			
HYBRID	Mid	Better	SH1	SH2	Mid	Better	SH1	SH2	Mid	Better	SH1	SH2
DRMRIJ-31XDRMR150-35	6.89	2.27	9.52	2.27	-1.15	-5.74	-7.61	-5.74	8.88	6.97	-2.22	6.97
DRMRIJ-31XDRMR1165-40	9.98	9.60	18.20**	10.37	5.02	4.65	3.31	5.39	23.23**	15.47**	5.55	15.47**
DRMRIJ-31XNRCDR-02	9.19	8.05	18.18**	10.35	0.63	-1.84	1.18	3.23	4.47	3.38	-5.50	3.38
DRMRIJ-31XPUSABOLD	-10.62*	-10.96	-4.65	-10.96	51.13**	45.09**	54.56**	57.68**	10.17*	4.51	6.48	16.49**
DRMRIJ-31XRH-749	3.48	2.27	12.14	4.71	-6.49	-21.65**	13.64*	15.94*	6.06	1.42	1.61	11.15
DRMRIJ-31XRH-761	2.59	-3.12	16.75**	9.01	51.37**	49.88**	49.87**	52.89**	10.13*	8.73	1.99	11.57*
DRMRIJ-31XJM-2	-6.98	-8.18	0.92	-5.76	22.43**	19.78**	22.72**	25.19**	3.87	-1.73	-10.17	-1.73
DRMRIJ-31XBRIJRAJ	2.10	-2.55	14.82*	7.22	57.30**	54.40**	57.14**	60.31**	3.89	0.41	-1.63	7.61
DRMRIJ-31XRH-406	-2.64	-7.44	9.97	2.69	-1.12	-1.39	-2.80	-0.84	20.15**	9.65	0.23	9.65
DRMR150-35XDRMR-1165-40	14.58**	9.26	17.84**	10.03	53.02**	45.42**	43.55**	46.45**	19.72**	14.07*	0.62	10.08
DRMR150-35XNRCDR-02	17.17**	10.98	21.39**	13.35*	25.76**	17.12**	20.73**	23.17**	18.78**	17.92**	5.54	15.46**
DRMR150-35XPUSABOLD	-3.26	-7.09	-1.28	-7.82	0.18	-8.10	-2.11	-0.13	-2.00	-8.57	-6.85	1.90
DRMR150-35XRH-749	15.44**	9.22	19.76**	11.83*	28.83**	3.91	50.71**	53.75**	3.97	-2.24	-2.06	7.14
DRMR150-35XRH-761	21.44**	10.02	32.58**	23.80**	47.38**	39.22**	39.20**	42.01**	-6.77	-9.55	-15.16**	-7.18
DRMR150-35XJM-2	16.85**	10.43	21.37**	13.33*	28.62**	20.13**	23.07**	25.55**	21.60**	17.02**	3.22	12.92*
DRMR150-35XBRIJRAJ	15.45**	5.65	24.49**	16.24**	50.45**	40.95**	43.45**	46.34**	17.64**	11.78*	9.51	19.80**
DRMR150-35XRH-406	-11.30*	-19.13**	-3.92	-10.29	51.68**	44.25**	42.19**	45.06**	20.25**	11.54	-1.61	7.64
DRMR1165-40XNRCDR-02	-0.09	-0.79	8.51	1.33	-11.85*	-13.72*	-11.06	-9.27	4.66	-0.96	-11.36*	-3.03
DRMR1165-40XPUSABOLD	5.52	4.74	12.96*	5.48	-12.79*	-15.99**	-10.50	-8.70	20.86**	7.82	9.85	20.17**
DRMR1165-40XRH-749	3.75	2.90	12.82*	5.35	-9.31*	-23.79**	10.53	12.76	5.20	-5.45	-5.28	3.62
DRMR1165-40XRH-761	5.43	-0.11	20.37**	12.40*	5.85	5.17	5.16	7.28	4.66	-3.10	-9.10	-0.56
DRMR1165-40XJM-2	15.37**	14.28*	25.61**	17.29**	-12.35*	-13.95*	-11.84	-10.06	10.87	9.74	-10.50*	-2.09
DRMR1165-40XBRIJRAJ	3.76	-0.64	17.08**	9.33	51.91**	49.63**	52.28**	55.36**	27.85**	16.06**	13.70**	24.38**
DRMR1165-40XRH-406	11.30*	6.17	26.14**	17.78**	-3.81	-3.88	-5.11	-3.20	21.21**	17.82**	-5.87	2.98
NRCDR-02XPUSABOLD	-0.70	-2.11	7.07	-0.03	50.87**	48.43**	58.12**	61.31**	14.94**	7.95	9.99	20.32**
NRCDR-02XRH-749	5.97	5.85	16.05*	8.37	26.65**	8.33	57.12**	60.29**	18.24**	11.94*	12.14*	22.68**
NRCDR-02XRH-761	-8.31	-12.55*	5.39	-1.59	51.34**	49.07**	53.67**	56.77**	18.75**	16.03**	8.83	19.06**
NRCDR-02XJM-2	-15.79**	-15.99**	-7.67	-13.78*	47.96**	47.51**	52.05**	55.12**	14.38**	9.31	-2.17	7.02
NRCDR-02XBRIJRAJ	-2.00	-5.51	11.33	3.96	13.24*	12.53*	15.99*	18.33**	31.42**	25.74**	23.18**	34.76**
NRCDR-02XRH-406	-9.61*	-13.20*	3.13	-3.70	-7.21	-9.24	-6.44	-4.55	19.70**	10.30	-1.29	7.99
PUSABOLDXRH-749	7.93	6.26	16.51*	8.80	-16.03**	-27.18**	5.62	7.75	16.12**	15.15**	17.33**	28.35**
PUSABOLDXRH-761	-6.06	-11.62*	6.51	-0.55	2.69	-0.46	6.04	8.18	11.80*	7.36	9.39	19.66**
PUSABOLDXJM-2	-2.12	-3.75	5.79	-1.21	21.24**	18.92**	26.68**	29.24**	28.74**	15.90**	18.09**	29.18**
PUSABOLDXBRIJRAJ	-14.61**	-18.80**	-4.32	-10.66	-19.29**	-21.09**	-15.95*	-14.25*	3.53	1.54	3.46	13.18*
PUSABOLDXRH-406	-3.82	-8.90	8.23	1.07	6.96	2.97	9.69	11.90	40.23**	22.02**	24.32**	36.01**
RH-749XRH-761	2.67	-1.96	18.15**	10.32	-7.36	-21.75**	13.50*	15.79*	10.16*	6.65	6.85	16.89**
RH-749XJM-02	13.01*	12.87*	24.06**	15.84**	-2.45	-16.77**	20.71**	23.15**	21.97**	10.63*	10.83*	21.25**
RH-749XBRIJRAJ	-1.17	-4.60	12.41	4.96	20.77**	2.75	49.04**	52.04**	8.64	7.44	7.63	17.75**
RH-749XRH-406	-2.08	-5.86	11.85	4.44	20.19**	0.94	46.41**	49.36**	15.04**	0.83	1.02	10.51
RH-761XJM-2	5.63	0.99	21.70**	13.64*	19.36**	17.92**	20.81**	23.25**	16.75**	9.13	2.36	11.98*
RH-761XBRIJRAJ	0.59	-0.52	19.88**	11.94*	-11.68*	-12.46	-10.90	-9.11	6.30	4.04	1.92	11.50*
RH-761XRH-406	-1.51	-2.21	17.85**	10.05	8.98	8.21	8.20	10.39	23.35**	11.27*	4.37	14.18*
JM-02XBRIJRAJ	3.38	-0.09	17.72**	9.93	-8.75	-9.05	-6.82	-4.94	7.08	-1.89	-3.88	5.15
JM-02XRH-406	-1.17	-4.87	13.02*	5.54	-7.65	-9.40	-7.18	-5.30	25.24**	20.54**	-1.69	7.55
BRIJRAJXRH-406	-2.85	-3.25	14.95*	7.33	10.21	8.48	10.40	12.63	5.77	-6.39	-8.30	0.32
S.E.Diff.	2.044	2.36	2.36	2.36	11.779	13.601	13.601	13.601	0.204	0.236	0.236	0.236
CD 95%	4.021	4.643	4.643	4.643	23.173	26.757	26.757	26.757	0.402	0.464	0.464	0.464

From the present study, it can be concluded that most of the hybrids showed significant heterosis for yield and yield contributing traits over the mid parent, better parent, and standard checks. The traits primary branches/plant, secondary branches/plant, main raceme length, siliqua on main raceme, silique/plant, siliqua length, seeds/ siliqua, seed yield/plant and oil content should be prioritized in selection programmes in order to develop high yielding hybrids. The crosses NRCDR-02 x PUSABOLD, NRCDR-02 x RH-761, NRCDR-02 x JM-2 and NRCDR-02 x BRIJRAJ exhibited positive significant economic heterosis for seed yield/plant.

Table 4 Estimates of relative heterosis (Ha), heterobeltiosis (Hb) and economic hetetrosis (Hc) for yield and yield attributing traits

Traits	Seeds/siliqua				Seed yield/plant				Oil content			
HYBRID	Mid	Better	Mid	Mid	Mid	Mid	SH1	SH2	Mid	Better	SH1	SH2
DRMRIJ-31XDRMR150-35	3.04	-5.12	-1.79	-1.79	-1.79	-1.79	-24.48**	-17.41*	-1.79	-2.77	0.43	-2.77
DRMRIJ-31XDRMR1165-40	-1.51	-5.21	-0.56	-0.56	-0.56	-0.56	-17.35*	-9.60	-0.56	-0.70	2.85	-0.42
DRMRIJ-31XNRCDR-02	8.21	7.10	-2.08	-2.08	-2.08	-2.08	-10.05	-1.62	-2.08	-2.33	0.88	-2.33
DRMRIJ-31XPUSABOLD	5.81	0.26	-2.01	-2.01	-2.01	-2.01	10.81	21.19*	-2.01	-2.16	1.06	-2.16
DRMRIJ-31XRH-749	9.13	5.48	-0.45	-0.45	-0.45	-0.45	17.96*	29.02**	-0.45	-1.79	1.44	-1.79
DRMRIJ-31XRH-761	8.45	8.37	3.51**	3.51**	3.51**	3.51**	18.33*	29.42**	3.51**	1.22	4.55**	1.22
DRMRIJ-31XJM-2	-1.65	-4.68	1.32	1.32	1.32	1.32	8.66	18.84*	1.32	-1.14	2.11	-1.14
DRMRIJ-31XBRIJRAJ	8.28	4.55	-2.50	-2.50	-2.50	-2.50	22.30**	33.76**	-2.50	-4.86**	-1.73	-4.86**
DRMRIJ-31XRH-406	-0.30	-1.91	0.32	0.32	0.32	0.32	-15.51*	-7.59	0.32	-1.37	1.87	-1.37
DRMR150-35XDRMR-1165-40	-10.38	-20.30**	-3.01*	-3.01*	-3.01*	-3.01*	-1.72	7.49	-3.01*	-4.11**	-0.68	-3.84**
DRMR150-35XNRCDR-02	18.57**	8.17	-2.73*	-2.73*	-2.73*	-2.73*	-8.71	-0.15	-2.73*	-3.45*	-0.78	-3.94**
DRMR150-35XPUSABOLD	29.94**	26.07**	-1.41	-1.41	-1.41	-1.41	-17.40*	-9.66	-1.41	-2.24	0.67	-2.53
DRMR150-35XRH-749	8.70	-2.96	2.51	2.51	2.51	2.51	5.32	15.18	2.51	2.13	3.40*	0.10
DRMR150-35XRH-761	17.17*	7.97	-1.62	-1.62	-1.62	-1.62	21.19**	32.55**	-1.62	-2.85	-1.65	-4.78**
DRMR150-35XJM-2	12.29	0.49	1.29	1.29	1.29	1.29	-2.18	6.99	1.29	-0.19	1.05	-2.17
DRMR150-35XBRIJRAJ	17.57*	11.92	-0.80	-0.80	-0.80	-0.80	27.01**	38.91**	-0.80	-2.25	-1.04	-4.19**
DRMR150-35XRH-406	9.37	-0.78	-0.35	-0.35	-0.35	-0.35	19.51*	30.71**	-0.35	-1.06	0.17	-3.02*
DRMR1165-40XNRCDR-02	6.77	3.79	-5.48**	-5.48**	-5.48**	-5.48**	-19.77**	-12.25	-5.48**	-5.85**	-2.48	-5.59**
DRMR1165-40XPUSABOLD	-2.67	-11.05	-1.61	-1.61	-1.61	-1.61	-27.22**	-20.40*	-1.61	-1.90	1.62	-1.62
DRMR1165-40XRH-749	1.95	1.50	-2.84*	-2.84*	-2.84*	-2.84*	-18.26*	-10.60	-2.84*	-4.29**	-0.86	-4.02**
DRMR1165-40XRH-761	-1.31	-5.09	-1.64	-1.64	-1.64	-1.64	1.24	10.73	-1.64	-3.96**	-0.52	-3.68*
DRMR1165-40XJM-2	-10.72	-11.35	-0.97	-0.97	-0.97	-0.97	-23.47**	-16.30*	-0.97	-3.51*	-0.05	-3.23*
DRMR1165-40XBRIJRAJ	6.80	-0.61	-1.11	-1.11	-1.11	-1.11	22.38**	33.84**	-1.11	-3.64*	-0.19	-3.37*
DRMR1165-40XRH-406	-8.73	-10.75	-0.45	-0.45	-0.45	-0.45	-12.18	-3.95	-0.45	-2.27	1.23	-1.99
NRCDR-02XPUSABOLD	12.58*	5.64	-1.47	-1.47	-1.47	-1.47	27.59**	39.54**	-1.47	-1.57	1.36	-1.86
NRCDR-02XRH-749	-0.29	-2.66	-1.80	-1.80	-1.80	-1.80	20.74**	32.05**	-1.80	-2.89	-0.20	-3.38*
NRCDR-02XRH-761	7.10	5.93	-0.94	-0.94	-0.94	-0.94	29.23**	41.34**	-0.94	-2.90*	-0.21	-3.39*
NRCDR-02XJM-2	4.54	2.34	-1.23	-1.23	-1.23	-1.23	29.19**	41.30**	-1.23	-3.39*	-0.72	-3.88**
NRCDR-02XBRIJRAJ	12.80*	7.85	-1.32	-1.32	-1.32	-1.32	26.14**	37.96**	-1.32	-3.47*	-0.80	-3.96**
NRCDR-02XRH-406	-1.13	-1.73	-0.13	-0.13	-0.13	-0.13	-17.08*	-9.31	-0.13	-1.57	1.16	-2.07
PUSABOLDXRH-749	4.92	-3.72	3.86**	3.86**	3.86**	3.86**	-0.95	8.33	3.86**	2.61	5.67**	2.30
PUSABOLDXRH-761	-3.01	-8.03	2.18	2.18	2.18	2.18	-17.63*	-9.91	2.18	0.06	3.04*	-0.24
PUSABOLDXJM-2	8.79	0.07	4.62**	4.62**	4.62**	4.62**	14.29	24.99**	4.62**	2.23	5.28**	1.92
PUSABOLDXBRIJRAJ	8.19	6.09	3.90**	3.90**	3.90**	3.90**	-15.61*	-7.71	3.90**	1.53	4.56**	1.23
PUSABOLDXRH-406	-7.87	-14.04*	1.15	1.15	1.15	1.15	-9.22	-0.71	1.15	-0.41	2.56	-0.71
RH-749XRH-761	-5.07	-8.31	1.72	1.72	1.72	1.72	15.52*	26.34**	1.72	0.82	1.32	-1.91
RH-749XJM-02	0.26	-0.01	6.71**	6.71**	6.71**	6.71**	14.81	25.56**	6.71**	5.53**	6.05**	2.67
RH-749XBRIJRAJ	4.98	-1.90	0.59	0.59	0.59	0.59	21.21**	32.57**	0.59	-0.52	-0.02	-3.21*
RH-749XRH-406	1.85	0.03	2.10	2.10	2.10	2.10	24.89**	36.60**	2.10	1.74	2.25	-1.01
RH-761XJM-2	-9.46	-12.32	3.38*	3.38*	3.38*	3.38*	2.35	11.94	3.38*	3.15*	1.82	-1.42
RH-761XBRIJRAJ	16.86**	12.92	0.31	0.31	0.31	0.31	-10.62	-2.24	0.31	0.09	-1.20	-4.35**
RH-761XRH-406	7.78	5.96	-1.62	-1.62	-1.62	-1.62	12.13	22.64**	-1.62	-2.16	-2.36	-5.47**
JM-02XBRIJRAJ	2.39	-4.08	3.92**	3.92**	3.92**	3.92**	-22.10**	-14.80	3.92**	3.91*	2.13	-1.12
JM-02XRH-406	-3.81	-5.27	-0.24	-0.24	-0.24	-0.24	-20.64**	-13.21	-0.24	-1.01	-1.20	-4.35**
BRIJRAJXRH-406	5.85	0.61	4.33**	4.33**	4.33**	4.33**	-15.06*	-7.10	4.33**	3.53*	3.33*	0.04
S.E.Diff.	0.771	0.891	0.489	0.489	0.489	0.489	1.133	1.133	0.489	0.565	0.565	0.565
CD 95%	1.518	1.752	0.962	0.962	0.962	0.962	2.23	2.23	0.962	1.111	1.111	1.111

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Performance of hydrogel and salicylic acid on productivity and economics of yellow sarson (*Brassica rapa*) in new alluvial zone

DHIMAN MUKHERJEE

Regional Research Station, Bidhan Chandra Krishi Viswavidayalaya, Jhargram-721 507, West Bengal

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ABSTRACT

A field experiment was conducted under new alluvial zone to evaluate the performance of hydrogel and salicylic acid for increasing the productivity of Indian mustard in restricted irrigation condition. The experiment consisting of ten treatment combinations, *viz.,* hydrogel @ 2.5 kg/ha, hydrogel @ 5 kg/ha, salicylic acid (SA) @ 100 ppm at flowering and siliqua formation, SA @ 200 ppm at flowering and siliqua formation, two irrigations at pre-flowering and siliqua development stage, hydrogel @ 2.5 kg/ha + SA @ 100 ppm at flowering and siliqua formation, hydrogel @ 2.5 kg/ha + SA @ 200 ppm at flowering and siliqua formation, hydrogel@ 5 kg/ha + SA @100 ppm at flowering and siliqua formation, hydrogel @ 5 kg/ha + SA @ 200 ppm at flowering and siliqua formation and control, was laid out in randomized block design with three replications. Among treatment combinations, application of hydrogel @ 5 kg/ha with two sprays of salicylic acid either 100 or 200 ppm at flowering and siliqua formation stage significantly increased various yield-attributing parameter. More seed yield obtained with two irrigation at pre-flowering and siliqua formation (1838 kg/ha) stage and showed parity with hydrogel @ 5.0 kg/ha + salicylic acid @100 ppm (1794 kg/ha) and hydrogel @2.5 kg/ha + salicylic acid @ 200 ppm (1719 kg/ha) and statistically superior to all other treatments. These treatments registered 128.6, 123.5and 113.2%, respectively, more grain yield over the control plot. Increased stover production was observed with hydrogel @2.5 kg/ha + salicylic acid @ 200 ppm and was closely followed by hydrogel @5.0 kg/ha + salicylic acid @ 200 ppm and hydrogel @2.5 kg/ha + salicylic acid @100 ppm. Furthermore, significant and highest improvement in growth, yield attributes, and economics was recorded under irrigation treatment applied at pre-flowering and siliqua formation stage over control and alone application of hydrogel and SA. Thus, the result showed that application of hydrogel either 2.5 or 5 kg/ha with two sprays of SA 100 ppm at flowering and siliqua formation was found beneficial for obtaining high seed yield as well as net returns. Application of hydrogel @ 2.5 kg/ha + salicylic acid 100 ppm at flowering stage and siliqua formation stage with maximum average benefit: cost ratio (2.66) may be recommended for mitigation of moisture stress in rainfed situations for obtaining higher crop yield in new alluvial region.

Keywords: *Brassica rapa,* Hydrogel, Oilseed, Salicylic acid, Stresses, Yield

Rapeseed mustard is an important oilseed crop grown in rabi season in the country, and contributes 23.33% share in terms of total acreage and 26.24% share in production among all oilseed crops grown in the country. In India, area, production and productivity of rapeseed-mustard is 6.31 million hectares, 9.29 million tonnes and 1203 kg/ha, respectively during 2022-23, leading to the total mustard production at 115.25 lakh tonnes (economictimes. indiatimes.com). Indian mustard is one of the most important winter-season oilseed crops which is grown in residual soil moisture conditions (Gandhimathy, 2022). The crop suffers moisture stress at various stages of growth, particularly at the flowering stage and the siliquae formation stage, which are most sensitive to moisture stress. Food security becomes a threat and challenge under such situation (Mukherjee, 2015; Chandrashekhar, 2023). Low soil moisture during the crop growth period due to frequent dry spells at different phases of crop growth results in drastic reduction in the crop yield of Indian mustard thereby resulting in lowered productivity. Also, India is the largest importer of edible oil ($10.5 billion) followed by China and the USA which share nearly 15% of world vegetable imports. Indian mustard is a predominant oilseed crop and covers nearly 80% of total rapeseed mustard growing area and contribute nearly 31.3% of domestic edible oilseed production (Rathore *et al.,* 2019). There is a significant gap between global productivity (20.47 q/ha) and India's productivity (13.24 q/ha) and it can be attributed to the crop's susceptibility to various abiotic and biotic stresses especially moisture stress (Mukherjee, 2020). The water requirement of Indian mustard is low (nearly 25-35 cm) but its cultivation is mainly affected due to untimely rainfall, shortage of moisture during the sowing window, and dependency on conserved soil moisture of previous *kharif* crop. Moreover, effective management options can enhance

Corresponding author's E-mail: dhiman_mukherjee@yahoo.co.in

yield to a great extent (Singh *et al.,* 2021; Chaurasiya *et al.,* 2022). In the recent past, the agricultural sector has begun to suffer a global water scarcity challenge due to the untimely shifting of weather patterns, which affect the mustard yield as heavy and scanty application both lower the yield. More than 42% of net cultivated area comes under dry land and 30 to 36 % area face insufficient rainfall. So, there is a need to have some technology that can preserve soil moisture without compromising crop yield and protect the crop from stress.

Hydrogel, popularly known as "root watering crystal," "water retention granules," or "raindrop," is a quasi-solid phase amorphous material. It has three-dimensional networks of loosely held cross-linked versatile hydrophilic macromolecules interconnected by covalent bonds or physical interactions with specially designed absorbency and biodegradability. The application of hydrogel as a soil conditioner can improve the hydro-physical, physicochemical, and biological environments of the soil; increase the soil water retention and release capacity; improve irrigation, water, and nutrient use efficiencies; enhance the yield and quality of agricultural produce; and sustain the environmental quality. This hydrogel technology may become a practically convenient and radical technology in water-stressed areas in terms of increased yield (cereals, vegetables, oilseeds, flowers, spices, plantation, etc.) and in alleviating soil moisture stress (Patra *et al.,* 2022). These are synthetic polymers that are biodegradable and can easily be degraded in high UV radiation. Further, application of salicylic acid (SA) for mitigation of moisture stress post flowering stage have been observed to be beneficial in solving the problem of moisture stress through changes in proline accumulation, and ethylene formation under drought stress. A number of studies have reported that SA is an important signaling molecule in the immune response of plants to biotic and abiotic stress (Song *et al.,* 2023). SA as a potent signaling molecule involved in defense mechanisms by regulating physiological and biochemical functions and has diverse effects on tolerance to biotic and abiotic stress factors (Yazdanpanah *et al.,* 2011). Exogenous SA application enhanced the growth and photosynthetic rate under water stress, and increases photosynthetic activity and stomatal conductance under drought stress (Habibi, 2012). In addition, it has been found that plants treated with SA generally exhibited better resistance to drought stress. The inhibition of ethylene synthesis under drought stress by SA may result in increasing plant response to ethylene and influencing proline metabolism and photosynthesis (Nazar *et al.,* 2015). By considering the effect of hydrogel and salicylic acid in plant under water stress condition, it was hypothesized that combined use of hydrogel and salicylic acid enhances plant development because hydrogel reduces water stress by increasing water efficiency, and SA minimizes the effect of environmental stress on productivity. Keeping this aspect, present study was planned to study the effect of hydrogel and salicylic acid at variable concentrations either alone or in combination with different doses on the Indian mustard productivity, and farm income under rainfed agro-ecosystems of West Bengal.

MATERIALS AND METHODS

A field experiment was carried out during the *rabi* season under new alluvial zone at Seed farm in Bidhan Chandra Krishi Viswavidyalay, Kalyani, West Bengal. for three consecutive years from 2018. The soil was sandy loam in texture, high in organic carbon (0.42%), available N (241.62 kg/ha), P_2O_5 (17.63 kg/ha) and K_2O (274.34 kg/ha) content with pH 7.3. The total rainfall recorded during crop growth period was 13.5, 14.2 and 11.9 mm, minimum temperature ranged from 11.9 to 17.8, 10.8 to 17.3, and 10.4 to 18.3 and maximum temperature from 18.7 to 36.3, 21.8 to 37.5 and 19.4 to 35.10°C during winter 2018-19, 2019-20 and 2020-21, respectively. Treatments comprised of different hydrogel application rates in soil and foliar spray of salicylic acid either alone or their combination. A total of ten treatment combinations, *viz.,* hydrogel @ 2.5 kg/ha, hydrogel @5 kg/ha, salicylic acid (SA) @ 100 ppm at flowering and siliqua formation, SA @ 200 ppm at flowering and siliqua formation, two irrigations at pre-flowering and siliqua development stage, hydrogel @ 2.5 kg/ha + SA @ 100 ppm at flowering and siliqua formation, hydrogel @ 2.5 kg/ha + SA @ 200 ppm at flowering and siliqua formation, hydrogel @ 5 kg/ha + SA @100 ppm at flowering and siliqua formation, hydrogel @ 5 kg/ha + SA @ 200 ppm at flowering and siliqua formation, and control (without any treatment), was laid out in randomized block design with three replications. Hydrogel developed by the Indian Agricultural Research Institute, New Delhi, was used in the study, and crystal form mixed well in the phosphate fertilizer was drilled in planting furrows / root zone at the time of sowing. All the inter-cultivation operations were kept uniform throughout the entire plot and the life cycle of the crop.

The recommended dose of fertilizer 60:40:40 kg N, P_2O_5 and K_2O/ha, respectively were applied in the form of urea, single superphosphate and muriate of potash. Yellow Sarsoo cultivar 'Pitambari' was sown in the first fortnight of October during the study years. The seed rate was 5 kg/ha at 40 x 15 cm spacing. Full amount of phosphorus and potash and half amount of nitrogen were applied at the time of sowing, while the remaining dose of nitrogen was top dressed at the pre-flowering stage. A thinning operation was done at 15- 20 DAS to maintain plant population.

For preparing an aqueous solution of salicylic acid, small amount of ethanol was used to dissolve SA and then required volume of water was added. The solution was foliar sprayed as per treatment at flowering and siliqua formation stage with the help of a knapsack sprayer fitted with holocone nozzle with a spray volume of 500 liters/ha. The five randomly selected plants from each plot were uprooted and later cleaned and observation like plant height and leaf area at peak growth stage i.e. 60 days after sowing (DAS) were recorded and averaged. The yield attributes were recorded at harvest to assess the contribution to yield. The branches of five randomly selected plants were counted and reported as number of branches/plant. Similarly, the total siliqua of five sample plants were counted and expressed as number of siliqua/plant. The 1000 seed weight were counted from the lot, weighed and expressed as 1000 seed weight. The seed and stover yield was computed from the harvest of net plot and expressed in tonnes/ha. Plant and soil sample were analyzed for uptake of nitrogen, phosphorus and potash as per standard laboratory procedures (Jackson, 1973). Available phosphorous was determined by Olsen's method as outlined by Jackson (1973), using spectrophotometer (660 nm wave length). Available potassium was extracted with neutral normal ammonium acetate and the content of K in the solution was estimated by flame photometer (Jackson, 1973). Oil per cent in the mustard seed was determined by Soxhlet apparatus using petroleum ether (60-80ºC) as an extractant (A.O.A.C., 1960). Oil yield (kg/ha) was calculated by multiplying seed yield and oil content in the seeds. Moreover, seed samples from all branches were collected and analysed for the nitrogen content in seeds. The crude protein yield (kg/ha) was calculated by multiplying seed yield with protein content in seeds. The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance of overall difference among treatments by the F test and conclusions were drawn at 5 % probability level. The effect of treatments was evaluated on pooled analysis basis on growth, yield attributes, and yields. The cost of cultivation (/ha) was calculated considering the prevailing charges of agricultural operations and market price of inputs involved. Gross returns were obtained by converting the harvest into monetary terms at the prevailing market rate during the course of studies. Benefit: cost ratio (B: C) was obtained by dividing the gross income with the cost of cultivation.

