ISSN 0970-2776

Volume 28 Number 1 June 2011

Journal of Oilseeds Research

Indian Society of Oilseeds Research
Estt : 1983

Indian Society of Oilseeds Research
Directorate of Oilseeds Research
Rajendranagar, Hyderabad-500 030, India

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Journal of Oilseeds Research is published biannually by the Indian Society of Oilseeds Research

JOURNAL OF OILSEEDS RESEARCH

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Best management practices for increasing productivity and resource use efficiency in oilseeds

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(Received: February, 2011; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

Demand for vegetable oils is out pacing the supply leading to low self sufficiency. Oilseeds are energy rich crops grown under sub-optimal agro-ecological condition resulting in low productivity. The general decline in *per capita* arable land coupled with shortage and poor quality of resources further puts limitation for realizing higher productivity of oilseeds. The major limitation for oilseeds production is water and nutrient. The factor productivity is declining in oilseeds and thus raising oilseeds productivity causes increase in cost of production and further low profits. Providing agro-ecological optima is the key to increased oilseeds production that is necessary for ensuring self sufficiency on a sustainable basis. Technological advancements in efficient use of resources are continuously upgraded and fine-tuned to operate at higher efficiency. Best Management Practices (BMP) is the term used to describe practices which have been proven to provide optimum production potential, input efficiency and environmental protection for specific site. The high genetic potential of the newer genotypes can be realized only when the agro-ecological optimum conditions are provided through best management practices (BMPs). Once in place, BMPs lead to Maximum Economic Yields (MEY) and together they lead to sustainability both economically and environmentally. Partial factor productivity of applied input is of practical relevance. This review discusses BMPs for increasing oilseeds productivity and resource use efficiency under broad categories of land management, crop management and fertilizer management.

Key words: 4Rs, BMPs, Fertilizer use efficiency, Oilseeds, Resource use efficiency, SSNM, Water use efficiency

India is one of the largest oilseeds producing countries with largest area under oilseeds sharing 14% of the country's gross cropped area and accounting for nearly 1.4% of the gross domestic product and 8% of the value of all agricultural products. India has the distinction of having highest production and consumption of oilseeds and vegetable oils. But the production falls far short of consumption. Paradoxically, despite the opportunity of cultivating nine annual oilseed crops under wide ranging agro-ecological situations and recording highest acreage under oilseeds, India remained the world's second-largest edible oil consumer after China, meeting more than half its annual requirement through imports. Currently, oilseeds are grown on an area of over 26 m. ha with a productivity of around 1000 kg a hectare. The average productivity of oilseeds in India is around 1.0 t/ha, which is far below that of the developed countries (2.5-3.0 t/ha) and of the world average (1.9 t/ha) (Damodaram and Hegde, 2010) mainly due to their cultivation under rainfed condition (73%) under low input use and poor crop management by majority small and marginal farmers. Oilseeds production varies directly as per the annual rainfall pattern. The factor productivity of oilseeds is decreasing indicating the need for higher input supply for maintaining the same level of production. Sustainability of the enhanced oilseeds production is as important as enhancing the production.

The demand for vegetable oil and oilseeds is increasing due to increase in population, increased standard of living and rapid industrialization. Vegetable oil consumption is both price and income elastic. The National Council of Applied Economic Research (NCAER) has projected the demand for edible oils in India under three scenarios on the basis of *per capita* income growing annually by 4%, 5% and 6%. Under the low growth scenario, the demand was to rise to 22.8 m.t. under medium growth scenario to 25.9 m. tonnes and under high growth scenario to 29.4 m.t. in the near future. Trade estimates show that India's demand is projected to rise to 16.5 m.t. by 2011 and 20.8 m.t. by 2015. The demand projections taking into account the trend of expenditure and price of food items suggest that the edible oil demand in the country to be 19.02 and 40.89 m.t. for 2025 and 2050 (Singh, 2006). India's oilseed deficit is likely to continue owing to an ongoing production shortage coupled with robust demand growth. The level of edible oils import is likely to touch 12 m.t. by 2015 due to increase in demand for edible oils and a near stagnant oilseeds production in the last decade due to low growth rate in acreage especially for

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the major oilseed crops. During the last two decades, edible oil consumption increased at a 4.3% compound annual growth rate and is expected to continue increasing with the growing population, changing demographic pattern and rising *per capita* consumption. This apart, across the world, the new dimension to demand for vegetable oil comes from the unlimited demand for biofuel due to the commitments under UN Kyoto protocol for binding emission reduction. Oilseeds are most sought renewable source of vegetable oil for biofuel production.

With increasing demand for land for industrial and urbanization, there will be sharp decline in *per capita* arable land for food crops in general and oilseeds in particular. Making oilseeds production more profitable and stable can stand the competition for area expansion. Apart from cultivable land, there is general decline and shortage of resources such as soil fertility, weather and rainfall pattern, manures and fertilizers, irrigation, quality seeds, timely labour availability, effective pest control, implements, harvesting and post harvest processing, etc., that compound the limitations for realizing higher productivity of oilseeds. With minimal scope for increase in area expansion, the additional production and profitability from oilseeds must come primarily from increase in crop productivity with efficient resource use resulting in reduced cost of production and environmental safety.

Yield plateau and declining crop yields even under higher input use is the main cause of concern for meeting the growing demands of agricultural production in general and oilseeds in particular. The input intensive agriculture immensely contributed towards the goal of increased food production, but has by passed the issues on sustainability and consequent deceleration in agriculture production. Indiscriminate use of irrigation water, fertilizers and unscientific crop management on a continued basis has resulted in reduced crop yields, profits and sustainability due to salinization, nutrient inadequacy and imbalance, decline in soil quality, build up of pest and diseases, besides causing environmental degradation. This has resulted in low use efficiencies of agricultural resources especially soil, water, fertilizers/arochemicals, etc., ultimately leading to decline in total factor productivity. Providing agro-ecological optima is the key to increased oilseeds production that is necessary for ensuring self reliance in vegetable oils on a sustainable basis. The high genetic potential of the newer genotypes can be realized only when the agro-ecological optimum conditions are provided through best management practices (BMPs). Once in place, BMPs lead to Maximum Economic Yields (MEY) and together they lead to sustainability both economically and environmentally.

BMP is the term used to describe practices which have been proven to provide optimum production potential, input efficiency and environmental protection for specific site. The variation in adoption of BMPs explains the variations in yield and profits realized on adjoining farms with similar fixed costs, soils and yield potential.

Continuous advancements in science to develop newer technologies of better genetic material and other agronomic practices will further raise the yield potential on successful implementation into crop production systems. A concerted effort to adopt the latest BMP technology satisfies the primary component of sustainability to achieve higher production levels. High yields and increased profit potential go hand in hand. A systematic effort to integrate BMPs for all the controllable crop production factors helps to attain MEY which gives the highest profit, the second component of sustainability. The implementation of new crop production technologies, soil management practices and other BMPs satisfy the third component of sustainability of safeguarding the environment. The use of BMPs, promotes a more vigorous, healthy and productive crop. A better yielding crop develops bigger root systems, more above-ground residues, reduced soil erosion, greater amounts of carbon assimilation, improved nutrient use efficiency, build up of organic matter, quicker ground cover, greater water use efficiency and more resistance to crop stresses such as drought, cold temperatures or late planting. All these factors make full utilization of inputs and resources leading to reduced environmental degradation.

Resource use efficiency is a measure of factor productivity in terms of output (seed yield) per unit of input (resource) or totality of inputs as combination. Any means that increase crop growth and productivity increases the use efficiency of all factors of production. Alteration in any *per se* input use or method of use affecting the crop yield affects the use efficiency of all other resources depending on their nature of interaction and overall resource use efficiency.

Among all the resources of crop production, more systematic assessment efforts have gone for assessing fertilizer use efficiency for its short supply and high cost. Fertilizer use efficiency is defined in different ways by the scientists belonging to different disciplines of agriculture. A set of simple indices that are frequently used in agronomic research to assess the efficiency of applied fertilizer (Novoa and Loomis, 1981; Cassman *et al.*, 2002) mainly for assessing the short-term crop response to a nutrient are presented in Table 1. Other indices are sometimes used (Gourley *et al.*, 1993; Huggins and Pan, 1993), but have no additional advantages for understanding fertilizer best management practices.

In field studies, nutrient use efficiencies are either calculated based on differences in crop yield and/or nutrient uptake between fertilized plots and an unfertilized control (difference method), or by using isotope labeled fertilizers to estimate crop and soil recovery of applied nutrients. Time scale is usually one cropping season. Spatial scale for measurement is mostly a field or plot. For the same soil and cropping conditions, nutrient use efficiency generally decreases with increasing nutrient amount added. Crop yield and plant nutrient accumulation/uptake typically increase with increasing nutrient addition and gradually approach a ceiling. The level of this ceiling is determined by the climatic-genetic yield potential. At low levels of nutrient supply, rates of increase in yield and nutrient uptake are large because the nutrient of interest is the primary factor limiting growth (de Wit, 1992). As nutrient supply increases, incremental yield gains become smaller because yield determinants other than that nutrient become more limiting as the yield potential is approached.

Table 1 Indices of nutrient use efficiency, their calculation using the difference method and their interpretation (Dobermann, 2007)

Index	Calculation	Interpretation
RE=Apparent crop recovery efficiency of applied nutrient (kg increase in N uptake per kg N applied)	$RE=(U-U_0)/F$	RE depends on the congruence between plant demand and nutrient release from fertilizer RE is affected by the application method (amount, timing, placement, N form) and factors that determine the size of the crop nutrient sink (genotype, climate, plant density, abiotic and biotic stresses)
PE=Physiological efficiency of applied N (kg yield increase per kg increase in N uptake from fertilizer)	$PE=(Y-Y_0)/(U-U_0)$	Ability of a plant to transform nutrients acquired from fertilizer into economic yield (grain) Depends on genotype, environment and management Low PE suggests suboptimal growth (nutrient deficiencies, drought stress, mineral toxicities, pests)
IE=Internal utilization efficiency of a nutrient (kg yield per kg nutrient uptake)	$IE=Y/U$	Ability of a plant to transform nutrients acquired from all sources (soil, fertilizer) into economic yield (grain) Depends on genotype, environment and management A very high IE suggests deficiency of that nutrient Low IE suggests poor internal nutrient conversion due to other stresses (nutrient deficiencies, drought stress, heat stress, miner toxicities, pests)
AE=Agronomic efficiency of applied nutrient (kg yield increase per kg nutrient applied)	$AE=(Y-Y_0)/F$ or $AE=RE \times PE$	Product of nutrient recovery from mineral or organic fertilizer (RE) and the efficiency with which the plant uses each additional unit of nutrient (PE) AE depends on management practices that affect RE and PE
PFP=Partial factor productivity of applied nutrient (kg harvested product per kg nutrient applied)	$PFP=Y/F$ or $PFP = (Y_0/F)+AE$	Most important for farmers because it integrates the use of efficiency of both indigenous and applied nutrients High indigenous soil nutrient supply (Y0) and high AE are equally important for PFP.

F = Amount of (fertilizer) nutrient applied (kg/ha)
Y = Crop yield with applied nutrients (kg/ha)
Y_0 = Crop yield (kg/ha) in a control treatment with no N
U = Total plant nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received fertilizer
U_0 = Total nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received no fertilizer

Because each of the indices in Table 1 has a different interpretation value, fertilizer research should include measurements of several indices to understand the factors governing nutrient uptake and fertilizer efficiency, to compare short-term nutrient use efficiency in different environments and to evaluate different management strategies. The 'difference method' is simple and cost efficient, which makes it particularly suitable for on-farm research. However, sampling and measurement must be done with great care.

Agronomic efficiency (AE) is also referred to as crop response or crop response ratio and is very useful term which is extensively used by Agronomists, Agricultural Statisticians, Economists and Planners in determining benefits derived from the fertilizer use and in calculating the fertilizer needs of an area or country as per the food needs.

Partial factor productivity (PFPf) is a very useful term for estimating the fertilizer use efficiency when a control plot yield is not available as in varietal trials and experiments on irrigation, weed control, sowing dates, plant population, crop establishment methods, etc., where a uniform fertilizer application is generally made. PFPf is also a useful term in comparing fertilizer use efficiency in different parts of a country or in different countries.

Apparent recovery (AR or RE) is used by Soil Scientists and Agronomists in determining the percentage of applied nutrient utilised by a crop. It is useful in preparing nutrient balance sheets and is also of interest to the environmentalists for finding out the proportion of applied nutrient contributing to the environmental pollution.

Physiological efficiency (PE) is used by the Plant Physiologists and Agronomists for comparing different species or different cultivars of a species in respect of a plant nutrient. Inter and intra-specific variation for plant growth and mineral nutrient use efficiency are known to be under genetic and physiological control and are modified by plant interactions with environmental variables.

It may be observed that the economic produce from the crop is directly or indirectly the numerator for all fertilizer use efficiency terms and the best way to increase the fertilizer use efficiency is to increase crop yields by increasing response to fertilizers through adoption of best management practices (BMPs).

While comparing the values of nutrient use efficiencies it is prudent to aim for higher value of NUE when the nutrients are used at recommended or above critical limit or sufficiency level for obtaining optimum yield rather than deciding solely on highest NUE values that can be obtained at lower levels of input use giving greatest marginal rate of return/product. At this situation, greatest soil mining will take place resulting in unsustainable crop yields, reduced soil fertility and quality.

This paper discusses BMPs for soil, crop, water, and fertilizer management for their role and potential in increasing productivity and resource use efficiency in oilseeds production. The high genetic potential of the genotypes can be realized only when the agro-ecological optimum conditions are provided.

BMPs related to soil management

Good soil management practice lays the foundation for good crop growth, development and yield (Prasad, 2007). Soil management practices that maximise root growth will increase nutrient and water recovery by plants and maximise yield potentials. Large root systems not only increase total nutrient uptake but also increase nutrient uptake rates, a key factor for high crop yields. A few soil management practices which have proven impact on improved crop response and resource use efficiency are indicated.

Land leveling and soil tilth: Uniform germination and desired plant stand establishment of field crops depends on the seedbed conditions and tilth. Low yields of oilseed crops under dryland cultivation is mainly due to the sub-optimal plant population, patchy spots of high or sparse plant stand, despite the use of quality seed due to the improper land preparation and tilth. Undulating land surface makes seed depth placement uneven resulting in poor germination and initial plant stand establishment. Due to this the effectiveness and efficiency of other inputs - moisture and nutrients will be low and uneconomical. Precise leveling with gentle slope as per the soil and moisture conservation recommendations for the site ensures better plant stand establishment, uniform growth and higher yields under dryland conditions (Prasad and Sudhakara Babu, 1997). Further, it provides ease of inter-culture operations for realizing optimum yields. Leveling requirement is more critical for surface methods of irrigation wherein significant impact of water and nutrients are involved of their efficiency and cost. Together with recommended land configuration as per the soil type helps higher soil moisture conservation/disposal resulting in higher yields.

Crops like sunflower require fine soil tilth for their best performance due to their extensive root system. Tractor drawn disk plough + rotovator in Alfisols under paddy fallows resulted in highest seed yield and fertilizer use efficiency in Alfisols (Table 2) (Reddy *et al.*, 2004a; Gurumurthy *et al.*, 2008). In deep Vertisols wherein rainy season cropping is not feasible and only post rainy cropping on residual moisture is the opportunity, land management practices of vertical mulching and compartment ditches are effective in reducing runoff and increasing infiltration for increasing soil moisture storage that is critical for better crop performance and increased use efficiency of all other factors of production *viz.*, seed, fertilizer, moisture, etc., especially for safflower, chickpea, sorghum, coriander, etc.

Soil moisture conservation: The potential crop yields in any agro-ecological situation depend on the length of growing period influenced by the rainfall and soil factors for moisture holding, retention and release. The risk of using fertilizers in dryland agriculture is due to the uncertainties of soil moisture. Efficient conservation of soil moisture is a basic prerequisite for successful production of crops under dryland conditions (Prasad and Sudhakara Babu 1997). Studies carried out at Solapur on safflower (Table 3) indicated that soil moisture conservation practices like compartment bunding, tied ridges and furrows and closing the furrows every 10M and border method of planting resulted in significantly higher safflower yield and PFP_{NP} over normal planting method (DOR, 1996). Improved land and water management methods like contour cultivation with conservation furrows (Table 4) and modified contour bunding had significant effect on crop yields and PFP_{NPK}. Firm soil base is essential to resist lodging due to large head or spike weight with good crop and to tolerate high wind or gales. Ridges and furrow method of planting was found to be more appropriate under Vertisols while in coarse textured Alfisols, flat sowing and later earthing up was better for castor and sunflower crops. In Vertisols at Gangavati, sunflower seed yield was significantly higher under different *in-situ* rain water harvesting practices compared to control with concomitant increase in fertilizer use efficiency (Table 5) (Balaganvi *et al.*, 2009). Tied rigdes and furrows recorded highest seed yield and FUE.

Under proper soil moisture conservation as per the soil type and situation and fertilizer use has given far greater benefit in groundnut, sunflower, soybean, safflower and castor crops compared to farmers' practice resulting in higher use efficiency of moisture and nutrients (Table 6) (Reddy *et al.*, 2004b; Reddy and Suresh, 2009). Soil moisture conservation practices of bunding, use of mulches and deep tillage have caused higher water storage and use efficiency of water and fertilizer under arid conditions of Rajasthan on taramira (Regar *et al.*, 2009).

Table 2 Effect of different tillage methods on seed yield of sunflower in Alfisols (mean of two years 1997-98 to 1998-99) (Gurumurthy *et al.*, 2008)

Treatment	Seed yield (kg/ha)	FUE
Zero tillage	719	4.8
Farmers Practice	930	6.2
Modified farmers practice	1054	7.0
Tractor drawn MB plough + 2 passages of cultivator	1172	7.8
Tractor drawn disc plough + rotavator	1311	8.7
CD (P=0.05)	72	

Table 3. Effect of *in situ* moisture conservation practices on seed yield and PFPNP of safflower at Solapur (DOR 1995-96)

Moisture conservation practice	Seed yield (kg/ha) (Mean of 1993-94 to 1995-96)	PFP_{NP}
Compartment bounding, 3 m x 3 m	1036	13.8
Tied ridges and furrows spaced 45 cm and closing the furrows every 10 m	1129	15.1
Border method of planting	1186	15.8
Normal planting	877	11.7
CD (P=0.05)	40	

Computed on the basis of 50 kg N and 25 kg P_2O_5

Table 4 Yields and PFP_{NPK} of different crops under improved land and water management systems at Sujala Watersheds, Karnataka (2005-06) (ICRISAT)

Crop	Mean crop yield (t/ha)		Increase in yields (%)	PFP_{NPK} (kg/kg)	
	Farmers' practice	Contour cultivation with conservation furrows		Farmers' practice	Contour cultivation with conservation furrows
Groundnut	1.18	1.49	26	14.7	18.6
Sunflower	1.25	1.42	14	8.3	9.5

Fertilizer levels (N, P_2O_5, K_2O, kg/ha); Groundnut: 20:40:20; Sunflower: 60:60:40

Table 5 Effect of different *in-situ* rain water harvesting practices on sunflower yield (Gangavati, saline Vertisols) (Mean of three years) (Balaganvi *et al.*, 2009)

Treatment	Yield (kg/ha)	FUE
Compartment bunding	770	5.38
Deep ploughing	750	5.24
Bedding	900	6.29
Ridges and furrows	930	6.50
Tied ridges and furrows	970	6.78
Control	530	3.71
CD (P=0.05)	60	

RDF = 60:33:50 kg $N:P_2O_5:K_2O$/ha

Table 6 Seed yield (kg/ha) of oilseeds under nutrients and moisture stress [Mean of 2 years (2001-02 to 2002-03)] (Reddy *et al.*, 2004; Reddy and Suresh 2009)

Moisture conservation and Fertilizer application	Groundnut	Soybean	Sunflower	Castor	Safflower
Recommended MC+FA	2194	2242	974	926	1440
Farmer's method (FM)	2035	1765	773	741	1283
Cultivar					
Improved cultivar	2195	2149	998	889	1475
Traditional	1944	2048	761	752	1258

MC: Moisture conservation and FA: Fertilizer application

		RDF	Farmers' method
Groundnut	:	20:40:20 kg $N:P_2O_5:K_2O$/ha	9:23:0 kg $N:P_2O_5:K_2O$/ha
Soybean	:	20:27:17 kg $N:P_2O_5:K_2O$/ha	No fertilizer
Sunflower	:	30:50:35 kg $N:P_2O_5:K_2O$/ha	17.5:25:17.5 kg $N:P_2O_5:K_2O$/ha
Castor	:	60:40:30 kg $N:P_2O_5:K_2O$/ha	30:20:15 kg $N:P_2O_5:K_2O$/ha
Safflower	:	50:25:0 kg $N:P_2O_5:K_2O$/ha	No fertilizer

Liming of acid soils: Soil acidity limits agricultural productivity in extensive areas in the world. With decline in use of organic manures and continuous applications of high analysis nitrogenous fertilizers, base saturation of soil seriously affected leading to build up of acidity. Calcium deficiency and Al toxicity are considered major yield limiting factors of tropical and sub-tropical acid soils. In India, about 30% of the cultivated land is considered acidic where efficient fertilizer management is a problem. Both root and overall plant growth are restricted in these soils. Plant nutrients such as P are rendered less available in acid soils due to precipitation with aluminium and iron. The most direct method to increase plant nutrient availability and growth in acid soils is to nutralize acidity by adding lime (calcium carbonate or calcium-magnesium carbonate). Correcting soil acidity in acid soils greatly helps in increasing crop response to fertilizers (Mathur, 1994). Long term use of lime in acid soils along with NPK can sustain high yields and fertilizer use efficiency of soybean - wheat rotation at Chotanagpur, Bihar (Prasad, 1998, Manna *et al.*, 2007) (Table 7). Increasing NPK rate to 150% without liming has even decreased the yield of soybean with low PFE. Significant response to application of Ca along with NPK was noticed on sunflower in Alfisols (DOR, 2010-11).

BMPs related to crop management

Agronomic practices for managing crops have tremendous influence on productivity and hence crop response to fertilizers and nutrient use efficiency. Practices such as selection of appropriate genotype best suited for the region, optimum date of planting/sowing, maintenance of required plant stand, weed control measures, proper water management, etc., have great impact on performance of crops. Most of these are knowledge based, low or no cost practices that rely on timeliness of operations rather than investments and inputs. Effects of some of these agronomic practices on crop response to fertilizers are presented hereunder:

Crop variety/hybrid: Improved variety of oilseed crop suitable for the agro-ecoregion is the prime mover for the potential productivity and resource use efficiency and factor productivity. The high yielding varieties also responded to fertilizers with better FUE. Sunflower hybrids have higher yield potential (Table 8) with higher PFP_{NPK} than varieties (DOR, 2009a). In almost all crops, hybrids have out yielded varieties with higher nutrient use potential. Therefore, selection of best suited variety/hybrid for each crop-growing situation is very important to get better response to fertilizers and higher production.

Most competing profitable crop for the region and season can be selected as per crop ecological requirements. Safflower crop for the post rainy season in the Malwa plateau of Madhya Pradesh is competitive and profitable compared to *rabi* sorghum, chickpea and wheat. Under dryland situations, crops and varieties have to be selected to match the effective growing season as determined by the soil type and rainfall. In post-rainy season, the available moisture in the soil profile at the time of sowing determines the crop to be grown. If the soil moisture at sowing is 50-75mm, only *taramira* can be grown. If it is 75-120mm, mustard and at 120-150mm mustard and chickpea are the options (Prasad and Sudhakara Babu, 1997).

Adoption of improved varieties of crops as per the development helps in continuous higher oilseeds production. 'Morden' variety of sunflower is suitable for a short growing season of 60-75 days and for late plantings. DCS-9 and DCH-32 genotypes of castor are early in maturity compared to variety Aruna besides high degree of wilt tolerance; Manjira and A-1 varieties of safflower for normal planting and APRR-3 for delayed planting in Andhra Pradesh and HUS-305 for salt affected areas of West Bengal; Kadiri-3 and ICGS76 varieties of groundnut are tolerant to mid-season drought and to some extent end-season drought; *toria, sarson* (yellow and brown), *taramira* and *gobhi sarson* are of short duration and are specifically grown as catch crops between two prominent crops in intensive cropping situations. In endemic areas of crop pests, available tolerant or resistant varieties of crops should be used. DCS-9 of castor for wilt situations, hybrids and LDMRSH-1 and 2 sunflower for downy mildew disease, Girnar-1 of groundnut for multiple foliar disease resistance and Tirupati-2 (Vemana) for Kalahasti malady resistance (Prasad and Sudhakara Babu, 1997). Under the opportunity of utilizing residual moisture and soil fertility in paddy fallows, sunflower crop competes over others due to its short duration and variety 'Morden' was preferred over hybrids under situations of late sowing (Reddy and Sudhakara Babu 1999).

Oilseeds in cropping systems: Oilseed crops offer great potential for increasing cropping intensity and profitability in wide ranging cropping systems. Oilseed crops by nature are hardy crops mostly grown under rainfed conditions and can impart stability of production system under harsh conditions. The premium price for oilseeds makes the cropping system profitable. Hegde *et al.* (2003) has detailed the alternative crop plans to convert and phase out gradually to remunerative crops such as vegetables, orchards, etc., to be complemented with other enterprises like sericulture, agro-forestry, livestock and poultry, etc. The land based and water based approach for diversification was suggested for effective planning and implementation. Detailed alternatives of horizontal approach with special significance to small holder production systems for increasing crop intensities and vertical approach that incorporates industrialization was detailed. Crop diversification for different states is accordingly suggested at different crop diversification indices *viz.*, 80-100%, 60-80%, 40-60% and less than 40%.

Oilseed based crop sequences help to utilize the residual fertility and provide safe crop rotations. Groundnut crop is efficient utiliser of residual fertility in sunflower based cropping system. Together, the system productivity and profitability can be increased under variable fertilizer management (Reddy and Sudhakara Babu 1996). Downy mildew disease incidence in sunflower can be effectively managed with crop rotation with groundnut or sorghum (Sudhakara Babu *et al.*, 1999).

Oilseed based intercropping system offer wide scope for utilizing both above ground and below ground resources for increasing productivity per unit area per unit time besides reducing the risk of crop failure under dryfarming condition with mono cropping. All the annual oilseed crops can fit well in major crops of the regions either as component crop or base crop. Intercrop management in terms of proper crop combinations, row ratio, planting time, fertilizer application can provide greater sustainability in terms of land, time, moisture, nutrient, employment, pest management, economics, quality and product mix, etc. under dryland conditions. Detailed agro-ecoregion-specific cropping systems (both inter and sequence crops) for sustainable oilseeds production in the country provide policy guidelines for adopting efficient cropping systems under different resource use patterns. (Hegde, 2007).

Date of planting/sowing: Every crop has an optimum range of planting period for expression of the genetic potential. Either early or late planting beyond this optimum range leads to reduction in yield and lower response to fertilizers. Some crops like safflower are very inelastic in their planting date needs while crops like sunflower are quite accommodative. Effect of planting date on safflower at Indore under irrigated conditions is presented in Table 9 (DOR, 2009b). The seed yield of safflower declined from 2996 kg/ha for 15 October planting to 2736 (8.7% reduction), 1376 (54.1% reduction) and 792 kg/ha (73.6% reduction) for 30 October, 15 November and 30 November plantings, respectively. The corresponding PFP_{NPK} values declined from 30.0 kg grain/kg NPK to 27.4, 13.8 and 7.9 kg grain/kg NPK. Beside unfavorable temperature regime, late planted safflower is severely susceptible to aphid infestation resulting in low yields. Thus early planting is a very effective way to control aphid in safflower. However, despite being considered relatively photo and thermo-insensitive, better performance of sunflower is found in early planting both in *kharif* and *rabi* seasons indicating the fuller utilization of seasonal ecological conditions. All over the country, specific planting dates/period is recommended for different crops for getting highest productivity and crop response to fertilizers. This is one of the best non-cash inputs for increasing yields and input use efficiency.

Table 7 Effect of long term use of lime from 1972-73 to 1996-97 on seed yield of soybean and wheat at Chotanagpur, Bihar (Prasad, 1998)

	Mean of 1972-73 to 1996-97		
	Soybean yield (kg/ha)	PFP (kg/kg)	Soil pH
100% NPK (No liming)	1611	12.88	4.8
150% NPK (No liming)	1496	7.98	4.7
100% NPK + Liming	1819	14.55	5.7
CD (P=0.05)	1.95		

Initial soil pH (1972) = 5.3; Liming once in four years @ 2.5t/ha; RDF (soybean) = 25:60:40 kg N:P_2O_5:K_2O/ha

Table 8 Relative response of varieties and hybrids of sunflower to fertilizer at Raichur under rainfed conditions (DOR 2009a)

Genotype	Seed yield (kg/ha)	PFP^{*}_{NPK}
Varieties		
DRSF-108	940	4.8
Morden	897	4.6
Hybrids		
DRSH-1	1239	6.4
RSFH-1	1181	6.1
SB-275	1279	6.6
CD (P=0.05)	126	6.6

* Applied fertilizer: 60 : 75 : 60 N, P_2O_5, K_2O, kg/ha

Table 9 Effect of planting date on seed yield and PFP_{NPK} of safflower at Indore under irrigated conditions (DOR 2009b)

Planting date	Seed yield (kg/ha)	Decline (%)	PFP^{*}_{NPK}
15 October	2996		30.0
30 October	2736	8.7	27.4
15 November	1376	54.1	13.8
30 November	792	73.6	7.9
CD (P=0.05)	467		

* Applied fertilizer: 40:40:20 N, P_2O_5, K_2O, kg/ha

Plant population: Maintenance of optimum plant population is essential to ensure proper utilization of other growth factors such as fertilizers and irrigation. The potential yield of any variety can be realized when optimum population is ensured. Under sub-optimal plant population, the resources are wastefully taken up by weeds that further increase the competition resulting in low crop yield and high cost of cultivation. Each crop has an optimum range of plant stand for getting the highest productivity. The crops which are indeterminate in growth habit or branching will have greater plasticity to adjust to varying plant populations and record the expected productivity levels. However, determinate crops and those which do not tiller or branch have limited plasticity to adjust to varying plant populations. In these corps, maintenance of optimum population is more important for realizing high yields. In crops like sunflower, safflower, mustard, etc., where removal of excess seedlings to maintain the desired plant stand is important, thinning at appropriate stage is very crucial to record high yields and FUE. The improvement in seed yield to the extent of 11 to 42% in mustard, 7 to 30% in sunflower and 24 to 37% in safflower were recorded due to maintenance of optimum population through thinning that has direct bearing on increase in use efficiency of inputs (Hegde, 2009). Without thinning, the high plant stand per hill results in higher susceptibility to drought and pests. Thinning in sunflower has resulted in 44% improvement in seed yield and FUE (Table 10) (Hegde, 2006).

Weed control: Weeds compete with crops for nutrients, water and space leading to reduced crop productivity and FUE. The reduction in yield depends on the extent of weed problem. In many crops, absence of weed control measures in some regions may result in total failure of the crop (Hegde, 2008). Weeds, in general, may reduce yields by 10 to 40% or more in different crops. Effective weed management practices increased grain yields by 64% and PFP from 5.2 kg grain/kg NPK to 18.6 kg grain/kg NPK, in mustard over unweeded control (Singh and Singh, 1998). Keeping the fields free during initial period of 5 to 6 weeks is very crucial for realising higher yields and FUE in crops like soybean (Table 11) (Nagaraju and Mohan Kumar, 2009). Besides, weeds even on bunds act as collateral host causing increased cost on pest management and reduced use efficiency and profits.

Weed control in Vertisols poses a special problem of inevitability with manual or physical methods due to high moisture conditions. Adopting integrated weed control practice by using pendimethalin + interculture at 25 DAS + hand weeding at 45 DAS has resulted in doubling the seed yield, highest weed control and FUE of sunflower (Table 12) (Suresh and Reddy, 2010).

Water management: Oilseed crops have low water requirement and are efficient under situations of limited water availability. Efficient water management is critical for high yield and FUE. Even with same level of fertilizer application, when soil moisture is a limiting factor, applying irrigation will have profound effect on productivity. In many oilseeds, application of a single irrigation at critical stage virtually doubles the productivity (Hegde, 2008). At the same level of fertilization, increasing the number of irrigations has significantly improved the seed yield and fertilizer use efficiency in linseed, safflower and mustard crops (Table 13) (Gouranga Kar *et al.*, 2007). Irrigating sunflower at IW/CPE ratio of 1.2 has given highest seed and oil yield but the highest water and fertilizer use efficiency was recorded at IW/CPE of 0.8 (Table 14) (Gurumurthy *et al.*, 2008).

Different methods of irrigation also have considerable effect on productivity and FUE. Micro irrigation methods such as drip and sprinkler have high use efficiency, low water use, besides improving crop quality.

Table 10 Effect of thinning in increasing FUE in sunflower (Hegde, 2006)

	Seed yield (kg/ha)				
	Coimbatore	Raichur	Nandyal	Mean	% increase
No thinning	825	1060	758	881	-
Thinning	1294	1298	1220	1271	44.3
FUE					
No thinning	8.25	10.6	7.58	8.81	-
Thinning	12.94	12.98	12.20	12.71	44.3

Table 11. Effect of weed control on seed yield and PFP_{NPK} of soybean (Nagaraju and Mohankumar 2009)

Treatment	Seed yield (kg/ha)	PFP_{NPK} (kg grain/kg NPK)
Unweeded control	1092	9.9
Weed free upto 10 DAS	1188	10.8
Weed free upto 20 DAS	1470	13.4
Weed free upto 30 DAS	1765	16.0
Weed free upto 40 DAS	1986	18.1
Weed free upto 50 DAS	2021	18.4
Weed free	2070	18.8
CD (P=0.05)	299	

Fertilizer level: 25:60:25, N, P_2O_5, K_2O, kg/ha

Table 12 Effect of weed control practices on seed yield of sunflower in Vertisols (mean of two years) (Suresh and Reddy, 2010)

Treatment	Seed yield (kg/ha)	Weed Index	WCE (%)	FUE
Un weeded control	1079	100	0	7.19
Farmers' practice	1781	31.0	59.5	11.87
Pendimethalin 1.0 kg Pre-em fb IC 25DAS + HW at 45DAS	2308	6.0	81.6	15.39
Weed free	2451	0	100	16.34
CD (P=0.05)	347			

Fertilizers applied: 60:60:30 kg $N:P_2O_5:K_2O$/ha

Table 13 Yield and water use efficiency of different crops with limited irrigation (pooled data of 2001-2002 and 2002-2003) (Dhenkanal, Orissa) (Gouranga Kar *et al.*, 2007)

Irrigation treatment	Linseed		Safflower		Mustard	
	Seed yield (kg/ha)	FUE	Seed yield (kg/ha)	FUE	Seed yield (kg/ha)	FUE
I_1	212c	2.65	392c	3.92	246c	2.73
I_2	701b	8.76	762b	7.62	547b	6.08
I_3	845a	10.56	1258a	12.58	938a	10.42
CD (P=0.05)	49.33		91.95		22.3	

I_1: One irrigation, I_2: two irrigations I_3: three irrigations. @ 60mm for each irrigation;
RDF ($N:P_2O_5:K_2O$/ha): Linseed: 40:20:20; Safflower: 40:40:20; Mustard: 40:30:20

Table 14 Seed yield, water use efficiency and fertilizer use efficiency of sunflower in Alfisols (mean of two years) (Gurunurthy *et al.*, 2008)

Irrigation level (IW/CPE)	Seed yield (kg/ha)	Oil yield (kg/ha)	WUE (kg seed/mm)	FUE_{NPK} (kg/kg NPK)
0.6	757	282	2.62	5.05
0.8	1002	389	2.81	6.68
1.0	1161	468	2.68	7.74
1.2	1231	500	2.60	8.21

RDF = 60:60:30 kg $N:P_2O_5:K_2O$/ha

BMPs related to fertilizer management

Low productivity of oilseeds is mainly their cultivation under energy starved conditions. Oilseeds are more hungry than thirsty and there is wide gap in fertilizer demand/requirement and the applications causing huge mining of soil fertility leading to complex nutrient imbalances and deficiencies that is difficult to manage. The grim situation of oilseeds nutrition in the country indicates that only about 1/3 of the fertilizer needs of oilseeds are actually applied (Fig. 1) leading to continuous mining of nutrients from the soil in oilseeds cultivation. Thus there is urgent need for stepping up use of major, secondary and micronutrients (Hegde, 2009).

The demand - supply nutrient gap in Indian agriculture is about 10 m. tonnes (Hegde *et al.*, 2008) and the competition from irrigated agriculture is higher from profitable assured food, horticulture and cash crops for the limited fertilizer stocks.

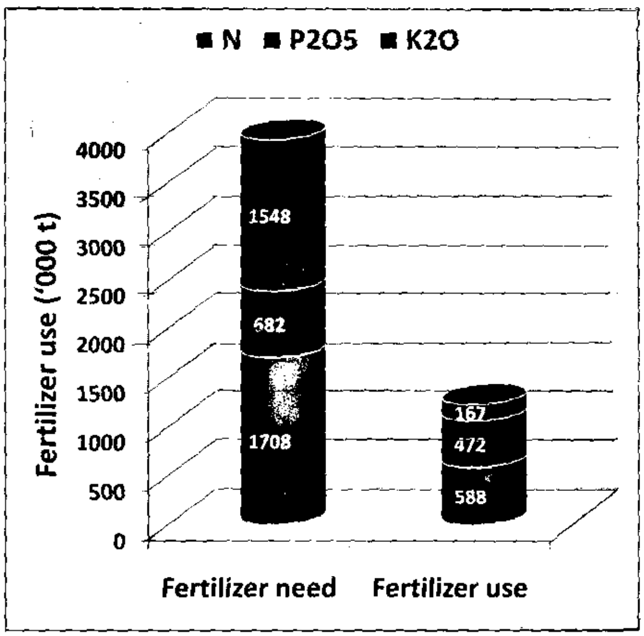

Fig. 1. Fertilizer use in oilseeds (2008-09), (Hegde, 2010)

On national average for all oilseed crops, only 52.5 kg/ha nutrients (NPK) are applied as against 140 kg/ha for rice and 160 kg/ha for wheat (Pasricha, 2010) and the national average of 117 kg/ha (Tiwari, 2008). Fertilizers are top in the hierarchy of factors limiting oilseeds production either singly and together with other factors (Biswas and Das 2002; Hegde, 2009). Recent review on nutritional management in oilseeds covers overall status, response and needed nutrient management strategies on nine annual oilseed crops in the country (Pasricha, 2010). Best management practices involving appropriate land, crop and fertilizer management strategies have been adequately described with clear possibility of increasing fertilizer use efficiency (Hegde and Sudhakara Babu, 2009a).

The general fertilizer use in oilseeds is low mainly because of their cultivation under rainfed condition. Fertilizing crops generally depends on the assured moisture/irrigation to avoid the additional economic loss on cost of fertilizer under unsure moisture conditions. However, nutrient management strategies for oilseed crops under rainfed conditions provide conclusive evidences of improving oilseeds productivity and fertilizer and moisture use efficiency significantly due to various nutrient management practices (Hegde and Sudhakara Babu, 2011).

BMPs related to fertilizer management involves two strategies

- Product strategy aim for enhanced efficiency of fertilizers. Here, primary focus is on product features *viz.*, coated fertilizers, slow release fertilizers, nitrification inhibitors and urease inhibitors. Importance will be on product features like fast acting, water soluble fertilizers;
- Fertilizer management strategy aim for enhanced efficiency of fertilization. Here focus is on nutrient management *viz.*, split application, N rate based on plant analysis, variable rate (time and space, precision farming).

Bottlenecks and strategies for increasing nutrient use efficiency can be well understood by analyzing the pathways of nutrients reaching the plant roots and its uptake and incorporation in plant tissues. Both these processes can be delineated as the factors external to plant and the factors internal to plant (Hegde *et al.*, 2008).

Field and crop-specific nutrient application programmes are developed to efficiently utilize applied nutrients. Crop, soil conditions, fertilizer characteristics and climatic effects must all be considered. For example, in humid climates, nitrate-based N fertilizers must be applied close to the time of plant nutrient need in order to prevent nitrate leaching losses, especially on sandy-textured soils, while organic N sources must decompose prior to nutrient release, and, therefore, must be applied further in advance of the crop's need. In addition, crop characteristics, such as root distribution and growth pattern, dictate the optimum placement of fertilizers. General plant nutrient characteristics (Table 15) have profound direct influence on fertilizer management (Hegde and Sudhakara Babu, 2009a).

Nitrogen management: On a global scale, higher crop yields are likely to be achieved through a combination of increased N applications in regions with low N fertilizer use, such as Africa and parts of Asia and Latin America, and improved N fertilizer efficiency in countries where current N fertilizer use is already high.

Approaches for N management and increasing N use efficiency have been discussed in many recent publications (Schroeder *et al.*, 2000; Cassman *et al.*, 2002; Giller *et al.*, 2004; Lemaire *et al.*, 2004; Ladha *et al.*, 2005; IFA, 2007; Prasad, 2007; Hegde and Sudhakara Babu, 2009a). The following are the major considerations for increasing N use efficiency with respect to oilseeds.

- Considering and managing the N supply from soil and other indigenous sources and maximizing the fertilizer efficiency (AEN = REN x PEN) are equally important components for achieving high PFPN.
- Achievable levels of REN depend on crop demand for N, supply of N from indigenous sources, fertilizer rate, timing, product and mode of application. With other factors held constant, REN declines with either increasing N rate, higher indigenous N supply or a smaller crop N sink. Holistic management concepts are required that jointly optimize the crop N sink for a specific environment and the availability of soil and fertilizer-N for plant uptake at critical growth stages.

Many technologies have synergistic effects on crop yield response to N. Hence, they must be applied in an integrated manner:

Phosphorus and potassium management: Understanding and management of P and K in agriculture have advanced significantly. Much of the current knowledge has been captured in models and decision support systems for predicting soil and crop response to P and K (Greenwood *et al.*, 2001; Karpinets *et al.*, 2004; Witt *et al.*, 2006). The main challenge for improving P and K use efficiency at the farm level is to apply the existing knowledge in a practical manner. Some of the important considerations with regard to oilseeds are as follows:

- P is requirement of oilseeds is high because of its direct involvement in growth and oil synthesis. The low use efficiency of P is due to its proneness for fixation. Utilising high soil total P through the use of P solubilizers holds a great promise in reducing P requirement. P management under cropping system is important to optimize the P requirement. It is possible to reduce 50% of P requirement in soybean - sunflower cropping system across locations and soil types with the use of P solubilizers and use of FYM (AICRP).

- Cumulative effects of repeated P additions on acid tropical soils are often more economical than single, large doses, primarily because of increasing RE_p and AE_p (Cassman *et al.*, 1993) and genotypic differences should be taken into account in P management strategies (Zhang *et al.*, 2006). Similar principles apply to the K management on K-fixing soils (Cassman *et al.*, 1989).
- With balanced fertilization (NPK), yield increased, primarily due to an increase in RE_p and hence AE_p and PFP_p. Plants draw P from a continuum of chemically extracted fractions that are assumed to have widely differing plant P availability. Regular P additions ar required to maintain the effective soil P supply.

Table 15 Plant nutrient ionic species and selected properties concerning plant availability and movement in soils

Element	Nutrient form	Ionic species	Soil reaction properties
Nitrogen (N) fertilizer	Ammonium	NH^+_4	This positively charged ion is held by negatively charged soil sites such as clay and organic matter. It is converted to nitrate by soil micro-organisms under warm moist conditions. It is taken up by plants as ammonium or after conversion to nitrate.
	Nitrate	NO^-_3	This negatively charged ion is not held by soil particles, moves with soil water and can be easily lost through leaching. It is readily taken up by plants.
	Organic	-	N is part of amino acids, humic acids and complex protein molecules in manures, plant residues and soil microorganisms. N is transferred to ammonium ions as organic material is mineralized by soil microorganisms. The rate of organic N conversion to ammonium depends on the total carbon content to total N content (C:N) ratio of the organic material as well as on soil temperature and moisture levels.
Phosphate (P) fertilizers	Water-soluble P	H_2PO_4; HPO_4^{2-} (orthophosphate anions)	These ions are readily taken up by plants but react with ion, aluminium and calcium ions in soil solution to form various compounds, some of which re-dissolve easily while others are highly insoluble. The solubility of soil P-containing compounds is greatest at pH 6.2 to 6.5 and is reduced as soil clay content increases. In addition, highly weathered clays (tropical soils) fix P or reduce its solubility to a greater extent than less weathered soil minerals found in temperate climates.
	Organic P	-	The organic molecules containing P must be mineralized before being available to plants. Mineralisation is dependent on soil microbial activity and the C:P ratio of the organic material.
Potassium (K) fertilizers	Water-soluble K	K^+	This positively charged ion is taken up by plants and is held in negatively charged clay and organic matter sites in soil. K+ held on the soil particles is in equilibrium with K+ in the soil solution
	Organic K	-	K content may be low in many manures and biosolids, but can be high in many crop residues. K release from organic residues is generally rapid
Calcium (Ca) and Magnesium (Mg) fertilizers	Water-soluble Ca and Mg	Ca^{2+}, Mg^{2+}	These ions are readily taken up by plants and are held on negative sites on soil clay and organic matter particles. Ca_2+ and Mg_2+ held on soil particles are in equilibrium with Ca_2+ and Mg_2+ in soil solution. Ca_2+ is the predominant cation held on soils that are not highly acidic.
	Organic Ca and Mg	-	Ca_2+ and Mg_2+ ions become plant available as organic materials are mineralized
Sulphur (S) fertilizers	Sulphate and elemental S	SO^{2-}_4, S^0	Sulphate ions are readily taken up by plants and move with soil water. However, these ions can be adsorbed on clay sites in acidic subsoil. Elemental S must be converted by soil microorganisms to sulphate before it can be taken up by plants
	Organic S	-	Sulphur in organic molecules such as amino-acids must be mineralized to sulphate by soil microorganisms prior to plant uptake.

As for N, the primary determinants for RE_P and RE_K are the size of the crop sink, soil supply and fertilizer rate. However, RE_P and RE_K also depend strongly on soil characteristics determining fixation of P and K in more recalcitrant soil fractions or losses by leaching or runoff. Hence, BMPs for P and K fertilizers must also consider the specific characteristic of crops, cropping systems, environments and soils.

BMPs across nutrients: There is need to advocate BMPs that foster the effective and responsible use of fertilizer nutrients with a goal to match nutrient supply with crop requirements and minimise nutrient losses from fields. If maximising fertilizer use efficiency is the goal, one needs to work lower on the yield response curve. Nutrient use efficiency is high at the bottom of the yield curve because any addition of a limiting nutrient gives a relatively large yield response as much of the applied nutrient is taken up by the nutrient-limited crop. Lower rates of fertilizer appear better for the environment, because more nutrients are removed by the crop, leaving less in the soil for potential loss. But, lower yielding crops produce less biomass and leave fewer residues and less root growth to build soil organic matter. As one move up the response curve, yields continue to increase; albeit at a slower rate and nutrient use efficiency typically declines. However, the extent of the decline in nutrient use efficiency will be dictated by the BMPs employed as well as soil and climatic conditions. The approach is to apply correct nutrient in the amount needed, timed and place to meet the crop demand-right product, right rate, right time and right place. These are the underpinning principles of fertilizer BMPs (Roberts, 2006; Prasad, 2009) which are reiterated below:

The 4R nutrient stewardship concept is being developed because sustainable agricultural production is important, and we need to ensure that fertilizer use contributes to it.