RESULTS AND DISCUSSION

It was observed that the different treatments affected the yield contributing characters significantly (Table 1). The data of agronomic traits showed a significant difference among treatment variables during the investigation. More plant height was observed with hydrogel @ 5.0 kg/ha + salicylic acid @100 ppm and it was statistically at par with hydrogel @5.0 kg/ha + salicylic acid @ 200 ppm, hydrogel @2.5 kg/ha + salicylic acid @ 200 ppm and hydrogel @2.5 kg/ha + salicylic acid @100 ppm. This may be ascribed that soil application of hydrogel improved the soil moisture availability and foliar spray of SA mitigated the drought stress and induced more auxin production which improves the cell elongation and cell development of plant even in unfavourable climatic conditions (Meena, 2020). Lowest height was observed with control and was closely followed by hydrogel @2.5 kg/ha. Application of hydrogel and salicylic acid and their combination had a significant effect on dry matter accumulation and LAI over control. The highest dry matter accumulation was seen with hydrogel @5.0 kg/ha + salicylic acid @ 200 ppm and was significantly better compared to all other treatments. More LAI was registered with hydrogel @5.0 kg/ha + salicylic acid @100 ppm and was at par with hydrogel @5.0 kg/ha and hydrogel @2.5 kg/ha + salicylic acid @100 ppm. Branches/plant were more when two irrigations at per-flowering and siliqua stage and was at par with hydrogel @5.0 kg/ha + salicylic acid @100 ppm, hydrogel @2.5 kg/ha + salicylic acid @ 200 ppm and salicylic acid @100 ppm treatments and significantly better than other treatments. Siliqua/plant was observed to be more with two irrigations at pre-flowering and siliqua stage and was at par only with hydrogel @5.0 kg/ha + salicylic acid @100 ppm and significantly better to other treatments. Hence, application of hydrogel @ 5 kg/ha + foliar spray of SA at flowering and siliqua formation showed similar trend in growth and yield attributes as that of two irrigations at pre-flowering and siliqua formation. Further, observation revealed that, hydrogel have the capacity to retain water 300-400 times of its weight and its gradual release helps to maintain soil moisture till the maturity which provided enough time for siliqua formation and seed filling under less frequent irrigation (Shim *et al.*, 2008). Thousand seed weight improved with the spray of salicylic acid @ 200 ppm and showed parity with hydrogel @5.0 kg/ha + salicylic acid @100 ppm and showed parity with two irrigations at pre-flowering and siliqua stage and significantly better to other treatments. Significantly higher yield attributes might be had been observed with the creation of congenial environment in soil due to application of hydrogel especially with respect to the improved soil-moisture conditions and thereby increased the uptake of nutrients by crop. This might be because hydrogel improved the soil-moisture conditions in addition to reducing the leaching losses of nutrients. When the superabsorbent hydrogel polymers are

incorporated in moist soil, it becomes swollen after absorbing and storing a large quantity of water and nutrients within a short period. It allows the absorbed water and nutrients within it to be slowly released to the soil, mitigating the water and nutrient requirements of the plant especially when the drought stress condition around the root zone periphery prevailed. The peculiar water-nutrient reservoir and lending characteristics of the hydrogel polymers for the soil-plant system, directly influence various yield attributing characters and seed weight, which ultimately improve the test weight of mustard crop (Li *et al.,* 2013).

Table 1 Effect of treatments on growth and yield attributing parameters of mustard (Pooled data of three years)

Treatments	Plant height at 60 DAS (cm)	Drymatter/plant at 60 DAS (g)	LAI at 60 DAS	Branches/plant (No.) at 60 DAS	Siliqua/plant (No.)	Seed/Siliqua (No.)	1000 seed weight (g)
Hydrogel @ 2.5 kg/ha	54.92	41.25	0.39	7.87	138.19	11.82	4.02
Hydrogel @ 5.0 kg/ha	63.25	43.26	0.37	9.73	149.78	12.99	3.87
Salicylic acid @ 100 ppm	59.48	46.21	0.36	9.97	171.54	13.66	4.55
Salicylic acid @ 200 ppm	66.44	44.36	0.34	8.91	170.33	12.21	3.89
Two irrigations (per-flowering and siliqua formation)	65.32	52.36	0.36	10.66	181.23	12.35	4.41
Hydrogel @2.5 kg/ha + Salicylic acid @100 ppm	69.47	49.36	0.39	9.66	163.07	14.36	4.18
Hydrogel @2.5 kg/ha + Salicylic acid @ 200 ppm	68.63	54.22	0.33	10.41	171.33	13.94	3.69
Hydrogel @5.0 kg/ha + Salicylic acid @100 ppm	71.36	58.36	0.40	10.19	176.56	14.11	4.43
Hydrogel @5.0 kg/ha + Salicylic acid @ 200 ppm	70.33	64.65	0.34	9.91	172.44	13.35	4.11
Control	46.73	32.21	0.31	7.03	127.42	9.45	3.41
CD (p=0.05)	4.31	4.65	0.02	0.79	7.65	2.31	0.23

Application of hydrogel with SA marked a significant difference in yield of mustard over the treatment without SA (Table 2). Yellow sarsoo showed more seed yield with the application of two irrigation at pre-flowering and siliqua formation (1838 kg/ha) and showed parity with hydrogel @5.0 kg/ha + salicylic acid @100 ppm (1794 kg/ha) and hydrogel @2.5 kg/ha + salicylic acid @ 200 ppm (1719 kg/ha) and statistically superior to all other treatments. These treatments registered 128.6, 123.5and 113.2 %, respectively, more grain yield over the control plot. A similar trend was observed in the stover yield during both years and the combined application of hydrogel (5 kg/ha) with SA (100 ppm) at the flowering and siliqua formation stage gave the highest stover yield which was statistically superior over the other treatments. The increase in yield might be due to better amendment of soil with hydrogel which modifies the cation exchange capacity of soil and delays the fertilizer dissolution and thus improves the nutrient absorption capacity, subsequently more translocation of nutrient-cum-photosynthates in the sink and finally leading to increased yield (Rathore *et al.,* 2019). Furthermore, SA showed a synergetic effect when sprayed two times and promoted flowering in combination with the other natural plant hormone. Spray of SA reduced stress and oxygen radical formation that might result in better growth even in unfavourable climatic conditions (Tirani *et al.,* 2013). Stover production improved with the application of hydrogel @2.5 kg/ha + salicylic acid @ 200 ppm and was closely followed by hydrogel @5.0 kg/ha + salicylic acid @ 200 ppm and hydrogel @2.5 kg/ha + salicylic acid @100 ppm, and statistically superior to all other treatments. This registered 174.08, 171.1 and 162.23 %, more production over the control respectively. Further, table 2 reveals that, more harvest index was observed with hydrogel @5.0 kg/ha, and was statistically superior to all other treatments.

The quality parameter *viz.,* oil content (%) in seed, oil yield (kg/ha), protein content (%) in seed and protein yield (kg/ha) were significantly increased with application of different rates of hydrogel and salicylic acid either alone or in combination. The oil content in seeds increased significantly from 37.21% in control upto 41.43 % in various treatments. Thus, addition of different rates of hydrogel and salicylic acid might have activated the enzymes responsible for producing oil and caused higher oil content (Nazar *et al.,* 2015). Among various treatments, two irrigations at different stages, recorded maximum and significantly higher oil yield (761 kg/ha) and showed parity with hydrogel @5.0 kg/ha + salicylic acid @100 ppm (741 kg/ha), hydrogel @5.0 kg/ha + salicylic acid @ 200 ppm

699 kg/ha) and hydrogel @2.5 kg/ha + salicylic acid @ 200 ppm (704 kg/ha) (Fig. 1). Oil yield is a function of oil content and seed yield and both the parameters increased with different levels of hydrogel and salicylic acid. Thus, resulted in a significant increase in oil yield. Increasing levels of hydrogel and salicylic acid significantly increased the protein content in mustard seed from 19.62 to 21.37 percent with full recommended practice for rainfed mustard under new alluvial zone. The increase in protein content owing to different treatments might be attributed to their involvement in the nitrogen metabolism (Mukherjee, 2010). This result might be due to the fact that with the increased dose of hydrogel or number of irrigation water turgidity of the cell, cell division and meristematic activity might have been enhanced ultimately leading to higher nutrient uptake. This directly increased the oil content of the Brassica species, thus oil content increased with the increasing frequency of irrigation. This finding is in agreement with the observations made by Rathore *et al.* (2019). Corresponding application of hydrogel either alone or in combination with salicylic acid also increased the protein yield from 152 to 392 kg/ha (Fig.2). Significantly higher protein yield was observed with two irrigation (pre-flowering and siliqua formation) and it showed parity with all the treatments except control, hydrogel @2.5 kg/ha and salicylic acid @100 ppm. Since variation in protein content has genetic and bio-chemical limitation, the protein yield is more influenced by seed yield and thus followed almost the same trend as seed yield. Similar results have been reported by Singh *et al.* (2009) and Chandan *et al.* (2018).

Table 2 Effect of treatments on yield and economics of mustard (Pooled data of three years)

Treatments	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	Oil content (%)	Protein content (%)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Hydrogel @2.5 kg/ha	1315	2962	30.75	38.69	19.62	54842	30256	2.23
Hydrogel @5.0 kg/ha	1684	3325	33.62	40.83	20.51	67416	41058	2.56
Salicylic acid @100 ppm	1454	3165	31.48	39.87	20.08	59133	35475	2.49
Salicylic acid @ 200 ppm	1563	3715	29.61	40.23	20.25	62026	37874	2.57
Two irrigation (pre-flowering and siliqua formation)	1838	3875	31.90	41.43	21.48	79130	48983	2.62
Hydrogel @2.5 kg/ha + Salicylic acid @100 ppm	1674	3957	29.73	40.73	20.48	65969	40515	2.59
Hydrogel @2.5 kg/ha + Salicylic acid @ 200 ppm	1719	4136	28.38	41.01	21.08	68450	41938	2.58
Hydrogel @5.0 kg/ha + Salicylic acid @100 ppm	1794	3789	32.13	41.36	21.37	76390	47685	2.66
Hydrogel @5.0 kg/ha + Salicylic acid @ 200 ppm	1708	4098	29.42	40.97	20.88	73902	44584	2.52
Control	804	1509	31.81	37.21	18.79	38195	17841	1.87
CD (p=0.05)	126	268	0.67	0.37	0.49			

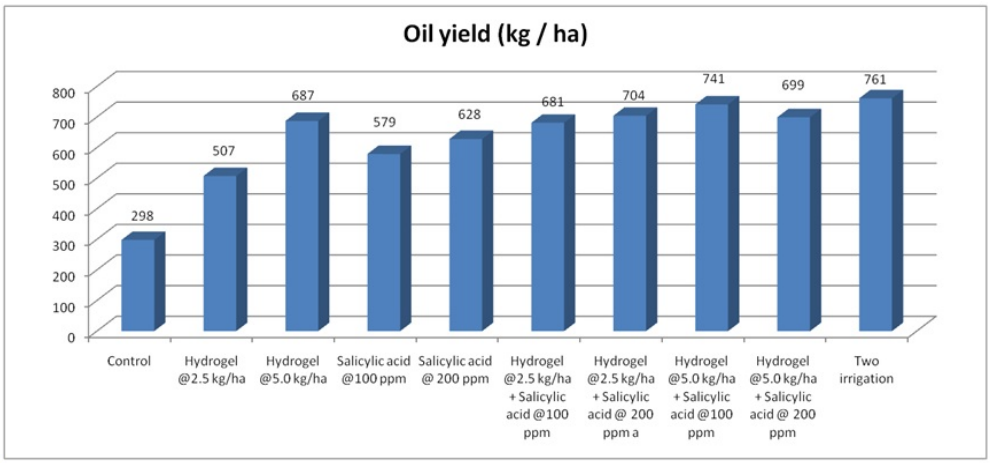

Fig. 1. Oil yield obtained with different treatments

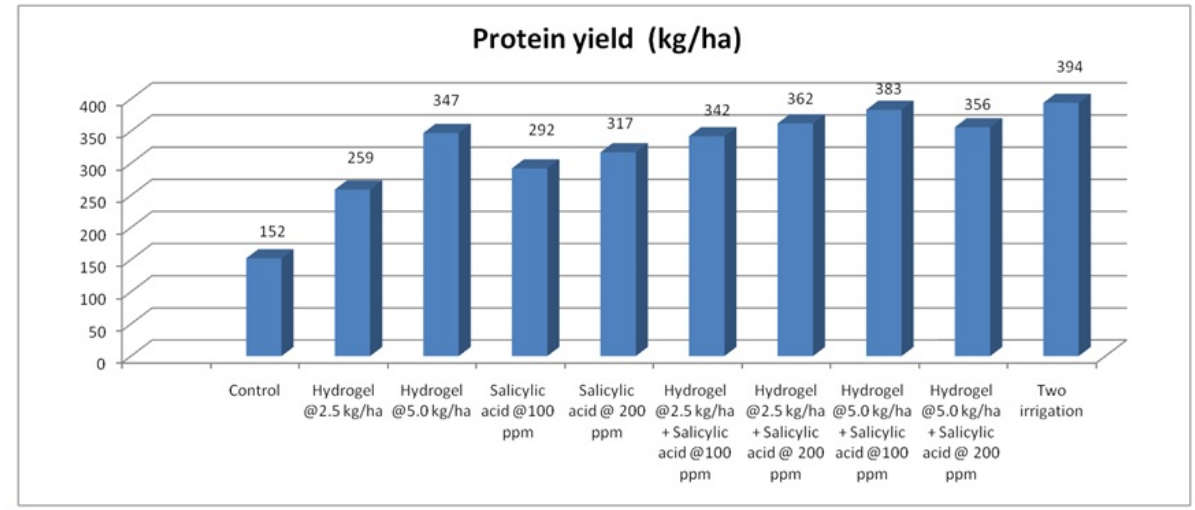

Fig. 2. Protein yield of mustard as influenced by different treatments

The economic analysis of the crop revealed that gross return and net returns were influenced significantly by various treatments. The highest net return was recorded with two irrigations and was followed by hydrogel @5.0 kg/ha + salicylic acid @100 ppm spray at flowering and siliqua formation stage (Table 2). These treatments earned maximum net profits of Rs. 48,983 and Rs. 47,685, which were found to be 174 and 167 % higher net returns over the control, respectively. However, critical analysis of table 2 revealed that, more B:C ratio was observed with hydrogel @5.0 kg/ha + salicylic acid @100 ppm (2.66) and was closely followed by two irrigation (pre-flowering and siliqua formation) treatment. Since hydrogel @5.0 kg/ha + salicylic acid @100 ppm showed a marked improvement in seed yields and thus yielded more profit in terms of B:C ratio, this becomes quite suitable where water scarcity is a threat for mustard cultivation. However, the rate of increase in net return was very less by application of hydrogel and SA at lower levels either alone or their combination, indicating the non-responsiveness and the non-suitability of this treatment for increasing mustard production.

From the results it was concluded that application of hydrogel either at the rate of 2.5 or 5 kg/ha with two foliar sprays of salicylic acid 100 ppm at flowering and siliqua formation was beneficial under rainfed moisture stress conditions. More returns and B:C ratio were obtained with hydrogel @5.0 kg/ha + salicylic acid @100 ppm and was followed by two irrigation and hydrogel @2.5 kg/ha + salicylic acid @100 ppm, without reducing the yield of Indian mustard significantly in restricted irrigation conditions in the new alluvial zone of West Bengal. This may be recommended for the mitigation of moisture stress problems during lean period of Rabi season and for obtaining higher crop yields with better average economic returns to the farming community in this region.

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Integrated nutrient management studies in mustard (*Brassica juncea* L.) in Southern Haryana

ROHIT, HANSRAJ SHIVAN, R S YADAV, RAJKUMAR SHARMA, AMIT KUMAR, MANJEET AND ASHISH KUMAR YADAV

Faculty of Agricultural Science, SGT University, Gurugram-122 505, Haryana

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ABSTRACT

A field experiment was conducted to study the influence of integrated nutrient management on mustard (*Brassica juncea*). The experiment was conducted in randomised block design with thirteen treatments. Highest plant height, branches/plant and higher dry matter accumulation were recorded with application of 100% NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* followed by 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*. Significantly higher yield and yield attribute traits like seed/siliqua, siliqua length and number of siliqua/plant/ were recorded with 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* which was statistically at par with 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*, 100 % NPK + 5 t Vermicompost + 40 kg S and 100 % NPK + 5 t Vermicompost. All integrated nutrient management treatments significantly increased the net returns in mustard. the highest net returns of ₹ 50,379 was recorded in the treatment with application of 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* over others.

Keywords: Mustard, NPK, Vermicompost, Yield attributes, Yield

Indian mustard (*Brassica juncea* L.) is commonly known as rai, raya and laha. Rai belonging to family Cruciferae is one of the most popular oilseed crops. Indian mustard has important role in providing mineral nutrition as oil to human being and feed to animals (Divya *et al.*, 2023). The estimated area, production and yield of rapeseed-mustard in the world was 36.59 million hectares (m ha), 72.37 million tonnes (mt) and 1980 kg/ha, respectively (GOI, Ministry of agriculture and farmer welfare, 2020-21; Gandhimathy, 2022; Barik, 2023). India registered 36.70 million tonnes of oilseed production from an area of 29.17 million hectare and with average productivity of 1292 kg/ha (GOI, Ministry of agriculture and farmer welfare, 2021-22). Mustard production in the country during 2021-22 recorded 11.75 million tonnes from 8.06 million hectare area and productivity of 1458 kg/ha. Rajasthan occupies first position in oilseed production in the country and in terms of rapeseed production Haryana is in second position after Rajasthan with an area of 0.71-million-hectare and production of 1.37 million tonnes (GOI, Ministry of agriculture and farmer welfare, 2021-22).

Mustard responds well to N, P, K and S fertilization depending upon the initial soil fertility status and moisture availability. Integrated use of organic and inorganic sources of nutrients can be an effective measure in boosting average yield of mustard. (Kumawat *et al.*, 2014). Chemical fertilizers are relatively costly inputs and their over use leads to pollution problem in atmosphere. So there is a need to integrate organic sources of nutrients especially nitrogen and phosphorus with the inorganic sources. Phosphorous solubilising bacteria (PSB) can help in minimizing the requirement of chemical fertilizers. PSB helps in solubilising and converting the unavailable form of phosphorous to the available form and increases yield and reduces the requirement of chemical fertilizers. Application of 10-15 tonne/ha farmyard manure with 100 per cent recommended NPK dose with biofertilizers like PSB and azotobacter enhances the physical, biological, and chemical properties of the soil (Singh *et al.*, 2017). Hence, a field experiment was conducted to study the influence of integrated nutrient management on mustard.

MATERIALS AND METHODS

The field experiment was conducted at the Research Farm of the Faculty of Agricultural Sciences, SGT University, Gurugram. The soil of the experimental field was sandy loam in texture, low in nitrogen (245 kg/ha), and medium in phosphorus (22.4 kg/ha) and potassium (232 kg/ha). The experiment was laid out in randomized block design (RBD) with three replicationswith thirteen treatments *viz*., control, 50 % NPK, 75 % NPK, 100 % NPK, 50 % NPK + 5 t Vermicompost, 75 % NPK + 5 t Vermicompost, 100 % NPK + 5 t Vermicompost, 50 % NPK + 5 t Vermicompost + 40 kg S, 75 % NPK + 5 t Vermicompost + 40 kg S, 100 % NPK + 5 t Vermicompost + 40 kg S, 50 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*, 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* and 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*.

The test the significance of variance in experiments, the data obtained for various treatment effects were statistically analysed as per procedure described by Panse and Sukhatme (1985). The critical differences were calculated to assess the significance of treatment means wherever, the "F" test was found significant at 5 per cent and 1 per cent level of significance.

RESULTS AND DISCUSSION

The results revealed that plant population of mustard at initial and at harvest stage was not significantly influenced by integrated nutrient management practices. Plant height and dry matter accumulation were significantly influenced due to various integrated nutrient management treatments at 30 and 60 DAS, and at harvest stage. At harvest the higher plant height and dry matter accumulation were recorded with 100% NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* and remained statistically at par with 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*, 100% NPK + 5 t Vermicompost + 40 kg S and 100% NPK + 5 t Vermicompost, 50% NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*, 75% NPK + 5 t Vermicompost + 40 kg S, 75% NPK + 5 t Vermicompost, 50% NPK + 5 t Vermicompost, 100% NPK and 75% NPK. This might be due to favourable effect on soil environment with farmyard manure and vermicompost to increase the plant height and dry matter accumulation. The results found from the present experiment are in conformity with findings of Indira *et al.* (2021).

Table 1 Effect of integrated nutrient management on plant population and plant height

Treatment	Plant stands per meter row length (no.)		Plant height (cm)		
	30 DAS	At harvest	30 DAS	60 DAS	At harvest
Control	6.33	6.00	11.67	48.67	74.00
50 % NPK	7.00	6.67	12.67	62.67	100.67
75 % NPK	6.67	6.67	13.33	64.67	104.00
100 % NPK	6.33	6.00	14.67	67.00	106.67
50 % NPK + 5 t Vermicompost	7.00	6.67	13.67	64.00	103.33
75 % NPK + 5 t Vermicompost	7.00	7.00	14.00	66.67	107.67
100 % NPK + 5 t Vermicompost	7.33	7.00	15.00	69.00	110.33
50 % NPK + 5 t Vermicompost + 40 kg S	6.33	6.00	14.33	64.67	106.33
75 % NPK + 5 t Vermicompost + 40 kg S	7.00	7.00	15.00	68.33	109.33
100 % NPK + 5 t Vermicompost + 40 kg S	6.33	6.33	16.00	69.33	112.00
50 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	6.67	6.33	14.67	65.33	109.33
75 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	6.33	6.33	16.00	70.33	112.67
100 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	7.00	6.67	17.00	72.00	115.33
S.Em (±)	0.31	0.36	0.47	1.95	5.51
CD (P=0.05)	NS	NS	1.37	5.68	16.09

Table 2 Effect of integrated nutrient management on dry matter accumulation, silique/plant, seed/siliqua and Pod length

Treatment	Drymatter accumulation (g/plant)			Silique/plant	No. of Seed/siliqua	Pod length (cm)
	30 DAS	60 DAS	At harvest			
Control	1.14	5.99	19.28	137.67	10.77	3.23
50 % NPK	1.24	6.22	20.52	154.00	12.22	3.83
75 % NPK	1.28	6.26	20.80	159.33	12.34	3.70
100 % NPK	1.30	6.32	20.92	162.33	12.45	3.95
50 % NPK + 5 t Vermicompost	1.31	6.32	20.89	155.67	12.44	4.00
75 % NPK + 5 t Vermicompost	1.33	6.34	21.06	161.33	12.67	4.04
100 % NPK + 5 t Vermicompost	1.36	6.41	21.36	164.00	12.78	4.18
50 % NPK + 5 t Vermicompost + 40 kg S	1.32	6.33	21.19	158.67	12.56	4.05
75 % NPK + 5 t Vermicompost + 40 kg S	1.35	6.36	21.63	165.67	12.89	4.07
100 % NPK + 5 t Vermicompost + 40 kg S	1.36	6.41	22.16	168.67	12.89	4.22
50 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	1.34	6.36	21.49	159.67	12.78	4.09
75 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	1.40	6.42	22.17	166.67	13.22	4.13
100 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	1.43	6.55	22.82	169.67	13.33	4.25
S.Em (±)	0.05	0.28	1.07	6.78	0.37	0.17
CD (P=0.05)	0.14	0.83	3.12	19.80	1.09	0.48

Table 3 Effect of integrated nutrient management on yields of mustard

Treatment	Pod yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Test weight (g)	Harvest index (%)
Control	840	1892	2732	4.07	30.67
50 % NPK	1073	2441	3514	4.11	30.56
75 % NPK	1119	2517	3636	4.13	30.80
100 % NPK	1200	2757	3957	4.17	30.35
50 % NPK + 5 t Vermicompost	1097	2548	3644	4.12	30.09
75 % NPK + 5 t Vermicompost	1160	2678	3838	4.17	30.23
100 % NPK + 5 t Vermicompost	1283	2949	4232	4.19	30.32
50 % NPK + 5 t Vermicompost + 40 kg S	1120	2581	3701	4.14	30.29
75 % NPK + 5 t Vermicompost + 40 kg S	1203	2775	3978	4.20	30.28
100 % NPK + 5 t Vermicompost + 40 kg S	1310	3015	4325	4.21	30.29
50 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	1167	2698	3865	4.15	30.24
75 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	1250	2861	4111	4.23	30.44
100 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	1370	3118	4488	4.23	30.54
SEm (±)	41	92	126	0.18	0.54
CD (P=0.05)	120	269	368	NS	NS

Table 4 Effect of integrated nutrient management on gross, net return and B: C ratio

Treatment	Gross return (₹/ha)	Net return (₹/ha)	B:C Ratio
Control	55241	22541	1.69
50 % NPK	70701	35894	2.03
75 % NPK	73588	37928	2.06
100 % NPK	79187	42673	2.17
50 % NPK + 5 t Vermicompost	72507	35440	1.96
75 % NPK + 5 t Vermicompost	76611	38691	2.02
100 % NPK + 5 t Vermicompost	84685	45911	2.18
50 % NPK + 5 t Vermicompost + 40 kg S	73943	36376	1.97
75 % NPK + 5 t Vermicompost + 40 kg S	79456	41036	2.07
100 % NPK + 5 t Vermicompost + 40 kg S	86472	47198	2.20
50 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	77073	38906	2.02
75 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	82431	43411	2.11
100 % NPK + 5 t Vermicompost + 40 kg S + Azotobacter	90253	50379	2.26
SEm (±)	2599	2599	0.07
CD (P=0.05)	7586	7586	0.21

Higher number of silique/plant, seed/silique and pod length were recorded with application 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* which was statistically at par with 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*; 50 % NPK + 5 t Vermicompost + 40 kg S 41 + *Azotobacter*; 100 % NPK + 5 t Vermicompost + 40 kg S, 75 % NPK + 5 t Vermicompost + 40 kg S, 50 % NPK + 5 t Vermicompost + 40 kg S, 100 % NPK + 5 t Vermicompost, 75 % NPK + 5 t Vermicompost. The enhancement in yield attributes noticed with the application of various integrated nutrient management practices could be attributed to improvement in growth attributes under this treatment. Further, the rate of nutrient in these treatments wherein, manure (FYM and vermicompost) and biofertilizers were used in combination with fertilizers might be well in tune with the crop needs. Yield increase accompanied by increased N concentration due to bacterial inoculation contributing to enhanced nitrogen utilization by plant leading to enhanced chlorophyll content, branches, and dry matter accumulation. The findings are also in conformity of Kumar *et al.* (2006) and Tripathi *et al.* (2011). Seed, straw and biological yield is a function of yield attributing traits i.e., number of siliquae/plant, number of seed/siliqua and test weight. Significantly higher seed yield of mustard was obtained with the application of 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* which was statistically at par with 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*, 100 % NPK + 5 t Vermicompost + 40 kg S and 100 % NPK + 5 t Vermicompost. The favourable effect of combined use of FYM and

vermicompost with inorganic fertilizers on seed yield was due to significantly higher dry matter accumulation, higher number of siliquae/plant, seed/siliquae and pod length perhaps due to increased concentration of primary nutrients. These results are in agreement with the findings of Singh and Singh, 2015, Regar *et al.*, 2009 and Singh and Meena 2004. The increase in straw yield with integrated nutrient management could be attributed to its direct influence on dry matter production through increased plant height and number of branches. Biological yield is a function of seed and straw yields. These was profound influence of integrated nutrient management on biological yield. These observations are in agreement with the findings of Kumar *et al.* (2006) and Singh and Pal (2011).

The integrated nutrient management practices resulted in significant increase in the net return in mustard. The highest net return of (₹50,379) was recorded with the application of 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*. It provided additional net returns of ₹43411, 38906, 47198, 45911 and 42673, with application of 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*; 50 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter*; 100 % NPK + 5 t Vermicompost + 40 kg S, 100 % NPK + 5 t Vermicompost and 100 % NPK, respectively. Highest B:C ratio was recorded with 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* (2.26) followed by 100 % NPK + 5t Vermicompost + 40 kg S (2.20), 100 % NPK + 5 t Vermicompost (2.18), 100 % NPK (2.17), 75 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* (2.11).The higher net return with 100 % NPK + 5 t Vermicompost + 40 kg S + *Azotobacter* might be due to the increased yield. These observations are in agreement with the findings of Tripathi *et al.* (2011). The experiments of Singh and Pal 2011 also reported that highest net and gross returns with recommended dose of fertilizer with organic manures.