Right product: Match the fertilizer source and product to crop need and soil properties. Be aware of nutrient interactions and balance nitrogen, phosphorus, potassium and other nutrients according to soil analysis and crop needs. Balanced fertilization is one of the keys to increasing nutrient use efficiency.

Right rate: Match the amount of fertilizer applied to the crop needs. Too much fertilizer tends to leaching and other losses to the environment and too little results in lower yields and crop quality and less residue to protect the soil. Realistic yield goals, soil testing, omission plots, crop nutrient budgets, tissue testing, plant analysis, applicator calibration, variable rate technology, crop scouting, record keeping and nutrient management planning are BMPs that will help determine the right rate of fertilizer to apply.

Right time: Make nutrients available when the crop needs them. Nutrients are used most efficiently when their availability is synchronised with crop demand. Application timing (pre-plant or split applications), controlled released technologies, stabilizers, inhibitors and product choice are examples of BMPs that influence the timing of nutrient availability.

Right place: Place and keep nutrients where crops can use them. Application method is critical for efficient fertilizer use. Root systems of many plants proliferate in soil zones containing higher concentrations of nutrient elements. Plant nutrients placed in localised concentrations (bands) reduce exposure to adverse soil chemical reactions and increase nutrient availability. Crop, cropping system and soil properties dictate the most appropriate method of application, but, incorporation is usually the best option to keep nutrients in place and increase their efficiency. Conservation tillage, buffer strips, cover crops and irrigation management are other BMPs that will help keep fertilizer nutrients where they were placed and accessible to growing crops.

There is not one set of universal fertilizer BMPs. By definition, BMPs are site-specific and crop-specific; they vary from one region to the next and one farm to the next depending on soils, climatic condition, crop and cropping history and management expertise. Right rate, right time and right place offer sufficient flexibility that these guiding principles can be applied to all crops, situations and regions throughout the world.

The four aspects of fertilizer management - source, rate, time, and place - are completely interconnected and also linked to the full set of management practices for the cropping system. None of the four can be right when any one of them is wrong. It is possible that for a given situation, there is more than one right combination of source, rate, timing, or placement, but when one of the four changes, the others may change as well (Bruulsema *et al.*, 2009).

Balanced fertilization: Crop yield is limited by the limiting nutrient or a growth factor. Basically, the law of the minimum governs balanced fertilization. It is the proper supply of macronutrients and micronutrients throughout the growth of a crop. It is not the supply of a single or a couple of nutrients but rather the complete supply to a crop or a cropping system, with optimum and adequate quantities of the required nutrients at appropriate times to achieve a target yield, which is profitable and sustainable. Balanced fertilization not only guarantees optimal crop production, better food quality and benefits for the growers, but is also the best solution for minimising the risk of nutrient losses to the environment. If the balance of nutrients applied is not appropriate, the crop will not be able to grow properly and its overall uptake of nutrients will be limited. The supply of other nutrients will then be of no or limited use, and these will accumulate in the soil, leading to potential environmental problems.

Any recommendation to supply a crop with balanced fertilization must first take into account the amount of nutrients supplied from the soil or from other sources such as irrigation water, green manure, animal manure, residues from previous crops, etc. Since these sources are very rarely sufficient, mineral fertilizer must be added to satisfy the remaining nutrient needs of the crop.

Balanced fertilization has received considerable attention in India in recent years (Ali *et al.*, 2004; Aulakh and Pasricha, 2004; Ganeshamurthy *et al.*, 2004; Ghosh *et al.*, 2004; Hegde and Sudhakara Babu, 2004; Katyal *et al.*, 1997; Swarup, 2004; Tiwari, 2002), but a real headway in achieving balanced fertilization in India is yet to be made. Balanced fertilization is not a static but a dynamic concept that can pave the way to a sustainable agriculture and which will provide the world population with high quality food while minimising the impact on the environment. A well-balanced fertilization also optimises the nutrient use efficiency of crops. Balanced nutrient requirements for different crops/cropping systems/regions vary to a great extent (Table 16). Studies carried out on farmers field show that in cereals, the increase in yield was only 46.8% with N alone but doubled when balanced NPK fertilizer was applied (Table 17). Similarly, in oilseeds, the increase in yield with balanced fertilization was almost three-folds of that obtained with N fertilizer, and in pulses it was four-fold. Thus, with adequate P and K, it is possible to use N more efficiently and to achieve higher yields. In many cases, application of deficient secondary and micronutrients along with balanced NPK further boosts up the productivity and fertilizer use efficiency (Table 18).

Table 16 Some examples of nutrients required for the balanced fertilisation of certain crops and cropping systems (Cisse, 2007)

Crops/cropping systems	Balanced nutrients requirements
Intensively cropped irrigated areas	N, P, K, Zn and S or N, P, S and Zn
Areas under oilseeds	N, P, K and S or N, P, Zn and S
Legumes in acid soils	N, P, K, Ca and Mo
Fruit trees in alkaline, calcareous soils	N, P, K, Zn, Mn and Fe
Cabbage, cauliflower and other crucifers	N, P, K, S and B
High yielding tea plantations	N, P, K, Mg, S and Zn
Coconut in light soils	N, P, K and Mg
Immature rubber plantations	N, P, K and Mg
Mature rubber plantation	N, P and K

Table 17 Importance of balanced (NPK) fertilisation of crops in India (Prasad 2007)

Crop group	No. of trials	Control (kg/ha)	% increase due to		
			N	NP	NPK
Cereals	2997	1803	46.8	74.3	96.3
Oilseeds	369	897	30.7	63.4	87.6
Pulses	42	586	33.4	99.2	117.0

Table 18 Effect of sulphur, zinc and iron yield and FUE of safflower at Dharwad (Ravi *et al.*, 2008)

Treatment	Seed yield (kg/ha)	% increase over NPK	FUE
NPK	1172	-	6.2
NPK + S	1553	32.5	8.2
NPK + S + Fe	1617	38.0	8.5
NPK + S + Zn	1691	44.3	8.9
NPK + S + Fe + Zn	1765	50.6	9.3
CD (P=0.05)	124		

NPK = 75:75:40kg N:P_2O_5:K_2O/ha; S = 30kg/ha; Fe and Zn = 0.5% foliar spray

Increasing use of S-free fertilizers, intensive cropping, and use of high yielding varieties have led to S deficiency in many countries. Sulphur deficiency is increasingly becoming one of the limiting factors to further sustainable increases in agricultural production. S fertilizer, besides enhancing yield and quality of crops, enhances nutrient uptake and fertilizer use efficiency through interaction of S with other fertilizer nutrients, from 4 to 39.2% increases in N use efficiency and from 5.4 to 10.5% in P use efficiencies (Mingxian Fan, 2006; Tandon and Messick, 2007). Residual effects have also been reported even at a low rate of 20 kg S/ha. Thus, S does not need to be applied every season (De Datta *et al.*, 2005). In rice - sunflower and sunflower - groundnut cropping system on low S Alfisol, significant improvement in seed yield of crops due to direct and residual effect of S application was recorded with higher efficiency in terms of harvest index, oil content in sunflower and S build up in soil (Table 19) (Sudhakara Babu and Hegde, 2002). Extensive S management trials in cropping systems involving oilseeds across the country involving 11 states with 231 field trials at 46 sites on direct and residual effect of S indicate that on an average, the direct effect varied from 4 to 30% and residual effect ranged from 6 to 39% depending on the crop and cropping system and soil type (TSI-FAI-IFA 2003). The soil S balance due to application of S in cropping systems was positive and high at 30 kg S/ha and above and it was higher in sunflower - groundnut cropping system compared to rice - sunflower cropping system (Fig. 2) (Sudhakara Babu and Hegde, 2010). Ca and Mg are also important secondary nutrients for oilseeds for increasing yield and quality with concomitant increase in FUE (Table 20) (Hegde, 2006). Depending on the sulphur status, available different sources *viz*., gypsum, elemental S, pyrites, SSP, ammonium sulphate, Ammonium phaoshate sulphate, sulphate of potash, etc., can be used for correcting the deficiency. The optimal dose and levels for the site should be assessed and the locally available and cheap sources can be used. Ideally, for most oilseed crops, using of single super phosphate as source of P (12% S and 9% P) will meet the S requirement automatically. The S build up should be monitored for continuous application.

Nutrient interactions: Nutrient interactions and their effects on crop yield is the most critical for achieving higher use efficiency. All crop growth limiting plant nutrients must be determined for each specific location. Only then can the proper fertilization be chosen and the appropriate rate of application determined.

The balanced use of fertilizers should be aimed at mainly at increasing crop yield, quality, farm income, correction of inherent soil nutrient deficiencies, maintaining or improving lasting soil fertility, avoiding damage to the environment, and restoring fertility and productivity of the land that has been degraded by wrong and exploitative practices in the past. Several studies have proven the benefits of nutrient interactions and the knowledge is reaching the farmers for the major nutrients. With the growing nutrient deficiencies of major, secondary and micronutrients, the need is higher to reap higher benefits of balanced fertilization to exploit nutrient interactions. It was assessed that the average increase in seed yield due to use of N alone ranged from 27 to 97%, with N and P from 51 to 210% and with N, P and K it ranged from 53 to 227% over control, across 8 crops including cereals, pulses and oilseeds under rainfed and irrigated conditions.

Table 19. Direct and residual effects of S on rice - sunflower and sunflower - groundnut cropping system in Alfisols (Sudhakara Babu and Hegde, 2002)

A. Effect of sulphur through SSP in rice - sunflower cropping system (mean of 2000-2002)

Treatment	Direct effect on rice			Residual effect on sunflower			System VCR
	Grain yield (kg/ha)	% response	Harvest index	Seed yield (kg/ha)	% response	Oil yield (kg/ha)	
NPK	5995	-	0.31	1535	-	636	-
NPK S_{15}	6877	14.7	0.33	2008	30.8	834	129.8
NPK S_{30}	7255	21.0	0.34	2177	41.8	912	91.3
NPK S_{45}	7623	27.2	0.35	2217	44.4	955	74.4
CD (P=0.05)	909			396		175	

B. Effect of sulphur through SSP in sunflower - groundnut cropping system (mean of 2000-2002)

Treatment	Direct effect on Sunflower			Residual effect on Groundnut			System oil yield (kg/ha)	System VCR
	Seed yield (kg/ha)	% response	Oil yield (kg/ha)	Pod yield (kg/ha)	% response	Oil yield (kg/ha)		
NPK	852	-	296	2204	-	825	1234	-
NPK S_{15}	976	14.5	352	2568	16.5	998	1474	75.0
NPK S_{30}	1059	24.3	378	2628	19.2	1010	1519	48.9
NPK S_{45}	1237	45.0	460	2814	27.7	1090	1682	51.2
CD (P=0.05)	138		90	316		144		

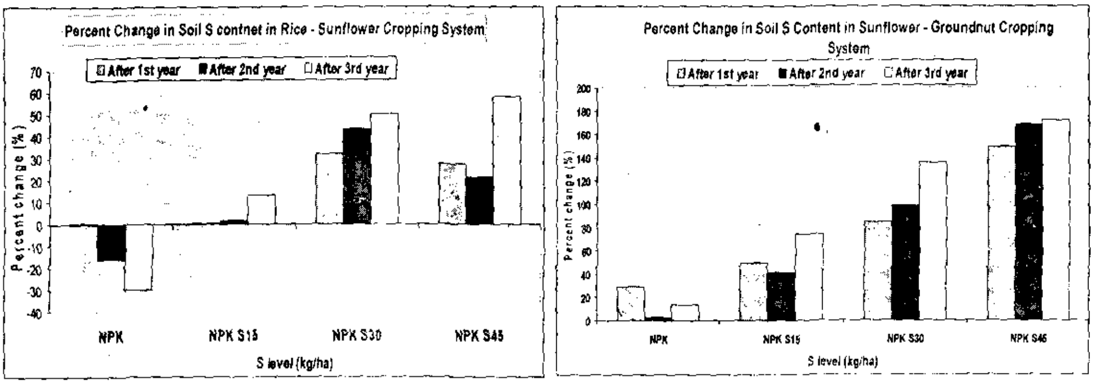

Fig. 2. Soil S status due to S management under rice-sunflower and sunflower-groundnut cropping system in Alfisols (Sudhakara Babu and Hegde, 2010)

Table 20 Effect of Ca and Mg application on FUE of sunflower at Bengaluru (Hegde, 2006)

	Seed yield (kg/ha)	FUE
No Ca and Mg	464	4.64
Ca @ 20 kg/ha as gypsum	654	6.54
Mg @ 20 kg/ha as $MgSO_4$	846	8.46

The multinutrient deficiency is increasing across many agro-ecoregions and over time (Tiwari, 2008). Beyond the limitation of soil moisture, use of secondary and micronutrients that can be supplied as foliar sprays is important in increasing oilseeds productivity at any given level of soil fertility and management. Also, with the complexity of handling micronutrient deficiencies through soil application, foliar application of micronutrients is the best and safe option. The magnitude of yield and quality gain by the use of secondary and micronutrients along with NPK is significant in most crops and most economical. Spraying B @ 0.2% at ray floret opening stage in sunflower has increased seed yield to the extent of 28% across three locations (Table 21) (Hegde, and Sudhakara Babu, 2009a, 2009b, 2004a). Under multi nutrient deficiency at Dharwad, there was significant improvement in seed yield and FUE of sunflower due to the individual and combined use of S, Fe and Zn along with NPK with significant increases in FUE (Ravi *et al.*, 2008). The benefit comes from increased seed setting, seed filling and higher seed index. Similarly, application of $FeSO_4$ or borax has doubled the seed yield of soybean compared to no manure control to the extent of 12% over NPK (Table 18) (Chaturvedi *et al.*, 2010).

The limitations for practical implementation of balanced fertilization are:

- The relative prices of fertilizers within general N fertilizers having very low prices compared with other fertilizers, in particular, P, K and S and thus skewed nutrient ratio in favor of N resulting serious nutrient imbalances.
- Timely availability of needed quantities and sources. For example, single super phosphate is the best form of P for oilseeds that can take care of S requirement. However, the availability and quality of SSP is limited and thus loss of opportunity for realizing high yield, quality and efficiency. So also, the gypsum availability in groundnut growing regions. Due to the cost of transportation, the availability and use of gypsum is limited and hence loss of opportunity for realizing high yield, quality and efficiency.

Integrated nutrient management (INM): Oilseed crops are energy rich crops and need higher nutrition for realizing high productivity of seed and oil. The availability of fertilizers in general and the competition from irrigated crops and food crops further limits the fertilizer use for oilseeds. It is estimated that even under best application methods, the contribution of fertilizers in oilseeds nutrient uptake is only 5.8 (K), 18.5 (N) and 22.3% (K) and rest of the nutrient uptake had occurred from other sources or soil reserves (Table 22) (Hegde, 2010). Under this situation, it is the only way to integrate different nutrient sources for meeting the nutrient requirement of oilseeds. INM is an approach focusing on the nutrient supply aspects of crop production and aims at a judicious combination of inorganic (fertilizers) and organic (manures, green manures, biofertilizers, crop residues, etc.) sources for meeting the nutrient needs of crops and cropping systems and is of great interest for sustaining high productivity in today's agriculture (Blaise and Prasad, 2005; Hegde, 1998; Hegde and Sudhakara Babu, 2004a; Prasad, 2005; Sharma, 2005; Subba Rao *et al.*, 2002; Prasad, 2009).

Adopting INM is further boosts the oilseeds production in drylands due to the beneficial soil moisture and biological strengths besides nutrient supplementation. Fertilizer is better applied in combination with organic resources. Additions of organic matter to the soil provide several mechanisms for improved agronomic efficiency, particularly increased retention of soil nutrients and water and better synchronization of nutrient supply with crop demand but it also improves soil health through increased soil biodiversity and carbon stocks. Based upon research findings across numerous countries and diverse agro-ecologies including India, a consensus has emerged that the highest and most sustainable gains in crop productivity per unit nutrient are achieved from mixtures of fertilizer and organic inputs (FAO, 1989; Vanlanwe *et al.*, 2001; Alley and Vanlauwe, 2009; Blaise and Ravindran, 2003; Swaminathan, 1990). Organic manures also meet part of secondary and micronutrients needs of crops (Mishra *et al.*, 2006) and their continued use can partly eliminate their deficiencies.

Regular application of FYM @ 10t/ha along with NPK has resulted in significant increase in organic carbon content from 0.32 to 0.54% with more than doubling the sustainable yield index (AICRPDA). Significant improvements in yield, OC and SYI were recorded with use of FYM along with 50% RDF in this long term trial. Similarly on Vertisols of Bhopal, use of FYM @ 5t/ha along with 75% RDF has resulted in 50% increase in yield and FUE over non use of FYM in soybean, (Table 23) (Ghosh *et al.*, 2004b). Although availability of organic manures and crop residues is less in India, there is need to integrate these resources with fertilizers to the extent possibly in each agro-ecoregion. Integrated plant nutrient supply and management (IPNM) considers field and crop specific nutrient applications to efficiently utilize applied nutrients. Crop, soil conditions, fertilizer characteristics and climatic effects are incorporated in IPNM.

Adoption of each BMP results in better crop yield and efficiency. Building crop management programmes by integrating available BMPs for the site with due consideration of interactions and their careful management result in huge cumulative benefits - additive and/or multiplicative from the biological system of crop production. This would greatly reduce external input supply and achieve highest fertilizer use efficiency and sustainability. With increased productivity, acreage under arable cropping can be reduced, fertilizer requirement rate can be reduced, residual accumulation and further wastages of nutrients can be reduced, more C can be fixed due to the higher biomass and higher oxygen to atmosphere can be released - a true sustainable meaning (Table 24). When optimum population and optimum fertility BMPs are showing positive effects over average practices, the additive effects of interactions of BMPs, using all the recommended BMPs results in highest benefit compared to compromised adoption.

Site-specific nutrient management (SSNM): The SSNM is a systematic approach to apply nutrients as per the crop need for a target yield considering the soil supplying capacity, limiting nutrients - major, secondary and micro, sources of nutrients as per the variations in the site. This is nothing but extension of soil test principle of crop nutrition with dynamic nutrient management principle incorporated. SSNM takes care of both imbalance in and the deficiency of nutrients. It aims to enable farmers to dynamically adjust their fertilizer use to optimally fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources such as soil, crop residues, organic inputs and irrigation water. It avoids over fertilizing the under productive site and under fertilizing high potential site. Thus higher efficiency is achieved with environmental protection (Prasad, 2009). The systematic implementation of these practices into site-specific systems is probably our best opportunity to develop a timely sustainable crop production system.

Site specific nutrient management (SSNM) in sunflower - groundnut cropping system in Alfisols revealed that the SSINM practices had substantially improved overall soil fertility from the initial (13% for N, 173% for P and 28% for K), thereby reducing the nutrient requirement (6% for N, 26% for P and 19% for K) to achieve the yield beyond the level of target for the site (Fig. 3). This had reduced the quantity of external application of manures and fertilizers to maintain the target yield and thus the profitability of the system has significantly increased besides realizing high quality produce fetching higher market value (Reddy and Sudhakara Babu, 2009).

To achieve high fertilizer use efficiency in rice, the emphasis now has been shifted to real-time N management based on crop and field-specific needs (Buresh, 2007). Chlorophyll meter and leaf colour chart as diagnostic tools based on spectral properties of leaves for guiding in season N topdressing in rice have been standardised. These tools allow field, season-and variety-specific N management while ensuring high yields, reduce N losses, efficient utilization of applied N and thus provide economic benefits to the farmers as well. These tools can help avoid application of excessive amount of N fertilizer by matching time of fertilizer application with plant need. These tools can also save a substantial quantity of fertilizer N leading to reduced cost of cultivation and lesser environmental pollution (Yadvinder Singh and Bijay Singh, 2009). The advantages of site-specific N management in rice using SPAD chlorophyll meter and leaf colour chart (LCC) in increasing grain yield, reducing N use and increasing N use efficiency has bee established at several locations in the country especially fo rice and need standardization for oilseeds.

Based on 15500 frontline demonstrations in oilseeds o farmers' fields during the last 20 years, it was consistentl found that amongst the constraints/resources to oilseed production, suitable genotype, optimum plant populatior adequate and balanced nutrition and plant protection are th major resources both under irrigated and rainfed situation (Table 25) (Hegde, 2009). Majority of the technologies ar of no cost or low cost that results in quantum jump i productivity and profitability.

Table 21 Effect of boron application on FUE of sunflower (Hegde, 2006)

	Seed yield (kg/ha)			
	Raichur	Bengaluru	Mean	% increase
No B	1835	937	1386	-
B as borax spray 0.2%	2236	1285	1774	28.0
FUE				
No B	18.35	9.37	13.86	-
B as borax spray 0.2%	22.36	12.85	17.74	28.0

Table 22 Estimated fertilizer use and its contribution to nutrient removal in oilseed crops (2008-09) (Hegde, 2010)

Nutrient	Uptake (000't)	Fertilizer use (000't)	Fertilizer use efficiency (%)	Contribution to uptake	
				Fertilizer (%)	Others (%)
N	1591	588	50	18.5	81.5
P_2O_5	635	472	30	22.3	77.7
K_2O	1442	167	50	5.8	94.2
Total	3668	1227		14.5	85.5

Table 23 Effect of nutrient management on grain yield (kg/ha) of crops in Vertisols (Ghosh *et al.*, 2004b)

	Soybean	PFP (kg/kg)
Control (No NPK)	955	-
75% NPK	1140	12.7
100% NPK	1256	10.5
75% NPK + FYM 5t/ha	1715	13.0
75% NPK + Poultry manure 1.5t/ha	1426	15.8

The recommended dose of $N:P_2O_5:K_2O$ for 100% NPK treatment were 30:60:30 kg/ha

Table 24 Comparison of environmental advantage of BMP system with the old standard for wheat production (Griffith)

Components	BMP system	Old standard	Environmental advantage
Yield, kg/ha	5249	3087	-
Hectares needed to produce 500 t	95.3	162.0	66.7
N used, kg/ha	157	118	-
N efficiency, kg/kg N	33.4	26.2	7.2
N used to produce 500 t	14.97	19.08	4.11
N remaining in soil after harvest, kg/ha	32.6	44.9	12.3
Total CO_2 in crop, t/ha	22.72	13.36	9.36
Total C in residue, t/ha	3.73	2.20	1.53
Total O_2 released, t/ha	16.52	9.73	6.79

Table 25 Productivity improvement through important interventions in oilseed crops (Hegde, 2009)

Crop	Productivity Improvement (%)					
	Variety/ Hybrid	Nutrient management	Plant protection	Irrigation management	Weed control	Thinning
Groundnut	9-72	14-75	8-27	4-16	10-11	-
Rapeseed-Mustard	4-109	18-115	15-33	32	21	11-42
Sunflower	40-49	5-42	4-29	-	21	7-30
Castor	10-112	11-31	17-25	67	63	-
Safflower	7-119	23-42	23-66	49-87	-	24-37
Sesame	12-190	16-169	18-147	198	17-141	-
Niger	50-120	22-208	36	-	43	-
Linseed	11-191	26-37	14-50	-	28-42	-
Soybean	16-51	12-42	11-42	-	-	-