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Response of sunflower-weed ecosystem to herbicide oxadiagryl and integrated weed management options

ANITA MAHAPATRA, LOPAMUDRA MOHANTY, KULASEKARAN RAMESH* AND RAJKUMARI BHOL

Odisha University of Agriculture and Technology, Bhubaneswar-751 003, Odisha

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ABSTRACT

Field experiment was conducted during summer, 2021 at Odisha University of Agriculture & Technology, Bhubaneswar to study the response of sunflower as a part of Integrated weed management with suboptimal, optimal and super optimal doses of oxadiargyl as pre-emergence spray with or without quizalofop ethyl 5 EC @ 37.5 g/ha at 15 - 20 DAS in sunflower hybrid "KBSH-44" revealed that weed free control has recorded the highest seed yield (2064 kg/ha), which remained at par with oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW at 30 DAS with a seed yield of 1962 kg/ha with a WCE of 92.6% at harvest.

Keywords: Oxadiagryl, Sunflower, Weed management

Sunflower (*Helianthus annuus* L.) is one of the important oilseed crops in India and contributed to rapid growth in oil production in India and has emerged as an important crop of the state of Odisha with an average productivity of 1193 kg/ha (Mahapatra *et al.,* 2021a, b & c; Ramesh *et al.,* 2019; Meena *et al.,* 2022). In the mono-cropped rice fallows of Odisha (Nayak *et al.,* 2019), sunflower is a preferred crop which occupies 25,000 ha (Mahapatra *et al.,* 2020). According Government of India Statistics (2021), Odisha is one among the three largest sunflower producing states of the country during 2019-20 (Ramesh *et al.,* 2021). Being a photo and thermo-insensitive, short duration fits to varied cropping systems, however the challenges from weeds continue to pose a threat for the sustainable production. Weed competition is one of the major biotic constraints in reducing sunflower productivity under irrigated conditions due to wider spacing and application of higher doses of fertilizers. They not only compete with crop plants for nutrients, soil moisture, space and sunlight but also serve as alternate host for several insect pests and diseases and causes yield reduction to be as high as 81% (Jaykumar *et al.,* 1988). Integrated weed management (IWM) is a sustainable approach to the management of weeds by combining all available weed control techniques, including crop rotations, tillage, crop competition, mechanical and physical control, herbicide rotation, herbicide mixtures, biological control, nutrition, irrigation, flaming, etc. in a way that minimizes economic, health, and environmental risks (Swanton *et al.,* 2008; Garikamukkala *et al.,* 2023). Managing sunflower-weed ecosystem is essential to obtain optimum crop yields in sunflower (Solaimalai *et al.,* 2022). Oxadiagryl is a broad-spectrum herbicide very effective for the control of grasses, sedges and some broad leaf weeds in rice and it offers a very high crop safety in transplanted rice when applied at recommended dose. An attempt has been in this study to study the response of sunflower-weed ecosystem to spray of Oxadiagryl as a pre-emergence herbicide.

*ICAR-Indian Institute of Oilseeds Research, Hyderabad;
Corresponding author's E-mail: K.Ramesh@icar.gov.in

MATERIALS AND METHODS

A field experiment was carried out at Instructional Farm of Odisha University of Agriculture & Technology (OUAT), Bhubaneswar during summer season of 2021. The soil of 0.37%), medium in available nitrogen (294 kg/ha), low in available phosphorous (9.7 kg/ha) and medium in available potassium (190.30 kg/ha). During the crop growth period, total rainfall received (January to April) was 14.7 mm with 3 rainy days. The mean maximum and minimum temperature observed was 34.80C and 20.10C respectively. The mean relative humidity ranged from 36% to 92.3%. The bright sunshine hours varied between 4.2 hrs/day to 7.0 hrs/day. Wind velocity during the crop growth period ranged from 2.6 km/hr to 7.3 km/hr. The experiment was laid out in a randomized block design with nine treatments replicated thrice *viz.,* T_1- Oxadiargyl @ 75 g a.i./ha as pre-emergence spray fb one HW/IC at 30 DAS; T_2-Oxadiargyl @ 100 a.i./ha as pre-emergence spray fb one HWat 30 DAS; T_3-Oxadiargyl @ 125 g a.i./ha as pre-emergence spray fb one HW at 30 DAS; T_4-Oxadiargyl @ 75 g a.i./ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g a.i./ha at 15-20 DAS directed post-emergence spray on weeds; T_5-Oxadiargyl @ 100 g a.i./ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g a.i./ha at 15-20 DAS directed post-emergence spray on weeds; T_6-Oxadiargyl @ 125 g a.i./ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g a.i./ha at 15-20 DAS directed post-emergence spray on weeds; T_7-Farmers' practice (Two HW at 20 & 40 DAS) ; T_8-Weed free (Three

HW at 15, 30 and 45 DAS); T_9-Unweeded control. Sunflower hybrid KBSH-44 was sown on 11.01.2021 and harvested on 12.04.2021. Weed density was recorded from one square meter quadrats. Dry weight of weeds was recorded at 60 DAS and at harvest. The weeds were uprooted from the area of one square meter and were oven dried at 70°C for obtaining a constant weight and the dry weight of weeds was expressed in g m-2. Weed control efficiency was calculated using the formula given by Mani *et al.* (1973).

$$WCE = \frac{X-Y}{X} \times 100$$

Where, X: Weed dry matter production in weedy plot,
Y: Weed dry matter production in treated plot

Weed index indicates the extent of reduction in yield due to crop weed competition. It was worked out for different treatments by adopting the formula given by Gill and Kumar (1969) [10].

$$\text{Weed index} = \frac{A-B}{A} \times 100$$

Where A: Seed yield of the weed free treatment, B: Seed yield of the particular treatment for which the index is computed.

RESULTS AND DISCUSSION

Data on weed density are presented in Table 1. At all the growth stages, treatments which received sequential application of herbicides and cultural practices recorded lower weed population than weedy check. At all the growth stages, weed free (three hand weeding at 15, 30 and 45 DAS) treatment recorded significantly lower weed population as compared to other weed control methods. This was followed by oxadiargyl @ 125 g/ha as pre- emergence spray fb one HW at 30 DAS. This was due to herbicide effect in this treatment along with effectiveness of hand weeding which reduce the weed population. Similar results were observed by Nagamani *et al.* (2011). Pre emergence application of oxadiagryl with one hand weeding reduced the number of total weeds which was more effective than application of oxadiagryl fb quizalofop-p-ethyl. This was due to oxadiagryl with one hand weeding showed effectiveness in controlling both dicot and monocot weeds due to the synergistic effect of necrotic action of the herbicide and hand weeding. Pre-emergence herbicide application of oxadiagryl led to the inhibition of weed seed germination and post emergence herbicide and cultural practices led to inhibition of weeds in later growth stages by inhibiting the process of photosynthesis and growth of roots with rapid translocation in the xylem and phloem to the meristematic region where the herbicide accumulates.

Table 1 Effect of integrated weed management on total weed population (no/m²) and weed dry weight (g/m²) at different growth stages of sunflower

	Treatments	Weed population (No./m²)			Weed dry weight (g/m²)
		30 DAS	60 DAS	Harvest	Harvest
T1	Oxadiargyl @ 75 g/ha as pre-emergence spray fb one HW/IC at 30 DAS	4.41 (19.0)	5.84 (33.7)	8.23 (67.3)	5.47 (29.5)
T2	Oxadiargyl @ 100 g/ha as pre-emergence spray fb one HW/IC at 30 DAS	3.34 (10.67)	5.46 (29.33)	7.03 (49.33)	4.58 (20.55)
T3	Oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW/IC at 30 DAS	2.96 (8.33)	5.08 (25.33)	5.33 (35.67)	4.38 (18.85)
T4	Oxadiargyl @ 75 g/ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g/ha at 15 – 20 DAS post-emergence spray on weeds	8.59 (73.3)	10.70 (114)	16.24 (263)	11.51 (100)
T5	Oxadiargyl @ 100 g/ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g/ha at 15 – 20 DAS post-emergence spray on weeds	8.34 (69.00)	9.51 (90.00)	14.49 (209.33)	10.20 (95.37)
T6	Oxadiargyl @ 125 g/ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g/ha at 15 –20 DAS post-emergence spray on weeds	6.14 (37.33)	6.46 (41.33)	9.80 (95.67)	6.77 (45.52)
T7	Farmers' practice (two HW at 20 & 40 DAS)	8.01 (63.67)	9.01 (80.67)	11.39 (129.33)	8.38 (69.66)
T8	Weed free (three HW at 15, 30 and 45 DAS)	1.86 (3.00)	2.73 (7.00)	5.05 (25.33)	3.68 (12.97)
T9	Unweeded control	10.90 (118.33)	12.53 (156.67)	18.87 (355.67)	13.28 (175.94)
	SEm(±)	0.17	0.14	0.33	0.22
	CD (p=0.05)	0.49	0.40	0.96	0.64

Original values are given in parentheses, which were transformed to $\sqrt{x + 0.5}$

Table 2 Effect of integrated weed management on weed control efficiency at different stages of sunflower and weed index at harvest

Treatments		Weed index	Weed control efficiency (%)	Seed yield (kg/ha)	Net returns (₹/ha)
T1	Oxadiargyl @ 75 g/ha as pre-emergence spray fb one HW at 30 DAS	16.1	83.3	1732	42500
T2	Oxadiargyl @ 100 g/ha as pre-emergence spray fb one HW at 30 DAS	11.3	88.3	1831	48124
T3	Oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW at 30 DAS	4.9	89.3	1962	55633
T4	Oxadiargyl @ 75 g/ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g/ha at 20 DAS post-emergence spray on weeds	29.4	42.9	1456	32211
T5	Oxadiargyl @ 100 g/ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g/ha at 20 DAS post-emergencespray on weeds	28.6	45.8	1474	33041
T6	Oxadiargyl @ 125 g/ha as pre-emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g/ha at 20 DAS post-emergence spray on weeds	17.5	74.1	1703	46271
T7	Farmers' practice (two HW at 20 & 40 DAS)	27.2	60.4	1503	25102
T8	Weed free (three HW at 15, 30 and 45 DAS)	-	92.6	2064	53573
T9	Unweeded control	56.5		898	1650
	SEm			77.8	-
	CD (p=0.05)			228	-

Total dry weight of weeds at different days after sowing differed significantly due to various weed control treatments. At all the sunflower growth stages, the highest weed dry weight was recorded with un-weeded control. It was mainly due to higher and uninterrupted growth of weeds which made best use of growth resources. On the other hand, lowest weed dry weight was recorded with weed free treatment at all crop growth stages. It was at par with Oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW at 30 DAS. This could be attributed to the cumulative effect of herbicide and HW which resulted in reduced dry matter production by weeds. These results were in good agreement with the findings of Bhan and Kolhe (2008).

Weed control efficiency (WCE) was worked out from total weed dry weight to consider the various weed species differing in their proportions, so that it will not manifest the individual weed species effect. Performance of the crop is directly proportional with the improvement in WCE. In the present study, weed free treatment recorded higher WCE due to timely uprooting of weeds which controlled them effectively. This was followed by Oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW at 30 DAS, Oxadiargyl @ 100 g/ha as pre-emergence spray fb one HW at 30 DAS (96% and 89.3% at 60 DAS and harvest respectively). This was attributed to lower weed population resulted in reduction of total dry weight of weeds.

Lowest weed index (4.9 %) was recorded in Oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW at 30 DAS. The lower value of weed index was due to lower weed infestation resulting in lower weed biomass production. In unweeded control (weedy) plot the profuse weed growth restricted the vegetative growth and nutrient availability to the crop, there by caused the highest yield reduction. This corroborates the findings of Chandrika (2004).

The highest seed yield of 2064 kg/ha was recorded with weed free (three HW at 15, 30 and 45 DAS) which remained at par with Oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW at 30 DAS (1962 kg/ha) and was significantly superior over rest of the treatments. The lowest seed yield of 898 kg/ha was recorded with control. Weed free (three HW at 15, 30 and 45 DAS) and Oxadiargyl @ 125 g/ha as pre-emergence spray fb one HW at 30 DAS recorded 129 % and 118.52 % increased seed yield over unweeded control respectively. Significant enhancement of yield obtained with these treatments was due to positive yield attributing characters like head diameter (cm), total seeds/head, test weight (g), number of filled seeds per head and harvest index(%), due to reduced weed competition as well as improvement in crop growth characteristics. Significant increase in yield attributes were observed with weed free treatment and pre-emergence use of Oxadiargyl with subsequent increase in concentration and integrating with one hand weeding and combination of pre-emergence and post emergence herbicides (Oxadiargyl and Quizalofop Ethyl respectively) over weedy check. This might be due to significantly lower weed dry weight and weed index value, thus enabling the crop for maximum utilization of nutrient, moisture, light and space which had positive influence on growth and yield components. The lowest seed yield (898 kg/ha) was obtained in weedy check

as a consequence of highest removal of nutrient and moisture by weed and severe crop weed competition resulting in poor source- sink relationship resulting in poor yield. Similar type of result was also reported by Sumathi *et al*. (2010). Several farmer groups have modified their land configuration into 3-4 rows of sunflower in a paired row for managing irrigation for sunflower and save irrigation water and labour (Ramesh *et al.,* 2018) in west Bengal where this herbicide may prove beneficial. The higher net return in these treatments could be attributed to higher seed yield and lower cost of cultivation. Maximum B:C ratio (1.93) was observed with Oxadiargyl @ 125g/ha as pre- emergence spray fb one HW at 30 DAS followed by Oxadiargyl @ 125 g/ha as pre- emergence spray fb Quizalofop Ethyl 5 EC @ 37.5 g/ha at 15 - 20 DAS post-emergence spray on weeds (1.86). This was due to lower cost of herbicides compared to cost of hand weeding and higher economic yield and net returns involved. The lower B:C ratio was recorded with unweeded control due to less gross return as a result of lower yield of sunflower. Similar type of results were also reported by Tadavi *et al*. (2017).

It is concluded that Oxadiargyl @ 125 g/ha as pre-emergence spray fb one hand weeding at 30 DAS was equally effective with weed free control in minimising weed population in sunflower and registered high net returns (₹55633/ha). Hence, application of oxadiargyl @ 125 g/ha as pre-emergence spray fb one hand weeding at 30 DAS may be considered as the most effective and economical weed management practice for summer sunflower in Odisha.

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Performance of castor-based intercropping in semi-arid zone of Haryana

K GANGADHAR, J S YADAV[1] AND ANIL KUMAR YADAV[1]

College of Agriculture, Hisar CCS Haryana Agricultural University, Hisar-125004, Haryana

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ABSTRACT

To enhance the productivity of castor per unit area and over time, a study was conducted during the *kharif* 2020-21 season at the Regional Research Station, CCS HAU, Bawal,. The study aimed to evaluate the compatibility, production potential, and optimal row proportions of component crops in intercropping systems involving castor. The field investigation was carried out to identify suitable intercrops for maximizing castor yield and analyse the economic viability of various treatments under two different row spacing for castor: 150 cm and 200 cm. The results indicated that the highest castor seed and stalk yield were achieved in sole castor (3,879 kg/ha and 5,656 kg/ha, respectively) with 200 cm row spacing, a similar performance was observed with a 150 cm row spacing. Further, intercropping of castor (150 cm) + mungbean (1:2) recorded higher seed yield (3,547 kg/ha) and stalk yield (5,248 kg/ha), highest castor equivalent yield (4,220 kg/ha) and land equivalent ratio (1.53) and resulted in higher economic returns with a benefit-cost ratio of 3.78.

Keywords: Castor, Economics, Intercropping system, Land equivalent ratio

Castor (*Ricinus communis* L.) is an important non-edible industrial oilseed crop, ideally suited for cultivation in arid and semi-arid regions of the country. It serves as a valuable resource to meet the ever-growing demand for industrial oils (Vijaya Kumari *et al.,* 2022; Yamanura *et al.,* 2022; Raghuwanshi *et al.,* 2023). Among the various factors that influence crop productivity, the optimum planting geometry and row ratio plays a significant role in enhancing yields in intercropping systems (Venkattakumar *et al.,* 2014). Castor, characterized by its long growth duration and wide spacing between plants, has a relatively lower plant density compared to closely spaced field crops. This unique characteristic creates an excellent opportunity for the incorporation of intercropping systems to maximize production within a given land area (Veeramani *et al.,* 2022). The introduction of suitable intercropping systems is crucial for boosting productivity and profitability per unit area and over time. Furthermore, the low input requirements of the castor crop, coupled with its ability to be cultivated at a relatively low production cost while yielding higher economic returns, have made it increasingly popular among farmers across the country. This economic efficiency and adaptability make castor a promising choice for sustainable agricultural practices in India.

MATERIALS AND METHODS

The experiment was conducted during the kharif 2020-21 season at the Regional Research Station, CCS HAU, Bawal. The soil texture at the experimental site had a loamy sand and slightly alkaline pH (8.5). It was characterized by low levels of organic carbon content and nitrogen (0.21 percent and 125 kg/ha, respectively), and medium levels of available phosphorus and potassium (16.2 kg/ha and 195.4 kg/ha, respectively). The experimental design followed a randomized block pattern, comprising eleven treatments that included both sole cropping and various intercropping systems. These treatments were evaluated with three replications, considering two different row proportions (1:2/4) and planting geometries (150/200 cm). The crops involved in the experiment included DCH-177 (castor hybrid), MH-421 (green gram variety), HHB-67 Imp. (pearl millet variety) and HT-2 (sesamum variety). All intercrops were sown at a 30 cm x 10 cm spacing. Throughout the cropping season, the region received 312.9 mm of rainfall. The crop underwent five pickings at intervals of 120, 150, 180, 230 and 270 DAS. Standard intercultural practices followed as recommended by CCSHAU, were implemented. The Land Equivalent Ratio (LER) was computed using the following formula: LER = La + Lb, (La = Yab/Yaa, Lb = Yba/Ybb), where La represents the LER of the main crop, and Lb stands for the LER of intercrops. Within this formula, Yaa and Yab denote the main crop yield in sole cultivation and intercropping, respectively, while Yba and Ybb represent the yields of intercrops in sole cultivation and intercropping, respectively. An LER value of more than 1 specified that the intercropping system was more advantageous than sole cropping, an LER value less than 1 suggested that the sole cropping system was more productive, and an LER of 1 signified no significant difference between intercropping and sole cropping, as per Willey (1985) criteria.

[1] Department of Agronomy Regional Research Station (Bawal), CCS Haryana Agricultural University, Hisar-125004, Haryana;
Corresponding author's E-mail: ganga0239@gmail.com

RESULTS AND DISCUSSION

The seed (economic) yield of castor exhibited variations due to different planting geometry adopted. Specifically, a wider intercropping system with a row spacing of 200 cm resulted in higher castor seed yield (3,879 kg/ha), over the narrower row spacing (150 cm). Sole castor, however, recorded a higher seed yield of castor compared to the intercropping system. This could be attributed to the competition for available resources between main and the intercrops. Among the different intercropping options, the highest castor seed yield was achieved in castor + mungbean (1:2) intercropping system. The castor + mungbean intercropping at two different row spacings (150 and 200 cm), recorded higher and at par castor seed yield of 3,547 kg/ha and 3,250 kg/ha, respectively, and was superior over the pearl millet and other intercropping system. The complementary interaction between mung bean's ability to enhance the nitrogen content of the soil through atmospheric nitrogen fixation, might have benefitted the castor crop after the legume's harvest. Reddy et al. (2008) also noted that pulses had a complementary effect, while cereals had a competitive effect when cultivated as intercrops with castor. Specifically, the castor with 200 cm row spacing with pearl millet intercropping in a 1:4 row ratio system yielded the lowest among all the intercropping systems with row ratios of 1:2/4. Furthermore, Rana *et al.* (2006) observed similar results, indicating that wider row spacing, such as 90 cm, led to higher castor yields compared to castor planted with 60 and 75 cm row spacing under rainfed conditions. Additionally, it was observed that intercropping castor with leguminous crops resulted in higher castor seed yields compared to non-leguminous crops, a finding consistent with the research of Narayan Mavarkar (2006) and Leela Rani (2008). These studies also noted a reduction in seed yield of castor under intercropping systems when equated with sole cropping system.

The stalk yield of castor differed due to different planting densities. Significantly the highest stalk yield (5,656 kg/ ha) was achieved in the case of sole castor with a 200 cm row spacing. This superior performance may be attributed to superior yield attributing characters in the sole cropping over intercropping. The highest castor stalk yield was recorded with 150 cm row spacing and intercropped with two rows of either mungbean, sesame, or pearl millet. These combinations resulted in a stalk yield of 5,248 kg/ ha, 5,150 kg/ ha, and 4,566 kg/ ha, respectively. In contrast, castor sown with 200 cm row spacing and intercropped with mungbean, sesame, or pearl millet with four rows resulted in significantly lower stalk yield of 4,792 kg/ ha, 4,751 kg/ha, and 3,628 kg/ha, respectively. Similar results were reported by Mohsin *et al.* (2018) in their study on castor-based intercropping, where the sole-planted castor consistently obtained higher stalk yield in comparison to the various intercropping systems (Table 1).

The seed yields of the intercrops (pearl millet, mungbean, and sesame) exhibited significant differences involving two rows of castor. The intercrops, *viz.,* pearl millet, mungbean, and sesame gave higher seed yield, compared to sole crops, with respective seed yields of 3,002 kg/ ha, 1,402 kg/ha and 556 kg/ha. The highest seed yield of intercrops was obtained when castor was planted with 200 cm row spacing and four rows of mungbean, pearl millet, or sesame. In these configurations, the seed yields for pearl millet, mungbean and sesame were 2,414 kg/ ha, 970 kg/ha, and 327 kg/ha, respectively. This outperformed the yields achieved in the intercropping systems where castor was sown at 150 cm row spacing with two rows of intercrops, resulting in yields of 551 kg/ha, 1,200 kg/ha, and 157 kg/ha for mungbean, pearl millet, and sesame, respectively (Table 1)

The straw/stover yield of the intercrops exhibited a similar pattern to their seed yield. The highest straw/stover yield was observed in the sole cropping of pearl millet (6,504 kg/ha) >, mungbean (4,137 kg/ha) and > sesame (1,631 kg/ha). The stalk yield was significantly higher under 1:4 row ratio compared to the 1:2 row ratio intercropping systems, which produced straw yields of 2,935 kg/ha, 5,233 kg/ha, and 960 kg/ha for mungbean, pearl millet, and sesame, respectively. This difference can be attributed to the higher plant densities of the intercrops when grown as sole crops. Among the different intercropping systems, the highest straw yield of pearl millet, greengram and sesame were recorded when they were intercropped with castor in 200 cm row spacing with a 1:4 row ratio (Table 1)

This finding is consistent with the results of with higher seed yield of pearl millet compared to mungbean and sesame (Vaghela *et al.,* 2019). Further, between the two different row ratios, sesame had the lowest yield compared to the other intercrops. This observation aligns with the findings of Agarwal (2005), who reported that sesame had a lower stover yield compared to other intercrops like greengram, blackgram, and clusterbean. The trends in straw and biological yields followed a pattern similar to that of the seed yield (Table 1).

In addition to the competitive effects, the predominant prices of economic produce play a significant role in determining the components of an intercropping system. To account for these factors, the yields of intercrops were transformed into castor equivalent yields and converted as additional castor yields. The castor equivalent yield was found to be significantly higher in the castor with 200 cm row spacing intercropped with mungbean (1:4) and castor

with 150 cm row spacing intercropped with mungbean (1:2) (Table 2). The higher yields can be attributed to the combination of higher prices for greengram, coupled with a lesser reduction in the seed yield of castor in these particular intercropping systems. These findings are consistent with the results reported by Narayan Mavarkar (2006) and Thanunathan *et al.* (2006). Mohsin *et al.* (2018) also recorded that the castor with green gram intercropping system yielded a greater castor equivalent yield. Conversely, pearl millet and sesame intercropping systems resulted in a more significant reduction in castor equivalent yield, leading to lower castor equivalent yields. This aligns with the observations made by Vaghela *et al.* (2019), who concluded that castor intercropped with sesame and pearl millet observed lower castor equivalent yields compared to the green gram intercropping system.

Table 1 Yield assessment of castor and associated intercrops in castor based intercropping systems

Treatments		Seed yield (kg/ha)		Stalk yield (kg/ha)	
		Castor	Inter crop	Castor	Inter crop
T1	Sole castor (150cm)	3,840	-	5,648	-
T2	Sole castor (200cm)	3,879	-	5,656	-
T3	Sole mungbean	-	1,402	-	4,137
T4	Sole pearl millet	-	3,002	-	6,504
T5	Sole sesame	-	556	-	1,631
T6	Sole castor (150cm) + mungbean (1:2)	3,547	551	5,248	1,681
T7	Sole castor (150cm) + pearl millet (1:2)	3,020	1,200	4,566	2,846
T8	Sole castor (150cm) + sesame (1:2)	3,443	157	5,150	463
T9	Sole castor (200cm) + mungbean (1:4)	3,250	970	4,792	2,953
T10	Sole castor (200cm) + pearl millet (1:4)	2,410	2,414	3,628	5,233
T11	Sole castor (200cm) + sesame (1:4)	3,195	327	4,751	960
	SEm±	110	61	164	154
	CD (p=0.05)	339	185	504	467

Table 2 Castor equivalent yield (CEY) and land equivalent ratio (LER) as influenced by castor based intercropping systems

	Treatments	CEY (kg/ha)	LER
T1	Sole castor (150cm)	3,840	-
T2	Sole castor (200cm)	3,879	-
T3	Sole mungbean	-	-
T4	Sole pearl millet sole	-	-
T5	Sole sesame sole	-	-
T6	Sole castor (150cm) + mungbean (1:2)	4,098	1.32
T7	Sole castor (150cm) + pearl millet (1:2)	3,570	1.19
T8	Sole castor (150cm) + sesame (1:2)	3,680	1.18
T9	Sole castor (200cm) + mungbean (1:4)	4,220	1.53
T10	Sole castor (200cm) + pearl millet (1:4)	3,516	1.43
T11	Sole castor (200cm) + sesame (1:4)	3,686	1.41
	SEm±	120	-
	CD (p=0.05)	367	-

Table 3 Economic Analysis of different castor intercropping systems

	Treatments	Gross returns (₹/ha)	Cost of cultivation (₹/ha)	Net returns (₹/ha)	B:C ratio
T1	Sole castor (150cm)	1,88,011	53,612	1,34,399	3.51
T2	Sole castor (200cm)	1,89,801	51,742	1,38,059	3.67
T3	Sole mungbean	70,439	30,458	39,981	2.31
T4	Sole pearl millet sole	72,688	41,434	31,254	1.75
T5	Sole sesame sole	69,527	24,643	44,884	2.82
T6	Sole castor (150cm) + mungbean (1:2)	2,02,643	57,362	1,45,281	3.53
T7	Sole castor (150cm) + pearl millet (1:2)	1,76,729	56,092	1,20,637	3.15
T8	Sole castor (150cm) + sesame (1:2)	1,97,397	56,072	1,41,325	3.52
T9	Sole castor (200cm) + mungbean (1:4)	2,14,055	56,602	1,57,453	3.78
T10	Sole castor (200cm) + pearl millet (1:4)	1,76,441	54,682	1,21,759	3.23
T11	Sole castor (200cm) + sesame (1:4)	2,02,493	54,572	1,47,921	3.71

The Land Equivalent Ratio (LER) analysis revealed that all the intercropping systems outperformed the sole crop stand, signifying that intercropping castor with pearl millet, mungbean, and sesame was more effective in terms of land utilization. Among all intercropping systems, the highest LER was observed in the castor at 200 cm row spacing with mungbean (1:4) intercropping system, with a value of 1.53 (Table 2). In contrast, the lowest LER was observed in the 1:2 row ratio of the castor at 150 cm row spacing with sesame intercropping system, with a value of 1.18. The LER value represents the comparative land area required under a sole crop stand to achieve an equivalent yield in an intercropping system under similar management practices, as outlined by Willey (1979). In terms of LER, the castor with 200 cm row spacing with mungbean in 1:4 row ratio intercropping system exhibited the highest yield advantage. With an LER value of 1.53, it suggests that this intercropping system would require 53 percent more land area for castor sole cultivation to produce an equivalent yield. This yield advantage demonstrates the higher efficiency of intercropping systems and their effective utilization of resources within a given unit of land area, in line with the findings of Varia and Sadhu (2011).