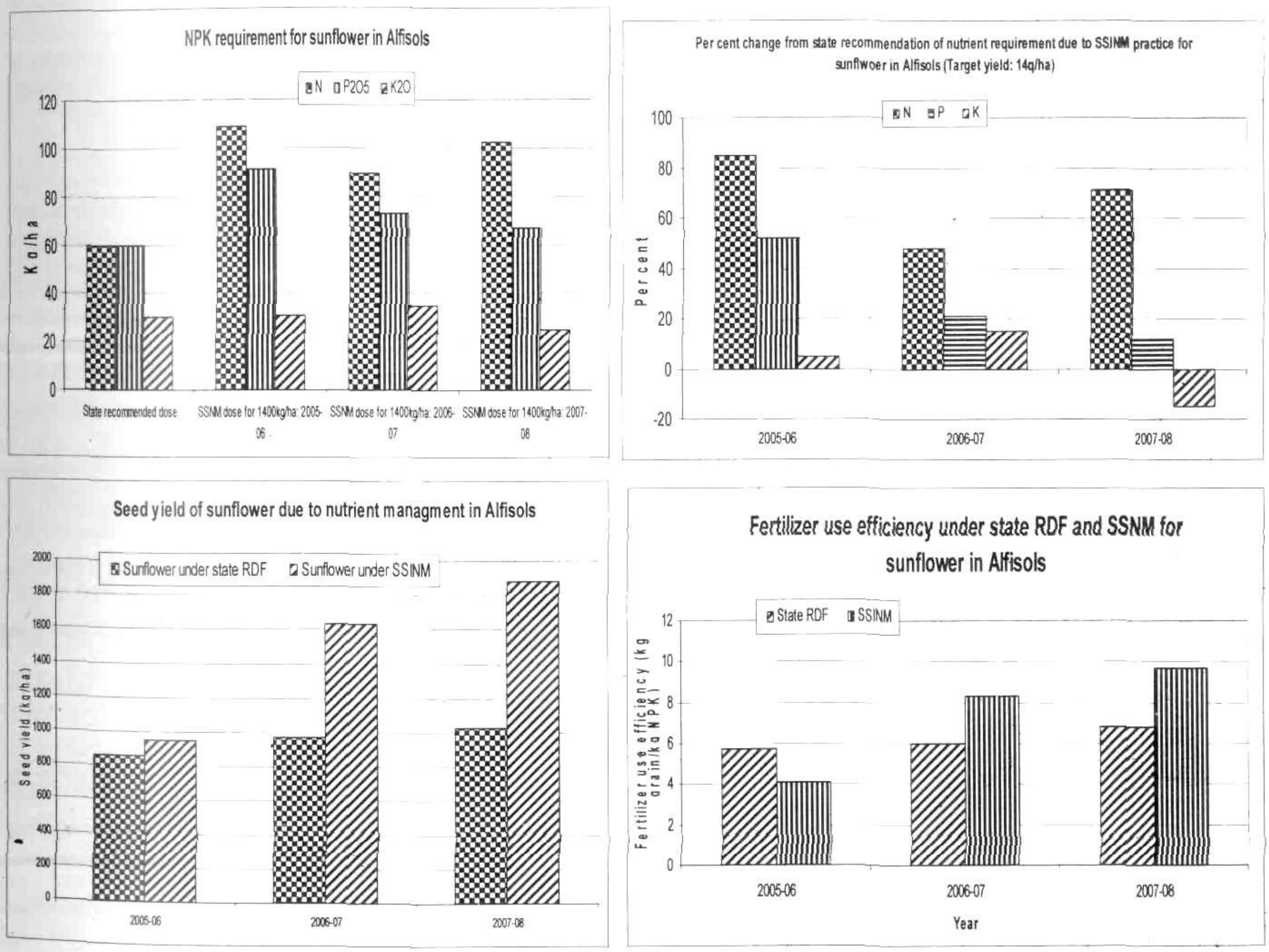

Fig. 3. Performance of SSNM vs. RDF practice for sunflower in Alfisols (Reddy and Sudhakara Babu, 2009)

Future line of work

The greatest challenge in Indian vegetable oil sector is the huge gap between demand and supply due to low self sufficiency in domestic production and increasing import bill. The fact that the production environments are unstable and degrading; the factor productivity and resource use efficiency is declining, cost of production increasing and overall, oilseeds cultivation is not remunerative. Experience over the past four decades in India has shown that mismatch between crop production methods and resource characteristics has led to decline in soil fertility, increased soil losses, loss of biodiversity, disturbed ecological balance and build up of insect-pests and diseases. By adopting the specific limiting/recommended technology aiming to improve the productivity of oilseed crops simultaneously improves the use efficiency of other factors and resources and profitability.

Research:

- Developing BMPs need standardization as per the site and cropping system. Pyramiding of BMPs for a given site and crop genotype is the crux of developing precision farming practice that ensure highest productivity, profitability, efficiency and least environmental hazards.
- Inter relationships between different resources across different levels to be generated and modeled of their synergism and antagonism.
- Interaction is the key to efficiency. Promote positive interaction and control negative interaction between factors or among factors.
- Assess farm level resource inventory of its primary and value added potential for integrating into BMPs.
- Perfect each of the agricultural practices into precision agricultural practices underlying 5Rs principle (right product - right dose - right time - right place - right combination).
- Assess cost of BMPs causing incremental increase in NUE for understanding economics of the gain.
- Assess the gains form different efficiencies and long term sustainability rather than mere short term and highest marginal returns/gains in yields or profits or fertilizer efficiency.

Development

- Correct inherent soil limitations of acidity, salinity or alkalinity, soil depth, drainage, etc.
- Higher investments in precision agricultural practices will prove profitable and sustainable in long term.
- Encourage custom hiring for undertaking timely and precise land preparation, laser leveling, precision planting and fertilizer application, combine harvesting, post harvest processing, storage and value addition, etc for reducing the burden on individual small holder and create employment opportunities in village level.
- Value no-cost and low cost agronomic practices that have very high impact on productivity and efficiency individually and in combination with other factors of production.
- Genuine and timely soil testing and farm advisory services are essential for reaping the benefits of technological advancements by the masses.
- Effective farmer and society/household education in terms of the power and dangers of many purchased inputs - seed, fertilizers, pesticides, agro-chemicals, irrigation water, timeliness of operations, etc. on crop productivity, profitability and environmental safety to demand BMPs for adoption.
- Follow the green principle of 'Reduce - Reuse - Recycle - Resurrect' for every resource use to achieve highest efficiency and sustainability.

Site-specific crop management through integration of all BMPs is the dictum for resource management that takes into consideration the on-farm resource potential and strategies for meeting the dynamic resource requirement of crops and cropping systems for sustainable oilseeds development.

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Multivariate studies in groundnut (*Arachis hypogaea* L.)

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(Received: December, 2009; Revised: November, 2010; Accepted: March, 2011)

ABSTRACT

The 40 accessions of groundnut (*Arachis hypogaea* L.) were evaluated under multivariate analysis on the basis of pooled performance in 12 different environments created by monthly sowing from July 2006 to June 2007. The analysis of variance for morphological and yield traits in 40 genotypes on the basis of pooled performance over 12 environments showed the existence of distinct genetic differences among the genotypes for all the characters studied. Highest genotypic coefficient of variation and phenotypic coefficient of variation were recorded for kernel yield/plant. The heritability was high for pod length (99.3%). The genetic advance as per cent of mean was recorded highest for kernel yield/plant (25.6 g). All the 40 groundnut accessions were grouped into five clusters. The cluster-I was the largest, involving 27 genotypes. In spite of variation in mean and D^2 values some genotypes *viz.*, VRR-232 and 1792 constantly occupied cluster-I in maximum of 12 environments including pooled over environment, indicating stable performance. The cluster-I had minimum (0.43) intra-cluster distance and was found to be the most compact cluster. The cluster-V ranked first in mean pod yield/plant (11.3 g). The analysis for estimating the contribution of various characters towards the expression of genetic divergence on pooled basis indicated that pod length (25.6%), plant height (15.1%), shelling per cent (11.7%), 100 seed weight (8.0%) and number of kernels/plant (7.2%) contributed maximum (67.5%) towards total divergence in the material. Therefore, these characters should be considered while selecting the parents for hybridization programme.

Key words: D^2 statistics, GCV, Heritability, Genetic advance, Genetic diversity, Groundnut, PCV

Groundnut (*Arachis hypogaea* L.) is the important oilseed crop of India and occupies a prominent position among edible oilseed crops. India though ranks first in world's area and production of groundnut, yet it's productivity is low (1687 kg/ha) compared to about 3000 kg/ha in other countries like USA (Reddy and Gupta, 1994). The crop is also known for its genetic potential displaying on an average yield of 6.7 t/ha as reported from Israel (Basu, 1993). Information on nature and degree of genetic divergence would help the plant breeders in choosing the right type of parents for purposeful hybridization. Moreover, the genetically divergent parents on crossing are known to produce hybrids with high heterosis followed by desirable segregants. The Mahalanobis's D^2 statistics has been used as potential tool for grouping diverse genetic stocks in various types of breeding material. This analysis becomes more meaningful when computed on multi-environment data, since genotypes are known to show differential phenotypic response in varying environments. Therefore, an attempt was made to estimate the genetic divergence among 40 groundnut genotypes grown in 12 environments.

MATERIALS AND METHODS

The present investigation was conducted on 40 genotypes of groundnut (20 from India, 3 from Argentina, 2 each from China, UN, Nigeria, Zimbabwe, Paraguay, Brazil and UNK and one each from USA, Uganda and Zaire). The experimental materials were evaluated on the basis of pooled performance of 12 different environments created by monthly sowing (first week of each month) from July 2006 to June 2007 at Research Farm of Botany, College of Agriculture, Dapoli. The genotypes were grown in randomized block design with three replications. The observations were recorded on five randomly selected plants in each genotype for 15 quantitative traits *viz.*, days to first flowering, days to 50% flowering, days to maturity, plant height, number of primary branches, number of pods/plant, pod length, number of kernels/plant, 100 seed weight, kernel yield/plant, shelling %, oil content, protein content, haulm yield and dry pod yield/plant. The mean, range, GCV, PCV, heritability, genetic advance and genetic advance as a mean percentage were calculated for these traits. The genetic divergences were estimated using Mahalanobis's D^2 statistics (1936) followed by Rao's (1952) clustering pattern.

RESULTS AND DISCUSSION

The analysis of variance for morphological and yield traits in 40 genotypes on the basis of pooled performance over 12 environments showed the existence of distinct genetic differences among the genotypes in all the characters studied. The mean, range, GCV, PCV, heritability, genetic advance and genetic advance as a mean percentage were

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calculated for these traits (Table 1). Perusal of the data revealed that highest GCV and PCV were recorded for kernel yield/plant followed by number of pods/plant, dry pod yield/plant and haulm yield/plant, while it was lowest for days to maturity, oil content and protein content. The heritability was high for pod length (99.3%), plant height (94.6%), days to first flowering (94.1%), days to 50% flowering (93.8%), 100 seed weight (93.5%) and number of primary branches/plant (94.3%). These traits were least affected by the environments and therefore can be effectively used as selection criteria. The genetic advance as per cent of mean was recorded highest for kernel yield/plant followed by number of kernels/plant, dry pod yield/plant, haulm yield/plant, number of kernels/plant and plant height. It showed that mass selection based on this character could be useful in improving kernel yield and dry pod yield/plant in breeding material studied. GCV together with heritability and genetic advance is considered as good estimates of genetic gain to be expected from selection on phenotypic basis (Mahmood *et al.*, 2003). A trait having high heritability and high genetic advance is considered under control of additive genes, which highlights the usefulness of plant selection based on phenotypic performance (Ghosh and Gulati, 2001). In the present study, the analysis of variance for different characters indicated that highly significant differences existed among the genotypes for all the characters in all the 12 environments (Table 1). The pooled analysis of variance indicated that higher significant differences existed among the genotypes, environments and GxE interactions for all the characters, which suggested varying response of genotypes to different environments. The simultaneous test of significance based on Wilk's criteria for the pooled effect of all the characters also showed significant differences among the genotypes, indicating that grouping of genotypes can be conducted in the present environments and will be fruitful. Similar results were reported by Venkataramana *et al.* (2000) The mean values indicated differential impact of environment on gene expression. These results were in conformity with those obtained by Deshmukh (2004).

Based on pooled performance over 12 environments, these 40 groundnut accessions were grouped into five clusters. The cluster-I was the largest, involving 27 genotypes. The cluster-III and IV included 7 and 4 genotypes, respectively. The remaining two clusters (II and V) were solitary and included only one genotype (Table 2). It was found that the number of clusters and constituents of the clusters were varied with the environments. A critical perusal of the composition of clusters in different environments revealed that in all environments cluster-I was the largest consisting of maximum genotypes. Thus, most of the genotypes were genetically close to each other in the cluster-I and apparent wide diversity was mainly due to rest of the genotypes distributed in the remaining clusters (Reddy and Reddy, 1993). Cluster-I was also found largest by Chavan (2002) and Khote (2006). The clustering pattern indicated that genotypes from different geographical regions clustered together in same cluster showing that distribution of genotypes from different geographical regions into different clusters was at random. It further suggested that geographical diversity did not necessarily related with genetic diversity (Awatade, 2007 and Mahalakshmi *et al.*, 2005). Plant populations restricted to small geographical areas are subjected to identical environmental pressures and help in evolving adaptive gene complexes. These gene complexes are conserved by genetic linkages or natural or human selections. Changes in the breeding systems also accelerated genetic divergence in natural populations (Reddy and Reddy, 1993).

Inspite of variation in mean and D^2 values, some genotypes *viz.*, VRR-232 and 1792 constantly occupied cluster-I in maximum of 12 environments including pooled over environment, indicating stable performance. The genotypes showing stability in D^2 values across the environments should be used to evolve genotypes with wider adaptability. It may be use in the varietal improvement programme through hybridization. Similarly, genotypes STARR and VRR-275 occupied cluster-I in 11 environments and genotypes *viz.*, K-491, J-39, EC-6902, K-3, EC-24411 and SB-11 occupied cluster-I in maximum of 10 environments including pooled over environments. The genotype Konkan Gaurav was found to be solitary in 10 environments, followed by genotype NCAC-973 in seven environments and genotypes VRR-361 and IC-22942 in six environments. This clearly suggested that with few exceptions, many genotypes tend to modify their behaviour and change the group constellation in response to change in environments. In fact the expression of genotypes occurs due to sum total of phenotypic expression occurring under the changes of different environment. Thus, the genetic distances measured in one season may not necessarily remain same in other season. Such kind of variation in pattern of genetic diversity was also reported by Venkataramana *et al.* (2001) and Deshmukh (2004) in groundnut.

The estimates of intra and inter-cluster distances have been given in table 3. The cluster-I had minimum (0.43) intra cluster distance and thus was found to be the most compact cluster, showing that the genotypes of this cluster resemble with one another genetically. The cluster-IV was found to be least compact cluster as it had maximum (0.48) intra-cluster distance. The inter-cluster distance between clusters-III and V was maximum (1.54). This revealed that the genotypes of cluster-III were genetically most diverse from those of the cluster-V. These clusters were also found high yielding. Hybrids between the genotypes of these clusters are expected to give high heterotic response and consequently yield desirable segregants. In breeding programmes, parents combining high yielding potential with wide genetic diversity are likely to yield superior segregants within a short period of time (Yadav *et al.*, 1991). The intra-cluster group means for 15 characters given in table 4 revealed marked differences between the five clusters in respect of cluster means for different characters. The cluster-V ranked first in mean pod yield/plant (11.3 g). It showed late first flowering (28.8 days), late 50% flowering (31.5 days), late maturity period (126.7 days), dwarf plant height (34.2 cm), maximum number of primary branches (7.1), maximum number of pods/plant (11.7) and highest haulm yield/plant (16.6 g). The genotype Konkan Gaurav was the only member of this cluster. The cluster-III ranked second highest for mean pod yield/plant (11.1 g) with highest kernel yield/plant (7.4 g), maximum pod length (27.5 mm), early first flowering (26.6 days), early 50% flowering (29.0 days) and early maturity period (124.2 days).

In the D^2 analysis, 15 characters of the growth and yield were considered simultaneously for making clusters. Usually, the members having common features of growth and yield behaviour are clustered together. However, the contribution of different characters for formation of distinct clusters may not necessarily be similar. Therefore, an understanding of relative contribution of different characters for diversity in multi-environment data would be of great importance for scheduling further programme. The analysis for estimating the contribution of various characters towards the expression of genetic divergence on pooled basis indicated that pod length (25.6%), plant height (15.1%), shelling % (11.7%), 100 seed weight (8.0%) and number of kernels/plant (7.2%) contributed maximum (67.5%) towards total divergence in the material. Therefore, these characters should be considered while selecting the parents for hybridization programme. Reddy *et al.* (1984) also reported that the plant height, number of mature pods, number of secondary branches and 100 seed weight/plant were found to be potent factors for identifying genetically diverse genotypes in groundnut.

Table 1 Multivariate analysis in groundnut on pooled basis

Character	Range	Mean	Genotype MSS (DF=39)	GCV	PCV	H2b	GA	GA as a % of mean
Days to first flowering	24.6 - 28.8	27.2	27.9**	3.1	3.2	94.1	1.7	6.3
Days to 50% flowering	27.0 - 31.5	29.5	28.2**	2.9	3.0	93.8	1.7	5.8
Days to maturity	123.3 - 126.7	124.8	19.9**	0.6	0.6	89.4	1.4	1.1
Plant height (cm)	34.3 - 52.3	41.2	726.6**	10.6	10.9	94.6	8.8	21.2
Primary branches/plant	4.5 - 7.1	5.2	8.2**	8.9	9.2	94.3	0.9	17.8
Number of pods/plant	7.8 - 15.3	10.9	79.2**	12.9	13.6	90.5	2.8	25.3
Pod length (mm)	21.0 - 28.3	24.5	147.8**	8.2	8.3	99.3	4.1	16.9
Number of kernels/plant	12.7 - 23.2	17.5	159.5**	11.3	12.0	87.7	3.8	21.7
100 seed weight (g)	35.9 - 46.9	40.2	264.5**	6.5	6.7	93.5	5.2	13.0
Kernel yield/plant (g)	4.9 - 9.4	7.1	33.2**	13.0	13.6	91.7	1.8	25.7
Shelling (%)	63.8 - 69.2	66.5	41.7**	1.2	1.6	59.0	1.3	2.0
Oil content (%)	45.9 - 48.1	46.6	10.0**	0.8	1.1	44.6	0.5	1.0
Protein content (%)	21.7 - 22.9	22.2	2.6**	0.9	1.2	50.4	0.3	1.3
Haulm yield/plant (g)	10.4 - 16.6	13.5	104.5**	12.1	12.6	92.2	3.2	23.9
Dry pod yield/plant (g)	7.6 - 14.0	10.6	68.5**	12.4	13.0	91.5	2.6	24.5

* $P < 0.05$, ** $P < 0.0$

Table 2 Composition of D^2 clusters on pooled basis

Cluster No.	No. of genotypes included	Genotypes (Origin)
I	27	K-491 (China), VRR-232 (India), J-39 (UN), NAN-251 (Nigeria), 680/73 (Paraguay), MS-24 (Zimbabwe), STARR (USA), EC-6902 (UN), LIU YUEH TSAO (China), K-3 (India), EC-24411 (Argentina), IC-16-6-4 (India), RCM-449-4 (Argentina), RCM-585 (Brazil), SAM COLL-106 (UNK), VRR-275 (India), RCM-556 (Brazil), B-353 (Zaire), 1792 (UNK), J-10 (India), SB-11 (India), J-5 (India), J-6 (India), J-17 (India), J-18 (India), J-33 (India), J-35 (India)
II	1	J-21 (India)
III	7	AMM-795 (Zimbabwe), B-704 (Uganda), RCM-455-3 (Paraguay), KANO (Nigeria), VRR-368 (India), J-46 (India), J-30 (India)
IV	4	NCAC-973 (Argentina), VRR-361 (India), IC-22942 (India), JLW-66 (India)
V	1	Konkan Gaurav (India)

Table 3 Intra and Inter cluster distance D^2 (above the diagonal) and D value (below the diagonal) on pooled basis

Cluster	I	II	III	IV	V	Intra cluster
I		0.41	0.48	0.45	0.72	0.18
II	0.64		0.14	1.19	1.37	0.00
III	0.69	0.37		1.25	1.54	0.22
IV	0.67	1.09	1.12		0.55	0.23
V	0.85	1.17	1.24	0.74		0.00
Intra-cluster	0.43	0.00	0.47	0.48	0.00	

Table 4 Intra-cluster means for different characters and contribution of character towards genetic divergence of groundnut on pooled environment basis

Character	Clusters					Contribution (%)
	I	II	III	IV	V	
Days to first flowering	27.3	26.9	26.6	26.7	28.8	1.8
Days to 50% flowering	29.6	29.3	29.0	29.1	31.5	0.2
Days to maturity	124.8	124.9	124.2	124.6	126.7	0.3
Plant height (cm)	41.0	43.6	42.1	42.1	34.3	15.1
Primary branches/plant	5.1	5.5	5.3	4.9	7.1	4.2
Number of pods/plant	11.0	10.9	10.7	11.1	11.7	5.9
Pod length (mm)	24.3	27.4	27.5	21.1	21.1	25.6
Number of kernels/plant	17.6	15.0	17.3	17.6	17.5	7.2
100 seed weight (g)	39.6	44.5	42.6	39.1	40.7	8.0
Kernel yield/plant (g)	7.0	6.7	7.4	6.9	7.4	2.0
Shelling (%)	66.7	66.5	66.3	66.4	65.0	11.7
Oil content (%)	46.6	47.7	46.4	46.3	46.4	4.1
Protein content (%)	22.2	21.9	22.3	22.2	22.3	0.5
Haulm yield/plant (g)	13.2	15.3	14.1	13.2	16.6	9.2
Dry pod yield/plant (g)	10.5	10.1	11.1	10.5	11.3	4.3

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Foraging behaviour of *Apis* spp. on *Brassica juncea*

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(Received: August, 2010; Revised: February, 2011; Accepted: March, 2011)

ABSTRACT

Abundance, foraging behaviour and ecology of honeybee pollinators visiting *B. juncea* flowers was studied in Kaithal and Kurukshetra, Haryana during January, 2009. The dwarf honeybee *Apis florea* was the most abundant flower visitor followed by *A. dorsata* and *A. mellifera* and *A. cerana*. Studies on foraging rate showed that *A. dorsata* visited significantly more number of flowers (14.7 flowers/min) as compared to *A. mellifera* (12.3), *A. florea* (9.3) and *A. cerana* (7.7 flowers/min). The mean foraging speed was maximum of *A. florea* (6.4 sec/ flower) followed by *A. cerana* (4.6 sec), *A. mellifera* (4.0) and *A. dorsata* (3.5sec/flower). The foraging population of honey bees was correlated significantly and positively with maximum temperature (r=0.79) and wind velocity ®= 0.81) while it showed significant negative correlation with relative humidity ®= - 0.66).

Key words: Abundance, *Brassica juncea*, Environmental factors, Foraging behaviour, Honey bees

Honeybees, *Apis mellifera* and *Apis cerana* have been widely recognized as the most efficient and potential pollinators of a wide variety of field and fruit crops (Free, 1993; Abrol, 1997). Among the various floral resources, Indian mustard is an important oilseed crop which constitutes approximately 80% of the total production of rapeseed and mustard in India (Yadav *et al.*, 1985). *Brassica juncea* usually grown as an annual or biennial crop which is two-third self-pollinating and one-third insect pollinating. The yield of rapeseed-mustard crops is greatly influenced by the insect visitors and pollinators. *Brassica* spp. are the main source of honey bee flora providing both nectar and pollen to honey bees. The foraging behaviour of honey bees has been studied by various workers in different agro-ecosystems *viz.*, apple (Verma and Dutta, 1986), cauliflower (Kapoor and Dhaliwal, 1989), *ber* (Kumar, 1990), carrot (Sharma and Singh, 1999), *Phalsa* (Kaushik *et al.*, 2002), sesamum (Sachdeva *et al.*, 2003). Besides colour, shape and odour of flowers, energy requirement, availability of nectar and caloric rewards offered by flowers also determine whether an insect can be a dependable flower visitor (Abrol, 2006). Nectar has been found to be a very significant parameter that decisively shapes the behaviour of pollinators in relation to their energy demands (Abrol, 1992). The purpose of the present investigation was to record the abundance, activity and foraging behaviour of different *Apis* species under agro-ecological conditions of Haryana.

MATERIALS AND METHODS

Brassica juncea variety RH-30 was grown with recommended package of practices in plot size of 40 m^2 replicated three times at village Devigarh, district Kaithal (Haryana) during *rabi* 2008-09.