The economic analysis, considering gross and net returns, revealed that the intercropping treatments were notably more economically rewarding compared to sole castor. The economic analysis showed that the castor at a 200 cm row spacing with mungbean (1:4) and castor at 150 cm row spacing with mungbean (1:2) intercropping systems resulted in higher net returns over other intercropping systems and sole castor. The higher net returns can be attributed to the higher yields of both castor and intercrops. In particular, the castor with 200 cm row spacing with mungbean intercropping system (1:4) achieved the highest net returns of ₹1,57,453/ha and a favorable benefit-to-cost (B:C) ratio of 3.78 (Table 3). This was primarily due to higher yield of mungbean and the relatively smaller reduction in castor seed yield in this intercropping system. These findings align with the results reported by Mohsin *et al.* (2018), wherein castor-mungbean intercropping resulted in higher net returns and benefit cost ratios. Conversely, the castor intercropping with sesame and pearl millet resulted in lower castor seed yields due to the suppressive result on castor growth, ultimately leading to reduced economic returns than the other intercropping systems and their respective sole crops. Comparable results were reported by Vaghela *et al.* (2019), where castor + summer sesame and castor + summer pearl millet exhibited lower gross and net returns in evaluation to the castor-mungbean intercropping system.

Introduction of legume intercrops in wider interspaces of castor offers several advantages, resulting in higher yields for castor, intercrops, castor equivalent yield, land equivalent ratio, net returns and benefit-to-cost (B:C) ratio in comparison to other intercropping and sole cropping systems. Intercropping of castor (200 cm) + mungbean in a 1:4 row ratio demonstrated superior performance and proven to be more profitable and remunerative when compared to sole castor cultivation, in the semi-arid region of Haryana.

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Standardization of different doses and duration of plant derived smoke water on growth, yield and yield attributing traits of linseed (*Linum usitatissimum* L.)

B LOHITHA, PRASHANT KUMAR RAI* AND SHIVAM KUMAR RAI

Naini Agril. Institute, Sam Higginbottom University of Agril. Technology & Sciences, Prayagraj-211 008, Uttar Pradesh

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ABSTRACT

Harnessing the potential of smoke water treatments, derived from plant combustion, this study delves into their impact on various growth and physiological parameters of linseed plants. Through a randomized controlled trial featuring 13 treatments along with control, we meticulously evaluated different concentrations and durations of smoke water application. Linseed seeds were meticulously sown under controlled conditions, enabling the comprehensive assessment of field emergence, plant height, flowering duration, branching patterns, chlorophyll content, seed yield, oil content, and protein content. Notably, Treatment 2 (1% smoke water for 16 hours) emerged as a frontrunner, showcasing superior performance across multiple parameters, including accelerated growth, enhanced flowering, increased branching, improved chlorophyll content, and higher seed yield and oil content. These findings underscore the promising role of smoke water as an environmentally sustainable and effective agricultural intervention to augment crop productivity and quality in linseed cultivation. Further research endeavors are warranted to delve deeper into the underlying mechanisms and refine application protocols, thereby unlocking the full potential of smoke water treatments in modern agricultural practices.

Keywords: Linseed, Plant growth, Physiological parameters, Smoke water

The utilization of plant-derived smoke in fostering seed germination and augmenting plant growth has garnered considerable attention in recent years (De and Boucher, 1990; Van *et al.,* 2004; Light *et al.,* 2007). Across diverse ecological niches, various fire-related stimuli, including heat, temperature fluctuations, chemicals, and smoke, have been identified as pivotal triggers for seed germination, particularly in post-fire environments (Paul *et al.,* 2007). Despite the efficacy of prescribed burning in agricultural practices, its implications can be multifaceted, encompassing the destruction of beneficial soil organisms, loss of essential minerals, and the exacerbation of air pollution (Mandal *et al.,* 2004). Nevertheless, plant species indigenous to fire-prone habitats have evolved mechanisms to positively respond to smoke generated during natural forest fires (Todorovic *et al.,* 2005).

Plant-derived smoke solutions have emerged as potent agents for enhancing the germination process across a spectrum of plant communities, spanning from Mediterranean shrub lands to Californian chaparrals. These solutions encapsulate stable compounds that exhibit activity even at low concentrations and possess enduring effects, rendering them invaluable in agricultural and horticultural contexts (Flematti *et al.,* 2004). Beyond their role in germination promotion, plant-derived smoke solutions have been demonstrated to expedite seedling vigor, alleviate seed dormancy, and positively modulate various biochemical parameters in plants (Aslam *et al.,* 2017; Jamil *et al.,* 2014). Furthermore, the application of plant-derived smoke solutions has shown promise in aiding plant recovery from a gamut of environmental stressors, including flooding, heavy metal contamination, drought, salinity, and extreme temperature fluctuations (Li *et al.,* 2018; Akhtar *et al.,* 2017).

As scientific inquiry delves deeper into the characterization of smoke solutions, the identification of active compounds, and elucidation of their mechanisms of action, the potential of plant-derived smoke as a germination cue and growth regulator in agricultural and conservation endeavors becomes increasingly evident (De and Boucher, 1990; Flematti *et al.,* 2004; Jamil *et al.,* 2014; Paul *et al.,* 2007). This burgeoning field holds promise for sustainable agricultural practices and ecosystem restoration efforts, highlighting the critical role of plant-derived smoke in shaping plant communities and ecosystems worldwide. Our hypothesis posits that the application of plant-derived smoke water will significantly enhance both the growth and yield of linseed, while also positively affecting key yield attributing traits. We anticipate that varying doses and durations of plant-derived smoke water will exert differential effects on these parameters, offering insights into the optimal conditions for promoting linseed productivity and quality.

In pursuit of these objectives, this study aims to investigate the impact of different doses and durations of plant-derived smoke water on the growth, yield, and yield

Corresponding author's E-mail: lohithabonthu123@gmail.com

attributing traits of linseed. Furthermore, we seek to evaluate the influence of varying application parameters on the chlorophyll content, oil content and protein content of linseed. Ultimately, through rigorous experimentation and analysis, we endeavor to identify the most suitable dose and duration of plant-derived smoke water application to maximize the performance and quality of linseed crops.

MATERIALS AND METHODS

Seed source: Seeds of linseed genotype LCK-9312 were procured from the Directorate of Research, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj. The study was conducted at the Field Experimentation Centre of the Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology, and Sciences, Prayagraj, Uttar Pradesh, during the *rabi* season of 2022-23 to assess the effect of pre-sowing treatments on seed quality parameters. Smoke Water Preparation: Smoke water solution was prepared by combusting 10 kg of dry paddy straw material in a 20-liter stainless steel barrel. The smoke produced was continuously bubbled through a 1000 ml graduated cylinder containing distilled water for 45 minutes using compressed air. The resultant smoke water was filtered and used as the stock solution. Different concentrations of smoke extract (0.5%, 1%, 2%, 5%, 10%, and 12%) were prepared by diluting the stock solution with distilled water. Linseed seeds were soaked in these solutions for 16 and 18 hours. Untreated seeds served as the control. After soaking, the seeds were air-dried to their original weight before sowing in the field.

Experimental design: The seeds of linseed (genotype LCK-9312) were treated with various concentrations of smoke water (T1 to T12) and subjected to different soaking durations (16 and 18 hours). The experimental setup included the following treatments: T1 (Unprimed), T2-T6 (Smoke water at concentrations of 0.5%, 1%, 2%, 5%, 10%, and 12% for 16 hours), and T7-T12 (Smoke water at concentrations of 0.5%, 1%, 2%, 5%, 10%, and 12% for 18 hours).

Assessment parameters: The performance of the linseed crop was evaluated based on several agronomic and biochemical parameters including field emergence, plant height (measured at 30, 60 and 90 days after sowing), first flowering, days to 50% flowering, number of capsules, seeds per capsule, number of branches, seed yield per plant, seed yield per plot, seed yield per hectare, biological yield, harvest index, oil content, protein content and chlorophyll content. Chlorophyll content was estimated by using Chlorophyll SPAD meter while oil content was determined using the Soxhlet extraction method (Luque and Garcia, 1998). Protein content was estimated using the Lowry *et al.* (1951) method.

Statistical analysis: Statistical analysis of the data was performed using the software package WASP (ICARGOA). Analysis of variance (ANOVA) was conducted, and the significance of the F-test was determined at the 5% level of probability. Critical difference values were calculated to assess significant differences among treatment means.

RESULTS AND DISCUSSION

The research findings presented in Tables 1, 2, and 3 offer comprehensive insights into the effects of smoke water treatments on various pre-harvest, post-harvest, and biochemical characteristics of linseed. The detailed overview of results is given below:

The field emergence of linseed seeds varied across treatments, with an average emergence time of 12.59 days. Treatment T1 (0.5% smoke water for 16 hours) showed a slightly delayed emergence (12.67 days), while T2 (1% for 16 hours) had the longest emergence time (15.5 days). Treatment T8 (1% for 18 hours) exhibited the highest emergence (14.67 days), while T5 (10% for 16 hours) had the shortest (11.5 days), though only marginally better than the control.

The plant height of linseed varied across treatments at different stages of growth. At 30 days after sowing (DAS), the tallest plants were observed in Treatment T8 (1% smoke water for 18 hours) with an average height of 10.19 cm, followed by T3 (2% for 16 hours) and T2 (1% for 16 hours). At 60 DAS, T8 remained the tallest (43.07 cm), followed by T2 and T9 (2% for 18 hours). By 90 DAS, T8 maintained its lead in plant height (81.28 cm), followed closely by T2 and T3.

The days to first flowering and days to 50% flowering in linseed were influenced by different treatments. Treatment T2 (1% smoke water for 16 hours) exhibited the shortest duration to first flowering (52.67 days), followed closely by T2 (1% for 18 hours) and T8 (0.5% for 18 hours). Similarly, for 50% flowering, T8 had the shortest duration (65.67 days), followed by T2 and T9 (2% for 18 hours). Conversely, the control group (T0) consistently showed the longest duration to both first and 50% flowering. These results suggest that treatments involving lower concentrations and shorter durations of smoke water may accelerate the flowering process in linseed compared to the control group.

The number of primary branches per plant and the number of secondary branches per plant in linseed were affected by different treatments. Treatment T8 (1% smoke

water for 18 hours) had the highest number of primary branches per plant (4.27), followed by T2 (1% for 16 hours) and T7 (0.5% for 18 hours). Similarly, for secondary branches per plant, T8 also had the highest count (24.83), followed by T2 and T7. Conversely, the control group (T0) consistently exhibited the lowest number of both primary and secondary branches per plant.

The days to maturity of linseed plants varied across different treatments. Treatment T2 (1% smoke water for 16 hours) exhibited the shortest duration to maturity, with plants maturing in approximately 111.67 days, followed closely by T8 (1% for 18 hours) and T3 (2% for 16 hours). Conversely, the control group (T0) took the longest time to mature, with plants reaching maturity in 123.67 days. Overall, treatments involving lower concentrations of smoke water tended to result in earlier maturity compared to higher concentrations and longer durations. The differences observed suggest that smoke water treatments have the potential to influence the maturation process in linseed plants, possibly accelerating or delaying it depending on the concentration and duration of exposure.

The number of capsules per plant and the number of seeds per capsule in linseed plants were examined across different treatments. On average, linseed plants produced approximately 96.78 capsules per plant, with an average of 7.39 seeds per capsule. Among the treatments, T8 (1% smoke water for 18 hours) had the highest number of capsules per plant at 97.6, followed closely by T2 (1% for 16 hours) and T9 (2% for 18 hours). However, there were no significant differences observed among the treatments regarding the number of seeds per capsule. Overall, the results suggest that smoke water treatments did not significantly impact the number of seeds per capsule but may have influenced the number of capsules produced per plant, with certain concentrations and durations showing a slight increase compared to the control.

The seed yield per plant, seed yield per plot, and seed yield per hectare were assessed across different treatments in linseed cultivation. On average, the seed yield per plant ranged from 2.6 to 4.37 grams, with a grand mean of 3.41 grams. Similarly, the seed yield per plot varied from 64 to 70 grams, with a grand mean of 67.59 grams. Regarding seed yield per hectare, the values ranged from 6.4 to 7.0 quintals per hectare, with a grand mean of 6.76 kg per hectare.

Among the treatments, T2 (1% smoke water for 16 hours) exhibited the highest seed yield per plant, while T8 (1% for 18 hours) had the highest seed yield per plot and T8 and T2 showed the highest seed yield per hectare. These results suggest that certain concentrations and durations of smoke water treatments positively influenced seed yield in linseed cultivation compared to the control group. However, statistical analysis indicated no significant differences in seed yield among most treatments, except for some variations observed within the range of standard error.

The test weight of seeds, which serves as an indicator of seed density and quality, was assessed across various treatments in linseed cultivation. On average, the test weight ranged from 5.23 to 6.4 grams, with a grand mean of 5.77 gm. Notable variations were observed among the treatments. Treatment 2 (Smoke water 1% for 16 hours) exhibited the highest test weight at 6.4 grams, indicating potentially improved seed quality. Conversely, Treatment 11 (Smoke water 10% for 18 hours) recorded the lowest test weight of 5.43 grams. However, statistical analysis revealed no significant differences in test weight among most treatments, as the values fell within the range of standard error.

Table 1 Mean performance of smoke water on Pre-harvest characters of linseed

Treatments	Field emergence (Days)	Plant height at 30DAS (cm)	Plant height at 60DAS (cm)	Plant height at 90DAS (cm)	Days to first flowering (Days)	Days to 50% flowering (Days)	No. of primary branches/ plant	Number of secondary branches/plant	Days to maturity (Days)
T0- CONTROL	11.25	8.07	38.00	77.20	61.00	76.33	3.10	22.93	123.67
T1-Smoke water 0.5% (16 hrs)	12.67	8.66	38.25	77.71	55.00	74.67	3.47	23.20	117.33
T2- Smoke water 1% (16 hrs)	15.50	9.70	42.38	80.93	52.67	67.00	3.87	24.17	111.67
T3- Smoke water 2% (16 hrs)	13.50	9.67	41.47	79.29	53.00	71.67	3.27	23.63	114.67
T4- Smoke water 5% (16 hrs)	12.00	8.39	37.67	77.06	55.67	75.33	3.33	23.27	117.67
T5- Smoke water 10% (16 hrs)	11.50	8.55	38.32	77.48	55.33	75.00	3.40	23.40	119.67
T6- Smoke water 12% (16 hrs)	12.17	8.49	38.16	77.22	55.00	74.67	3.37	23.33	117.00
T7- Smoke water 0.5% (18 hrs)	11.25	8.83	38.15	77.63	54.67	74.00	3.50	23.27	118.67
T8- Smoke water 1% (18 hrs)	14.67	10.19	43.07	81.28	52.00	65.67	4.27	24.83	112.33
T9- Smoke water 2% (18 hrs)	12.50	9.25	41.41	77.74	53.67	70.00	3.67	23.40	115.33
T10- Smoke water 5% (18 hrs)	11.50	8.55	38.03	77.03	55.00	75.00	3.57	23.13	113.33
T11- Smoke water 10% (18 hrs)	12.50	9.17	38.25	76.69	55.00	74.67	3.53	23.60	114.67
T12- Smoke water 12% (18 hrs)	12.67	8.44	38.11	76.31	54.67	74.00	3.40	23.00	117.67
SE (d)	1.31	0.64	2.10	1.86	2.36	3.48	0.35	0.69	3.32
SE (m)	0.21	0.10	0.34	0.30	0.38	0.56	0.06	0.11	0.53
CD at 5%	0.73	0.38	1.62	2.23	2.32	2.19	0.43	0.90	1.88

Table 2 Mean performance of smoke water on post-harvest characters of linseed

Treatments	Number of capsules/plant	Number of seeds/capsule	Seed yield/ plant (g)	Seed yield/plot (g)	Seed yield (kg/h)	Test weight (g)	Biological yield (g)	Harvest index (%)
T0- Control	95.73	7.35	2.60	66.67	6.67	5.23	10.51	24.72
T1-Smoke water 0.5% (16 hrs)	96.23	7.37	3.40	67.00	6.70	5.90	11.23	30.30
T2- Smoke water 1% (16 hrs)	97.90	7.43	4.37	70.00	7.00	6.40	12.04	36.26
T3- Smoke water 2% (16 hrs)	97.00	7.38	4.07	68.67	6.87	5.80	11.75	34.31
T4- Smoke water 5% (16 hrs)	96.53	7.37	3.70	67.67	6.77	5.77	12.11	30.14
T5- Smoke water 10% (16 hrs)	96.63	7.38	3.20	67.33	6.73	5.63	10.70	29.88
T6- Smoke water 12% (16 hrs)	96.90	7.38	3.03	64.00	6.40	5.80	11.45	26.49
T7- Smoke water 0.5% (18 hrs)	96.70	7.38	2.93	67.67	6.77	5.87	11.21	26.18
T8- Smoke water 1% (18 hrs)	97.60	7.41	4.23	69.33	6.93	6.00	12.02	35.22
T9- Smoke water 2% (18 hrs)	97.23	7.47	3.50	68.33	6.83	5.93	11.15	31.40
T10- Smoke water 5% (18 hrs)	96.63	7.41	3.00	67.00	6.70	5.60	10.55	28.47
T11- Smoke water 10% (18 hrs)	96.73	7.35	3.25	67.33	6.73	5.43	10.63	30.63
T12- Smoke water 12% (18 hrs)	96.27	7.36	3.10	67.67	6.77	5.70	11.27	27.51
SE (d)	0.74	0.07	0.55	1.94	0.19	0.30	0.61	3.87
SE (m)	0.12	0.01	0.09	0.31	0.03	0.05	0.10	0.62
CD at 5%	1.010	NS	0.332	2.714	0.271	0	0.512	3.018

Table 3 Mean performance of smoke water on Biochemical characters of linseed

Treatments	Chlorophyll content 60DAS (mg/g)	Chlorophyll content 90DAS (mg/g)	Oil content (%)	Protein content (µg)
T0- CONTROL	0.025658	0.027244	35	0.909752
T1-Smoke water 0.5% (16 hrs)	0.025364	0.027704	35.16667	0.965449
T2- Smoke water 1% (16 hrs)	0.026148	0.028977	36	1.055131
T3- Smoke water 2% (16 hrs)	0.025064	0.027636	35.83333	1.072123
T4- Smoke water 5% (16 hrs)	0.025826	0.027778	35.16667	0.989049
T5- Smoke water 10% (16 hrs)	0.025853	0.028813	35.66667	0.924856
T6- Smoke water 12% (16 hrs)	0.025548	0.028977	35.66667	0.979609
T7- Smoke water 0.5% (18 hrs)	0.025921	0.028082	35.33333	0.966393
T8- Smoke water 1% (18 hrs)	0.025426	0.028973	35.66667	1.062683
T9- Smoke water 2% (18 hrs)	0.025055	0.027954	35.16667	0.950345
T10- Smoke water 5% (18 hrs)	0.024528	0.028195	35.5	0.984329
T11- Smoke water 10% (18 hrs)	0.025126	0.028088	36	0.939016
T12- Smoke water 12% (18 hrs)	0.024677	0.027968	35	0.93524
SE (d)	0.000491	0.000575	0.359050663	0.05323
SE (m)	0.001772	0.00016	0.359050663	0
CD at 5%	0.001	0.001	NS	0.020

The biological yield and harvest index were evaluated as key indicators of overall crop productivity and efficiency across different treatments in linseed cultivation. On average, the biological yield ranged from 10.51 to 12.11 g, with a grand mean of 11.28 grams. Treatment 4 (Smoke water 5% for 16 hours) exhibited the highest biological yield at 12.11 grams, indicating a potentially favorable impact on overall yield. Conversely, Treatment 5 (Smoke water 10% for 16 hours) recorded a slightly lower biological yield of 10.7 gm. Regarding the harvest index, which reflects the proportion of total biomass allocated to seed production, Treatment 2 (Smoke water 1% for 16 hours) demonstrated the highest index at 36.26%, suggesting enhanced seed yield efficiency. Conversely, Treatment 10 (Smoke water 5% for 18 hours) exhibited the lowest harvest index at 28.47%. Statistical analysis indicated significant differences in both biological yield and harvest index among treatments, as the values exceeded the

critical difference at 5% level of probability. These findings suggest that the application of smoke water treatments had a discernible impact on both biological yield and harvest index in linseed cultivation, highlighting the potential for optimizing crop productivity through targeted treatments.

The chlorophyll content at 60 and 90 days after sowing (DAS) was analyzed to assess the photosynthetic activity in linseed plants treated with different concentrations of smoke water. At 60 DAS, the chlorophyll content ranged from 0.025 to 0.026 mg/g, with Treatment 2 (Smoke water 1% for 16 hours) exhibiting the highest content, while Treatment 10 (Smoke water 5% for 18 hours) showed the lowest. Similarly, at 90 DAS, the chlorophyll content varied from 0.028 to 0.029 mg/g, with Treatment 2 again recording the highest value and Treatment 10 the lowest. Statistical analysis indicated significant differences among treatments for both time points, as the values exceeded the critical difference at a 5% level of probability. These results suggest that smoke water treatments could influence chlorophyll content at different stages of plant growth, potentially impacting photosynthetic efficiency and overall plant vigor.

The oil content of linseed seeds was evaluated to investigate the impact of smoke water treatments on seed quality. Across different treatments, the oil content ranged from 35.00% to 36.00%. Treatment 2 (Smoke water 1% for 16 hours) and Treatment 11 (Smoke water 10% for 18 hours) recorded the highest oil content, both at 36.00%, while control and Treatment 12 (Smoke water 12% for 18 hours) had the lowest oil content at 35.00%. The grand mean oil content was calculated at 35.474%. Statistical analysis indicated no significant differences among treatments, as the critical difference at a 5% level of probability was not exceeded. These findings suggest that the application of smoke water at varying concentrations and durations did not significantly alter the oil content of linseed seeds.

The protein content of linseed seeds was analyzed to assess the impact of different smoke water treatments on seed quality. Across the various treatments, the protein content ranged from 0.910 µg to 1.072 µg. Treatment 3 (Smoke water 2% for 16 hours) exhibited the highest protein content at 1.072 µg, while control had the lowest protein content at 0.910 µg. The grand mean protein content was calculated to be 0.980 µg. Statistical analysis revealed no significant differences among treatments, as the critical difference at a 5% level of probability was not exceeded. These results suggest that the application of smoke water at different concentrations and durations did not significantly impact the protein content of linseed seeds.

The discussion of our findings is supported by several studies in the literature. Chumpookam *et al.* (2012) and Gupta *et al.* (2019) have explored the effects of similar agricultural interventions on crop growth and yield, providing valuable insights into the potential benefits of smoke water application. Similarly, Jamil *et al.* (2014) and Kulkarni *et al.* (2011) have investigated the physiological responses of plants to smoke water treatments, shedding light on mechanisms underlying observed outcomes. Moreover, (Abou, 2021) contributes to our understanding of the application of smoke water in agriculture, corroborating some of our findings. Additionally, studies by Light *et al.* (2007) provide context on the broader impacts of smoke water on crop productivity and quality. Furthermore, the work of Kulkarni *et al.* (2011) extends our discussion by considering long-term effects, while Ghebrehiwot *et al.* (2013) offer insights into the ecological implications of smoke water application. Recent research by Komatsu et al. (2022) also supports our findings, highlighting the relevance of smoke water treatments in modern agricultural practices. Finally, the studies by Aslam *et al.* (2017), Iqbal *et al.* (2016) and Rehman *et al.* (2018) provide additional perspectives on the diverse applications and potential benefits of smoke water in crop production systems. These collective findings underscore the importance of further research and application of smoke water as a sustainable agricultural intervention.

In our present study, smoke water treatments revealed remarkable potential in enhancing the growth and physiological attributes of linseed plants. Among these, Treatment 2 (1% smoke water for 16 hours) emerged as the standout performer, showcasing significant improvements in plant height, flowering duration, branching patterns, chlorophyll content, and oil yield. These findings underscore the transformative impact of smoke water as a sustainable agronomic intervention for optimizing crop productivity and quality in linseed cultivation. Further exploration and refinement of smoke water application protocols hold promise for unlocking even greater benefits in agricultural practices.

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Standardization of pre-sowing seed treatment with selected botanicals on growth, yield and yield attributing traits of linseed (*Linum usitatissimum* L.)

MATTAPELLY DIVYA*[1] AND PRASHANT KUMAR RAI[1]

Sam Higginbottom University of Agriculture, Technology and Sciences, Naini, Prayagraj-211 007, Uttar Pradesh

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ABSTRACT

The present study was aimed to determine the effect of different doses and duration of pongamia, tulsi, moringa and neem leaf extract on growth, yield and yield attributing traits of linseed (cv. GP-I-44). A field study was conducted during *rabi* 2022-2023 at the field experimentation centre of Department of Genetics and Plant breeding, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj. The study was carried out in a Randomized Block Design with 13 treatment combinations in three replications to assess the effect of seed priming with botanicals on linseed seeds under various levels of pongamia leaf extract, tulsi leaf extract, moringa leaf extract and neem leaf extract. The highest recorded yield attributes were observed in T3, where pongamia leaf extract at a concentration of 10% resulted in 114.33 capsules/plant, 8.77 seeds/capsule, 4.5 g/plant, 73.37 g/plot, and 733 kg/ha, with a 1000-seed weight of 8.15 g. Conversely, the lowest values were recorded in T7, with moringa leaf extract at 3% resulting in 105.00 capsules/plant, 7.67 seeds/capsule, 2.4 g/plant, 67.13 g/plot, and 671 kg/ha, with a 1000-seed weight of 7.15 g. Thus, the application of pongamia leaf extract at 10% concentration (T3) emerged as the most effective dosage for priming linseed.

Keywords: Botanicals, Leaf extracts, Linseed, Priming, Seed treatment

There are 13 genera of linseed, but only one species is cultivated *Linum usitatissimum* which originated in the Middle Eastern countries or Indian regions. The family Linaceae contains the genus Linum, which was cultivated for oil and fiber from the beginning of agriculture i.e. eight thousand years ago. In terms of area and production, it is the second-largest winter season oilseed crop in India, after rapeseed-mustard (Kumar *et al.,* 2022; Minz *et al.,* 2022). It is widely cultivated in Rajasthan, Bihar, Uttar Pradesh, Assam, and Jharkhand followed by other states. Madhya Pradesh has the largest growing area (1.16 lakh ha) and production (0.55 lakh tonnes) with a productivity 474 kg/ha (Anand and Pragnya, 2020). The process of seed priming involves exposing the seeds to a low water potential, which inhibits germination but permits pre-germinate physiological and biochemical changes (Vazquez *et al.,* 2020). In many species, this allows greater tolerance to environmental stresses and a reduction of dormancy, which prevents radical protrusion through seed coats and allows a more uniform germination rate. It also stimulates indigenous microbes in the root zone (Kursinga *et al.,* 2019). Natural chemical compounds from plants are cheap, readily available and cost effective in growing nations where synthetic fungicides are scarce and high priced for poverty-stricken farmers (Sneha *et al.,* 2022). Plant extracts are considered non-phytotoxic and effective in controlling pathogenic diseases in plants. It has a synergistic effect on early and uniform seed germination and enhances tolerance to pests during the early crop stage. Botanical leaf powders might also stimulate germination and related processes. Botanicals like neem leaf, pongamia leaf, tulsi leaf, and moringa leaf are used for seed treatment. *Azadirachtin* is the main pesticidal component of neem and it is widely available, cheap and safe to use for beneficial organisms. In addition to its allelochemical properties, *Moringa oleifera* is also considered a potential allelopathic crop because of its natural antioxidant, mineral element, vitamin, and growth-promoting properties (Kumar *et al.,* 2017). Moringa leaf extracts via seed priming are also known to enhance seedling emergence and establishment and enhance crop development and growth (Sarwar *et al.,* 2020). Plants are rich in secondary metabolites that have antiviral, antibacterial, and antifungal properties (Maria *et al.,* 2018). In addition to pinnalin and pongamol, the leaves of Pongamia pinnata contain saponin, phytosterol, and tannins that could have stimulated the germination and establishment of seedlings. Therefore, these leaf powders could be used as an organic fertilizer to improve plant quality and yield since they increased nutrient uptake, which results in enhanced growth and development. They can also be used to replace chemical fertilizers, reducing environmental pollution (Prakash *et al.,* 2021). Hence, the present study carried out to determine the effect of different doses of leaf extracts of neem, pongamia, tulsi, and moringa on growth, yield and yield attributing traits of linseed.

Corresponding author's E-mail: mattapellydivya1997@gmail.com

MATERIALS AND METHODS

The experiment on linseed genotype GP-I-44 was carried out at the Field Experimentation Centre and Notified State Seed Testing Laboratory of the Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh during *rabi* season 2022-2023. A factorial experiment was conducted based on a randomized block design with three replications in the field conditions. Solutions with different concentrations of leaf extracts of neem, pongamia, tulsi, and moringa were prepared and mixed with 100 ml of distilled water. The seeds were then soaked in different concentrations (10%, 5%, and 3%) of botanical solutions for 12 h and untreated seeds served as control. After 12 h of soaking the solution was drained out of the beaker and the pre-soaked seeds were air-dried to their original weight and sown in the field. Observations were recorded on growth and yield parameters of linseed. Treatments (No gap between treatment and description; bring the % concentration to the front as indicated) are T0- Control, T1- 3% Pongamia leaf extract, T2- 5% Pongamia leaf extract, T3- 10% Pongamia leaf extract, T4 - 3% Tulsi leaf extract, T5- 5% Tulsi leaf extract, T6 - Tulsi leaf extract - 10%, T7 - Moringa leaf extract - 3%, T8 - Moringa leaf extract - 5%, T9 - Moringa leaf extract - 10%, T10 - Neem leaf extract - 3%, T11 - Neem leaf extract - 5%, T12 - Neem leaf extract - 10%. Main objectives of the experiment were to find out suitable doses and duration of selected botanicals for linseed and to estimate the benefit cost.

RESULTS AND DISCUSSION

All the parameters that are affected by treatments showed significant variation for growth and yield attributes (Table 1 to 3).

Growth parameters: Plant height at 90 DAS recorded the highest (90.3 cm) with the treatment T2-Pongamia leaf extract - 5% and lowest in T9-Moringa leaf extract - 10% with 77.1 cm respectively. Maximum number of primary (5.3) and secondary branches of and (37.4) were recorded with the treatments T10-Neem leaf extract - 3% and T3-10% Pongamia leaf extract, respectively; the lowest of the same were recorded with T6-10% Tulsi leaf extract and untreated control respectively. The treatment T11-5% Neem leaf extract recorded the minimum number of days (78.3 days) required for days to 50% flowering and the minimum number of days required for maturity (120.6 days). The maximum number of days for 50% flowering and maturity and were recorded with treatments T7-3% Moringa leaf extract (85.3 d) and T6-10% Tulsi leaf extract (130.7 days) respectively.

Yield parameters: The treatment T3-10% Pongamia leaf extract recorded the maximum capsules/plant of 114.33; seeds/capsule of 8.7; test weight of 8.2 g; seed yield/plant of 4.5 g, seed yield/plot of 73.37 g; seed yield/hectare of 733.7 kg; biological yield of 13.21 g/plant; and harvest index of 34.29% respectively. The treatment T7-3% Moringa leaf extract recorded the minimum capsules/plant, seeds/capsule, test weight, seed yield/plant g, seed yield/plot, seed yield/hectare, biological yield and harvest index.

Correlation coefficient analysis: Correlation studied between growth and yield attributing traits of linseed. Growth and Yield traits are significant to each other. Therefore, selection of a suitable treatment should be based on growth traits, which influence 16 characters in linseed and also finds that 15 characters showed significant differences. The influence of treatment for various characters plant Height at 30, 60 and 90 DAS, number of primary branches/plant, number of secondary branches/plant, days to 50% flowering, days to maturity, number of capsules/plant, test weight, number of seeds/capsule, seed yield/plant, seed yield/plot, seed yield/hectare, indicated the influence of botanicals treatments under field conditions in a crop linseed.

It is necessary to have a good knowledge of those characters that have significant association with growth and yield because the characters can be used as indirect selection criteria or indices to enhance the mean performance of varieties in a new plant. In the present phenotypic correlation coefficient computed from the estimates of variance and covariance for all possible combinations of the characters were studied and their values are given in table 1 and 2 and their brief description as follows:

Phenoypic correlation coefficient analysis

Correlation between growth and yield attributing traits of linseed

Pre-harvest parameters: Plant height at 30 DAS: Plant height at 30 DAS showed non-significant positively association with plant height at 60 days (0.28), days to 50% flowering (0.27), days to maturity (0.19), number of capsules/plant (0.00), and biological yield (0.15). while negatively non- significant association with plant height at 90 days (-0.09), primary branches (-0.03), secondary branches (-0.10), number of seeds/capsules (-0.10), seed yield/plant (-0.08), seed yield/plot (-0.24) and seed yield/hectare (-0.44), test weight (-0.44), harvest index (-0.33).

Plant height at 60 DAS: Plant height at 60 DAS showed a highly significant positively association with plant height at 90 days (0.53), primary branches (0.30), secondary branches (0.32), days to 50% flowering (0.48), days to maturity (0.24), number of seeds/capsules (0.38), seed yield/plant (0.04). while negatively significant association with number of capsules/plant (-0.10), seed yield/plot (-0.16) and seed yield/hectare (-0.47), test weight (-0.47), biological yield (-0.15), harvest index (-0.30).

Plant height at 90 DAS: Plant height at 90 DAS showed a highly significant positively association with primary branches (0.44), days to 50% flowering (0.38), days to maturity (0.36), number of seeds/capsules (0.08). while negatively significant association with secondary branches (-0.14), number of capsules/plant (-0.20), seed yield/plant (-0.40), seed yield/plot (-0.05) and seed yield/hectare (-0.49), test weight (-0.49), biological yield (-0.51), harvest index (-0.32).

Number of primary branches/plant: Number of primary branches/plant showed a highly significant positively association with secondary branches (0.16), days to 50% flowering (0.38), days to maturity (0.62). while negatively significant association with number of capsules/plant (-0.48), number of seeds/capsules (-0.31), seed yield/plant (-0.54), seed yield/plot (-0.31) and seed yield/hectare (-0.38), test weight (-0.38), biological yield (-0.31), harvest index (-0.53).

Number of Secondary branches/plant: Number of secondary branches/plant showed a highly significant positively association with capsules/plant (0.33), number of seeds/capsules (0.18), seed yield/plant (0.58), seed yield/plot (0.27), seed yield/hectare (0.49), test weight (0.49), biological yield (0.49), harvest index (0.38). while negatively significant association with number of days to 50% flowering (-0.12), days to maturity (-0.05).

Days to 50% flowering: Days to 50% flowering showed a highly significant positively association with days to maturity (0.53), number of seeds/capsules (0.07). while negatively significant association with number of capsules/plant (-0.53), seed yield/plant (-0.38), seed yield/plot (-0.22) and seed yield/hectare (-0.77), test weight (-0.77), biological yield (-0.64), harvest index (-0.71).

Days to maturity: Days to maturity showed a negatively significant association with number of capsules/plant (-0.55), number of seeds/capsules (-0.49), seed yield/plant (-0.56), seed yield/plot (-0.46) and seed yield/hectare (-0.61), test weight (-0.61), biological yield (-0.32), harvest index (-0.61).

Post-harvest parameters

No. of capsules/plant: No. of capsules/plant showed a highly significant positively association with number of seeds/capsules (0.58), seed yield/plant (0.72), seed yield/plot (0.52), seed yield/hectare (0.62), test weight (0.62), biological yield (0.83), harvest index (0.70).

No. of seeds/capsules: No. of seeds/capsules showed a highly significant positively association with seed yield/plant (0.67), seed yield/plot (0.38), seed yield/hectare (0.13), test weight (0.13), biological yield (0.24), harvest index (0.25).

Seed yield/plant: Seed yield/plant showed a highly significant positively association with Seed Yield/Plot (0.43), seed yield/hectare (0.62), test weight (0.62), biological yield (0.66), and harvest index (0.59).

Seed yield/plot: Seed yield/plot showed a highly significant positively association with seed yield/hectare (0.61), test weight (0.61), biological yield (0.26), and harvest index (0.61).

Seed yield/hectare: Seed yield/hectare showed a highly significant positively association with test weight (1.00), biological yield (0.65), and harvest index (0.86).

Test weight: Seed yield/hectare showed a highly significant positive association with biological yield (0.65), harvest index (0.86).

Biological yield: Seed yield/hectare showed a highly significant positively association with harvest index (0.70).

The study revealed significant variations in plant height, branch numbers, flowering, and maturity periods among different treatments. Notably, the treatment with 5% Pongamia leaf extract (T2) resulted in the tallest plants at 90 DAS, reaching 90.2 cm. Meanwhile, treatments T10 (3% Neem leaf extract) and T3 (10% Pongamia leaf extract) demonstrated the highest numbers of primary and secondary branches, with 5.33 and 37.42, respectively.

Pongamia pinnata leaves are known to contain various beneficial compounds like pinnalin, pongamol, saponin, ?-sitosterol, and tannins. These substances likely facilitated nutrient uptake, thereby promoting enhanced growth and development. Consequently, the incorporation of these leaf powders as organic amendments holds promise for improving plant quality and yield. Furthermore, the increased capsule count observed due to Pongamia leaf

powder aligns with previous studies by Sathiya Narayana *et al.* (2013) and Nandha (2010), indicating a consistent trend in the literature.

Regarding flowering and maturity periods, treatments T7 (3% Moringa leaf extract) and T6 (10% Tulsi leaf extract) exhibited the longest durations, with 85.33 and 130.67 days, respectively. Both Moringa and Tulsi leaves are recognized for their rich content of antioxidants, mineral elements, vitamins, and growth-promoting substances. These attributes, along with their allelochemical properties, likely contribute to improved seedling emergence and crop development, particularly under unfavorable climatic conditions, as suggested by Narayanan *et al.* (2016).

From the present experiment, based on the positive results obtained indicates that seed priming enhanced the growth and yield attributes of Linseed; priming with 10% Pongamia leaf extract maintains the growth and yield of Linseed to a particular extent.

The treatment T3-10%Pongamia leaf extract found to be promising amongst the treatments respectively. Similarly, the performance of at par treatment T6-10% Tulsi leaf extract also performed well. Were found to be most promising and can be recommended as a priming agents of linseed.

Table 1 Analysis of variance for growth and seed yield parameters of linseed

Characters	Mean sum of square		
	Replications (df=2)	Treatments (df=12)	Error (df=24)
Plant height at 90 DAS	469.904	39.15*	0.91
No.of Primary branches / plant	25.744	2.14*	0.18
No .of Secondary branches / plant	126.382	10.53*	0.33
Days to 50% flowering	144.923	12.07*	0.32
Days to maturity	316.667	26.38*	0.5
No.of Capsules / plant	263.026	21.91*	0.58
No.of Seeds / capsule	4.33	0.26*	0.08
Seed yield / plant	3.209	0.26*	0.05
Seed yield / plot	13.876	1.15*	0.16
Seed yield / hectare	3664.586	305.38*	1.59
Test weight	36.715	3.06*	0.15
Biological yield	74.638	6.22*	0.27
Harvest index	48.346	4.02*	0.23

*Significant @ 5% level of significance

Table 2 Effect of treatments on mean performance of growth and yield attributes

Treatments	Plant height at 90 DAS	Primary Branches	Secondary Branches	Days to 50% flowering	Days to maturity	Capsules / plant	Seeds / capsule	Test weight (g)	Yield / Plant (g)	Yield / Plot (g)	Yield / hectare (kg/ha)	Biological yield (g/plant)	Harvest Index (%)
T0	79.93	3.33	31.32	82.00	123.33	105.67	7.73	7.18	3.47	69.31	693	9.61	36.10
T1	82.32	4.33	32.81	83.33	125.67	108.33	8.43	7.58	3.50	68.00	680	9.79	35.75
T2	90.26	4.67	33.12	80.33	125.33	111.67	8.23	7.38	4.47	71.19	711	12.31	36.31
T3	80.92	3.33	37.42	80.67	120.67	114.33	8.77	8.15	4.53	73.37	733	13.21	34.29
T4	82.38	4.33	36.81	83.33	128.33	107.33	8.07	7.78	4.20	68.00	68	11.85	35.44
T5	84.55	4.00	35.13	79.67	127.33	107.67	8.63	7.45	3.33	70.13	701	10.61	31.38
T6	78.48	2.67	33.79	79.33	122.33	112.67	7.90	8.05	3.47	69.39	693	9.95	34.87
T7	88.38	5.33	32.71	85.33	130.67	105.00	7.73	7.15	2.43	67.13	671	8.97	27.09
T8	80.95	3.67	33.11	81.33	129.33	109.67	8.03	7.58	3.87	68.11	681	9.39	41.21
T9	77.11	5.00	34.56	79.33	127.33	109.67	7.67	7.38	3.33	68.33	683	10.91	30.52
T10	82.38	5.67	36.71	81.67	126.67	107.00	8.07	7.55	3.53	69.00	690	10.83	32.59
T11	81.87	4.00	34.13	78.33	124.00	108.67	8.03	7.78	3.03	69.33	693	9.31	32.54
T12	81.69	4.00	32.93	80.00	122.67	107.67	8.40	7.58	4.47	68.60	686	9.41	47.50
GMean	82.40	4.18	34.20	81.13	125.67	108.87	7.77	7.58	3.66	69.22	692	10.53	34.75
F Test	S	S	S	S	S	S	S	S	S	S	S	S	S
SE (M)	2.36	0.41	0.73	0.36	0.8	1.61	0.23	0.009	0.41	8.99	0.009	0.71	0.68
CD@5%	0.19	0.19	0.07	0.12	0.08	0.06	0.36	0.1	0.32	0.05	0.05	0.09	0.17
CV	4.96	17.09	3.70	0.78	1.11	2.57	4.89	0.211	19.7	2.02	0.207	3.17	3.12
SE (D)	5.71	1.14	2.10	2.02	3.12	3.62	0.54	0.34	1.00	9.97	0.99	1.73	1.49
SD (E)	0.91	0.18	0.33	0.32	0.50	0.58	0.08	0.05	0.16	1.59	0.15	0.27	0.23

Table 3 Correlation coefficient analysis for different traits in linseed

Characters	Plant height at 90 DAS	Primary Branches	Secondary Branches	Days to 50% flowering	Days to maturity	Capsules / plant	Seeds / capsule	Test weight(g)	Yield / Plant (g)	Yield / Plot (g)	Yield / hectare (kg/ha)	Biological yield (q/ha)	Harvest Index (%)
Plant height at 90 DAS	1												
Primary Branches	0.44	1											
Secondary Branches	-0.14	0.16	1										
Days to 50% flowering	0.38	0.38	-0.12	1									
Days to maturity	0.36	.624*	-0.05	0.53	1								
Capsules / plant	-0.20	-0.48	0.33	-0.53	-0.55	1							
Seeds / capsule	0.08	-0.31	0.18	0.07	-0.49	.581*	1						
Test weight(g)	-0.40	-0.54	.588*	-0.38	-.560*	.722**	.670*	1					
Yield / Plant (g)	-0.05	-0.31	0.27	-0.22	-0.46	0.52	0.38	0.43	1				
Yield / Plot (g)	-0.49	-0.38	0.49	-.770**	-.612*	.627*	0.13	.623*	.619*	1			
Yield / hectare (kg/ha)	-0.49	-0.38	0.49	-.770**	-.611*	.625*	0.13	.623*	.618*	1.000**	1		
Biological yield (q/ha)	-0.49	-0.31	0.49	-.646*	-0.32	.830**	0.24	.669*	0.26	.654*	.654*	1	
Harvest Index (%)	-0.51	-0.53	0.38	-.710**	-.610*	.709**	0.25	.598*	.611*	.867**	.867**	.709**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

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Standardization of pre-sowing treatments of bio-fertilizer and botanicals on growth, yield and yield attributing traits of linseed (*Linum usitatissimum* L.)

R PRASANNA, PRASHANT KUMAR RAI* AND P INDRAJITSINGH GIRASE

Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj-211 008, Uttar Pradesh

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ABSTRACT

Field experiment was conducted to standardize pre-sowing treatments of bio-fertilizer and botanicals on growth, yield and yield attributing traits of linseed [cv. GP(I) 101]. The experiment involved one genotype replicated thrice with 12 distinct treatments using Randomized Block Design. The findings demonstrated notable results across various parameters but significantly higher values were recorded for treatments involving neem leaf and neem seed extract (T11) across all parameters, indicating their potential efficacy in enhancing linseed growth and yield like field emergence (89.10%), plant height (72 cm), days to 50% flowering (81 days), number of primary branches per plant (8.46), number of secondary branches per plant (28), days to maturity (111 days), number of capsules per plant (143), number of seeds per capsule (8.8), seed yield per plant (7.53 g), seed yield per plot (91.2 g), seed yield per hectare (11.58 kg), test weight (6.40 g), biological yield (26.06 g), harvest index (36.04%) and seed index (8.58).

Keywords: Bio-fertilizer, Botanicals, Linseed, Pre-sowing treatments

Linseed or flax (2n=30) is the only species of agricultural significance within the Linaceae family of 14 genera and 200 species (Wang *et al.,* 2012; Diederichsen and Richards, 2003). This self-pollinated crop has been cultivated for centuries primarily for its seed oil (linseed), stem fibers (flax), or both (Zohary, 1999). Linseed oil is remarkable for its health benefits primarily attributed to its high content of dietary fiber (20-25%) and omega-3 alpha-linolenic acid (45-65%) as well as linseed oil cake, is prized for its nutritional richness and serves as a valuable feed for poultry, animals, and milch cattle, commanding a premium price compared to alternatives like rapeseed and mustard cake (Green and Marshall, 1981; Rabetafika *et al.,* 2011; Minz *et al.,* 2022; Kumar *et al.,* 2022). Given its impressive drying properties, it is also a prerequisite for its use as an industrial product (Cullis, 2007). Moreover, linseed cake finds application as organic manure, boasting significant nitrogen, phosphorous, and potash content, further enhancing its agricultural value. The significance of linseed transcends its nutritional and medicinal attributes; it has established itself as a cornerstone of global agriculture (Puppel *et al.,* 2023). India's position as the fifth-largest linseed producer underscores its pivotal role in global agricultural markets. Madhya Pradesh, in India, stands out as the leading producer and cultivator of linseed, dominating both in terms of production area Globally, linseed cultivation spans across 32.23 lakh hectares, yielding 30.68 lakh tons with an average productivity of 952 kg/ha. In contrast, India's linseed cultivation encompasses 1.7 lakh hectares, yielding approximately 1 lakh tons with a productivity of 574 kg/ha (Mohammad *et al.,* 2022).

Corresponding author's E-mail: prashant.rai@shiats.edu.in

Biofertilizers and botanicals enhance crop growth by providing nutrients through natural processes like nitrogen fixation and phosphorus solubilization, stimulating plant growth, nodulation (Muthusamy *et al.,* 2023). It also enhance crop germination and growth by solubilizing soil nutrients and producing growth-stimulating substances like siderophores and hormones (Aloo *et al.,* 2022). Neem extract significantly inhibits seed mycoflora by 93.7% and enhances seed germination, while Tulsi shows 62.5% inhibition both can be used oilseed crops. Despite its historical prominence and nutritional richness, linseed cultivation faces challenges and opportunities in the modern agricultural landscape. This research aims to investigate the standardization of pre-sowing treatments involving bio-fertilizers and botanicals, specifically targeting the linseed genotype, GP(I)101. By elucidating the effects of these treatments, this study seeks to contribute to the optimization of linseed cultivation practices, thereby enhancing productivity and sustainability in linseed farming.

MATERIALS AND METHODS

A study was conducted during the rabi season of 2022-23 at the Field Experimentation Centre, Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Science, Prayagraj. The genotype GP(I)101 of linseed, obtained from the Directorate of Research, SHUATS, Prayagraj, Uttar Pradesh.

Procedure of preparation of leaf and seed extracts: Make the powdered of separately shade dried leaves using electric grinder. Take one gram Powder and dissolved in 100 ml of

distilled water to make 1 per cent leaf extract solution. These solutions were kept at room temperature for 48 hours. After 48 hours the leaf extracts were filtered by two layer of muslin cloth to remove unwanted material and leaf debris. Seeds were soaked independently in different leaf extracts at room temperature for twelve hours. prepared all solutions according to required concentration.

Procedure for Rhizobium and *Azotobacter:* Calculated the volume of bacterial suspension required to achieve a final concentration of 2% (w/v). Diluted the harvested bacterial suspensions with an appropriate volume of sterile saline solution to achieve the desired concentration.

The experiment was conducted in Randomized Block Design (RBD) with a spacing of 30 cm within rows and 10 cm between the plants. The seeds of linseed variety GP(I)101 were treated with different concentrations and combination of Neem seed Extract, Neem, Moringa, Pungamia, Tulsi leaf extracts as well as biofertilizer *viz.,* Rhizobium, and *Azotobacter,* for a duration of 12 hours. Observations were recorded based on five randomly selected plants in each replication for all important characters viz., plant height (cm), number of primary branches per plant, number of secondary branches per plant, days to maturity (days), number of capsules per plant, number of seeds per capsule, seed yield per plant (g), seed yield per plot (g), seed yield per hectare (kg), test weight (g), biological yield (g), harvest index (%), and seed index except Field emergence percentage and days to 50% flowering where the observations recorded on plot basis. Field emergence was observed in each plot on the 4^{th}, 7^{th} and 10^{th} days after sowing. The data was calculated using the formula suggested by Heydecker (1972).

$$\text{Field Emergence} = \frac{X1+X2+X3}{4+7+10} \times 100$$

Plant height (cm) was measured from ground level to the base of the topmost leaf at 30,60 and 90DAS. The average height of five plants was recorded in centimeters. The number of capsules for each plant was counted. The number of seeds per capsule was taken from each sample and an average number of seeds in a capsule was determined. One thousand clean dried seeds in five samples were counted randomly from the clean seed of each plot at the time of harvest and were weighed by an electrical balance. At harvest, all capsules were separated manually from five tagged plants individually and dried, the seed weight from each plant was recorded, and the means value of five plants was expressed as seed yield per plant in grams.

Statistical analysis: The analysis of data was worked out to test the signification tests. It was done according to the procedure of RBD for each character as per the methodology suggested by Fisher. The total variance and degree of freedom were partitioned into three components viz. treatment, Replications, and error. The data were subjected to analysis of variance adopting standard statistical methods. Analysis of variance was carried out according to the procedure of Randomized Block Design (RBD) for each character as per the methodology advocated by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Table 1 and 2 revealed that the differences among twelve treatments were significant for growth and yield, this indicates that there is ample scope for the selection of superior treatment for the improvement of the yield of linseed.

The field emergence varied significantly among treatments, with the highest emergence recorded in the treatment T11 (Neem seed extract + Neem leaf extract 2% for 12 hours) reaching (89.10%), while the lowest emergence of (11.60%) was observed in the (T0) control. Field emergence holds significant importance due to its direct impact on crop establishment. The plant height of treatment T11 (Neem seed extract + Neem leaf extract 2% for 12 hours) consistently resulted in maximum from 30 days to 90 DAS, with plants reaching (15.00cm), (52.00cm) and (73.00cm) respectively. It was followed by T12 (Pungamia + moringa 4% for 12 hours) (14.60cm), (50.40cm), (70.50cm). Whereas lowest was recorded in treatment with (T0) Control (7.40cm), (43.20cm), (63.00cm) accordingly. Plant height reflects the growth and development of crops and is closely associated with yield potential.

The number of primary branches per plant and the number of secondary branches per plant in linseed were affected by different treatments. T11 (Neem seed extract + Neem leaf extract 2% for 12 hours) had the highest number of primary branches per plant (8.46), Similarly, for secondary branches per plant (28), Conversely, the control (T12) consistently exhibited the lowest number of both primary and secondary branches per plan (6.2) and (24). So branching pattern of plants plays a crucial role in determining their architecture and overall productivity.

Days to 50% flowering, the shortest duration was observed in the Treatment T11 (Neem seed extract + Neem leaf extract, 2% for12 hours), with plants flowering in just (81.00) days. In contrast, the longest duration was noted in T7 the treatment involving (Tulsi leaf extract 6 % for 12 hours), with plants taking (87.00) days to reach 50% flowering.

The days to maturity of linseed plants varied across different treatments. Treatment T11 (Neem seed extract + Neem leaf extract, 2% for12 hours) exhibited the shortest duration to maturity, with plants maturing in approximately 111.00 days. Conversely, the control (T0) took the longest time to mature, with plants reaching maturity in 121.00 days. Timing of flowering and days to maturity is a directly influencing reproductive and yield potential.

The number of capsules per plant and number of seed per capsule ranged from (130 to 143) and (6 to 8.8), with the treatment T11 (Neem seed extract + Neem leaf extract, 2% for12 hours) showing the highest count at 143 capsules per plant and 8.8 seeds per capsules, while the lowest count of 130 capsules per plant was observed in the treatment involving T7 (Tulasi leaf extract 6% for 12 hours) and the control T0 performs the lowest count i.e 6.00 seeds per capsule. Number of capsules per plant and the number of seeds per capsule are key determinants of seed yield and quality.

The seed yield per plant ranged from 5.13 grams to 7.53 grams. Similarly, the seed yield per plot varied from 61.8 to 91.2 grams. Regarding seed yield per hectare, the values ranged from 7.21 to 11.58 kg per hectare.

Among the treatments, T11 (Neem seed extract + Neem leaf extract, 2% for12 hours) exhibited the highest seed yield per plant, seed yield per plot and seed yield per hectare (7.53g, 78.9g and 11.58kg) respectively. Whereas lowest seed yield per plant were recorded by (T0) Control with 5.13g, 61.8g and 7.08kg) respectively. Seed yield is a critical determinant of the economic viability and productivity of linseed cultivation so concentrations and durations of Neem seed extract and leaf extracts treatments positively influenced seed yield in linseed cultivation.

The test weight of seeds, which serves as an indicator of seed quality. On average, the test weight ranged from 5.23 to 6.40 grams, Notable variations were observed among the treatments. T11 (Neem seed extract + Neem leaf extract, 2% for12 hours) exhibited the highest test weight at 6.40 grams, indicating potentially improved seed quality. Conversely, Treatment T2 (*Azotobacter*, 2% for12 hours) recorded the lowest test weight of 5.23 grams.

The biological yield and harvest index were evaluated as key indicators of overall crop productivity. The biological yield ranged from 21.63 to 26.06 g, Treatment T11 (Neem seed extract + Neem leaf extract, 2% for12 hours) exhibited the highest biological yield at 26.06 grams, indicating a potentially favourable impact on overall yield. Conversely, T7 (Tulasi leaf extract 6% for 12 hours) recorded a slightly lower biological yield of 21.63 gm. Harvest index, which reflects the proportion of total biomass allocated to seed production, Treatment T11 (Neem seed extract + Neem leaf extract, 2% for12 hours) demonstrated the highest index at 36.04%, suggesting enhanced seed yield efficiency. Conversely, Treatment T5 (Moringa leaf extract, 4% for 12 hours) exhibited the lowest harvest index at 30.92%.

Seed index also varied significantly among treatments, with the highest index recorded in the treatment T11 (Neem seed extract + Neem leaf extract 2% for 12 hours) reaching 8.58, while the lowest index of 6.12 was observed in the treatment T0 Control.

This finding is consistent with previous studies that have reported the stimulatory effects of Neem extracts on seed germination and plant growth (Srinivas *et al.,* 2016). The enhanced emergence in T11 may be attributed to the presence of bioactive compounds such as gibberellins and cytokinins, which promote cell division and elongation, leading to faster and more uniform emergence (Kumar *et al.,* 2018). Additionally, the superior emergence observed in T11 likely contributed to the enhanced plant growth parameters, including plant height, branching, and flowering duration.

Treatment T11 exhibited superior performance in terms of seed yield parameters, including seed yield per plant, per plot, and per hectare. The higher seed yield observed in T11 is consistent with the findings of previous studies that have highlighted the positive effects of Neem extracts on crop yield and quality (Singh *et al.,* 2019). Neem extracts are known to possess growth-promoting properties and enhance nutrient uptake, resulting in increased biomass accumulation and ultimately higher seed yields (Patel *et al.,* 2020). Moreover, the higher test weight observed in T11 suggests denser and potentially higher-quality seeds, which is essential for ensuring better germination and crop establishment in subsequent seasons (Rathore *et al.,* 2017). The higher biological yield in T11 reflects increased vegetative growth and biomass accumulation, which can contribute to higher seed yields (Agrawal and Gupta, 2018). Furthermore, the higher harvest index observed in T11 suggests that a greater proportion of the total biomass produced is allocated towards seed production, highlighting the efficiency of seed utilization and conversion into harvestable yield (Mandal *et al.,* 2021).

Treatment T11, which exhibited the highest seed index, likely produced larger and heavier seeds with higher nutritional value and germination potential (Kumar *et al.,* 2020). These results highlight the significance of seed quality assessments and the potential of seed treatments to enhance seed size, weight, and overall quality in linseed cultivation.

It is concluded that the positive effects of Neem seed extract and leaf extract treatments on field emergence, plant growth, seed yield, and quality parameters in linseed cultivation. These findings underscore the potential of botanical extracts as sustainable and effective tools for enhancing productivity, yield and seed quality of linseed.