Abundance: Observations on number of honey bees visiting mustard flowers during 50% flowering to full bloom were counted at an interval of every three days from three places for each replication. Such counts were made for different bee species during the month of January. Abundance of different bee species *viz.*, *A. dorsata, A mellifera, A florae* and *A cerana* were recorded on *raya* inflorescence by taking total number of each bee species visiting per inflorescence for 5 minutes using hand telly counter at 1000 hrs, 1200 hrs, 1400 hrs and 1600 hrs of a day following the method given by Free (1993). The observations were recorded on a calm clear day during full bloom stage.

Foraging behaviour: Foraging behaviour of bees was recorded in terms of foraging speed and foraging rate. Foraging speed (time spent in seconds by bee/flower) was recorded in terms of time spent on each flower for nectar reward following the method given by Free (1993). The total of 10 bees of each species/ plot were observed for recording time spent by them on *B. juncea* flowers between 1130 hrs and 1230 hrs when the bee activity was found to be maximum. Observations were repeated on calm, clear and sunny days during flowering time for eight days. The time spent to insert the proboscis and suck up the nectar or brushing/collecting pollen was considered as the time spent per flower, which was recorded with the help of a chronometer having an accuracy of 0.01 seconds. Foraging rate (total number of flowers visited/minute) of each *Apis* species was also assessed with the help of a hand telly counter. The number of flowers visited per minute was recorded including the flying time from one flower to another flower. The observations following similar methodology were repeated at village Adhon in district Kurukshetra (Haryana) during *rabi* 2008-09.

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RESULTS AND DISCUSSION

All the four *Apis* spp. *viz., A. dorsata, A. mellifera, A. florea* and *A. cerana* were observed on *B. juncea* flowers during the present investigation. Perusal of data revealed that irrespective of the duration, *A. florea* was found to be significantly the most abundant species (7.86 bees/inflorescence/5 min) followed by *A. dorsata* (6.60) and *A. mellifera* (5.70 bees/inflorescence/5 min) (Table 1). *A. cerana* (5.26 bees/inflorescence/5 min) was found to be least in number. The number of bees of different species significantly differed with each other. The activity of the bees was significantly high at 1200 hrs (11.5 bees/inflorescence/5min) corresponding to the highest nectar and pollen collection at 1200 noon as compared to 0900 and 1500 hrs in other studies (Raj, 1993; Raj *et al.*, 1993). Thereafter, the bee activity significantly declined as the day progressed and the activity of *A. cerana* and *A. florea* ceased between 1400-1600 hrs. The results are also in conformity with the findings of Sharma *et al.* (2000) and Negi and Joshi (2006) who recorded highest population of three *Apis* spp. on *Brassica* flowers during 1200 and 1300 hrs. Similarly, Kakkar (1981) observed maximum activity of *A. mellifera* and *A. cerana* indica between 12 noon and 2 pm while Thakur *et al.* (1982) found peak activity of above two species at 1200 hrs and smaller peak between 2.00 and 3.30 pm on mustard bloom. Maximum abundance of *A. cerana indica* was reported between 1300 and 1400 hrs on *B. campestris* (Mishra *et al.*, 1988). Singh *et al.* (2009) recorded highest intensity of *A. mellifera* at 1000-1200 hrs (3.7-3.8 bees/m^2/min) on *B. rapa* var. *toria*.

Number of flowers visited by the bee species differed significantly in present studies (Table 2). The mean foraging rate varied from 7.66 to 14.66 flowers. Among different bee species, *A. dorsata* visited significantly more number of flowers (14.66 flowers/min) followed by *A. mellifera* (12.33) and *A. florea* (9.33 flowers/min). *A. cerana* visited minimum number of flowers. The results are in line with those of Sachdeva *et al.* (2003) who reported maximum flower visits (7 flowers/min) by *A. dorsata*. Negi and Joshi (2006) recorded *A. mellifera* to visit 15 flowers of *B. juncea*/ minute. However, Pandey and Tripathi (2003) noted that *A. cerana indica* visited maximum number on mustard flowers than *A dorsata, A. mellifera* and *A. florea*. While Kumar (1990) observed *A. florea* to be the most mobile species than *A. dorsata* and *A. mellifera* on *ber* flowers. Time spent per flower by four bee species also differed significantly (Table 2). The mean foraging speed varied from 3.5 to 6.4 seconds. The maximum time (6.4 sec/flower) was spent by *A. florea* followed by *A. cerana* (4.6 sec) and *A. mellifera* (4.0 sec). *A. dorsata* spent minimum time in the present study. However, on carrot and sesamum flowers, high *A. dorsata* activity was reported by Sharma and Singh (1999) and Sachdeva *et al.* (2003), respectively. The time spent by *A. cerana* indica and *A. florea* as 3.0 seconds and 6.45 seconds, respectively on *B. campestris* (Murrell and Williams, 1981) come in close proximity of present results. Present results are contrary to those reported by Kaushik *et al.* (2002) who noted significantly less time spent by *A. florea* as compared to *A. mellifera* and *A. dorsata* on *Phalsa* flowers. The time spent by *A. mellifera* on other crops include 30 seconds on apple, apricot, raspberry and black current (Rymahesvskii, 1956); 21 seconds on almond and peach (Kumar, 1995); 5.29 seconds on cherry and 6.65 seconds on apple (Verma and Dutta, 1986). It is thus evident that there is a variation in time spent by the same species on different trees.

In the present studies, efficiency of *A. dorsata*, on the basis of less time spent/ flower and highest flower visited/minute was highest amongst *A. florea, A. mellifera* and *A cerana*. Sharma and Singh (1999) also reported *A. dorsata* as efficient pollinator of carrot crop as compared to other species. The differences may further be due to change in the amount and viscosity of nectar present in flowers and microclimate.

Foraging behaviour of bee pollinators visiting *B. juncea* flowers was also studied in relation with environmental variables. Commencement of flight activity occurred when a minimum threshold of environmental variables was surpassed, while cessation was governed mainly by declining values of light intensity and radiation. In between commencement and cessation, the foraging population correlated significantly and positively with air temperature, wind velocity and negatively with relative humidity. The study revealed that among abiotic factors, maximum temperature and relative humidity played a significant role in the bee visits on *B. juncea* flowers during the day. Significant positive correlation was recorded between bee visits and maximum temperature (r=0.79) within the range of 12.6 to 21.1°C (Table 3) and with wind velocity (r= 0.81). The data recorded during the investigations revealed low bee activity (Fig.1) in the beginning of January. However, the peak of all the four species was observed during second fortnight of January when the average maximum temperature was 18.5°C. Similar observations were summarized by Free (1993) who stated that metabolic activity of insects and subsequent flower visitation increase as temperature increases. Path coefficient analysis studied by Abrol (2006) revealed that the direct effect of temperature was high and positive followed by light intensity and solar radiation on *A. florea* visiting carrot flowers. Relative humidity showed a significant negative correlation (r= - 0.66) with bee visits within the range of 86.6 to 100% (Table 3). The abundance decreased during the end of January with increase in relative humidity. Results are in conformity with Abrol (2006) who showed that the direct effect of relative humidity was high and negative analysis on *A. florea* visiting carrot flowers.

Table 1 Relative abundance of *Apis* spp. on *Brassica juncea* flowers during different hours of day

Species (A)	Number of honey bees/ inflorescence /5 minutes during different day hours (B)*				Mean (A)
	10.00	12.00	14.00	16.00	
A. dorsata	5.2 (2.49)	12.8 (3.71)	6.4 (2.72)	2.0 (1.73)	6.60 (2.66)
A. mellifera	5.0 (2.44)	10.4 (3.37)	5.2 (2.49)	2.2 (1.78)	5.70 (2.52)
A. cerana	3.8 (2.19)	7.6 (2.93)	4.4 (2.32)	0.0 (1.00)	5.26 (2.11)
A. florea	2.4 (1.84)	15.2 (4.02)	6.0 (2.64)	0.0 (1.00)	7.86 (2.37)
Mean (B)	4.1 (2.24)	11.5 (3.51)	5.5 (2.54)	2.1 (1.37)	

CD (P=0.05) for bee species (A) = 0.037; day hours (B) = 0.037; CD (P=0.05) for bee species x day hours= 0.074
*Based on 20 observations/ hour. Figures in parentheses are square root transformation

Table 2 Foraging behaviour of *Apis* sps. on *Brassica juncea* flowers

Bee Species	No. of flowers visited/min.* (Mean ± S.E.)	Time spent (sec./flower)* (Mean ± S.E.)
A. dorsata	14.66 ± 0.14	3.50 ± 0.12
A. mellifera	12.33 ± 0.11	4.00 ± 0.14
A. cerana	7.66 ± 0.13	4.60 ± 0.11
A. florea	9.33 ± 0.11	6.40 ± 0.14
SEm±	0.128	0.135
CD (P=0.05)	0.388	0.408

*Based on 20 observations /plot

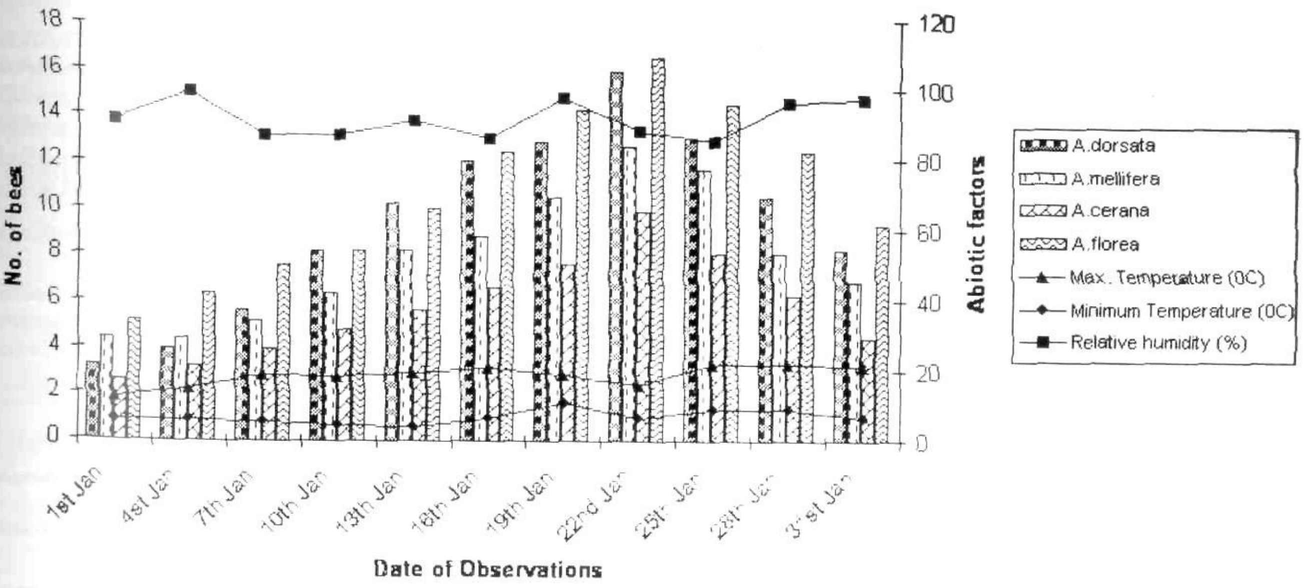

Fig. 1. Interaction between number of bees and abiotic factors at different observation dates

Table 3 Correlation matrix between bee visits and abiotic factors

	Bee visit/ flower/day	Maximum temperature (°C) (12.6°-21.1°C)	Minimum temperature (°C) (3.8°-11.1°C)	Relative humidity (%) (86.6-100%)	Wind velocity (2.3-7.33 km/h)	Rainfall (0-9.8 mm/week)
Bee visit/flower/day	1.00					
Maximum temperature (°C)	0.79*	1.00				
Minimum temperature (°C)	0.42NS	0.65*	1.00			
Relative humidity (%)	-0.66*	-0.59*	-0.63*	1.00		
Wind velocity (km/hr)	0.81*	0.25	0.44	-0.33	1.00	
Rainfall (mm/week)	0.51 NS	0.10	0.01	0.22	0.54	1.00

* = significant; NS = non-significant

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Combining ability and heterosis for yield and its component characters in sunflower (*Helianthus annuus* L.)

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(Received: May, 2010; Revised: December, 2010; Accepted: February, 2011)

ABSTRACT

Four cytoplasm male sterile lines were crossed with 7 testers in line x tester mating design for estimation of combining ability and heterosis for yield and its component characters in sunflower (*Helianthus annuus* L.). Among the 28 hybrids, CMS7-1A x RHA-856 recorded the highest heterosis and standard heterosis over check (KBSH-44) for seed yield/plant and CMS-335A x RHA-418 for oil content. The estimates of specific combining ability (*sca*) variances were higher than general combining ability (*gca*) variances for all the characters which indicated non-additive gene action had more effects. The parents CMS-234A, CMS7-1A, CMS-335A, RHA-2, RHA-348 and RHA-856 can be considered as superior parents with respect to yield and oil content. The crosses CMS-335A x RHA-344, CMS7-1A x RHA-856, CMS-234A x RHA-2 and CMS-234A x RHA-297 can be considered as the most promising crosses since they observed high *per se* performance and significant *gca* and *sca* effects for major characters.

Key words: Combining ability, Heterosis, Sunflower, Yield

An important landmark in the development of commercial sunflower (*Helianthus annuus* L.) hybrids was the discovery of cytoplasmic male sterility by Leclercq (1969) and genes for fertility restoration by Kinman (1970). The first sunflower hybrid BSH-1 (CMS-234A x RHA-274) was released for commercial cultivation in 1980 (Seetharam *et al.*, 1980). Since then several hybrids have been developed and released for cultivation all over India by exploitation of heterosis. To develop sunflower hybrids with improved yield potential, choice of parents through critical evaluation and careful selection is very important. Combining ability analysis elucidates the nature and magnitude of gene action involved in the inheritance of character by providing the information of the two components of variance *viz.*, additive and dominance genetic variance. The present investigation aims at determining the combining ability of 11 parents for yield and yield contributing traits and to select parents with good general combining ability (*gca*) and crosses with good specific combining ability (*sca*) effects through line x tester mating design.

MATERIALS AND METHODS

Four CMS lines CMS-234A, CMS7-1A, CMS-343A and CMS-335A were crossed with seven restorer lines (RHA2, RHA-344, RHA-418, RHA-348, RHA-297, RHA-856 and RHA-6D-1) according to line x tester mating design (Kempthorne, 1957) during the winter season of 2006-07 at Pulses and Oilseed Research Station, Berhampore, West Bengal. Twenty eight F_1 hybrids so produced were evaluated along with parents in a randomized block design with three replications during the winter season of 2007-08 for ten morphological and quantitative characters to estimate combining ability effects and heterosis. The mean values were subjected to line x tester analysis (Kempthorne, 1957) to estimate combining ability effects and variances. Mid parent heterosis and standard heterosis was determined by Falconer and Mackey (1980) procedure.

Each replication comprising 39 entries (28 F_1s and 11 parents) were sown in 4.5m x 3.0m plot maintaining plant to plant distance 30 cm and row to row distance 60 cm with recommended package of practices. Observations were recorded on five randomly selected plants from each plot of all replications to record data on the following characters except 50% flowering and maturity which were taken on plot basis *viz.*, i) 50%flowering (days) ii) maturity (days) iii) stem girth (cm.) iv) plant height (cm.) v) head diameter (cm.) vi) leaves/plant (number) vii) seed filling (%) viii) 100 seed weight (g.) ix) seed yield (g/plant) and x) oil content (%).

RESULTS AND DISCUSSION

The estimate of heterosis (%) over mid parent (Table 4) revealed that most of the F_1 hybrids showed significant positive heterosis except CMS-335A x RHA-856 which showed negative heterosis for plant height. Although the two parents 234A and RHA-348 were phenotypically apart for this trait but showed the highest heterosis in F_1 generation

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(67.7%). This might be due to the interaction of recessive or dominant alleles from both parents. Yilmaz and Emiroglu (1994) mentioned positive heterosis for this trait. Loganathan and Gopalan (2006) reported both positive and negative heterosis for this trait.

For head diameter, all 28 crosses exhibited positive heterosis. The heterosis ranged from 18.4 to 142.9% with mean value of 78.3%. The maximum heterosis was observed in the cross CMS-234A x RHA-297. Gill *et al.* (1998) confirmed maximum heterosis in head diameter of his cross CMS-234A x RHA-271.

For stem girth, all 28 cross combinations showed positive significant heterotic effect. The heterosis ranged from 8.8 to 142.9%. The maximum heterosis was shown by the cross CMS-343A x RHA-348 with mean heterotic value of F_1 over mid parent 40.2%. Positive heterotic effect for this trait was also reported by Yilmaz and Emiroglu (1994).

For days to 50% flowering and days to maturity, the cross CMS-234A x RHA-2 showed highest negative significant heterosis -12.4% and -5.6% respectively. Thus, the cross combination can be considered for earliness. Such findings of heterosis in early flowering and maturity were reported by Khan *et al.* (2008).

For number of leaves/plant, the highest heterotic value was observed in the cross CMS-343A x RHA-297 (63.9%). Ahmad *et al.* (2005) have reported low level of heterosis (-0.9 to 39.7%) for this character.

For seed filling percentage, 23 crosses showed positive significant heterosis. Maximum heterosis for this character was observed in the cross CMS-234A x RHA-2 (18.8%).

Significant positive heterosis was recorded in all crosses for 100 seed weight. Maximum heterosis was depicted in the cross CMS-343AxRHA-348 (104.5%). Similar observations have earlier been reported by Khan *et al.* (2008).

For seed yield (g/plant), six out of 28 crosses registered negative heterosis. All other crosses showed positive heterosis. The range of heterosis was -29.42 to 150.7% with average value of F_1 generation over mid parent 56.0%. The cross CMS-7-1A x RHA-856, CMS-335A x RHA-297 registered high heterosis. The results were in agreement with that of Ashok *et al.* (2000), Ahmad *et al.* (2005) and Loganathan and Gopalan (2006).

In case of oil content, 21 out of 28 crosses displayed positive significant heterosis. The maximum heterotic effect was exhibited in the cross CMS-335A x RHA-344. The average heterotic effect of F_1 over mid parent was 8.9%. Similar positive heterosis for oil content % was also observed by several workers *viz.*, Rather *et al.* (1999) and Nehru *et al.* (2000).

The estimates of combining ability revealed that variation due to lines and testers was significant for all the traits except basal girth (Table 1). The interaction effect (line x tester) was significant for all the traits except basal girth. The variance due to *sca* was greater than the variance due to *gca*, indicating the predominant role of non-additive gene action for all the characters. Similar results were reported by Madhavilatha *et al.* (2005) and Loganathan and Gopalan (2006).

The first important criterion of selection is *per se* performance of hybrids (Table 5). There were significant differences among the hybrids. CMS-7-1A x RHA-856 cross combination recorded the highest seed yield/plant (96.07 g.) with high 100 seed weight (8.29 g.), seed filling% (91.6%), head diameter (26.0cm.) and oil content (38.6%). The cross CMS-335A x RHA-418 produced the highest oil content (40.1%) with moderate seed yield (63.513 g), 100 seed weight (6.910 g), seed filling % (90.99) and head diameter (23.6cm.). Based on *per se* performance of seed yield/plant and oil content %, CMS-335A, CMS-7-1A, RHA-856 and RHA-418 were identified as desirable parents.

The estimates of *gca* effects of parents (Table 2) is the second important criteria because parents with high mean value may not necessarily be able to transmit their superior traits to their progenies. The line CMS-234A might be considered the best general combiner for days to 50% flowering, days to maturity, number of leaves/plant and oil content %, CMS-7-1A for plant height, CMS-335A for head diameter, basal girth, 100 seed weight, and seed yield. Among the testers, RHA-2 may be selected as donor for earliness and oil content %. RHA-348 was a good general combiner for the traits like 100 seed weight and basal girth. RHA-856 was found to be a very good general combiner for head diameter and seed yield (g/plant). Rao and Singh (1977) observed that no parent was found to contain all the favourable or unfavourable genes for all the characters as in the case of present study. Therefore, for improvement of a specific character the parents showing high *gca* in desirable direction can be used as good donors for improvement of that character. Hence, based on *gca* effects CMS-234A, CMS-335A, CMS-7-1A, RHA-856, RHA-2 and RHA-348 can be considered as superior parents for future breeding purposes.

In contrast to *gca* effects being attributable to additive genetic effects, *sca* denotes dominance and epistatic gene effects. The results of *sca* effects of crosses (Table 3) depicted that CMS-343A x RHA-2 was a good combination for tallness, CMS-335A x RHA-344 for larger head diameter. For basal girth, leaves number/plant and seed filling %, CMS-7-1A x RHA-6D-1 cross recorded good combination. For early flowering, CMS-234A x RHA-2 hybrid was good combiner but for early maturity CMS 7-1A x RHA-344 hybrid was a good combination. CMS-7-1A x RHA-856 showed high *sca* for days to maturity and seed yield but for 100 seed weight, CMS-343A x RHA-348 and for oil content, CMS-234A x RHA-2 were found to be a good combination.