Table 1 Mean influence of different treatments on growth characters in linseed

Treatments	Field emergence (%)	Plant height (cm)			Days to 50% flowering (Days)	Number of primary branches/plant	Number of secondary branches/plant	Days to maturity (Days)
		30DAYS	60DAYS	90DAYS				
T0 -Control	77.60	7.40	43.20	63.00	83.00	6.2	24	121.00
T1-Rhizobium	84.90	13.70	49.50	69.30	84.00	6.73	26	113.00
T2-Azotobacter	84.00	13.10	48.90	68.70	83.00	7.4	25	114.00
T3-Neem seed extract	82.60	12.50	48.30	68.10	82.00	6.6	26	115.00
T4-Neem leaf extract	82.50	12.40	48.20	68.00	84.00	7.15	25	116.00
T5-Moringa leaf extract	81.60	11.50	47.30	67.10	83.00	6.53	25	117.00
T6-Pungamia leaf extract	80.60	10.50	46.30	66.10	84.00	6.4	24	118.00
T7-Tulasi leaf extract	79.80	9.70	45.50	65.30	87.00	6.53	26	119.00
T8-Rhizobium + Azotobacter	87.30	14.20	50.00	69.80	83.00	7.5	27	112.00
T9-Rhizobium + Tulasi	82.90	12.80	48.60	68.40	84.00	7.4	26	114.00
T10-Azotobacter + Tulasi	82.00	11.90	47.70	67.50	84.00	7.53	26	116.00
T11-Neem seed extract+ Neem leaf extract	89.10	15.00	52.00	72.00	81.00	8.46	28	111.0
T12 - Pungamia leaf extract+ Moringa leaf extract	88.30	14.60	50.40	70.50	82.00	7.83	27	112.00
SE (m)	0.624	0.333	0.396	0.416	0.558	0.292	0.288	0.496
SE (d)	3.897	2.084	2.477	2.601	3.489	1.825	1.804	3.102
CD at 5%	4.27	0.58	2.20	2.71	2.95	1.08	0.36	4.04

Table 2 Mean Influence of different treatments on yield characters in Linseed

Treatments	Number of capsules/plant	Number of seeds/capsule	Seed yield/plant (g)	Seed yield/plot (g)	Seed yield/ hectare (kg/ha)	Test weight (g)	Biological yield (g)	Harvest index (%)	Seed index
T0 -Control	134	6.00	5.13	61.8	7.08	5.60	22.98	32.99	6.12
T1-Rhizobium	137	7.23	5.73	75.03	7.5	5.43	25.41	34.89	9.12
T2-Azotobacter	134	8.2	6.53	70.86	8.18	5.23	22.38	33.69	8.46
T3-Neem seed extract	135	6.9	6.33	67.16	9.71	5.87	24.44	34.07	8.25
T4-Neem leaf extract	136	7.23	6.06	82.33	8.23	5.80	24.92	32.88	8.02
T5-Moringa leaf extract	137	7.76	6.76	75.9	7.59	5.63	21.92	30.92	7.68
T6-Pungamia leaf extract	136	7.2	6.66	73.6	9.36	6.00	24.05	34.44	7.45
T7-Tulasi leaf extract	130	6.13	5.39	78.43	7.84	5.80	21.63	34.6	7.16
T8-Rhizobium + Azotobacter	135	7.56	6.3	86.53	8.65	5.93	22.47	34.29	9.12
T9-Rhizobium + Tulasi	140	7.13	5.23	65.13	8.51	5.77	25.59	33.45	8.3
T10-Azotobacter + Tulasi	139	7.9	6.56	72.13	7.21	5.70	24.11	31.73	7.99
T11-Neem seed extract+ Neem leaf extract	143	8.8	7.53	91.2	11.58	6.40	26.06	36.04	8.58
T12 - Pungamia leaf extract+ Moringa leaf extract	141	8.03	7.0	78.9	8.89	5.90	24.13	35.51	7.51
SE (m)	0.603	0.139	0.087	1.753	0.175	0.05	0.472	0.341	0.133
SE (d)	3.766	0.869	0.547	10.947	1.094	0.30	2.951	2.134	0.832
CD at 5%	1.66	1.44	0.51	15.42	154.28	0	15.35	1.49	0.39

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Extraction and characterization of glycerides from oilseed of *Pongamia pinnata* plant found in Manipur

MD ABDUL HALIM SHAH[1] AND NAOREM SHUBHASCHANDRA SINGH[2]

Department of Chemistry, D M College of Science, Dhanamanjuri University, Imphal-795 001, Manipur

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ABSTRACT

The extraction of *Pongamia pinnata* seed oil was accomplished through the solvent extraction technique, employing petroleum ether as the solvent on the crushed kernel. Subsequent to extraction, the oil underwent purification for further analysis via column chromatography over silica gel (60-120 mesh), utilizing a mixture of petroleum ether and ethyl acetate (20:1) as the eluent. The resulting purified oil was then subjected to transesterification, producing the final product recognized as biodiesel, characterized by its composition of fatty acid methyl ester (FAME). The FAME composition of *Pongamia pinnata* seed oil was meticulously determined through NMR, IR, and GC-MS analyses. The transesterified oil of Pongamia pinnata revealed a FAME composition consisting of 10.53 wt% of methyl palmitate (C16:0), 68.05 wt% of methyl oleate (C18:1), 12.58 wt% of methyl stearate (C18:0), 3.65 wt% of methyl arachidate (C20:0), and 5.22 wt% of methyl behenate (C22:0).

Keywords: Biodiesel, Dambu, Non-edible vegetable oil, *Pongamia pinnata,* Transesterification

In the Manipur region of India, both plain and hilly areas are home to numerous wild plants producing fruits with seeds rich in non-edible oils. Many of these plants, despite their ecological significance, are often overlooked due to their perceived lack of economic value. Consequently, the commercial utilization of such oils is limited, leading to the gradual disappearance of these plants. Farmers, government bodies, and various public and private sectors tend to disregard these plants, resulting in a decline in plant diversity. Furthermore, the global concern over large-scale biodiesel production from edible oils potentially disrupting the food supply and demand balance is acknowledged. To mitigate this, non-edible oils can serve as an alternative feedstock for biodiesel industries, preserving edible oils for other uses, as highlighted in Leung *et al.* (2010) research.

The contemporary significance of biodiesel is underscored by its increasing use in diesel engines worldwide. Recognized for its renewability, biodegradability, non-toxicity, and carbon neutrality, biodiesel has garnered attention (Moser *et al.,* 2009; Satyarthi *et al.,* 2009; Knothe, 2010). Developed countries like Brazil, Indonesia, Malaysia, the USA, the UK, Canada, and Germany have already incorporated biodiesel-blended petro-diesel into their energy strategies. This shift is crucial for countries like ours, aiming for self-reliance in reducing dependence on petro-diesel, as emphasized in Diwani *et al.* (2011) and Aliyu *et al.* (2011) studies. In this context, the identification of fatty acid constituents in glycerides becomes imperative.

Biodiesel typically comprises methyl esters of long-chain fatty acids derived from non-toxic biological resources, such as vegetable oils and animal fats, through transesterification with methanol in the presence of a catalyst (Leung *et al.,* 2010; Rejila *et al.,* 2012; Moser *et al.,* 2009). Catalysts may include acids, bases, or enzymes (lipase). The advantages of biodiesel, contributing to both addressing global warming and energy issues, have been extensively reported (Leung *et al.,* 2010; Satyarthi *et al.,* 2009; Li *et al.,* 2008). Consequently, non-edible vegetable oils emerge as a viable alternative feedstock for biodiesel production (Srivastava *et al.,* 2000; Zhang *et al.,* 2003; Aliyu *et al.,* 2012).

One notable plant in this context is *Pongamia pinnata,* known as "Dambu" in Manipuri. Belonging to the Fabaceae family, this large evergreen tree, reaching 15-25 meters in height, is native to tropical and temperate Asia, including parts of India (Manipur), China, Japan, Malaysia, Australia, and Pacific islands.

Characterized by a large canopy casting moderate shades, Pongamia pinnata produces brown seed pods shortly after flowering, maturing in 10 to 11 months. These pods contain one or two bean-like brownish-red seeds measuring 1.5-2.5 cm with a brittle, oily coat. The plant's juices and oil are known for their antiseptic properties and resistance to pests. Pongamia oil, derived from the seeds, has been utilized for thousands of years as lamp oil, in soap making, and as a lubricant.

This versatile oil, known for its resilience in rainwater conditions, has found applications in diesel generators and is being explored in numerous projects across India and the third world as a biodiesel feedstock (Karmee *et al.,* 2005). Some un-electrified villages have successfully employed Pongamia oil in diesel generators, creating self-sustaining grid systems for water pumps and electric lighting. Notably, the Indian Institute of Science initiated a project in 1997, promoting the use of Pongamia oil in stationary generators

for electricity and irrigation pumps in rural areas. With over 20 million trees planted and 45,000 farmers involved since 2003, this initiative has received significant support.

Beyond its biodiesel potential, *Pongamia pinnata* exhibits biocidal activities against *V. cholera* and *E. coli,* along with applications as an inflammatory, antiseptic, and antipyretic agent. It serves as a natural insecticide and a non-toxic alternative to Jatropha oil for biodiesel production, ensuring sustainability without competing with food resources. The oil's non-edible nature, attributed to bitter-tasting flavonoids, further enhances its suitability for diverse agricultural purposes, including nitrogen fixation and use as a windbreak between fields and farms (Anandalakshmi *et al.,* 2015; Gandhimathy, 2022).

MATERIALS AND METHODS

Chemicals like methanol, ethyl acetate, silica gel were procured from Merck Mumbai. All the chemicals were of analytical grade and used without further treatment. BUCHI Rota-vapour R-200, Gas Chromatography Mass Spectro-photometer (GC-MS model-Perkin Elmer Clarus 600),

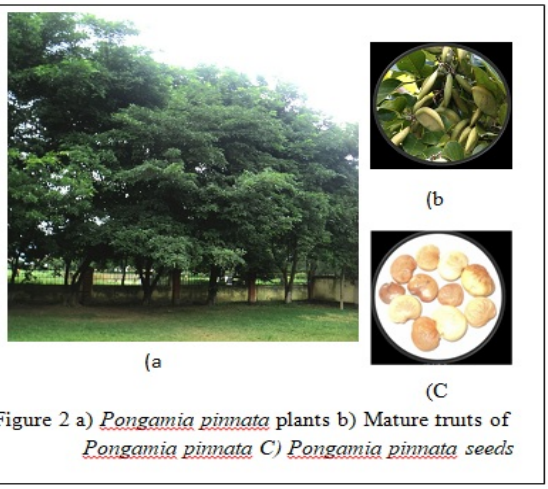

Figure 2 a) *Pongamia pinnata* plants b) Mature fruits of *Pongamia pinnata* C) *Pongamia pinnata* seeds

FT-IR (Perkin Elmer RXI), H1NMR and CNMR (Bruker Avance III 300 MHz/54mm NMR) were used for determination and analyses of the oil seeds of *Pongamia pinnata.*

Collection and seed extraction: Seeds were collected from the Imphal war Cemetery, Imphal East, Manipur (India) (24.8°N; 93.95°E) during June and July. Seeds were extracted manually. The seeds were first cleaned and dried for 5/6 days in the sunlight. Since the seeds of *Pongamia pinnata* have soft outer shell and can be easily dehusked before carrying out the estimation of the oil content. Kernel content is moderate i.e., about 10.95 g kernel in 24.36 g of seed

Extraction of oil: The kernels were crushed using a grinder. Oil was extracted from crushed and powdered Kernel in petroleum ether (b.p. 40-60°C) (10 ml/g) by solvent extraction technique under constant stirring for 3 hours using a magnetic stirrer at room temp (23°C). The solvent was removed at 15°C using a rotary vacuum evaporator (BUCHI Rota vapour R-200) to yield crude oil. This process was repeated 2-3 times with the seed cake using fresh solvent each time in order to extract most of the oil which was further dried by using vacuum pump.

Purification and determination of oil content: The oil was purified by column chromatography over silica gel (60-120 mesh) using a mixture of petroleum ether and ethyl acetate (20:1) as the eluent before transesterification was done.

$$\% \text{ oil content} = \frac{\text{Weight of oil}}{\text{Weight of powdered seeds}} \times 100 \quad \text{.....(1)}$$

Characterization of oil: The parameters of glycerides such as density, colour, refractive index, acid value iodine value and saponification value were experimentally determined in accordance with the Association of Official Analytical Chemical Procedures as reported in Horwitz (2010).

a) Determination of acid value: The oil samples were subjected to chemical characterization for acid value which is an important indicator of vegetable oil quality. Acid value is expressed as the amount of potassium hydroxide (in milligram) necessary to neutralize free fatty acid contained in 1 g of oil. Acid value was determined for the oil sample by dissolving 0.20g of the oil sample in 2.5ml of 1:1 v/v ethanol: diethyl ether solvent and titrating with 0.1N sodium hydroxide (NaOH) while swirling using phenolphthalein as indicator.

$$\text{Acid value (mg KOH/g)} = (56.1 \times V \times N)/W \quad \text{..... (2)}$$

Where,
V = titre value (mL)
N = normality of KOH solution (determined by standardizing KOH solution with oxalic acid).
W = weight of test sample taken in g.

b) Determination of refractive Index: Refractive indices of purified seed oils were determined by using the Abbe Refractometer (AW-24) at room of temperature. The refractometer was first standardized to 1.33 using distilled water at a temperature of 300C. This water was cleaned off with tissue paper and replaced with about 0.5g of oil sample. The dark and light regions of the refractometer were adjusted to meet at an intercept of a crossbar before the readings were taken.

c) Determination of density: Density of the purified oil were determined at room temperature (32°C). For this, a clean and empty plastic centrifuge tube was taken and weighed. Accurately 1000 µL (= 1 mL) of the liquid sample was transferred into the tube with the help of a syringe and then weighed again. Then the density is determined based on mass per unit volume of oil.

d) Determination of Iodine value: Iodine value of the oil was determined using Wiji's method AOAC official Method 993.20. In this method 0.20 g of the oil sample was dissolved in 15ml of carbon tetrachloride in 100ml glass stoppered conical flask. 25ml of Wiji's solution was then added and the flask was stoppered. The mixture was then allowed to stand for 2h in the dark at room temperature. 20ml of potassium iodide solution (10%) was added. The mixture was then titrated with 0.2N sodium thiosulphate solution using starch as indictor. The same procedure was used for a blank (without the oil). The iodine value was calculated as

Iodine value = (12.69 x N x (VB-VS))/W..... (3)

Where,
VB = Volume of sodium thiosulphate solution used for the blank (mL)
VS = Volume of sodium thiosulphate solution used for the oil sample (mL),
N = Normality of sodium thiosulphate solution used,
W = Weight of oil sample taken in g

e) Determination of saponification value: Saponification value, a measure of fatty acid chain length in oil was determined and expressed in milligrams of potassium hydroxide absorbed per gram of oil. 1 g of oil was dissolved in 12.5 ml of 0.5% ethanolic potassium hydroxide and the mixture refluxed for 30 minutes. 1 ml of phenolphthalein indicator was added and the hot soap solution titrated with 0.5N hydrochloric acid. A blank determination was also carried out under the same condition and saponification value determined using the equation 4.

Saponification value = 56.1 x M x (VB-VS)W..... (4)

Where,
VB = Volume of 0.5 M HCl solution used for the blank (mL)
VS = Volume of 0.5 M HCl solution used for the oil sample (mL)
M = Molarfity of HCl used
W = Weight of oil sample taken in g % Moisture = (W_1-W_2W_1 x 100)
in which where W_1 = Initial weight of oil, W_2 = Final weight of oil

f) Determination of % moisture: A known quantity of the oil was dried in an open air oven at 105°C for 4 hours. The oil sample was removed from the oven, cooled in a desiccator for about 30 minutes and then weighed. The procedure was repeated until a constant weight was observed. The % moisture was then calculated as follows.

% Moisture = W1-W2/W1 x 100 ..... (5)

where,
W_1 = Initial weight of oil
W_2 = Final weight of oil

g) Trans esterification of the seed oil sample to fatty acid methyl ester (FAME): The purified oil was trans-esterified to fatty acid methyl esters (FAME) using a catalyst called Athia, a banana plant (ashes from the peel of banana fruits, variety used *Musa balbisiana,* 20 wt% of the oil) (Dekka *et al.,* 2011). A mixture of the oil in methanol (10ml/g of the oil) and the catalyst (20wt% of the oil) was stirred vigorously magnetically at room temp (33°C) and the conversion completion of the reaction was monitored by Thin Layer Chromatography (TLC). After completion of the reaction, the product mixture was extracted with petroleum ether. The organic layer was washed with brine, dried over anhydrous Na_2SO_4 overnight and the solvent was removed under vacuum to yield the crude product which was further purified by column chromatography over silica gel using petroleum ether and ethyl acetate (20:1) as the eluent. The product was concentrated and evaporated to dryness on a rotatory evaporator which was further dried using vacuum pump to remove the last traces of the solvents to yield pure biodiesel (FAME).

h) Determination of the composition of FAME: The composition of FAME mixture was estimated using Perkin Elmer Clarus 600 GC-MS. The column used was Elite 5MS with dimension 30.0 x 250 µm. The oven temperature was initially held at 140°C for 5 min, increased to 240°C at 4°C/min, and then held for 5min. The injector, transfer and source temperatures were 250°C and 150°C respectively. Carrier gas was Helium and total scan time 35 min. EI mode of ionization was applied and mass gas was from 20 to 400 Da. For identification of FAME library search was carried out using National Institute of Standards Technology (NIST), National Bureau of Standards (NBS) and Wiley GC-MS library. Fatty acid profile of biodiesel from *Pongamia pinnata* seed oil is reported in table 2. The ^1H and ^{13}C NMR spectra were recorded in Carbon Deuterium Trichloride (CDCl3) at 300 and 75 MHz respectively using Bruker Advance III 300MHz/5 mm NMR spectrometer and IR spectrum were recorded with a Perkin Elmer RX1FT-IR spectrometer as a thin film on KBr plate.

RESULTS AND DISCUSSION

The refractive index (RI) is an intensive property and serves as a valuable material characteristic. RI detectors are common place in various chromatographic techniques employed for molecular characterization. The RI values

recorded for the non-conventional oil sample, i.e., *Pongamia pinnata,* do not differ significantly from those documented for conventional seed oils such as palm oil (1.445-1.451), cottonseed oil (1.468-1.472), safflower oil (1.473-1.476), and soybean oil (1.4728) at 25°C (Malek, 2000).

Density is another pivotal intrinsic material property aiding in the characterization of the oil samples. The density of the oil sample aligns with that of numerous commercial vegetable oils, including soybean, safflower, sesame, sunflower, corn, and cottonseed oil (Hui *et al.,* 2005). Seed oils with a density lower than that of water can serve as water evaporation retardants, particularly in arid regions where acute water shortages pose a threat.

The Iodine value (IV) serves as a measure of the degree of unsaturation in oils and fats. The degree of unsaturation influences various desirable and undesirable properties, including shelf-life, volatility, and reactivity, dictating their applications. While the iodine value of the oil sample indicates a moderate level of unsaturation, it is slightly lower than those reported for corn oil, cottonseed oil, soybean oil, and sunflower oil, falling within the range of 100-144gI2/100g of oil.

The Saponification number (SN) of seed oils provides insights into the average molecular weight and chain length of the fatty acids present. A higher SN suggests the presence of higher molecular weight and shorter chain length fatty acids. Consequently, the average molecular weight and chain length of the fatty acids in *Pongamia pinnata* seed oil are lower. Oils with high SN are ideal raw materials in soap making and the cosmetic industries (Akanni *et al.,* 2005).

Seed oils with low moisture content signify extended storage life. The moisture content of the sample oil (0.115) indicates favorable qualities, making it resistant to contamination. High moisture content in plant seed oils typically leads to increased microbial loads and lipid oxidation, resulting in rancidity. A higher moisture value can retard the trans-esterification of oils (Bussy, 1975). Given that low moisture content is a crucial criterion for commercial oil, the seed oil from the sample holds potential as a raw material for various industrial applications.

The acid value serves as a measure of the free fatty acid content in seed oil. The observed acid value of the oil sample was 0.462mg KOH/g, indicating a low presence of free fatty acids. Seed oils with low fatty acid content find utility in the manufacturing of varnish, paints, and medicine. Conversely, seed oils with high free fatty acid content, i.e., a high acid value, fall within industrially acceptable limits for useful oil (Oydeji *et al.,* 2006).

The physico-chemical properties of the seed oil determined using equation 1 to 5 are presented in table 1.

Table1 Physical parameters of *Pongamia pinnata* seed oil calculated using eqn. (1-5)

Parameters	Observed values
colour	Light yellow
Oil content (%)	10.26
Density (g/cm3)	0.8580
Acid value (mg KOH/g)	0.462
Iodine value (g I2/100g)	89.11
Saponification value (mg KOH/g)	188.60
Refractive index	1.4722
Moisture (%)	0.115

Fatty acid composition of the FAME prepared from *Pongamia pinnata* seed oil was determined by GC-MS analysis. The individual peak of the gas chromatogram (Figure 2) was analysed and the fatty acid was identified using MS database. Each peak represents a distinct fatty acid methyl ester. The presence of five peaks in the gas chromatogram indicate the presence of five different fatty acid methyl Easters. The rightmost peak in the mass spectrum of any fatty acid methyl ester provides the molecular weight of the fatty acid, known as molecular ion peak. Retention time is the time taken when any peak develops. The based peak represents the tallest peak in the mass spectrum and indicated the ion with the highest relative abundance. The peak with the greatest m/z value is likely to be the molecular ion peak.

Individual fatty acid methyl esters (FAME) was identified using the MS database (Figure 3a-e). The relative percentage of FAME was calculated from the total ion chromatography using a computerized integrator, and the results are presented in Table 2. The yield of extracted and purified glycerides from *Pongamia pinnata* seed oil was determined to be 10.26 wt% at room temperature (23°C) over three hours. In contrast, the yield of trans-esterified glycerides, known as the biodiesel or fatty acid methyl ester (FAME), was 67.9 wt% at 30°C for 4.30 hours. The trans-esterified products underwent purification through column chromatography and subsequent analysis.

The light yellow color of *Pongamia pinnata* seed oil resulted from the presence of natural pigments such as tocopherols, carotenoids, and their derivatives. The oil yield was moderate, with a density of 0.8580 g/cm^3 and an iodine value of 89.11 g I2/100 are comparable to those of soybean oil and sunflower oil. The acid value was 0.462 mg KOH/g, within the limits for industrially useful oil which is also a favourable factor for a good source of glycerides. The saponification value was 188.60 mg KOH/g, indicating the suitability of this oil for soap making and the cosmetic industries. The refractive index of 1.4722 was not significantly different from conventional seed oils like palm oil (1.445-1.451), cottonseed oil (1.468-1.472), safflower oil

(1.473-1.476), and soybean oil (1.4728) at 25°C. The low moisture content of 0.115% indicated high-quality oil, resistant to contamination, and met the essential criterion for commercial oil.

Analysis of FAME of *Pongamia pinnata*

The ^{1}H NMR spectrum (300 MHz, CDCl3) revealed distinct peaks at δ 0.85-0.87 (multiplet), 1.59-1.63 (multiplet), 1.99-2.05 (multiplet), 2.32 (multiplet), 2.76 (multiplet), 3.66 (singlet), and 5.312-5.35 (multiplet). In the ^{13}C NMR spectrum (75 MHz, CDCl3), notable chemical shifts were observed at δ 29.05-34.04, 51.38, 127.85, 127.88, 129.68, 129.93, 129.97, 130.14, and 174.26. The FT-IR spectrum (thin film) displayed distinctive peaks at 724, 1735, 1658, 1187, 1020, 2929, and 2783/cm.

The relative percentages of fatty acid esters were determined through total ion chromatography using a computerized integrator, and the outcomes are detailed in Table 2. The composition of Fatty Acid Methyl Ester (FAME) from *Pongamia pinnata* is characterized by 10.53 wt% of methyl palmitate (MP) (C16:0), 68.05 wt% of methyl oleate (MO) (C18:1), 12.58 wt% of methyl stearate (MS) (C18:0), 3.65 wt% of methyl arachidate (MA) (C20:0), and 5.22 wt % of methyl behenate (MB) (C22:0). In the above notation (C16:0), for example in case of methyl palmitate (C16:0), C16 is the number of carbon atoms and 0 signifies the absence of double bond. The Oleic acid is the major fatty acid followed by stearic acid and palmitic acid in *Pongamia pongamia* seed oil comprising of about 68.05wt% of unsaturated and 31.98 wt% of saturated fatty acids. It is interesting to note that this FAME contains no linoleate instead shows the presence of two uncommon FAMES. They are arachidate and behenate. Behenic and arachidic acids which are a few rarely observed fatty acids in seed oils.

Table2: Fatty Acid profile of FAME from *Pongamia pinnata* seedoil

Retention time (min)	FAME	wt %
18.52	MP	10.53
22.86	MO	68.05
23.35	MS	12.58
27.66	MA	3.65
31.94	MB	5.22

The mass spectra depicting biodiesel derived from *Pongamia pinnata* seed oil are illustrated in Figures 3a to 3c. Molecular ion peaks and base peaks of the FAME are detailed in Table 3, aligning with the anticipated values. As expected, the molecular ion peaks of methyl palmitate (MP), methyl oleate (MO), methyl stearate (MS), methyl arachidate (MA), and methyl behenate (MB) were observed at 270, 296, 298, 326, and 354, respectively. Similarly, the base peaks of the FAME of MP, MO, MS, and MB were also observed at 74, 55, 74, and 74, respectively, in accordance with expectations. It is interesting to note that all saturated FAMES showed CH_3OC (=OH^+) CH_2 fragment which appeared at m/z = 74 as the base peak (100%) which is the result McLarfferty rearrangement (Chien *et al.,* 2009). During the MS Analysis due to a six membered ring structure of an intermediate. Methyl oleate shows $(CH_2{=}CHCH_2CH_2]^+$ fragment which appeared at m/z = 55 as the base peak (100%).

Table 3: Molecular ion and base peaks of FAME from seed oil of *Pongamia pinnata*

Fame	Molecular ion peaks (m/z)	Base peaks (m/z)
MP	270	74
MO	296	55
MS	298	74
MA	326	74
MB	354	74

The presence of olefinic protons (-CH=CH-) is implied by the multiplet observed at δ 5.312 - 5.35 ppm (Figure 4). A singlet at ? 3.66 ppm signifies the methoxy protons associated with the ester.

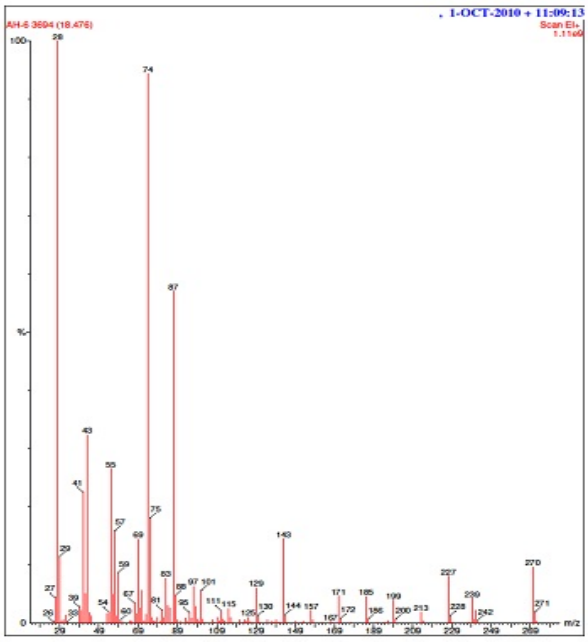

Fig. 3a : Mass spectrum of methyl palmitate

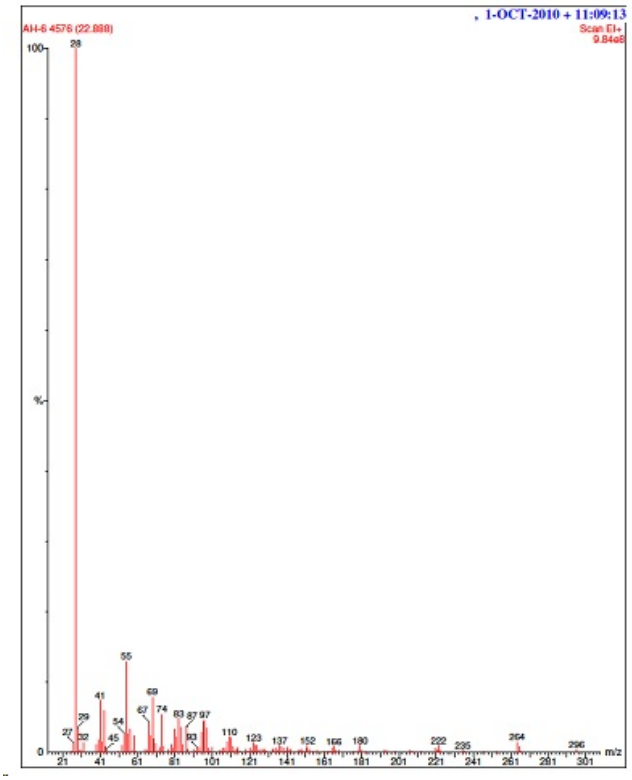

Fig. 3b: Mass spectrum of methyl oleate

Functionality in the biodiesel. The triplet at δ 2.76 ppm (t, 3J=5.7 Hz) indicates bis-allylic protons (-C=C-CH2-C=C-) within the unsaturated fatty acid chain. Another triplet at δ 2.32 ppm (t, 3J=7.5 Hz) points to the α-methylene protons adjacent to the ester (-CH2-CO2CH3). The δ-methylene protons adjacent to the double bond (-CH2-C=C-) manifest as a multiplet at δ 1.99 - 2.05 ppm. A multiplet at δ 1.59 - 1.63 ppm represents the β-methylene protons adjacent to the ester (-CH2-C-CO2CH3), attributed to the protons in the backbone methylene of the elongated fatty acid chain. The multiplet at δ 0.85 - 0.87 ppm corresponds to the terminal methyl protons (C-CH3).