Table 1 Analysis of variance for sunflower seed yield and other ancillary characters

Source of variation	d.f.	Days to 50% flowering (days)	Plant height (cm)	Head diameter (cm.)	Stem girth (cm)	Days to maturity	Leaves/ plant	Seed filling (%)	100 seed weight (g.)	Seed yield (g/plant)	Oil content (%)
Replications	2	0.92	185.12	3.42	0.97	0.03	445.09	9.53	0.11	14.35	872.90
Genotypes/treatments	38	47.89**	1646.67**	83.62**	5.46**	53.01**	355.44**	90.95**	6.24**	1121.4**	780.61**
Parents	10	76.20**	808.60**	40.33**	2.83*	81.49**	1298.5**	79.62**	0.43ns	438.60**	29.27**
Parents vs. hybrids	1	21.14**	31869.54**	2540.04**	146.69**	74.81**	15.47**	1500.6**	124.26**	7111.62**	13.15**
Hybrids	27	38.40**	837.70**	8.67**	1.20ns	41.66**	18.75**	42.93**	4.03**	1152.43**	1087.30**
GCA lines	3	24.83**	2265.75**	4.36ns	0.86ns	29.38**	8.95**	66.26**	1.47ns	797.56**	893.8**
GCA testers	6	118.71**	1851.66**	23.77**	2.07ns	126.34**	64.62**	25.79**	3.45**	988.57**	1014.46**
SCA line x testers	18	13.89**	261.71**	4.36**	0.97ns	15.48**	5.10**	44.76**	4.65**	1266.19**	1143.83**
Error	76	1.03	44.20	3.84	0.64	0.38	381.35	9.78	0.63	37.61	776.04
σ^2 GCA		0.544	12.79	0.096	0.005	0.582	0.303	-0.041	-0.014	-2.528	-1.256
σ^2 SCA		4.285	72.50	0.171	0.108	5.032	-125.41	11.661	1.337	409.52	122.598
σ^2 GCA / σ^2 SCA		0.127	0.706	0.560	0.048	0.116	-0.0002	-0.0003	-0.01	-0.0001	-0.0002
σ^2 A		2.178	51.199	0.383	0.020	0.327	1.213	-0.162	-0.054	10.11	-5.0252
σ^2 D		17.141	290.015	0.684	0.433	20.130	-501.66	46.647	5.348	1638.11	490.392

* significant at 5%, ** significant at 1%, ns= non significant. σ^2A: Additive variance, σ^2D: Dominance variance

Table 2 Estimates of general combining ability effects of lines and testers for seed yield and its components of sunflower

	Plant height (cm)	Head diameter (cm)	Stem girth (cm)	Days to 50% flowering	Days to maturity	Leaves/ plant	Seed filling (%)	100 seed weight (g)	Seed yield (g/plant)	Oil content (%)
Lines										
CMS-234A	7.39**	-0.49	-0.25	-1.15	-1.59	0.73	-2.59	0.04	2.35	9.72**
CMS-7-1A	-9.26**	0.08	-0.01	0.56	0.21	-0.32	0.35	-0.38	0.66	-4.16**
CMS-343A	10.47**	-0.17	0.02	-0.63	0.12	0.32	1.36	0.12	-8.69**	-2.25
CMS-335A	-8.59**	0.59	0.24	1.22	1.26	-0.73	0.88	0.22	5.69**	-3.30*
CD (P=0.05)	2.89	0.85	0.35	0.44	0.27	8.50	1.36	0.35	2.67	12.13
CD (P=0.01)	3.84	1.13	0.46	0.59	0.36	11.29	1.81	0.46	3.55	16.10
Testers										
RHA-2	-6.34**	0.32	-0.80	-6.38**	-5.59**	-3.42	0.69	-0.11	-6.30**	20.66**
RHA-344	5.62**	-0.55	-0.03	1.37	2.15	1.99	-1.74	0.12	9.17**	-3.60*
RHA-418	11.91**	-0.71	-0.23	2.45	4.40**	0.41	-0.86	-0.24	6.53**	-2.15
RHA-348	0.46	1.12	0.45	0.37	-0.76	1.04	0.79	1.14	-14.64**	-3.91*
RHA-297	5.18**	-1.08	0.15	1.79	0.99	3.04	2.27	-0.41	-0.45	-3.04*
RHA-856	-24.90**	2.47	0.17	-1.71	-2.26	-2.41	0.48	-0.07	9.81**	-5.82**
RHA-6D-1	8.06	-1.57	0.29	2.12	1.07	-0.64	-1.63	-0.42	-4.13**	-2.13*
CD (P=0.05)	3.83	1.13	0.46	0.59	0.36	11.25	1.80	0.46	3.53	16.04
CD (P=0.01)	5.08	1.49	0.61	0.78	0.47	14.93	2.39	0.61	4.69	21.30

* significant at 5% level, ** significant at 1% level

Table 3 Estimates of specific combining ability effects for seed yield and its components in sunflower

Crosse	Plant height (cm.)	Head diameter (cm.)	Stem girth (cm.)	Days to 50% flowering	Days to maturity	Leaves/ plant	Seed filling (%)	100 seed weight (g.)	Seed yield (g/plant)	Oil content (%)
CMS-234Ax RHA-2	-2.02*	-0.05	0.44	-3.09**	-2.07*	-0.06	4.57**	1.13	-8.69**	65.69**
CMS-234Ax RHA-344	8.21**	-0.04	0.24	1.82*	2.51**	1.40	-7.62**	-0.73	-6.72**	-7.31**
CMS-234Ax RHA-418	-4.20**	-0.15	0.58	3.40**	2.59**	1.31	1.12	1.02	13.11**	-13.07**
CMS-234Ax RHA-348	1.77*	1.15	0.06	0.49	1.76*	-0.75	4.41**	-0.81	-3.52**	-13.89**
CMS-234Ax RHA-297	0.92	-0.24	-0.11	-0.59	-0.99	-0.52	2.34	-0.44	-18.86**	-11.39**
CMS-234Ax RHA-856	7.21**	0.48	-0.03	-2.09*	-2.74**	0.59	0.84	0.05	8.15**	-11.52**
CMS-234Ax RHA-6D-1	-11.89**	-1.15	-1.18	0.07	-1.07	-1.97*	-5.67**	-0.21	16.54**	-8.51**
CMS-7-1Ax RHA-2	-6.50**	0.85	-0.29	1.52	0.78	-0.34	0.54	-0.57	-22.91**	-20.49**
CMS-7-1Ax RHA-344	-9.07**	-1.21	-0.54	-1.23	-2.96**	-1.01	4.47**	-0.11	-22.96**	3.71**
CMS-7-1Ax RHA-418	4.71**	-0.85	-0.49	-2.31**	-1.21	-0.77	-0.01	0.01	-1.56	-0.05
CMS-7-1Ax RHA-348	*-0.31*	*-1.02*	*-0.14*	*-1.89**	*-1.71**	*0.54*	*-6.38***	*-1.18*	*-8.06***	2.61**
CMS-7-1Ax RHA-297	3.37**	0.99	0.36	0.36	0.53	1.34	-2.69**	0.52	17.86**	4.15**
CMS-7-1Ax RHA-856	-5.48**	-0.43	0.06	2.52**	2.78**	-1.35	-1.19	1.48	28.02**	7.10**
CMS-7-1Ax RHA-6D-1	13.28**	1.67	1.05	1.02	1.78*	1.61	5.28**	-0.14	9.65**	2.96**
CMS-343Ax RHA-2	15.13**	0.29	0.01	-0.62	-0.45	0.35	-0.53	-0.79	18.69**	-20.42**
CMS-343Ax RHA-344	6.60**	-1.19	0.63	0.29	2.46**	1.01	1.78*	-0.62	28.02**	2.26**
CMS-343Ax RHA-418	-7.55**	1.19	0.16	0.55	-1.12	0.32	-0.13	-0.69	-5.26**	5.46**
CMS-343Ax RHA-348	-0.47	1.03	0.15	2.63**	2.05*	-0.80	0.47	3.46**	-3.97**	6.92**
CMS-343Ax *RHA-297*	-3.46**	-0.86	-0.25	0.21	-0.70	-1.60	-0.38	-0.48	-20.53**	3.46**
CMS-343Ax RHA-856	4.42**	0.55	0.03	-2.95**	-2.45**	1.51	-0.59	-0.66	0.92	3.47**
CMS-343Ax RHA-6D-1	-14.67**	-1.01	-0.72	0.12	0.21	-0.79	-0.61	-0.21	-17.87**	-1.14
335-Ax RHA-2	-6.61**	-1.09	-0.15	2.19*	1.74*	0.04	-4.57**	0.24	12.91**	-24.78**
CMS-335Ax RHA-344	-5.74**	2.45**	-0.33	-0.89	-2.01*	-1.40	1.36	1.47	1.66	1.33
CMS-335Ax *RHA-418*	7.04**	-0.19	-0.25	-1.64	-0.26	-0.86	-0.97	-0.33	-6.29**	7.66**
CMS-335Ax RHA-348	-0.98	-1.16	-0.07	-1.23	-2.09*	1.02	1.49	-1.47	15.55**	4.35**
CMS-335Ax RHA-297	-0.83	0.11	-0.001	0.02	1.15	0.78	0.73	0.40	21.58**	3.79**
CMS-335Ax RHA-856	-6.15**	-0.60	-0.06	2.52**	2.40**	-074	0.95	-0.86	-37.09**	0.95
CMS-335Ax RHA-6D-1	13.28**	0.49	0.86	-0.98	-0.93	1.16	1.00	0.56	-8.32**	6.69**
CD (P=0.05)	7.66	2.26	0.93	1.17	0.71	22.49	3.60	0.92	7.06	32.09
CD (P=0.01)	10.17	2.99	1.22	1.56	0.95	29.87	4.78	1.22	9.38	42.61

** and * Significant at 1% and 5% level of significance

The entire cross combinations in F_1 generation exhibited heterosis for all the characters. The cross combination CMS-234A x RHA-297 was observed to display maximum heterosis for head diameter. For plant height, the cross CMS-234A x RHA-348 depicted maximum effects for tallness and CMS-335A x RHA-856 depicted maximum effect for dwarfness. For early flowering and maturity, CMS-234A x RHA-2, for basal girth and 100 seed weight, CMS-343A x RHA-348, and for oil content, CMS-335A x RHA-344 showed maximum heterosis. CMS-7-1A x RHA-856 showed maximum heterosis for seed yield/plant.

Considering the overall performance of parents and hybrids for seed yield/plant (Table 5), the cross CMS-7-1A x RHA-856 ranked first followed by the cross CMS-343A x RHA-344. Both the crosses showed highest *sca* effects for seed yield/plant. Parents involved in the first cross had intermediate x high *gca* effects and in the second cross had low x high *gca* effects. Another cross CMS-335A x RHA-297 also recorded high seed yield/plant with high *sca* effects and in this cross parents involved had high x low *gca* effects. Hence heterosis was due to presence of non-additive gene action. Similar results of heterotic crosses involving high x low *gca* cross combination as revealed in the present investigation were earlier reported by Limbore *et al.* (1997).

The present research work revealed differential interaction of *gca* and *sca* variance. The ratio of *gca* : *sca* was less than unity for all the characters under study indicating greater influence of non-additive gene action. To improve yield and oil content (%), some suitable parents and promising hybrids were identified. Among the lines, CMS-234A, CMS-7-1A, CMS-335A and among the testers, RHA-2, RHA-348, RHA-856 possess good general combining ability effects for various traits. CMS-335A x RHA-344 recorded good *sca* for larger head diameter. CMS-7-1A x RHA-856 showed high *sca* for days to maturity and seed yield. CMS-234A x RHA-2 was found good combiner for oil content. These lines may be used in hybridization programme. The results of this study suggest that CMS-335A x RHA-344 for high oil content, CMS-234A x RHA-297 for larger head diameter, CMS-7-1A x RHA-856 for yield/plant, 100 seed weight, seed filling % and head diameter, CMS-234A x RHA-2 for early flowering and early maturity can be considered as the most promising crosses for manifestation of highest heterotic effect of yield and other important characters in sunflower.

ACKNOWLEDGEMENT

The first author is grateful to Dr. D.M. Hegde, Project Director, Directorate of Oilseeds Research, Rajendranagar, Hyderabad-500030, for providing seed materials and co-operation to conduct the experiment.

Table 4 Estimates of heterosis (%) over mid parent (MP) and popular hybrid KBSH-44 (SH) of sunflower

Crosse	Plant height (cm.)		Head diameter (cm.)		Stem girth (cm.)		Days to 50% flowering		Days to maturity		Leaves/ plant		Seed filling (%)		100 seed weight (g.)		Seed yield (g/plant)		Oil content (%)	
	MP	SH	MP	SH	MP	SH	MP	SH	MP	SH	MP	SH	MP	SH	MP	SH	MP	SH	MP	SH
CMS-234Ax RHA-2	47.1	-31.1	97.2	26.7	39.3	-1.2*	-12.4	-21.6	-5.6	-11.5	18.2	-12.2	18.8	3.6	65.9	41.2	19.1	34.7	4.0	-8.4
CMS-234Ax RHA-344	67.0	-19.8	62.9	18.5	51.7	5.8	10.6	-8.1	11.9	-1.3*	53.4	11.9	0.2ns	-12.3	42.8	13.4	61.4	87.1	9.5	-8.0
CMS-234Ax RHA-418	54.6	-22.9	112.9	20.6	60.0	7.0	6.8	-5.3	8.4	0.5ns	40.5	5.9	6.3	-1.7*	60.1	37.0	135.6	138.7	-2.6	-9.2
CMS-234Ax RHA-348	67.7	-25.7	105.4	37.4	66.4	9.3	-0.2ns	-10.6	2.2	-4.1	34.0	1.0*	12.8	3.6	56.2	29.3	14.5	25.3	6.0	-5.6
CMS-234Ax RHA-297	62.2	-23.8	142.9	18.2	58.9	3.5	3.9	-10.3	4.5	-5.1	60.6	8.7	10.3	2.9	34.6	9.3	13.0	21.8	1.2*	-9.9
CMS-234Ax RHA-856	41.4	-35.9	92.6	41.0	53.9	4.7	-5.4	-15.6	-2.9	-8.7	35.9	-6.3	9.5	-0.6ns	56.7	23.5	107.2	133.6	19.9	2.8
CMS-234Ax RHA-6D-1	23.4	-28.9	85.1	10.7	28.0	-7.0	-1.4*	-9.2	0.0ns	-5.1	11.4	-9.1	-4.0	-10.0	35.8	13.1	98.0	117.0	17.3	2.0
CMS-7-1Ax RHA-2	23.0	-41.9	46.4	34.6	8.8	-7.0	-7.0	-14.8	-4.2	-8.2	11.0	-16.8	14.5	2.5	23.1	5.0	-24.5	-12.9	3.4	-5.1
CMS-7-1Ax RHA-344	29.9	-37.1	18.4	18.9	17.2	-1.2*	6.5	-9.5	6.6	-3.7	35.2	-0.3ns	16.1	4.14	46.7	16.8	12.9	33.9	-0.6ns	-12.7
CMS-7-1Ax RHA-418	45.5	-26.9	42.2	19.9	20.0	-2.3	-0.2ns	-9.5	4.4	-1.0ns	24.9	-4.9	5.9	0.1ns	31.5	12.7	83.2	89.6	-12.6	-15.2
CMS-7-1Ax RHA-348	44.8	-35.3	36.3	28.9	36.2	9.3	-3.1	-11.3	-1.8	-5.7	33.6	1.7*	1.0ns	-4.9	39.7	16.0	-4.5	6.6	-14.3	-20.4
CMS-7-1Ax RHA-297	45.5	-31.0	69.8	29.6	40.2	11.6	4.8	-7.4	5.5	-2.1	63.1	11.5	1.5	-2.9	45.5	18.5	106.1	126.8	-8.7	-15.4
CMS-7-1Ax RHA-856	7.5	-50.8	38.0	39.2	31.0	8.1	0.1ns	-8.8	0.2ns	-3.7	19.4	-16.8	7.9	0.3ns	78.0	40.6	150.7	188.2	18.4	5.9
CMS-7-1Ax RHA-6D-1	30.2	-24.5	47.4	28.9	38.7	20.9	-0.4ns	-6.3	1.9	-1.3	21.1	-0.3ns	9.7	5.1	28.4	7.2	71.1	91.3	1.4*	-7.9
CMS-343Ax RHA-2	47.5	-20.8	89.6	30.3	36.1	-3.5	-11.1	-18.4	-5.1	-8.7	25.9	-12.2	15.7	2.4	29.0	9.7	55.9	83.8	8.2	-7.0
CMS-343Ax RHA-344	47.5	-19.1	52.4	17.6	61.6	12.8	6.6	-9.2	10.2	0.0ns	59.4	9.1	15.34	2.3	46.95	16.6	114.03	158.2	-5.3	-22.5
CMS-343Ax RHA-418	35.6	-23.1	112	29.6	58.2	5.8	1.6	-7.7	3.9	-1.0ns	42.5	1.0ns	8.0	1.1	27.8	9.3	41.9	50.5	13.5	3.3
CMS-343Ax RHA-348	46.0	-25.3	94.0	38.5	71.6	12.8	0.6ns	-7.7	0.9ns	-2.7	40.1	-0.7ns	11.3	3.6	104.5	69.3	-20.4	-9.1	23.2	7.0
CMS-343Ax RHA-297	40.3	-24.4	119.5	16.6	60.7	4.7	3.0	-8.8	3.5	-3.5	63.8	3.5	10.3	4.3	35.5	10.1	-25.6	-16.2	8.5	-5.8
CMS-343Ax RHA-856	23.1	-35.7	84.3	43.1	58.9	8.1	-7.9	-15.9	-4.2	-7.6	48.2	-4.5	11.0	2.1	43.1	12.8	52.2	78.8	-0.5ns	-16.8
CMS-343Ax RHA-6D-1	10.6	-28.7	76.0	13.1	39.2	1.2*	-3.1	-8.8	0.0ns	-2.7	21.1	-6.6	5.2	-0.2ns	37.4	14.4	-29.4	-19.3	3.2	-12.3
CMS-335Ax RHA-2	13.0	-41.6	71.3	26.9	10.5	-2.3	-9.6	-13.5	-3.9	-6.0	13.7	-17.1	15.0	-2.5	47.0	29.1	88.7	109.6	8.3	-10.7
CMS-335Ax RHA-344	22.9	-35.1	71.0	41.2	20.0	4.7	2.5	-8.5	5.3	-2.7	35.2	-3.1	19.3	1.3*	87.4	53.8	95.3	122.3	33.6	4.6
CMS-335Ax RHA-418	36.5	-25.4	89.8	26.2	22.7	3.5	-3.2	-8.1	3.8	0.5ns	26.0	-6.6	11.0	-0.2	32.8	17.2	92.1	90.5	25.9	10.2
CMS-335Ax RHA-348	31.8	-35.3	70.48	30.8	35.6	12.8	-5.8	-9.8	-3.2	-5.1	37.9	2.1	16.8	4.2	41.8	21.3	79.5	92.5	16.4	-2.9
CMS-335Ax RHA-297	29.6	-32.8	115.3	25.8	33.8	10.5	0.3ns	-7.1	4.3	-1.0ns	62.9	8.0	15.7	5.0	51.0	26.8	139.5	153.2	19.5	-0.4
CMS-335Ax RHA-856	-1.9	-50.8	69.8	41.0	29.2	10.5	-3.7	-8.1	-0.8ns	-2.7	24.1	-16.1	17.1	3.2	36.3	11.1	-2.4	7.9	29.5	3.7
CMS-335Ax RHA-6D-1	21.5	-24.1	80.0	25.3	35.4	22.1	-6.1	-7.7	-1.6	-2.7	20.3	-3.5	11.1	1.0ns	50.4	29.4	41.8	52.4	23.2	0.1ns
Mean	35.5	-30.6	78.3	27.8	40.1	5.9	-1.1	-10.3	1.5	-3.8	35.1	-2.6	10.4	0.6	47.0	21.9	55.9	72.7	8.9	-5.6

ns = non significant, * significant at only 5% probability, other unmarked values = significant at both 1% and 5% probability.
MP= Mid parent heterosis, SH= Standard heterosis over KBSH-44

Table 5 Superior sunflower hybrids identified on the basis of *per se* performance, *sca* effects and heterosis

Character	*Per se* performance	*sca* effects	SH over KBSH-44
Plant height (cm.)	CMS-343AxRHA-344(159.0cm.) CMS-234AxRHA-344(157.53cm.) CMS-343AxRHA-2(155.57cm.)	CMS-343AxRHA-2(15.13) CMS-7-1AxRHA-6D-1 & CMS-335Ax RHA-6D-1(13.28) CMS-234AxRHA-344(8.21)	CMS-7-1AxRHA-856(-50.83) & CMS-335AxRHA-856(-50.83) CMS-7-1AxRHA-2 (-41.62)
Head diameter (cm.)	CMS-343AxRHA-856(26.73cm.) CMS-335AxRHA-344(26.37cm.) CMS-335AxRHA-856 &CMS-234AxRHA-856 (26.33cm.)	CMS-335AxRHA-344(2.45) CMS-7-1AxRHA-6D-1 (1.67) CMS-343AxRHA-418(1.19)	CMS-343AxRHA-856(43.17) CMS-335AxRHA-344(41.24) CMS-335AxRHA-856 & CMS-234AxRHA-856 (41.03)
Stem girth (cm.)	CMS-335AxRHA-6D-1(10.5cm.) CMS-7-1AxRHA-6D-1(10.4cm.) CMS-343AxRHA-344, CMS-343AxRHA-348 & CMS-335AxRHA-348(9.7cm.)	CMS-7-1AxRHA-6D-1(1.05) CMS-335AxRHA-6D-1 (0.86) CMS-343AxRHA-344(0.63)	CMS-335AxRHA-6D-1(22.1) CMS-7-1AxRHA-6D-1(20.9) CMS-343AxRHA-344, CMS-343AxRHA-348 (12.8)
Days to 50% flowering (days)	CMS-234AxRHA-2(73.7 days) CMS-343AxRHA-2(76.7 days) CMS-343AxRHA-856(79.0days)	CMS-234AxRHA-2(-3.09) CMS-343AxRHA-856 (-2.95) CMS-7-1AxRHA-418(-2.31)	CMS-234AxRHA-2(-21.6) CMS-343AxRHA-2(-18.4) CMS-343AxRHA-856(-15.96) CMS-234AxRHA-856(-15.64)
Days to maturity (days)	CMS-234AxRHA-2(107.3 days) CMS-234AxRHA-856 & CMS-343AxRHA-2 (110.7 days) CMS-7-1AxRHA-2(111.3 days)	CMS-7-1AxRHA-344(-2.96) CMS-234AxRHA-856 (-2.74) CMS-343AxRHA-856(-2.45)	CMS-234AxRHA-2(-11.54) CMS-7-1AxRHA-2(-8.74) CMS-234AxRHA-856(-8.74)
Leaves/plant (number)	CMS-234AxRHA-344(31.9) CMS-7-1AxRHA-297(31.8) CMS-343AxRHA-344(31.1)	CMS-7-1AxRHA-6D-1(1.61) CMS-343AxRHA-856 (1.51) CMS-234AxRHA-344(1.40)	CMS-234AxRHA-344(11.93) CMS-7-1AxRHA-297(11.58) CMS-343AxRHA-3449.12)
Seed filling (%)	CMS-7-1AxRHA-6D-1(95.94) CMS-335AxRHA-297(95.83) CMS-343AxRHA-297(95.20)	CMS-7-1AxRHA-6D-1(5.28) CMS-234AxRHA-2 (4.57) CMS-7-1AxRHA-344(4.47)	CMS-7-1AxRHA-6D-1(5.14) CMS-335AxRHA-297(5.02) CMS-343AxRHA-297(4.33)
100 seed weight (g.)	CMS-343AxRHA-348(9.979) CMS-335AxRHA-344(9.068) CMS-234AxRHA-2(8.323)	CMS-343AxRHA-348(3.46) CMS-7-1AxRHA-856 (1.48) CMS-335AxRHA-344(1.47)	CMS-343AxRHA-348(69.34) CMS-335AxRHA-344(53.88) CMS-234AxRHA-2(41.24)
Seed yield (g/plant)	CMS-7-1AxRHA-856(96.072) CMS-343AxRHA-344(86.076) CMS-335AxRHA-297(84.402)	CMS-7-1AxRHA-856 & CMS343A x RHA-344(28.02) CMS335AxRHA-297 (21.58) CMS343AxRHA-2(18.69)	CMS-7-1AxRHA-856(188.24) CMS-343AxRHA-344(158.25) CMS-335AxRHA-297(153.23)
Oil content (%)	CMS-335AxRHA-418(40.09) CMS-343AxRHA-348(38.93) CMS-7-1AxRHA-856(38.55)	CMS-234AxRHA-2(65.69) CMS-335AxRHA-418 (7.66) CMS-7-1AxRHA-856(7.10)	CMS-335AxRHA-418(10.23) CMS-343AxRHA-348(7.04) CMS-7-1AxRHA-856(5.99)

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(Received: January, 2010; Revised: January, 2011; Accepted: February, 2011)

ABSTRACT

Stem and root rot of sesame caused by *Macrophomina phaseolina* is a serious disease and caused great yield losses under rainfed conditions in Rajasthan. The present investigation carriedout with biocontrol agents alone or in combination on the incidence of stem and root rot and seed yield of sesame under field conditions. Results showed that biological seed treatment and soil application i.e., seed treatment with *T. viride* 0.4% + *P. fluorescens* 0.4% + soil application of *T. viride* 2.5 kg/ha + soil application of *P. fluorescens* 2.5 kg/ha is economical and eco-friendly method of disease control and can be exploited for the management of *Macrophomina* stem and root rot of sesame.

Key words: Biological control, Sesame, Stem and root rot

Sesame (*Sesamum indicum* L.) is the oldest indigenous oilseed crop cultivated in India. Stem and root rot of sesame caused by *Macrophomina phaseolina* is a serious disease and inflicting great yield losses in rainfed crop especially in Rajasthan. The continuous use of chemicals has deleterious effect on the beneficial microorganism in soil, in addition to the residual problem and development of resistance by the pathogen. Under these conditions, biological control using an antagonistic microorganism offers a practical and economic alternative for the management of the disease. The present investigation was carried out to find out the effect of biocontrol agents *Trichoderma viride* and *Pseudomonas fluorescens* seed treatment and soil application alone or in combination on incidence of stem and root rot and seed yield of sesame under field condition.

MATERIALS AND METHODS

An experiment was conducted in randomized block design with eight treatments and four replications during rainy season of 2005 to 2007 at Agricultural Research Station, Mandor, Jodhpur (Rajasthan) to find out the effect of biocontrol agent on the incidence of stem and root rot of sesame. Sesame (var. RT 127) was sown in the month of July with plot size of 3 m x 2.4 m. Seed treatment with *Trichoderma viride* and *Pseudomonas fluorescens* and soil applications of *T. viride* and *P. fluorescens* were done before sowing. Talc-based powder formulation of these bioagents was used. About 2.5 kg of powder formulation of bioagents was added separately in 200 kg farm yard manure (FYM) and kept in shade for 15 days. All plots received 2.5 t FYM/ha uniformly irrespective of treatments imposed.

RESULTS AND DISCUSSION

The results showed that all the treatments were found significantly superior in reducing *Macrophomina* stem and root rot compared to control (Table 1).

Table 1 Effect of bio-control agents on root rot incidence and seed yield

Treatment**	*Macrophomina* stem and root rot (%)				Seed yield (kg/ha)			B:C ratio
	2005	2006	2007	Mean	2006	2007	Mean	
Seed treatment (ST) with *Trichoderma viride* (0.4%)	15.6 (23.2)*	7.6 (16.0)*	7.8 (16.2)*	10.3	545	969	757	47.9
ST with *T. viride* (0.4%) + Soil application of *T. viride* @ 2.5 kg/ha	10.7 (19.1)*	4.4 (12.1)*	4.4 (12.1)	6.5	605	1062	833	5.5
ST with *T. viride* (0.4%) + soil application of *T. viride* @ 2.5 kg/ha + *P. fluorescens* @ 2.5 kg/ha	10.1 (18.5)*	3.3 (10.3)*	2.2 (8.3)	5.2	659	1133	896	5.3
ST with *T. viride* 0.4% + *P. fluorescens* 0.4%+ soil application of *T. viride* 2.5 kg/ha	10.5 (18.8)*	4.0 (11.5)*	4.5 (12.2)	6.3	620	1049	834	5.2
ST with *T. viride* 0.4% + ST with *P. fluorescens* 0.4%+ soil application of *P. fluorescens* 2.5 kg/ha	12.7 (20.8)*	4.0 (11.6)*	5.3 (13.3)	7.3	553	1014	783	3.8
ST with *T. viride* 0.4% + *P. fluorescens* 0.4% + soil application of *T. viride* 2.5 kg/ha + soil application of *P. fluorescens* 2.5 kg/ha	9.3 (17.8)*	2.2 (8.6)*	1.7 (7.3)	4.4	730	1168	949	4.6
ST with Carbendazim 50 WP 0.1% + Thiram 0.2%	14.1 (22.0)*	7.2 (15.5)*	7.1 (15.4)	9.4	512	993	752	45.6
Check- untreated control	22.3 (28.2)*	15.1 (22.8)*	13.9 (21.8)	17.1	425	889	657	-
SEm ±	0.7	0.5	0.9		16.6	39.4		
CD (P=0.05)	2.2	1.4	2.0		19.0	81.9		
CV (%)	7.3	7.0	10.3		6.5	5.32		

*Angular transformation value; **2.5t/ha FYM was common for all treatments

Three years results revealed that minimum disease incidence (DI) of *Macrophomina* stem and root rot (4.4%) and highest seed yield (949 kg/ha) was recorded in T_6 (ST with *T. viride* 0.4% + *P. fluorescens* 0.4% + soil application of *T. viride* 2.5 kg/ha + soil application of *P. fluorescens* 2.5 kg/ha) closely followed by T_3 (DI 5.2%, seed yield 896 kg/ha), and T_2 (DI 6.5%, seed yield 833 kg/ha). Seed treatment with chemicals i.e., Carbendazim + Thiram is at par with seed treatment with bioagent i.e., *T. viride*. Rajpurohit (2004), Rajpurohit *et al.* (2005) and Jayrajan *et al.* (1993) also reported that seed treatment of *T. viride* reduced stem and root rot of sesame and increased seed yield. Meena *et al.* (2001) reported that seed treatment or soil application of *P. fluorescens* effectively reduces groundnut root rot caused by *Macrophomina phaseolina* and increases pod yield in field trials and Kim *et al.* (1998) observed that seed treatment with *P. fluorescens* significantly increases the emergence rates and reduces natural infection of damping off. These findings support the results obtained in the present study. The present investigation showed that biological seed treatment and soil application i.e., seed treatment with *T. viride* 0.4% + *P. fluorescens* 0.4% + soil application of *T. viride* 2.5 kg/ha + soil application of *P. fluorescens* 2.5 kg/ha is economical and eco-friendly method of disease control and can be exploited for the management of *Macrophomina* stem and root rot of sesame.

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Application of fertilizer nitrogen, sulphur and zinc for specific yield targets of rainfed castor (*Ricinus communis* L.) in semi arid Alfisol

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(Received: January, 2011; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

Field based soil test crop response (STCR) calibration investigations in respect of N, S and Zn fertilizers were conducted at the Directorate of Oilseeds Research, Hyderabad with castor (*Ricinus communis* L.) variety 48-1 as a test crop in semi arid Alfisol of Andhra Pradesh during rainy season of 2008 in a fractional factorial design. In targeted yield approach for calibrating and formulating fertilizer recommendations, the basic data computed were: (i) nutrient requirement in kg/100 kg of economic produce, (ii) the per cent contribution from soil available nutrients (% CS), and (iii) the per cent contribution from applied fertilizer nutrients (% CF). The nutrient requirement (kg/100 kg) of N, S and Zn were found to be 3.14, 1.08, and 0.01, respectively for producing 100 kg of castor seed yield in Alfisol under rainfed conditions. The per cent contribution from soil and applied fertilizer nutrients in an Alfisol were found to be 13.15 and 12.76 for nitrogen, 34.61 and 63.26 for sulphur, and 6.25 and 0.34 for zinc, respectively. The fertilizer adjustment equations and ready reckoner for interpolating optimum fertilizer doses at varying soil test values for attaining seed yield targets of 1000-1400 kg/ha of castor have been developed.

Key words: Alfisol, Castor, Fertilizer adjustment equations, Semi-arid, Soil test crop response calibration, Target yield

Castor (*Ricinus communis* L.) is a drought hardy, non-edible industrial oil seed crop grown in India with considerable export potential to the tune of ₹ 2400 crores/annum. With the advent of high yielding and disease resistant hybrids, cultivation of castor on commercial basis has been increasing considerably with its growing demand for various industrial purposes as well as export. Continuous cultivation of castor in Alfisols impoverishes the soil leading to deficiencies of secondary and micronutrients apart from macronutrients resulting in declining productivity. The resource poor castor farmers, not withstanding the low and unassured rainfall are unable to invest in fertilizer input consequently reaping low yields. Targeted yield approach developed by Ramamoorthy *et al.* (1967) provides a scientific basis for balanced fertilization not only among the fertilizer nutrients but also to the soil available nutrients (Subba Rao and Srivastava 1999). Nitrogen, sulphur and zinc play key role in improving the yield and oil content in the oilseed crops. However, systematic investigation with a major (N), secondary (S) and micro (Zn) nutrient has not been made so far. Hence, N, S and Zn fertilizer requirements based on soil test values for castor grown in Alfisols were studied. A field experiment was conducted to study the relationship between the nutrients supplied by the soil and added fertilizers, their uptake and yield of castor in an intensive cropping system and to develop balanced fertilizer schedule for maximum production of castor in Alfisols of semi arid region.

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MATERIALS AND METHODS

A field experiment based on soil test crop response methodology with castor (*Ricinus communis* L.) variety 48-1 was conducted at Narkhoda research farm, Directorate of Oilseeds Research, Hyderabad during rainy season of 2008 in Alfisol. The soil is a sandy loam with pH 6.8 and EC 0.2 dS/m. The organic carbon and available nitrogen content were 3.0 g/kg and 227 kg/ha, respectively. The soil available phosphorus (30.0 kg P_2O_5/ha) and potassium (360 kg K_2O/ha) were medium and high, respectively. The layout of the experiment was based on the fertility gradient approach developed by Ramamoorthy *et al.* (1967). Initially, the field selected for the study was made uniform in fertility by raising an exhaustive crop of fodder sorghum during the rainy season of 2006. In the subsequent year (rainy season, 2007), the gradient required in soil fertility levels was created by dividing the field into 3 equal strips of 675 m^2 raised with maize crop receiving nitrogen @ 0, 100 and 200 kg/ha (N_0, N_{100} and N_{200}) levels. After the harvest of maize crop, each gradient strip was divided into 30 treatments, of which 27 treatments constituted combinations of three levels each of nitrogen (40, 60 and 80 kg/ha), sulphur (10, 20 and 30 kg/ha) and zinc (5, 10 and 15 kg/ha) and three no fertilizer controls were superimposed to different plots in each strip in a fractional factorial block design. Inorganic nutrients at the rate of 40 kg P_2O_5/ha and 30 kg K_2O/ha were also applied uniformly to all the plots to maintain the soil fertility. Soil samples for the estimation of initial fertility were collected from each sub-plot (0-0.15 m depth) before super-imposition of 27 fertilizer treatments and 3 controls and were analysed for available nitrogen by alkaline permanganate method (Subbaiah and Asija, 1956), available sulphur by turbidimetric method (Chesnin and Yien, 1950) and available zinc by Lindsay and Norvell method (1978). The castor cv. 48-1 crop was sown on August 8, 2008, at a row spacing of 90 cm and plant spacing of 60 cm. The castor spikes based on physiological maturity were harvested at 110, 150 and 180 days after sowing. The plot wise seed yield was recorded after proper drying and threshing. The rainfall received during the crop period was 894 mm. The plant samples of castor collected at final harvest were analysed for N, S and Zn and plant uptake of nutrients was computed by using castor stalk dry matter and cumulative seed yield data. Using the castor seed yield and nutrient uptake data, soil test values and applied fertilizer dose of treated and control plots, the basic data *viz*., nutrient requirement (kg/ha), soil and fertilizer nutrient use efficiencies (%) for making fertilizer recommendation were estimated by following the conventional procedure as described by Ramamoorthy *et al.* (1967) and Reddy *et al.* (1994).

Soil nutrient use efficiency was computed from unfertilized plot (controls) only, while the fertilizer use efficiency was estimated from fertilized plots. The estimates of basic data were used for developing fertilizer adjustment equations for deriving optimum fertilizer doses for achieving different yield targets. The soil test based fertilizer recommendations were given in the form of a ready reckoner for different yield targets.

RESULTS AND DISCUSSION

Castor seed yield, range, mean and standard deviation of soil test values of treated and control plots are presented in table 1. The alkaline permanganate N ranged from 124.3 to 369.1 kg/ha with a mean of 234.3 kg/ha while the soil available S varied between 8.5 to 44.4 kg/ha with a mean of 24.8 kg/ha, whereas the DTPA Zn varied from 0.05 to 2.78 kg/ha with 1.3 kg/ha mean value. The castor seed yield ranged from 744 to 1944 kg/ha in fertilizer treated plots while that in control plots varied from 500 to 1466 kg/ha with a mean of 776 kg/ha. It is obvious from the data that a wide variability existed in the soil test values and castor seed yield of treated and control plots which is essential for developing basic data and targeted yield equations for calibrating the optimum fertilizer doses.

As shown in table 2, the basic data *viz*., the nutrient requirement (kg/100 kg) for producing 100 kg of castor seed yield, soil and fertilizer nutrient use efficiencies or the per cent contribution from soil and fertilizer nitrogen, sulphur and zinc have been calculated from each plot based on the data obtained from the field. The results indicate that nutrient contributions from the fertilizer source were lower with respect to N and Zn than those from the soil source. In case of sulphur, the percent nutrient contribution from fertilizer source was more (63.2%) than that from soil source (34.6%), suggesting positive response to applied S fertilizer. Similar trends were reported by Raghavaiah *et al.* (2008) earlier. However, by conducting similar type experiment with N, P and K with castor as test crop, Riazuddin *et al.* (2000) reported that there was more contribution from applied N and K fertilizer than soil source.

Employing the targeted yield equations derived from the basic data, a ready reckoner of soil test based fertilizer doses of N, S and Zn for attaining a castor yield target of 1000 to 1400 kg/ha have been worked out and presented in table 3. The results amply revealed that the fertilizer doses required for attaining a specific seed yield target of castor show a decrease with increasing soil test values. The derived optimal fertilizer doses were found to be within the range of levels of expected doses and are meaningful for attaining the targeted yields under rainfed conditions. However, validation of these equations and fertilizer recommendations under real farm situation is needed to have a gainful insight into this STCR concept and to have a practical relevance to the farmer's field conditions to enhance castor productivity.

Table 1 Range, mean, standard deviation of soil test parameters (N, S, Zn) and seed yield of castor (cv. 48-1) in treated and control plots

Variable	Range	Mean	Standard deviation	Coefficient of variation (%)
Soil test values				
Alkaline permanganate N (kg/ha)	124.3-369.1	234.2	41.5	17.7
Available S (kg/ha)	8.5-44.4	24.8	8.1	32.4
DTPA-Zn (kg/ha)	0.05-2.78	1.3	0.5	36.7
Castor seed yield (kg/ha)				
Treated plots	744-1944	1245	212	17.0
Control plots	500-1466	776	305	39.3

Table 2 Basic data and fertilizer adjustment equations of rainfed castor cv. 48-1 in Alfisols

	Basic data			Fertilizer adjustment equations
	NR (kg/100 kg)	CS (%)	CF (%)	
N	3.14	13.15	12.76	FN = 24.61 X T-1.03 X SN
S	1.08	34.61	63.26	FS = 1.71 X T-0.55 X SS
Zn	0.01	6.25	0.34	FZn =2.53 X T-18.53 X SZn

NR = Nutrient required in kg/100 kg of seed production; CS = per cent nutrient contributed from soil; CF = per cent nutrient contributed from fertilizer; T = yield target (100 kg/ha); SN, SS and SZn = soil available N, S and Zn in kg/ha; FN, FS and FZn =fertilizer N, S and Zn required in kg/ha.

Table 3 Fertilizer N, S and Zn prescription at varying soil test values for attaining specific seed yield targets of rainfed castor cv. 48-1 grown in alfisols of semiarid tropical region

Soil available nutrients (kg/ha)			Fertilizer nutrients required (kg/ha) for yield target of														
			1000 kg/ha			1100 kg/ha			1200 kg/ha			1300 kg/ha			1400 kg/ha		
N	S	Zn	N	S	Zn	N	S	Zn	N	S	Zn	N	S	Zn	N	S	Zn
200	15.00	1.35	39.98	8.86	0.32	64.59	10.57	2.85	89.20	12.28	5.39	113.81	13.98	7.92	138.41	15.69	10.45
205	17.50	1.40	34.83	7.50	0.00	59.44	9.20	1.93	84.05	10.91	4.46	108.65	12.62	6.99	133.26	14.32	9.53
210	20.00	1.45	29.68	6.13		54.29	7.83	1.00	78.89	9.54	3.53	103.50	11.25	6.07	128.11	12.96	8.60
215	22.50	1.50	24.53	4.76		49.13	6.47	0.07	73.74	8.17	2.61	98.35	9.88	5.14	122.96	11.59	7.67
220	25.00	1.55	19.37	3.39		43.98	5.10	0.00	68.59	6.81	1.68	93.20	8.51	4.21	117.80	10.22	6.75
225	27.50	1.60	14.22	2.02		38.83	3.73		63.44	5.44	0.75	88.04	7.15	3.29	112.65	8.85	5.82
230	30.00	1.65	9.07	0.66		33.68	2.36		58.29	4.07	0.00	82.89	5.78	2.36	107.50	7.48	4.89
235			3.92			28.53			53.13			77.74			102.35		
240			0.00			23.37			47.98			72.59			97.20		
245			0.00			18.22			42.83			67.44			92.04		
250			0.00			13.07			37.68			62.28			86.89		

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Path coefficient analysis for seed yield in linseed (*Linum usitatissimum* L.) under late sown conditions

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(Received: September, 2010; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

One hundred forty genotypes of linseed (*Linum usitatissimum* L.) were studied for their variability, correlation and path coefficients with regard to eight agronomic characters under late sown conditions. The estimates of heritability (broad sense) were high for 1000 seed weight, seed yield and days to 50% flowering. The phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) and genetic advance (GA) values were high only for number of primary branches. Days to maturity, plant height, number of primary branches, number of capsules and number of seeds had significant positive correlation with seed yield at genotypic level. High positive direct effect of number of capsules, number of seeds and 1000 seed weight on seed yield was observed at genotypic level. The selection strategy for seed yield under late sown conditions should be based on number of capsules and primary branches.

Key words: Correlation, GA, Heritability, Linseed, Path analysis, Variability

Linseed (*Linum usitatissimum* L.), a winter oilseed crop, occupies an area of 27.2 thousand ha in Odisha with annual production of 11.9 thousand t. The district of Mayurbhanj is the leading one. However, a significant number of farmers are forced to sow linseed about one month late due to excess moisture in the field. Seed setting is highly affected due to higher temperature during later phase of growth decreasing seed yield significantly. An experiment was, therefore, laid out to evaluate the nature and extent of variability and association of the component characters inter se and with seed yield, and also to partition their correlations with seed yield into direct and indirect effects under late sown conditions. It would facilitate identification of selection criteria for late sown conditions.

MATERIALS AND METHODS

One hundred forty genotypes of linseed including six local land races of Odisha and 134 cross-derivatives and selections from different sources within and outside Odisha were grown in a randomized block design in the winter season of 2007 with two replications with a spacing of 30 cm x 5 cm between and within row, respectively. The local land races were purified during previous two years. The crop was seeded one month late on 22 November 2007 in the farm of the Regional Research and Technology Transfer Substation of OUAT at Jashipur. Each genotype was sown in single row of 3m length. Observations were recorded for eight quantitative characters, *viz.*, days to 50% flowering, days to maturity, plant height (cm), number of primary branches/plant, number of capsules/plant, number of seeds/capsule, 1000 seed weight (g) and seed yield/plant (g). Ten randomly selected competitive plants were used for observation of all the characters except flowering, maturity and 1000 seed weight which were recorded on whole row basis.

The values of phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in broad sense (H) and genetic advance as percentage of mean (GA%M) at 5% selection intensity were estimated following standard biometrical methods. Phenotypic and genotypic correlation coefficients were estimated from the respective variance and covariance components (Burton, 1952; Searle, 1961). Path coefficient analysis was done as described by Dewey and Lu (1959)..

RESULTS AND DISCUSSION

Variation and genetic parameters

Analysis of variance revealed highly significant differences among the genotypes for all the characters (Table 1). The range indicated a broad base of variation among the test genotypes for all the characters except number of primary branches and seeds. A wide range of variation was also found for all or almost all these characters by Muduli and Patnaik (1993), Naik and Satapathy (2002), Sarkar (2005) and Rao (2007). However, Gupta *et al.* (1999) observed broad range only for number of primary branches and capsules and seed yield. The values of GCV exhibited

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similar pattern of PCV for all the eight characters. Similar pattern of PCV and GCV was reported by several workers for all or most of these characters (Gupta *et al.*, 1999; Naik and Satapathy, 2002; Rao, 2007). The values of PCV and GCV were high for number of primary branches only. High values of PCV and GCV were reported for number of primary branches by Naik and Satapathy (2002). The estimates of H were high for 1000 seed weight, seed yield and days to 50% flowering. High estimates of H were reported earlier for 1000 seed weight, seed yield and days to flowering (Naik and Satapathy, 2002; Rao, 2007). The value of GA%M was high only for number of primary branches. This corroborated the earlier findings of Gupta *et al.* (1999) and Naik and Satapathy (2002).

Correlation coefficients

For all the character pairs except plant height and number of primary branches and number of primary branches and number of seeds (Table 2), phenotypic and genotypic correlation coefficients were of the same direction. Except the correlation of number of capsules with plant height and number of primary branches, the genotypic correlation coefficients were higher than the phenotypic ones in other cases. Significance indicated the masking effect of environment.

At the genotypic level, seed yield had highly significant positive correlation with days to maturity, plant height, number of primary branches, number of capsules and number of seeds. Significant positive correlation of seed yield with number of primary branches and capsules was reported by Gupta *et al.* (1999) and Naik and Satapathy (2002). However, Rao (2007) reported significant positive correlation of seed yield with number of capsules.

Path coefficient analysis

High positive direct effect of number of capsules, number of seeds and 1000 seed weight on seed yield was observed only at genotypic level. The low positive direct effect of number of primary branches increased manifold mainly by high positive indirect effect via number of capsules resulting in highly significant positive correlation with seed yield (Table 3). Similar direct effects were found for number of capsules, number of seeds (Naik and Satapathy, 2002) and 1000 seed weight (Rao, 2007).

Table 1 Genetic parameters for eight characters in linseed under late sown condition

Character	MSS	Range	Mean	PCV (%)	GCV (%)	H (%)	GA %M
Days to 50% flowering	33.30**	60.00-84.50	69.16	6.79	4.86	51.2	7.16
Days to maturity	20.49**	113.50-129.00	121.17	3.26	1.83	31.7	2.12
Plant height (cm)	33.93**	44.05-69.15	55.58	8.66	5.90	46.5	8.29
Number of primary branches/plant	0.26**	0.00-1.70	0.37	121.93	64.94	28.4	70.27
Number of capsules/plant	72.08**	10.35-40.25	21.92	35.16	16.27	21.4	15.51
Number of seeds/capsule	0.60**	6.90-10.65	8.28	8.71	3.31	14.4	2.54
1000 seed weight (g)	0.85**	4.60-7.85	5.93	12.18	9.67	63.0	15.85
Seed yield/plant (g)	0.13**	0.33-1.69	0.81	34.94	27.57	62.3	44.44

**=Significant at P=0.01

Table 2 Genotypic correlation coefficients among various traits in late sown linseed

Character	Days to maturity	Plant height (cm)	No. of primary branches/plant	Number of capsules/plant	Number of seeds/capsule	1000 seed weight (g)	Seed yield/plant (g)
Days to 50% flowering	0.447**	0.122	0.539**	0.158	0.341**	-0.430**	0.039
Days to maturity		0.634**	0.465**	0.582**	0.019	0.195*	0.500**
Plant height (cm)			-0.088	0.271**	0.624**	0.153	0.317**
Number of primary branches/plant				0.499**	-0.176*	0.042	0.804**
Number of capsules/plant					0.331**	-0.210*	1.381**
Number of seeds/capsule						-0.528**	0.420**
1000 seed weight (g)							0.081

*, ** = Significant at P=0.05 and 0.01 level, respectively

Table 3 Path coefficient analysis of genotypic correlation in late sown linseed

Correlated character	Direct (diagonal) and Indirect effects via							Total indirect effect	Total effect	Correlation with seed yield
	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches/plant	Number of capsules/ plant	Number of seeds/ capsule	1000 seed weight (g)			
Days to 50% flowering	-0.148	-0.062	-0.090	0.187	0.216	0.364	-0.424	0.191	0.043	0.039
Days to maturity	-0.066	-0.138	-0.466	0.161	0.796	0.020	0.194	0.639	0.501	0.500
Plant height (cm)	-0.018	-0.088	-0.736	-0.030	0.371	0.665	0.152	1.052	0.316	0.317
Number of primary branches/plant	-0.080	-0.064	0.065	0.346	0.683	-0.187	0.042	0.459	0.805	0.804
Number of capsules/plant	-0.023	-0.080	-0.200	0.173	1.368	0.353	-0.209	0.014	1.382	1.381
Number of seeds/capsule	-0.051	-0.003	-0.459	-0.061	0.453	1.006	-0.525	-0.646	0.360	0.420
1000 seed weight (g)	0.064	-0.027	-0.113	0.015	-0.288	-0.563	0.993	-0.912	0.081	0.081

Residual effect = -1.3868

In the present study, number of primary branches, number of capsules and number of seeds had positive direct effect on seed yield with highly significant positive correlation at genotypic level. And the low positive direct effect of number of primary branches increased manifold by high positive indirect effect via number of capsules. Number of seeds had low GCV and GA%M. So, it may not respond well to selection. Number of primary branches had high GCV and GA%M whereas number of capsules had optimum levels of these parameters. Number of primary branches had highly significant positive correlation with number of capsules and the phenotypic correlation coefficient is higher than genotypic one indicating favourable influence of environment. Thus, this study indicates that number of capsules and primary branches are the most promising selection criteria to improve seed yield under late sown conditions.