The signal at δ 174.26 ppm corresponds to the carbonyl carbon of the ester molecules, while olefinic carbons are evident at ? 127.85, 127.88, 129.68, 129.93, 129.97, and 130.14 ppm (Figure 5). The presence of methoxy carbons in esters is indicated by the signal at δ 51.38 ppm in the ^{13}C NMR spectrum of biodiesel. Methylene and methyl carbons of the fatty acid moiety are observed in the range from δ 29.05 - 34.04 ppm.

In the FT-IR spectrum (Figure 6), a sharp signal at 1735/cm signifies strong absorption related to the ester carbonyl stretching frequency. A weaker signal at 1658/cm indicates C=C stretching frequency. Bands at 1182 and 1020/cm suggest C-O-C stretching vibrations. Strong and sharp signals at 2929 and 2783/cm indicate C-H stretching frequencies. The absorbance at 3093.82/cm suggests =C-H stretching frequency. Lastly, the signal at 713/cm indicates CH2 rocking.

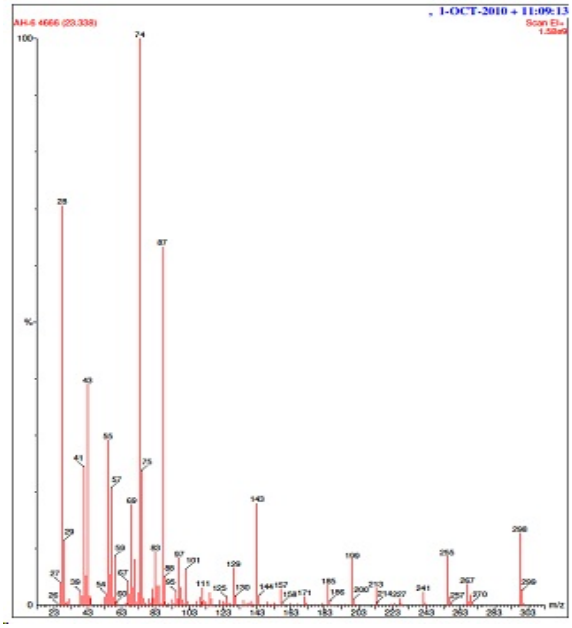

Fig. 3c: Mass spectrum of methyl stearate

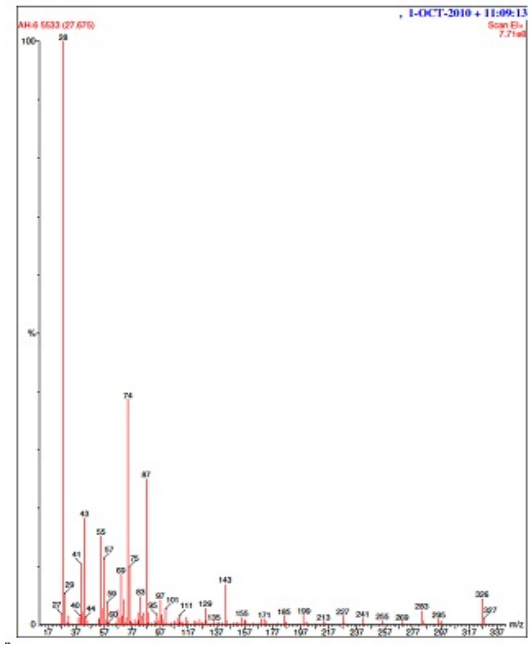

Fig.3d: Mass spectrum of methyl arachidate

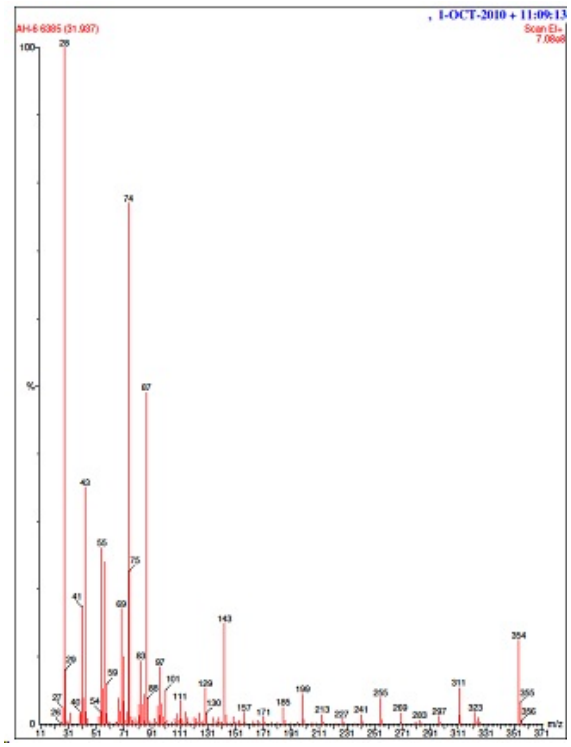

Fig.3e: Mass spectrum of methyl behenate

Theoretical determination of physic-chemical properties viz. Iodine Value (IV), Saponification Number (SN) and Cetane Index (CI) of FAMEs

The important physical properties of biodiesel, *viz.* iodine value (IV), saponification number (SN) and cetane index (CI) were calculated using equations (6), (7) and (8) respectively applying theoretical calculation based upon fatty acid profile shown in the Table 4.

$$IV=\Sigma(254xDxAi)/MWi \quad \text{..... (6)}$$

$$SN=\Sigma(560xAi)/MWi \quad \text{..... (7)}$$

$$CI=46.3+\frac{5458}{S}-0.225R \quad \text{..... (8)}$$

where,
D = number of double bonds in the ith component
Ai= percentange of the i^{th} component in the chromatogram
MWi = molecular weight of the i^{th} component of the FAME in the oil
S = saponification number (SN) as calculated by the equation [6]
R = iodine value (IV) as calculated by equation (5)

The Cetane Index (CI) serves as a theoretically derived numerical value that can be employed as a proxy for the cetane number of diesel fuel. The Cetane Number (CN) should either equal or exceeds CI, contingent upon the quantity of additives utilized. Notably, CI is determined in the absence of additives. As of the year 2000, in Europe, the Cetane Number was set at 51, while the Cetane Index was established at 46.

Table 4 .Calculated IV, SN, CI of FAME Profile *Pongamia pinnata* plant

Name of the oil plant	IV(g/100g)	SN(mg KOH/g)	CI
Pongamia pinnata	58.39	187.60	62.26

Based on the aforementioned findings, it is noteworthy to highlight that the non-edible oil extract derived from the *Pongamia pinnata* plant in Manipur holds potential as a viable feedstock for biodiesel production within the diesel industry.

The yield of extracted and purified glyceride from *Pongamia pinnata* was determined to be 10.26 wt% at a temperature of 23°C over a 3-hour extraction period. In contrast, the yield of transesterified glyceride, known as Fatty Acid Methyl Ester (FAME), reached 67.9 wt% at a temperature of 30°C within an 11.30-hour extraction duration. The characteristics of *Pongamia pinnata* oil, including its light yellow color, density of 0.8580 g/cm³, acid value of 0.462 mg KOH/g, iodine value of 89.11 g I2/g, saponification number of 188.60 mg KOH/g, refractive index of 1.4722, and moisture content of 0.115 wt %, were determined.

For the biodiesel obtained from *Pongamia pinnata* seed oil, a heterogeneous transesterification process was employed after extraction and purification through column chromatography. Analysis of its fatty acid methyl esters (FAME) composition was conducted using IR, NMR, and GC-MS techniques. The relative percentage of all the FAME of Pongamia pinnata seed oil was found to comprise of 10.53 wt% of methyl palmitate (C16:0), 68.05 wt% of methyl oleate (C18:1), 12.58 wt % of methyl stearate (C18:0), 3.65 wt % of methyl arachidate (C20:0), and 5.22 wt% of methyl behenate (C22:0). The molecular ion peaks of methyl palmitate, methyl oleate, methyl stearate, methyl arachidate, and methyl behenate of biodiesel of Pongamia pinnata were observed at 270, 296, 298, 326, and 354, respectively, as anticipated.

Theoretical calculations yielded an Iodine value (IV) of 58.39, a Saponification number (SN) of 187.60, and a Cetane index (CI) of 62.26 for the FAME obtained from *Pongamia pinnata* seed oil. After considering oil content and quality of the oil sample, we are of the opinion that Pongamia pinnata is the potential non-conventional source of non-edible vegetable oil which is worthy of consideration as the source of glyceride for the production of bio-diesel.

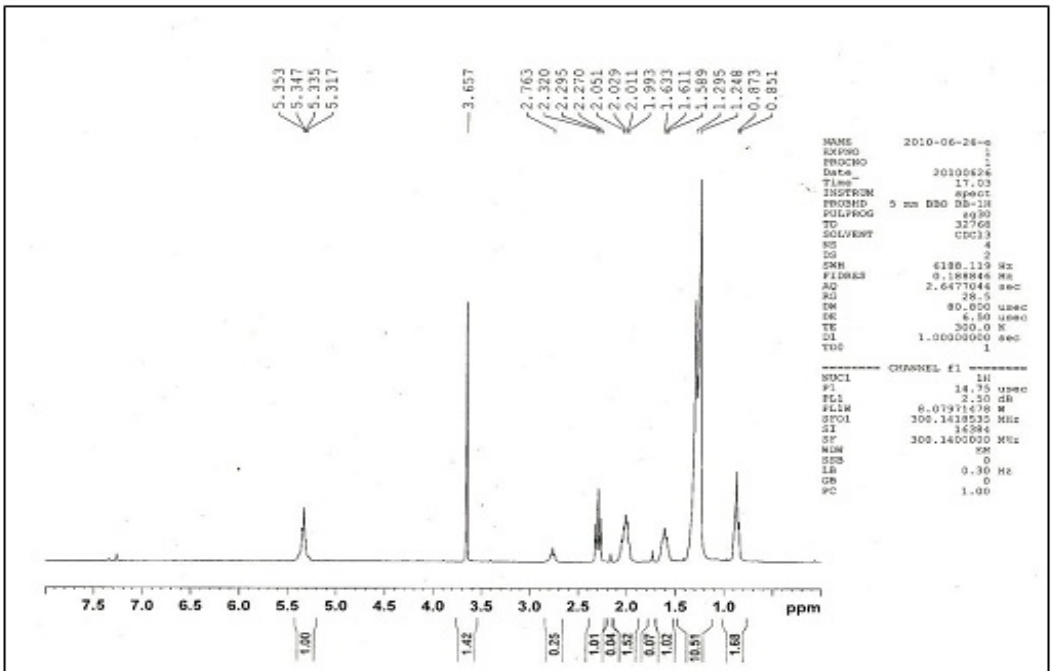

Fig.4: ^{1}H NMR spectrum of biodiesel from *Pongamia pinnata* seed oil

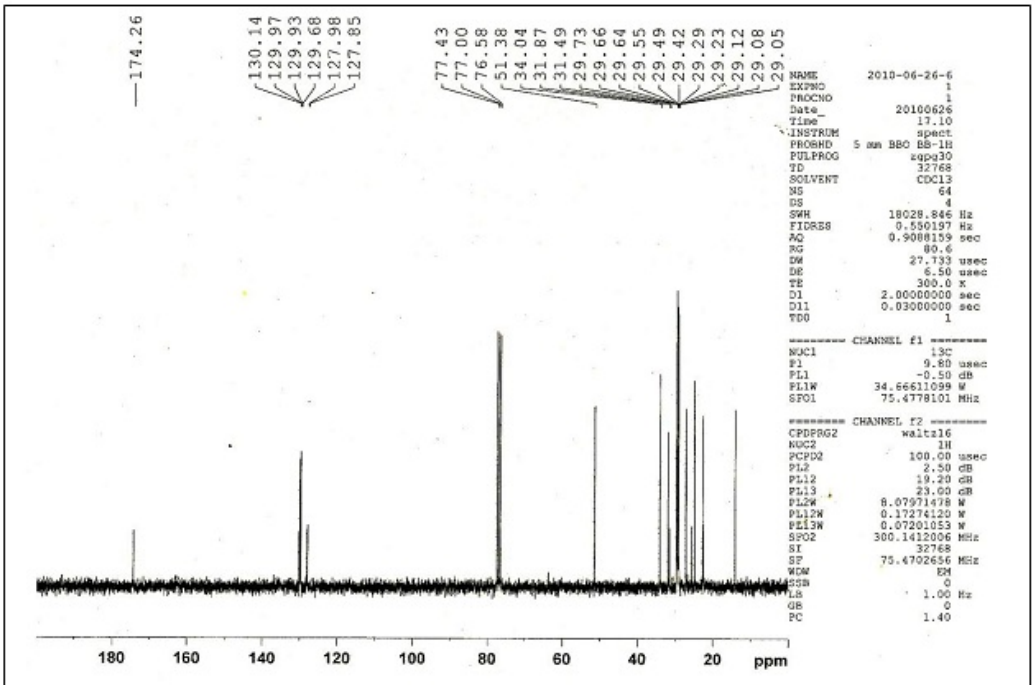

Fig. 5: ^{13}C NMR spectrum of biodiesel from *Pongamia pinnata* seedoil

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Screening of castor hybrids and their parents against wilt disease

DIYOL ASHA, P T PATEL[1], A M PATEL[2] AND Y N PATEL[2]

Agriculture Research Station, Kholwada, S D Agricultural University, Sardarkrushinagar- 385506, Gujarat

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ABSTRACT

Castor is an industrially important non-edible oilseed crop widely cultivated in the arid and semi-arid regions of the world. Wilt (*Fusarium oxysporum* f. sp. *ricini*) disease has become a serious problem in India, though wilt resistant hybrids *viz.,* GCH-4, GCH-5, GCH-7, GCH-8, GCH-9 and GCH 10 have been released. So investigation on screening of castor hybrids and their parents against wilt disease was undertaken under poly house conditions. The results revealed that out of six, three parent's *viz.,* SKP-84, JI-368 and 48-1 were resistant, while two hybrids i.e. SKP-84 x JI- 368 and GEETA x SH-72 were found resistant to wilt disease. Parent GEETA found moderately resistant, whereas susceptibility for the disease was observed in parents *viz.,* VP-1, VI-9, SH-72 and JI-35 and Hybrid VP-1 x VI-9 reported susceptibility to wilt disease. Our findings confirmed the importance of selecting the parents for the development of resistant hybrids in disease-resistance breeding programmes.

Keywords: Castor, *Fusarium oxysporum* f. sp. *ricini*, Screening and hybrids, Wilt

Castor [*Ricinus communis* (L.)] is an industrially important non-edible oilseed crop widely cultivated in the arid and semi-arid regions of the world (Govaerts *et al.,* 2000). Castor seed contains 47 to 52% oil (Jeong and Park, 2009). Due to its unique chemical and physical properties, the oil from castor seed is used as raw material for numerous and varied industrial applications, such as for manufactures of polymers, coatings, lubricants for aircrafts, cosmetics etc. and for the production of biodiesel (Jeong and Park, 2009; Lavanya *et al.,* 2022).

Castor is grown in tropical, subtropical and temperate climates and cultivated in almost 30 different countries. Among those India, Brazil and China are the most important castor growing countries. At present, India is the world leader in castor production and sole exporter of castor oil, seed and some derivatives. India contributes 80 per cent of the world production and meets about 90 per cent world castor oil demands. The major castor growing states in India are Gujarat, Andhra Pradesh, Rajasthan, Tamilnadu, Karnataka and Orissa. Gujarat is the leading castor growing state. Total area under castor crop in Gujarat for the year 2013-14 was 5.73 lakh hectares and production was 8.28 lakh tonnes. The average yield for the year 2013-14 was 1445 kg/ha (Anonymous, 2013-2014).

Like other crops, castor also suffers from many diseases and so far 15 different diseases have been recorded in this crop in India (Rangaswami, 1979 and Kolte, 1995). Out of these, important diseases are seedling blight, wilt, root rot, Alternaria blight, grey mold and bacterial leaf spot. Release of castor hybrids and production and protection technology commensurate to them, has made the castor a high profit crop. As a result, area under the crop has tremendously increased. Due to intensive cultivation, with high inputs, high fertilizers and more number of irrigations without proper crop rotation, wilt (*Fusarium oxysporum* f. sp. *ricini*) disease started its appearance and has become a serious problem in India, though wilt resistant hybrids *viz.,* GCH-4, GCH-5 and GCH-7 had been released.

As the wilt disease is primarily soil-borne, it becomes difficult to manage it through chemical or physical means. Therefore, the only practical solution to this problem lies in the breeding of host plant resistance, for which knowledge of the genetics of resistance to wilt pathogen is the basic necessity. The effectiveness of host-plant resistance in breeding programme largely depends on the development of a reliable screening technique, identification of resistance source(s), selection of breeding procedures to incorporate resistance into agronomically superior backgrounds, and finally the selection of resistant and desirable materials to develop high yielding resistant hybrid /varieties. Even though, the crop has got great commercial value, the information on genetics of yield and its associated traits and resistance to Fusarium wilt is extremely limited. In the present investigation i.e., screening of castor hybrids and their parents against wilt disease was undertaken in the polyhouse conditions.

MATERIALS AND METHODS

Three castor hybrids and their six parents were screened for wilt reaction by root dip inoculation technique under poly house conditions along with checks JI-35 and 48-1 as susceptible and resistant, respectively (Desai and Dange, 2003). Thirty seedlings were maintained for each hybrid and parents accession with transplanting of ten seedlings in plastic bags.

[1]Registrar, S. D. Agricultural University, Sardarkrushinagar-385 506; [2]Centre for Oilseeds Research, S D Agricultural University, Sardarkrushinagar-385 506; Corresponding author's E-mail: ankitp.patel224@gmail.com

Raising of seedling: The seeds of each castor hybrids and their parents were surface sterilized separately with 2.5 per cent sodium hypochlorite solution for five minutes and then sown in seedling plastic trays containing cocopeat: vermicompost (1:1). The trays were watered as and when needed.

Preparation of fungal inoculum: The inoculum was prepared by multiplying the fungus on sorghum grain medium (sorghum grains were soaked in two per cent sucrose solution overnight and then 100 g sorghum grains were autoclaved in 250 ml conical flask) by putting aseptically mycelial disc cut from the periphery of seven days old culture of the fungus grown on PDA medium. The flasks were incubated at 27 ± 2°C temperature for 10 days. The spore suspension was prepared by transferring the sorghum grain medium with sporulating fungus into distilled water, stirred well and filtered through double layered muslin cloth. The concentration of the spore suspension was adjusted to 1 x 10^6 spores per milliliter with the help of haemocytometer.

Inoculation of seedlings: Ten days old seedlings of individual castor hybrids along with parents grown in seedling trays were uprooted, washed in running tap water separately then clipped from distal one-third root system and were dipped for one minute in the fungal spore suspension (1 x 10^6 spores/ml). Inoculated seedlings were transplanted into the plastic bags filled with autoclaved moistened soil. Thirty seedlings were maintained for each hybrid and their parents. The bags were watered as and when needed and left undisturbed for disease development. The observations on wilting symptoms were recorded periodically in a 1 to 2 scale (1=partial wilting; 2=complete wilting) and percent disease incidence (PDI) was calculated as per formula:

$$PDI = \frac{\Sigma \text{ of disease rating scale}}{\text{No. of plants observed}} \times \frac{100}{\text{Maximum scale (2)}}$$

Based on disease reactions, tested hybrids and their parents were grouped into four categories as described below (Desai and Patel, 2010).

1) R (Resistant) = ≤ 20 % wilt incidence
2) MR (Moderately resistant) = > 20-40 % wilt incidence
3) MS (Moderately susceptible) = > 40-60 % wilt incidence
4) S (Susceptible) = > 60 % wilt incidence.

RESULTS AND DISCUSSION

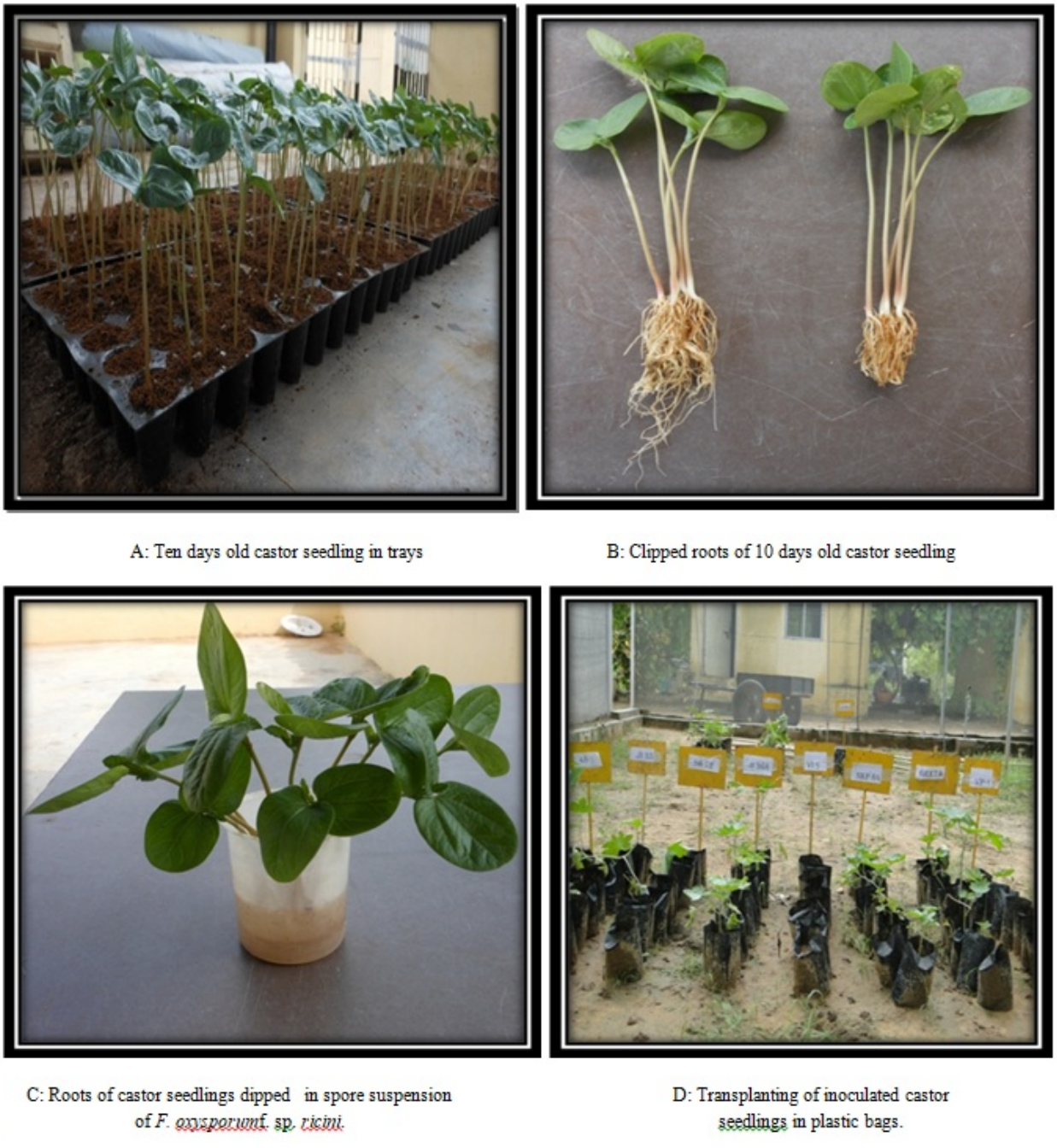
Six parents and three hybrids were screened by root dip inoculation method for resistance against *F. oxysporum* f. sp. *ricini* (Fig. 1 and 2). Out of them three parents *viz.,* SKP-84, JI-368, and 48-1were found resistant (0.00 to 19.96% wilt), while one hybrid *viz.,* GEETA × SH-72 was found moderately susceptible (51.97 % wilt). One hybrid SKP-84 × JI-368 and one parent GEETA were moderately resistant (24.97-25.35 % wilt). The susceptible reaction (70 to 90% wilt) to Fusarium wilt was recorded in four parents *viz.,* VP-1, VI-9, SH-72, JI-35 and one hybrid VP-1×VI-9 (Table 1).

These results suggest that the hybrids developed by crossing any one of resistant parents showed resistance for wilt disease. The known susceptible check JI-35 and resistant check 48-1 showed highly susceptible (100 %) and resistant (100 %) reaction, respectively to *F. oxysporum* f. sp. *ricini* under the study of root dip inoculation technique at the inoculums concentration of 1×10^6 spores per millilitre.

Table 1 Reaction of castor hybrids and their parents to Fusarium wilt

Hybrids and their parents	wilt incidence (%)	Disease Reaction
VP-1 × VI-9	100 (90.00)	S
GEETA × SH-72	62.71 (51.97)	S
SKP-84 × JI-368	18.33 (25.35)	MR
VP-1	100 (90.00)	S
GEETA	17.24 (24.97)	MR
SKP-84	11.11 (19.96)	R
VI-9	100 (90.00)	S
JI-368	0 (0.00)	R
SH-72	100 (90.00)	S
JI-35	100 (90.00)	S
48-1	0 (0.00)	R
SEm	0.18	
CD (1%)	0.69	
CD (5%)	0.49	
CV	0.55	

Figures in parenthesis are Arcsine transformed value



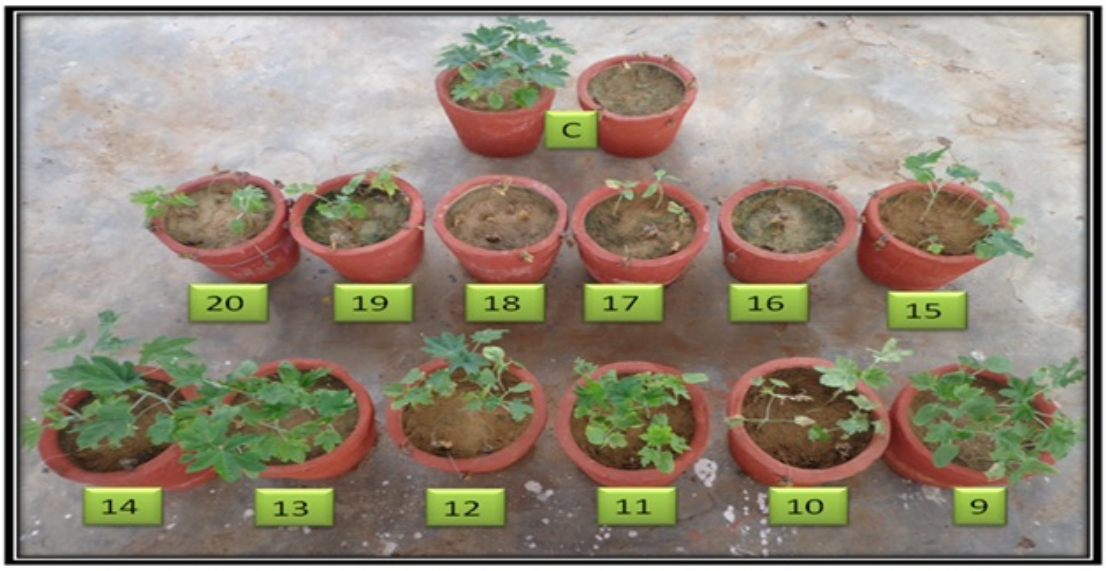
A: Ten days old castor seedling in trays

B: Clipped roots of 10 days old castor seedling

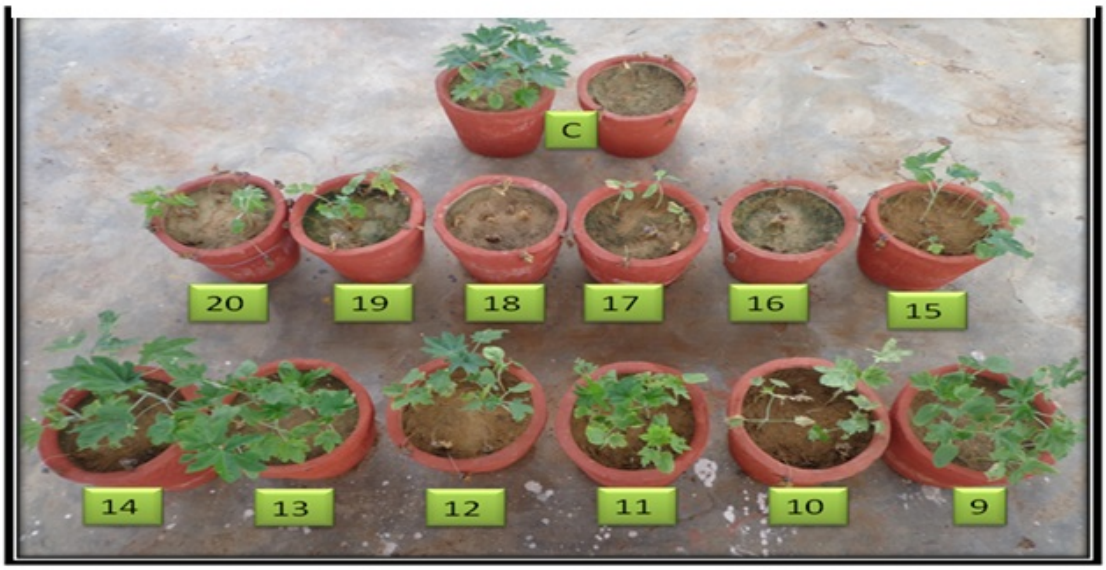
C: Roots of castor seedlings dipped in spore suspension of *F. oxysporumf.* sp. *ricini*

D: Transplanting of inoculated castor seedlings in plastic bags.

Fig. 1. Screening of castor genotypes for resistance against wilt through root dip inoculation method



R 9. GEETA×48-1, 10. GEETA×VI-9, 11. GEETA×SKI-215, 12. GEETA×JI-35, 13. GEETA×1379, 14. GEETA×GC-2
15. VP-1×48-1, 16. VP-1×VI-9, 17. VP-1×SKI-215, 18. VP-1×JI-35, 19. VP-1×1379, 20. VP-1×GC-2, C. Checks



1. GEETA, 2. VP - 1, 3. VI-9, C. Checks 48-1 (R) and JI-35 (S).

Fig. 2. Reaction of castor hybrids and their parents to *Fusarium* wilt after 30 days of inoculation by root dip inoculation technique

For the identification of resistant materials to Fusarium wilt disease, the root dip inoculation technique has been tried in watermelon (Zhang *et al.,* 1991), pigeonpea (Haware and Nene, 1994) and castor (Raoof and Rao, 1996, Desai and Patel, 2010 and also the results we observed were in accordance with earlier reports by Desai and Dange, 2003, Patel, (2005), Patel *et. al.* (2010) and Darge, (2013).

Three parents *viz.,* SKP-84, JI-368, and 48-1 and two hybrids i.e. SKP-84 × JI- 368 and GEETA × SH-72 were resistant for wilt disease in root dip inoculation studies. Our results confirmed the importance of utilizing the resistant parents in wilt disease breeding programme.

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INDIAN SOCIETY OF OILSEEDS RESEARCH

Instructions to Authors for Preparation of Manuscript for Journal of Oilseeds Research

Prospective author(s) are advised to consult **Issue No. 27(1) June, 2010 of the Journal of Oilseeds Research** and get acquainted with the minor details of the format and style of the Journal. Meticulous compliance with the instructions given below will help quick handling of the manuscript by the reviewers, editor and printers. **Manuscripts are considered for publication in the Journal only from members of the ISOR.**

General

Full-length articles, short communications, book reviews and review articles are published in the Journal. Review articles and book reviews are published usually by invitation. Full length articles and short communications should report results of original investigations in oilseeds, oil bearing plants and relevant fields of science. Choice of submitting the paper(s) either as full length paper or short communication rests with the authors. The Editor(s) or Reviewer(s) will examine their suitability or otherwise only in that specific category. Each article should be written in English correctly, clearly, objectively and concisely. All the statements made in the manuscript should be clear, unambiguous, and to the point. Plagiarism is a crime and therefore, no part of the previously published material can be reproduced exactly without prior permission from the original publisher or author(s) as deemed essential and the responsibility of this solely rests on the authors. Also, authors shall be solely responsible for the authenticity of the results published as well as the inferences drawn thereof. Telegraphic languages should be avoided. The data should be reported in a coherent sequence. Use active voice. Active voice is clear, unambiguous and takes less space. Use past tense while reporting results. Do not repeat ideas in different forms of sentences. Avoid superfluous sentences such as `it is interesting to note that', `it is evident from the table that' or `it may be concluded that' etc. Use % for percent, %age for percentage, / for per, @ for at the rate of hr for hours, sec for seconds. Indicate date as 21 January 2010 (no commas anywhere). Spell out the standard abbreviations when first mentioned eg. Net assimilation rate (NAR), general combining ability (GCA), genetic advance (GA), total bright leaf equivalents (TBLE), mean sum of squares (MSS).

Manuscript

The language of the Journal is English. Generally, the length of an article should not exceed 3,000 words in the case of the full-length article and 750 words in the case of short communication. However, completeness of information is more important. Each half-page table or illustration should be taken as equivalent to 200 words. It is desirable to submit the manuscript online https://epubs.icar.org.in/index.php/JOR/about/submissions (preferred because of ease of handling during the review process) or as an e-mail attachment (in MS Word document; double line space; Times New Roman; font size 12) to editorisor@gmail.com. Every page (of the manuscript), including the title page, references, tables, etc. should be numbered. Punctuation marks help to show the meanings of words by grouping them into sentences, clauses, phrases, and other ways. These marks should be used properly if the reader of a paper is to understand exactly the intended meaning. Receipt of the manuscript (received online or as an email attachment) will be acknowledged by the editorial office of the Society, giving a manuscript number which should be quoted in all subsequent correspondence regarding that particular article.

Full-length Articles

Organization of the Manuscript

Before reading the instructions given below, the author(s) would better have a close look at the latest issue of the Journal.

Full-length article comprises the following sections.

(a) Short title
(b) Title
(c) Author/Authors
(d) Institution and Address with PIN (postal) code
(e) Abstract (along with key words)
(f) Introduction
(g) Materials and Methods
(h) Results and Discussion
(i) Acknowledgments (if any)
(j) References
(k) Tables and figures (if any)

Guidelines for each section are as follows:

All these headings or matter thereof should start from left hand side of the margin, without any indent.

Short Title

A shortened title (approximately of 30 characters) set in capital letters should convey the main theme of the paper.

Title

Except for prepositions, conjunctions, pronouns and articles, the first letter of each word should be in capital letter. The title should be short and should contain key words and phrases to indicate the contents of the paper and be attractive. Jargons and telegraphic words should be avoided. In many cases, actual reading of the paper may depend on the attractiveness of the title.

Author/Authors

The name(s) of author(s) should be typed in capital letters a little below the title, starting from the left margin. Put an asterisk on the name of the corresponding author. **Give the Email ID of the corresponding author** as a footnote.

Institution and Address

This matter will come below the name(s) of the author(s). Name of the Laboratory/Department, followed by the name of the Institution/Organization/University where the work reported in the paper was carried out shall come below the name(s) of author(s). Complete postal address, which should include city/town, district, and state, followed by PIN (postal) code is to be furnished. In case any author has left the above address, this should be indicated as a footnote.

Abstract

The paragraph should start with the word Abstract (in bold font). The abstract should comprise brief and factual summary or salient points of the contents and the conclusions of the investigation reported in the paper and should refer to any new information therein. As the abstract is an independent entity, it should be able to convey the gist of the paper in a concise manner. It will be seen by many more people than will read the paper. The abstract, as concise as possible, should not exceed 250 words in length. Everything that is important in the paper must be reflected in the abstract. It should provide to the reader very briefly the rationale, objectives or hypothesis, methods, results and conclusions of the study described in the paper. In the abstract, do not deflect the reader with promises such as 'will be discussed' or 'will be explained'. Also do not include reference, figure or table citation. At first mention in the abstract, give complete scientific name for plants and other organisms, the full names of chemicals and the description of soil order/series. Any such names or descriptions from the abstract need not be repeated in the text. It must be remembered that the abstracting journals place a great emphasis on the abstract in the selection of papers for abstracting. If properly prepared, they may reproduce it verbatim.

"Key words" should, follow separately after the last sentence of the abstract. "Key words" indicate the most important materials, operations, or ideas covered in the paper. Key words are used in indexing the articles.

Introduction (To be typed as side-heading, starting from the left-hand margin, a few spaces below the key words)

This section is meant to introduce the subject of the paper. Introduction should be short, concise and indicate the objectives and scope of the investigation. To orient readers, give a brief reference to previous concepts and research. Limit literature references to essential information. When new references are available, do not use old references unless it is of historical importance or a landmark in that field. Emphasis should be given among other things on citing the literature on work done under Indian conditions. Introduction must include: (a) a brief statement of the problem, justifying the need for doing the work or the hypothesis on which the work is based, (b) the findings of others that will be further developed or challenged, and (c) an explanation of the approach to be followed and the objectives of the research described in the paper. If the methods employed in the paper are new, it must be indicated in the introduction section.

Materials and methods (To be typed as side-heading, starting from the left-hand margin, a few spaces below the introduction)

This part of the text should comprise the materials used in the investigation, methods of experiment and analysis adopted. This portion should be self-explanatory and have the requisite information needed for understanding and assessing the results reported subsequently. Enough details should be provided in this section to allow a competent scientist to repeat the experiments, mentally or in fact. The geographical position of soil site or soils used in the experiment or site of field trial should be identified clearly with the help of coordinates (latitude & longitude) and invariably proper classification according to Soil Taxonomy (USDA), must be indicated to the level of Great-group, Suborder or Order as far as possible. Specify the period during which the experiment(s) was conducted. Send the article after completion of the experiment(s) not after a gap of 5 years. Instead of kharif and rabi use rainy and winter season respectively. Please give invariably the botanical names for local crop names like raya, bajra moong, cholam etc. Botanical and zoological names should confirm to the international rules. Give authorities. Go through some of our recent issues and find out the correct names. Give latest correct names from authentic source. For materials, give the appropriate technical specifications and quantities and source or method of preparation. Should a product be identified by trade name, add the name and location of the manufacturer or a major distributor in parenthesis after the first mention of the product. For the name of plant protection chemicals, give popular scientific names (first letter small), not trade names (When trade name is given in addition, capitalize the first letter of the name). Known methods of analysis should be indicated by referring to the original source, avoiding detailed description. Any new technique developed and followed should be described in fair detail. When some specially procured or proprietary materials are used, give their pertinent chemical and physical properties. References for the methods used in the study should be cited. If the techniques are widely familiar, use only their names in that case.

Results and Discussion (To be typed as a side-heading, a few spaces below the matter on "Materials and Methods")

This section should discuss the salient points of observation and critical interpretation thereof in past tense. This should not be descriptive and mere recital of the data presented in the tables and diagrams. Unnecessary details must be avoided but at the same time significant findings and special features should be highlighted. For systematic discussion, this section may be divided into sub-sections under side-heading and/or paragraph side heading. Relate the results to your objectives. While discussing the results, give particular attention to the problem, question or hypothesis presented in the introduction. Explain the principles, relationships, and generalizations that can be supported by the results. Point out any exceptions. Explain how the results relate to previous findings, support, contradict or simply add as data. Use the Discussion section to focus on the meaning of your findings rather than recapitulating them. Scientific speculation is encouraged but it should be reasonable and firmly founded in observations. When results differ from previous results, possible explanations should be given. Controversial issues should be discussed clearly. References to published work should be cited in the text by the name(s) of author(s) as follows: Mukherjee and Mitra (1942) have shown or It has been shown (Mukherjee and Mitra, 1942)..... If there are more than two authors, this should be indicated by et al. after the surname of the first author, e.g., Mukherjee et al. (1938).

Always conclude the article by clearly crystallizing the summary of the results obtained along with their implications in solution of the practical problems or contribution to the advancement of the scientific knowledge.

Acknowledgments (To be typed as given above, as a side-heading, well below the concluding portion of Conclusions)

The author(s) may place on record the help, and cooperation, or financial help received from any source, person or organization. This should be very brief, and omitted, if not necessary.

References (To be typed as above, as side heading below Acknowledgement)

The list of references must include all published work referred to in the text. Type with double line spacing. Do not cite anonymous as author; instead cite the name of the institute, publisher, or editor. References should be arranged alphabetically according to the surnames of the individual authors or first authors. Two or more references by the same author are to be cited chronologically; two or more in the same year by the letters a, b, c, etc. All individually authored articles precede those in which the individual is the first or joint author. Every reference cited in the article should be included in the list of References. This needs rigorous checking of each reference. Names of authors should not be capitalized.

The reference citation should follow the order: author(s), year of publication, title of the paper, periodical (title in full, no abbreviations, italics or underlined), volume (bold or double underlining), starting and ending pages of the paper. Reference to a book includes authors(s), year, title (first letter of each word except preposition, conjunction, and pronouns in capitals and underlined), the edition (if other than first), the publisher, city of publication. If necessary, particular page numbers should be mentioned in the last. Year of publication cited in the text should be checked with that given under References. Year, volume number and page number of each periodical cited under "References" must be checked with the original source. The list of references should be typed as follows:

Rao C R 1968. *Advances in Statistical Methods in Biometrical Research*, pp.40-45, John Wiley & Sons, New York.

Kanwar J S and Raychaudhuri S P 1971. *Review of Soil Research in India*, pp 30-36. Indian Society of Soil Science, New Delhi.

Mukherjee J N 1953. The need for delineating the basic soil and climatic regions of importance to the plant industry. *Journal of the Indian Society of Soil Science*, **1** : 1-6.

Khan S K, Mohanty S K and Chalam A B, 1986. Integrated management of organic manure and fertilizer nitrogen for rice. *Journal of the Indian Society of Soil Science*, **34** : 505-509.

Bijay-Singh and Yadvinder-Singh 1997. Green manuring and biological N fixation: North Indian perspective. In: Kanwar J S and Katyal J C (Ed.) *Plant Nutrient Needs, Supply, Efficiency and Policy Issues 2000-2025.* National Academy of Agricultural Sciences, New Delhi, India, pp.29-44.

Singh S, Pahuja S S and Malik R K 1992. Herbicidal control of water hyacinth and its effect on chemical composition of water *(in) Proceedings of Annual Weed Science Conference*, held during 3-4 March 1992 by the Indian Society of Weed Science, at Chaurdhary Charan Singh Haryana Agricultural University, Hisar, 127p.

AICRP on Soybean 1992. *Proceedings of 23rd Annual Workshop of All-India Co-ordinated Research Project on Soybean*, held during 7-9 May 1992 at University of Agricultural Sciences, Bangalore, Karnataka, National Research Centre for Soybean, Indore, pp.48.

Devakumar C. 1986. Identification of nitrification retarding principles in neem (*Azadirachta indica* A.Juss.) seeds. Ph D Thesis, Indian Agricultural Research Institute, New Delhi.

Reference to unpublished work should normally be avoided and if unavoidable it may be mentioned only in the text.

Short Communication

Conceptually short communication is a first report on new concept, ideas and methodology which the author(s) would wish to share with the scientific community and that the detailed paper would follow. Short Communication is akin to an advance booking for the report on the findings. Short communications may include short but trend-setting reports of field or laboratory observation(s), preliminary results of long-term projects, or new techniques or those matters on which enough information to warrant its publication as a full length article has still not been generated but the results need to be shared immediately with the scientific community. The style is less formal as compared with the "full-length" article. In the short communications, the sections on abstract, materials and methods, results and discussion, and conclusion are omitted; but the material is put concisely in the same sequence but without formal sections. The other instructions are the same as in the case of the full-length articles.

Tables

Tables should not form more than 20% of the text. Each table should be typed on separate sheet and should have on the top a table number (in Arabic numerals *viz*. 1, 2, 3 etc.) and a caption or title which should be short, but sufficiently explanatory of the data included in the table. Information in the table should never duplicate that in the text and vice versa. Symbols (asterisks, daggers, etc. or small letters, *viz*., a, b, etc.) should be used to indicate footnotes to tables. Maximum size of table acceptable is what can be conveniently composed within one full printed page of the journal. Over-sized tables will be rejected out-right. Such tables may be suitably split into two or more small tables.

The data in tables should be corrected to minimum place of decimal so as to make it more meaningful. Do not use full stop with CD, SEm $\pm$, NS (not C.D., S.E.m $\pm$, N.S.). Do not put cross-rules inside the table. Tables should be numbered consecutively and their approximate positions indicated in the margin of the manuscript. Tables should not be inserted in the body of the text. Type each table on a separate sheet. Do not use capital letters for the tabular headings, do not underline the words and do not use a full-stop at the end of the heading. All the tables should be tagged with the main body of the text i.e. after references.

Figures

Figures include diagrams and photographs. Laser print outs of line diagrams are acceptable while dot-matrix print outs will be rejected. Alternatively, each illustration can be drawn on white art card or tracing cloth/ paper, using proper stencil. The lines should be bold and of uniform thickness. The numbers and letterings must be stenciled; free-hand drawing will not be accepted. Size of the illustrations as well as numbers, and letterings should be sufficiently large to stand suitable reduction in size. Overall size of the illustrations should be such that on reduction, the size will be the width of single or double column of the printed page of the Journal. Legends, if any, should be included within the illustration. Each illustration should have a number followed by a caption typed/ typeset well below the illustration.

Title of the article and name(s) of the author(s) should be written sufficiently below the caption. The photographs (black and white) should have a glossy finish with sharp contrast between the light and the dark areas. Colour photographs/ figures are not normally accepted. One set of

the original figures must be submitted along with the manuscript, while the second set can be photocopy. The illustrations should be numbered consecutively in the order in which they are mentioned in the text. The position of each figure should be indicated in the margin of the text. The photographs should be securely enclosed with the manuscript after placing them in hard board pouches so that there may not be any crack or fold. Photographs should preferably be 8.5 cm or 17 cm wide or double the size. The captions for all the illustrations (including photographs) should be typed on a separate sheet of paper and placed after the tables.

Expression of Plant Nutrients on Elemental Basis

The amounts and proportions of nutrient elements must be expressed in elemental forms e.g. for ion uptake or in other ways as needed for theoretical purposes. In expressing doses of nitrogen, phosphatic, and potassic fertilizers also these should be in the form of N, P and K, respectively. While these should be expressed in terms of kg/ha for field experiments, for pot culture studies the unit should be in mg/kg soil.

SI Units and Symbols

SI Units (System International d 'Unities or International System of Units) should be used. The SI contains three classes of units: (i) base units, (ii) derived units, and (iii) supplementary units. To denote multiples and sub-multiples of units, standard abbreviations are to be used. Clark's Tables: Science Data Book by Orient Longman, New Delhi (1982) may be consulted.

Some of these units along with the corresponding symbols are reproduced for the sake of convenience.

Names and Symbols of SI Units

Physical quantity | Symbol for SI Unit | Remarks | Physical quantity | Symbol for SI Unit | Remarks

Primary Units

length	l		time	t	
metre	m		second	s	
mass	m		electric current	I	
kilogram	kg		ampere	A	

Secondary Units

plane angle	radian	rad	Solid angle	steradian	sr

Unit Symbols

centimetre	cm	microgram	µg
cubic centimetre	cm^3	micron	µm
cubic metre	m^3	micronmol	µmol
day	d	milligram	mg
decisiemens	dS	millilitre	mL
degree-Celsium	°C [=(F-32)x0.556]	minute	min
gram	g	nanometre	nm
hectare	ha	newton	N
hour	h	pascal	Pa
joule J	(=10^7 erg or 4.19 cal.)	second	s
kelvin	K (=°C+273)	square centimetre	cm^2
kilogram	kg	square kilometre	km^2

kilometre	km	tonne	t
litre	L	watt	W
megagram	Mg		

Some applications along with symbols

adsorption energy	J/mol (=cal/molx4.19)	leaf area	m^2/kg
cation exchange capacity	cmol (p+)/kg (=m.e./100 g)	nutrient content in plants (drymatter basis)	µg/g, mg/g or g/kg
Electrolytic conductivity	dS/m (=mmhos/cm)	root density or root length density	m/m^3
evapotranspiration rate	$m^3/m^2/s$ or m/s	soil bulk density	Mg/m^3 (=g/cm^3)
heat flux	W/m^2	specific heat	J/kg/K
gas diffusion	$g/m^2/s$ or $m^3/m^2/s$ or m/s	specific surface area of soil	m^2/kg
water flow	$kg/m^2/s$ (or) m^3m^2s (or) m/s	thermal conductivity	W/m/K
gas diffusivity	m^2/s	transpiration rate	$mg/m^2/s$
hydraulic conductivity ion uptake	m/s	water content of soil	kg/kg or m^3/m^3
(Per kg of dry plant material)	mol/kg	water tension	kPa (or) MPa

While giving the SI units the first letter should not be in capital i.e cm, not Cm; kg not Kg. There should not be a full stop at the end of the abbreviation: cm, not cm. kg, not kg.; ha, not ha.

In reporting the data, dimensional units, viz., M (mass), L (length), and T (time) should be used as shown under some applications above. Some examples are: 120 kg N/ha; 5 t/ha; 4 dS/m etc.

Special Instructions

I. In a series or range of measurements, mention the unit only at the end, e.g. 2 to 6 cm2, 3, 6, and 9 cm, etc. Similarly use cm2, cm3 instead of sq cm and cu m.

II. Any unfamiliar abbreviation must be identified fully (in parenthesis).

III. A sentence should not begin with an abbreviation.

IV. Numeral should be used whenever it is followed by a unit measure or its abbreviations, e.g., 1 g, 3 m, 5 h, 6 months, etc. Otherwise, words should be used for numbers one to nine and numerals for larger ones except in a series of numbers when numerals should be used for all in the series.

V. Do not abbreviate litre to` l' or tonne to `t'. Instead, spell out.

VI. Before the paper is sent, check carefully all data and text for factual, grammatical and typographical errors.

VII. Do not forget to attach the original signed copy of `Article Certificate' (without any alteration, overwriting or pasting) signed by all authors.

VIII. On revision, please answer all the referees' comments point-wise, indicating the modifications made by you on a separate sheet in duplicate.

IX. If you do not agree with some comments of the referee, modify the article to the extent possible. Give reasons (2 copies on a separate sheet) for your disagreement, with full justification (the article would be examined again).

X. Rupees should be given as per the new symbol approved by Govt. of India.

Details of the peer review process

Manuscripts are received mainly through e-mails and in rare cases, where the authors do not have internet access, hard copies of the manuscripts may be received and processed. Only after the peer review the manuscripts are accepted for publication. So there is no assured publication on submission. The major steps followed during the peer review process are provided below.

Step 1. ***Receipt of manuscript and acknowledgement***: Once the manuscript is received, the contents will be reviewed by the editor/associate editors to assess the scope of the article for publishing in JOR. If found within the scope of the journal, a Manuscript (MS) number is assigned and the same will be intimated to the authors. If the MS is not within the scope and mandate of JOR, then the article will be rejected and the same is communicated to the authors.

Step 2. ***Assigning and sending MS to referees***: Suitable referees will be selected from the panel of experts and the MS (soft copy) will be sent to them for their comments - a standard format of evaluation is provided to the referees for evaluation along with the standard format of the journal articles and the referees will be given 4-5 week time to give their comments. If the comments are not received, reminders will be sent to the referees for expediting the reviewing process and in case there is still no response, the MS will be sent to alternate referees.

Step 3. ***Communication of referee comments to authors for revision***: Once the referee comments and MS (with suggestions/ corrections) are received from the referees, depending on the suggestions, the same will be communicated to the authors with a request to attend to the comments. Authors will be given stipulated time to respond and based on their request, additional time will be given for attending to all the changes as suggested by referees. If the referees suggest no changes and recommend the MS for publication, then the same will be communicated to the authors and the MS will be taken up for editing purpose for publishing. In case the referees suggest that the article cannot be accepted for JOR, then the same will be communicated to the authors with proper rationale and logic as opined by the referees as well as by the editors.

Step 4. ***Sending the revised MS to referees***: Once the authors send the revised version of the articles, depending on the case (like if major revisions were suggested by referees) the corrected MS will be sent to the referees (who had reviewed the article in the first instance) for their comments and further suggestions regarding the acceptability of publication. If only minor revisions had been suggested by referees, then the editors would look into the issues and decide take a call.

Step 5. ***Sending the MS to authors for further revision***: In case referees suggest further modifications, then the same will be communicated to the authors with a request to incorporate the suggested changes. If the referees suggest acceptance of the MS for publication, then the MS will be accepted for publication in the journal and the same will be communicated to the authors. Rarely, at this stage also MS would be rejected if the referees are not satisfied with the modifications and the reasoning provided by the authors.

Step 6. ***Second time revised articles received from authors and decision taken***: In case the second time revised article satisfies all the queries raised by referees, then the MS will be accepted and if not satisfied the article will be rejected. The accepted MS will be taken for editing process where emphasis will be given to the language, content flow and format of the article.

Then the journal issue will be slated for printing and also the pdf version of the journal issue will be hosted on journal webpage.

Important Instructions

- Data on field experiments have to be at least for a period of 2-3 years
- Papers on pot experiments will be considered for publication only as short communications
- Giving coefficient of variation in the case of field experiments Standard error in the case of laboratory determination is mandatory. For rigorous statistical treatment, journals like Journal of Agricultural Science Cambridge, Experimental Agriculture and Soil Use and Management should serve as eye openers.

SPECIAL ANNOUNCEMENT

In a recently conducted Executive Committee meeting of the Indian Society of Oilseeds Research, it was decided to increase the scope of the Journal of Oilseeds Research by accommodating vibrant aspects of scientific communication. It has been felt that, the horizon of scientific reporting could be expanded by including the following types of articles in addition to the Research Articles, Shor Communications and Review Articles that are being published in the journal as of now.

Research accounts (not exceeding 4000 words, with cited references preferably limited to about 40-50 in number): These are the articles that provide an overview of the research work carried out in the author(s)' laboratory, and be based on a body of their published work. The articles must provide appropriate background to the area in a brief introduction so that it could place the author(s)' work in a proper perspective. This could be published from persons who have pursued a research area for a substantial period dotted with publications and thus research account will provide an overall idea of the progress that has been witnessed in the chosen area of research. In this account, author(s) could also narrate the work of others if that had influenced the course of work in authors' lab.

Correspondence (not exceeding 600 words): This includes letters and technical comments that are of general interest to scientists, on the articles or communications published in Journal of Oilseeds Research within the previous four issues. These letters may be reviewed and edited by the editorial committee before publishing.

Technical notes (less than 1500 words and one or two display items): This type of communication may include technical advances such as new methods, protocols or modifications of the existing methods that help in better output or advances in instrumentation.

News (not exceeding 750 words): This type of communication can cover important scientific events or any other news of interest to scientists in general and vegetable oil research in particular.

Meeting reports (less than 1500 words): It can deal with highlights/technical contents of a conference/ symposium/discussion-meeting, etc. conveying to readers the significance of important advances. Reports must

Meeting reports should avoid merely listing brief accounts of topics discussed, and must convey to readers the significance of an important advance. It could also include the major recommendations or strategic plans worked out.

Research News (not exceeding 2000 words and 3 display items): These should provide a semi-technical account of recently published advances or important findings that could be adopted in vegetable oil research.

Opinion (less than 1200 words): These articles may present views on issues related to science and scientific activity.

Commentary (less than 2000 words): This type of articles are expected to be expository essays on issues related directly or indirectly to research and other stake holders involved in vegetable oil sector.

Book reviews (not exceeding 1500 words): Books that provide a clear in depth knowledge on oilseeds or oil yielding plants, production, processing, marketing, etc. may be reviewed critically and the utility of such books could be highlighted.

Historical commentary/notes (limited to about 3000 words): These articles may inform readers about interesting aspects of personalities or institutions of science or about watershed events in the history/development of science. Illustrations and photographs are welcome. Brief items will also be considered.

Education point (limited to about 2000 words): Such articles could highlight the material(s) available in oilseeds to explain different concepts of genetics, plant breeding and modern agriculture practices.

Note that the references and all other formats of reporting shall remain same as it is for the regular articles and as given in Instructions to Authors

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Web site: http://www.isor.org.in; E-mail: oilseedsociety@gmail.com