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Efficiency of marketing channels, constraints in production and marketing of rapeseed-mustard in Rajasthan

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(Received: September, 2010; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

The study was conducted in Alwar and Sri Ganganagar districts of Rajasthan state with the objectives to identify the marketing channels, estimate the price spread and to analyse the constraints in production and marketing of rapeseed-mustard. Primary data were collected from 120 rapeseed-mustard growers spread over in the both districts during 2007-08. Four marketing channels were found in both the districts for disposing the produce, where in the share of producer in the consumer rupee was higher when they sold their produce directly to processor. Hence, the farmers may be educated to sell their produce directly to the processor to get better price. Lack of technical guidance and non-availability of fertilizer on time were the major problems in production and price information and fluctuations and delayed payments were the major problems in marketing of rapeseed-mustard faced by the farmers.

Key words: Constraints, Marketing efficiency, Rapeseed-mustard, Shepherd's

India ranks third in the production of rapeseed-mustard in the world contributing about 16% of the world production. In India, acreage under rapeseed-mustard has been 7.31 m. ha. It is grown widely in seven major states namely, Rajasthan, U.P, Haryana, West Bengal, M.P, Gujarat and Assam, accounting for 92% of total production. Rajasthan is one of the key oilseed producing states in India. The production of rapeseed-mustard in the state is 37.39 lakh t. from an area of 24.58 lakh ha during 2007-08. It occupies first position in area and production of rapeseed-mustard in the country, which accounted for 42.8% area and 64.5% production, respectively during the year 2007-08. Among the total oilseeds in the state rapeseed-mustard accounted 71.2% area and 72.1% production, respectively during the year 2007-08. Other predominant states producing rapeseed-mustard are Uttar Pradesh, Madhya Pradesh and Gujarat. In Rajasthan state, production of rapeseed-mustard crop is highest in Sri Ganganagar (3.98 lakh t.) followed by Alwar (3.56 lakh t.) and Bharatpur (2.81 lakh t.) during 2007-08.

Efficient marketing of rapeseed-mustard plays an important role in increasing the producer's share in the consumer's rupee and maintains the tempo of increased production. In India, oilseeds marketing in general and rapeseed-mustard marketing in particular is mainly in the hands of middlemen like money lenders, village traders, wholesalers and private oil millers. Hence, the producer is only a price receiver. Therefore, many a time oilseeds producers have to resort to distress sale due to uncertain situation in the marketing of oilseeds. In the process of marketing, the producer has to incur various marketing costs. Agricultural marketing is costly with high commission charges, trader's profit margins, wastage and malpractices. The costs are determined by the performance and efficiency of different marketing functionaries in different channels which in turn influence the return to the producer. In this context, there is a need for the study of marketing channels in the marketing of rapeseed-mustard that is cultivated and marketed extensively in the study area. The objectives of the study are to identify the marketing channels, estimate the price spread and to analyse the constraints in production and marketing of rapeseed-mustard.

MATERIALS AND METHODS

At the first stage, two districts *viz.*, Alwar and Sri Ganganagar were selected based on the highest area under rapeseed-mustard. At the next stage, two taluks were selected based on the largest area under cultivation from each of the districts selected. Eight villages from selected taluks were considered, based on the criterion of area dominance. In the case of sampling frame for the farmers, farmers from both the selected districts *viz.*, Alwar and Sri Ganganagar were selected randomly. Fifteen rapeseed-mustard growers were selected at random from each of the selected villages making an overall sample size of 120 farmers. The data pertained to rapeseed- mustard crop for the winter season of 2007. Twenty intermediaries belonging to different trading activity were interviewed to estimate the price spread/ marketing margin.

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The study utilized primary data to fulfil the objectives. Primary data pertaining to cost of cultivation and marketing of rapeseed-mustard were collected through a well structured pre-tested schedule.

Tabular analysis was employed for estimating marketing cost and profit accrued to the farmers. The problems faced by the farmers in production and marketing were enumerated and ranks have been assigned based on the responses. The different channels followed in the marketing of rapeseed-mustard by the farmers were identified and price spread in each channel were computed for comparison. In addition the Shepherd's method was also used for computing marketing efficiency and the details are follows.

The Sherpherd's formulae (Chole *et al.*, 2003) for marketing efficiency is given as:

$$\text{Marketing efficiency index} = \frac{\text{Value of goods sold (consumer price)}}{\text{Total marketing cost}}$$

RESULTS AND DISCUSSION

The data collected were subjected to statistical analyses and the results obtained have been presented under the following headings.

Marketing channel and price spread for rapeseed-mustard marketing

The details relating to marketing channel and price spread for rapeseed-mustard marketing has been discussed under following heads:

Marketing channels

In the present study, the marketing channels involving the flow of rapeseed-mustard have been identified upto the processor level.

The important channels identified were as under:

Producer - Village trader - Commission agent - Wholesaler - Processor
Producer - Commission agent - Wholesaler - Processor
Producer - Wholesaler - Processor
Producer - Processor

In the channels identified (Table 1), the bulk of the produce from the primary producers reached the oil miller through the commission agents (39.1%), followed by the wholesalers (27.2%), village traders (19.6%) and processors (14.2%).

The main reason for disposing the large amount of rapeseed-mustard through the commission agents and village merchants was the prior commitments with the commission agents and village traders forced the farmers to sell only through these channels. The village traders purchased the rapeseed-mustard in small quantities and sold the same in the market. Further, small quantity of marketable surplus was also an important factor which makes it uneconomical to take to the far off markets.

Price spread in rapeseed-mustard marketing under different channels in Alwar district

The results of the price spread (Table 2), marketing costs and profits for intermediaries are discussed in this section.

The producers' marketing cost worked out to be 4.96%, 2.48% and 2.45% of the purchasing price of processor in the case of channels-II, III and IV respectively. The marketing cost incurred by the village trader and commission agent amounted to ₹ 53.98 and ₹ 20.29, respectively, per quintal rapeseed-mustard handled under channel -I. The wholesaler incurred a marketing cost of ₹ 40.85 in channel-I & channel-II and ₹ 28.70 in channel-III. The processor incurred the marketing cost of ₹ 33.20 in first three channels whereas in channel-IV, the processor incurred the marketing cost of ₹ 25.20. This difference in marketing cost was mainly because, in first three channels processor collected rapeseed-mustard from the wholesalers, whereas in channel-IV, processor collected rapeseed-mustard directly from the producers. The village traders earned a net profit of ₹ 93.52 while the commission agents received ₹ 77.21 as net margin on each quintal of rapeseed-mustard sold through them. The wholesalers obtained a net profit of ₹ 76.65 in channel-I & channel-II and ₹ 88.80/quintal in channel-III. The net profits or net margins of village trader and wholesaler were high because they purchased the produce in peak months and stored before disposing off in the lean months at a higher price.

The profit realised by the village traders, commission agents and wholesalers formed 4.23%, 3.49% and 3.47% of the processor's purchasing price, respectively in channel-I. It is clear from the study that on an average the producers realised 82.10%, 83.80%, 90.71% and 96.39% of the processors' price when they disposed of their produce through village traders, commission agents, wholesaler and processor respectively.

The analysis of price spread in rapeseed-mustard marketing revealed that producer share in consumer's rupee showed continuous increase from channel-I to channel-IV. In channel-I producer share in consumer's rupee was 82.10% while in channel-IV was 96.39%. This increase of 14.29% from channel-I to channel-IV may be attributed to the decrease in the share of intermediaries in consumer's rupee. The channel-II by passes the village trader link, channel-III by passes both village trader as well as commission agent link. Lastly, in channel-IV all the intermediaries are omitted from the trading scene. The direct contact between producer and processor is beneficial from the producer perspective.

From the above, it can be concluded that channel-IV is the best marketing system for uplifting the socio-economic condition of the farmers. Similar results were also obtained through Shepherd's method of marketing efficiency.

Price spread in rapeseed-mustard marketing through different channels in Sri Ganganagar district

The results of the price spread (Table 3) marketing costs and profits for intermediaries are discussed in this section.

The marketing cost incurred by the village trader and commission agent amounted to ₹ 39.26 and ₹ 19.45/quintal rapeseed-mustard handled, respectively. The wholesaler incurred the marketing cost of ₹ 32.30 in channel-I & channel-II and ₹ 26.78 in channel-III. The processor incurred the marketing cost of ₹ 30.13 in first three channels whereas in channel-IV, the processor incurred the marketing cost of ₹ 21.96. This difference in marketing cost was mainly because, in first three channels processor collected rapeseed-mustard from the wholesalers, whereas in channel-IV, processor collected rapeseed-mustard directly from the producers. The village traders earned a net profit of ₹ 91.74 while the commission agents received ₹ 80.55 as net margin on each quintal of rapeseed-mustard sold through them. The wholesalers obtained a net profit of ₹ 82.70/quintal in channel-I & channel-II and ₹ 88.22/quintal in channel-III. The net profits or net margins of village trader and wholesaler were high because they purchased the produce in peak months and stored before disposing off in the lean months at a higher price.

The producers' marketing cost worked out to be 5.23%, 2.73% and 3.61% of the purchasing price of processor in the case of channels-II, III and IV, respectively. The profit realised by the village traders, commission agents and wholesalers formed 4.18%, 3.67% and 3.77% of the processor's purchasing price, respectively in channel-I. It is clear from the study that on an average the producers realised 82.87%, 83.58%, 90.65% and 95.36% of the processors' price when they disposed off their produce through village traders, commission agents, wholesaler and processor respectively. Similar results were also obtained through Shepherd's method of marketing efficiency.

The analysis of price spread in rapeseed-mustard marketing revealed that producer share in consumer's rupee showed continuous increase from channel-I to channel-IV. In channel-I producer share in consumer's rupee was 82.87% while in channel-IV it was 95.36%. This increase of 12.49% from channel-I to channel-IV may be attributed to the decrease in the share of intermediaries in consumer's rupee. The channel-II by passes the village trader link, channel-III by passes both village trader as well as commission agent link. Lastly, in channel-IV all the intermediaries were omitted from the trading scene. The direct contact between producer and processor is beneficial from the producer perspective. These results corroborates the studies conducted by Gupta and Singh (1998) in Punjab. Thus, it can be concluded that the channel-IV is the best marketing system for uplifting the socio-economic conditions of the farmers, as it ensures higher share of producer share in the consumer's rupee.

Problems faced by the farmers in production and marketing of rapeseed-mustard

The problems confronted by the producers in the production and marketing of rapeseed-mustard are presented in table 4. The problems faced in both the districts by the farmers were relatively of the same magnitude. Nearly 76% of the sample farmers expressed their un-awareness of recommended package of practices due to lack of technical guidance. Hence, the State Department of Agriculture may educate these farmers on the cultivation of rapeseed-mustard on scientific lines through demonstrations. In addition, the extension mechanism of the Agriculture Department as well as University may be strengthened to provide sufficient guidance to the needy farmers. About 65% of the farmers experienced the problem of non-availability of fertilizer in time. Hence, average quantity of fertilizers used per acre was below the recommended level. In this regard, the Government may ensure the availability of fertilizers in adequate quantity and also make proper arrangement for the distribution of fertilizer.

About 57% of the farmers opined that labours were not easily available and around 52% of the farmers expressed that labour wages were high. Hence, the availability of labour during peak seasons is an equally important factor in influencing the exploitation of potential farm yield. Appropriate measures should be adopted to improve the efficiency of labour.

About 51 and 48% of the sample farmers felt that the cost of credit was higher and amount of loan provided was not adequate. Hence, the concerned financial institutions may review the scale of finance and bring it in line with the current cost of cultivation. About 42% of the sample farmers experienced the problem of lack of irrigation facilities. Hence, state government may enhance the expansion of irrigation facilities along with consolidation of the existing system and measures may be taken for construction of check dams and water conservation practices on farmer's field.

Despite the supply of seeds from both government and private agencies, 40% of the respondents expressed that good quality of rapeseed-mustard seeds was a limiting factor to increase the production. Hence, the concerned agency may take necessary steps to provide good quality seeds of rapeseed-mustard with reasonable prices to the farmers and seed production activity may be initiated from the farmers.

The analysis of results on the opinion of the respondents on the problems of marketing of rapeseed-mustard indicated that about 83% of the farmers experienced the problem of non-availability of price information & fluctuations in prices of rapeseed-mustard. It is well known fact that heavy arrivals of produce to the market immediately after the harvest create glut in the market there by reducing the prices. Hence, to minimise price fluctuations there is a need to phase out the supply of produce to the markets. Therefore, it needs creation of storage facilities at farmers door step on one hand and on the other hand to strengthen the dissemination of market news and supply of marketing credit to the farmers to tide over the situation.

The delay in cash payment after the sale of the produce was a serious problem for about 70% of the respondents. Hence, the concerned market committee may pursue the commission agents to pay the cash immediately after the sale of rapeseed-mustard. About 68% farmers expressed that transportation cost was high. This was the major problem for large farmers since most of the large farmers sold their produce in regulated market of Rajasthan state. About 66% of sample farmers expressed that they were forced to sell the produce at a relatively lower price due to immediate financial need and lack of storage facilities. The warehousing corporation may provide necessary storage facilities as well as credit by using their produce as security. Absence of regulated markets, far off distance to markets and lack of transportation facilities were also other problems expressed by the farmers.

Table 1 Marketed surplus disposed by producers through different intermediaries (quantity in quintals)

Intermediaries	Alwar	Sri Ganganagar	Overall
Village traders	230 (17.7)	254 (21.7)	484 (19.6)
Commission agents	522 (40.2)	444 (37.9)	966 (39.1)
Wholesalers	357 (27.5)	314 (26.8)	671 (27.2)
Processers	195 (15.0)	155 (13.2)	350 (14.2)
Total	1304 (100.0)	1167 (100.0)	2471 (100.0)
Percent of marketed surplus to total production	92.2	89.5	91.0

Figures in parentheses indicate percentage to their totals

Table 1 Price spread in rapeseed-mustard marketing through different channels in Alwar district

Particulars	Channel-I		Channel-II		Channel-III		Channel-IV	
	(₹/q)	%	(₹/q)	%	(₹/q)	%	(₹/q)	%
A) Producer's net price	1815.0	82.1	1850.6	83.8	2007.6	90.7	2084.5	96.4
B) Marketing cost incurred by								
Producer	--	--	109.45	4.96	54.91	2.48	52.96	2.45
Village trader	53.98	2.44	---	---	---	---	---	---
Commission agent	20.29	0.92	20.29	0.92	---	---	---	---
Wholesaler	40.85	1.85	40.85	1.85	28.70	1.30	---	---
Processor	33.20	1.50	33.20	1.50	33.20	1.50	25.20	1.17
Total marketing cost (TC)	148.32	6.71	203.78	9.23	116.81	5.28	78.16	3.61
C) Margin earned by								
Village trader	93.52	4.23	---	---	---	---	---	---
Commission agent	77.21	3.49	77.21	3.50	---	---	---	---
Wholesaler	76.65	3.47	76.65	3.36	88.80	4.01	---	---
Total margin (TM)	247.38	11.19	153.86	6.85	88.80	4.01	---	
D) Producer's selling price	1815.00	82.10	1960.00	88.76	2062.50	93.19	2137.50	98.83
E) Village trader selling price	1962.50	88.77	---	---	---	---	---	---
F) Wholesaler selling price	2177.50	98.50	2175.00	98.50	2180.00	98.50	---	---
G) Processor's purchasing price	2210.70	100.00	2208.20	100.00	2213.20	100.00	2162.70	100.00
H) Shepherd's marketing efficiency [G/(TC+TM)]	5.59		6.17		10.76		27.67	

Table 3 Price spread in rapeseed-mustard marketing through different channels in Sri Ganganagar district

Particulars	Channel-I		Channel-II		Channel-III		Channel-IV	
	(₹/q)	%	(₹/q)	%	(₹/q)	%	(₹/q)	%
A) Producer's net price	1819.0	82.9	1830.5	83.6	1985.3	90.7	2018.6	95.4
B) Marketing cost incurred by								
Producer	--	--	114.45	5.23	59.74	2.73	76.37	3.61
Village trader	39.26	1.79	---	---	---	---	---	---
Commission agent	19.45	0.89	19.45	0.89	---	---	---	---
Wholesaler	32.30	1.47	32.30	1.47	26.78	1.22	---	---
Processor	30.13	1.37	30.13	1.38	30.13	1.38	21.96	1.04
Total marketing cost (TC)	*121.15*	*5.52*	*196.33*	*8.96*	*116.65*	*5.33*	98.33	4.64
C) Margin earned by								
Village trader	91.74	4.18	---	---	---	---	---	---
Commission agent	80.55	3.67	80.55	3.68	---	---	---	---
Wholesaler	82.70	3.77	82.70	3.78	88.22	4.03	---	---
Total margin (TM)	254.98	11.62	163.25	7.45	88.22	4.03	---	
D) Producer's selling price	1819.00	82.87	1945.00	88.81	2045.00	93.37	2095.00	98.96
E) Village trader selling price	1950.00	88.33	---	---	---	---	---	---
F) Wholesaler selling price	2165.00	98.63	2160.00	98.62	2160.00	98.62	---	---
G) Processor's purchasing price	2195.13	100.00	2190.13	100.00	2190.13	100.00	2116.96	100.00
H) Shepherd's marketing efficiency [G/(TC+TM)]	5.84		6.09		10.69		21.53	

Table 4 Problems faced by farmers in production and marketing of rapeseed-mustard

Particulars	Alwar		Sri Ganganagar		Over all	
	%	Rank	%	Rank	%	Rank
Production problems						
Lack of technical guidance	75.44	I	77.19	I	76.31	I
Non-availability of fertilizers on time	70.18	II	61.40	II	65.39	II
Non-availability of labourers on time	52.63	III	61.40	II	57.01	III
High cost of labour	49.12	IV	56.14	IV	52.63	IV
High cost of borrowing	49.12	IV	52.63	III	50.87	V
In adequate credit supply by the financial **institutions**	45.61	V	50.88	V	48.24	VI
Lack of irrigation facilities	38.60	VI	45.61	VII	42.10	VII
Non-availability of quality seeds on time	33.30	VIII	47.37	VI	40.18	VIII
High cost of seeds	33.33	VII	38.60	VIII	35.96	IX
Non-availability of credit on time	26.31	IX	38.60	IX	32.45	X
Marketing problems						
Price information and fluctuations	78.95	I	87.72	I	83.33	I
Delay in cash payment	68.42	III	71.91	II	70.16	II
High cost of transportation	70.18	II	66.67	IV	68.42	III
Lack of storage facilities	61.40	IV	71.93	III	66.66	IV
Absence of regulated markets	40.35	V	35.09	V	37.72	V
Distant market	38.60	VI	36.84	VI	37.72	V
Lack of transportation facilities	29.82	VII	26.32	VII	28.07	VI

Conclusion and policy implications

From the above results and discussion it could be concluded that the farmers received the highest net price per quintal when they marketed their produce through processor followed by wholesalers, commission agents and village traders. The net margin of the wholesaler was more than that of commission agent. The agencies like village traders and wholesaler earned very high net margins as these agencies speculated by withholding the produce purchased in peak months. Thus, the farmers particularly the small farmers were deprived of higher price due to their earlier commitments with village trader and also with commission agent. Farmers borrowed both cash and kind in advance. So, they were bound to sell the produce only to them. Lack of technical guidance, non-availability of fertilizer on time, non- availability of labour on time, high cost of labour, inadequate credit supply were some of the major problems faced in production of rapeseed-mustard by the farmers. Price information and fluctuation, delayed payments, high cost of transportation and lack of storage facilities were the major problems faced by the rapeseed-mustard producers in marketing of their produce.

From the policy point of view, four marketing channels were found in both the districts for disposing the produce, where in the share of producer in the consumer rupee was higher when they sold their produce directly to processor. Hence, the farmer may be educated to sell their produce directly to the processor to get better price. To overcome the problem related to lack of technical guidance, there is a need for integrated efforts on the part of extension agency and University in research and development as well as transfer of technology for better reachout to farming community. To overcome the problems related to delayed payments, there is a need on the part of APMC to have strict regulation of practices to ensure prompt receipts of sale proceeds by the farmers.

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Effect of different nutrient management practices on yield of post rainy season groundnut (*Arachis hypogaea* L.)

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(Received: July., 2010; Revised: November, 2010; Accepted: January, 2011)

ABSTRACT

A field experiment was conducted during the winter season of 2005 on sandy clay loam soils of dryland to study the effect of different nutrient management practices on export oriented groundnut (*Arachis hypogaea* L.). All the yield attributes of groundnut *viz.*, number of total and filled pods/plant, 100 pod weight, 100 kernel weight and shelling percentage were found to be the highest with 60-80-100 N-P_2O_5-K_2O kg/ha, along with application of all the four micronutrients, while all of them were found to be at their lowest with 30-40-50 N-P_2O_5-K_2O kg/ha, and with the no micronutrient application. Among the quality parameters, significantly the highest oil content in kernel was registered with the lowest level of major nutrients tried, compared to higher application rates, where as protein content in the kernel was significantly highest with higher level of major nutrients compared to lower levels. Combined application of four micronutrients resulted in the highest protein and oil content in the kernel.

Key words: Groundnut, Micronutrients, Protein content

Groundnut (*Arachis hypogaea* L.) is a leading edible oilseed crop mainly used for extraction of edible oil, a small quantity (6-7%) is being used for table purposes. Bold kernel type of groundnut has got vast export potential and fetches premier price in the market compared to normal sized kernel types. One of the prime factors responsible for low yields of groundnut is the inadequate and imbalanced use of nutrients. Application of micronutrients has become inevitable to realize the yield potential of groundnut and especially it becomes more imperative in bold sized kernel type of groundnut. Hence, an experiment was conducted to develop a nutrient management package consisting of both macro and micronutrients for an effective yield and quality parameters of export oriented groundnut.

A field experiment was conducted during the winter season of 2005 in dryland farm, of Tirupati campus of Acharya N.G. Ranga Agricultural University (S.V. Agricultural College, Tirupati), which is geographically situated at an altitude of 182.9 m above mean sea level at 13.27°N latitude and 79.5°E longitude, in the southern agro-climatic zone of Andhra Pradesh. The initial nutrient status of experimental field have available major nutrients N, P_2O_5, K_2O, 230, 21.4, 205 kg/ha and micro nutrients Zn, Fe, Cu, B 0.85, 6.60, 0.45, 0.58 mg/kg, respectively.

The experiment was laid out in a split plot design replicated thrice with the treatments consisting of three levels of major nutrients *viz.*, 30-40-50 N-P_2O_5-K_2O kg/ha (M_1), 45-60-75 N-P_2O_5-K_2O kg/ha (M_2) and 60-80-100 N-P_2O_5-K_2O kg/ha (M_3) assigned to main plots and six micronutrient management practices *viz.*, no micronutrient application (S_1), $ZnSO_4$ @ 10 kg/ha (S_2), Borax @ 5 kg/ha (S3), $FeSO_4$ @ 2.5 kg/ha (S_4), $CuSO_4$ @ 5 kg/ha (S_5) and combined application of all the four micronutrients (S_6) allotted to sub plots. Net plot size of experimental plot was 5.4 m × 2.7 m. The test cultivar was Asha (ICGV-86564), which matures in 120-130 days with yield potential of 3 t/ha and the protein content ranging from 30 to 35%. The crop was sown on 19 December 2005 and harvested on 5 May 2006. Five irrigations were scheduled at 12, 38, 62, 90 and 115 days after sowing (DAS) apart from the pre-sowing irrigation. During the crop growth period the average maximum and minimum temperature was 33.17°C and 20.16°C, respectively, the average relative humidity was 64.6% and a total rainfall of 69.0 mm was received. Entire dose of all the fertilizers except nitrogen were applied basally. Nitrogen was applied in 2 equal splits *viz.*, first half at the time of sowing as basal and remaining half as top dressing at 32 DAS. Various yield components such as number of pods/plant, kernels/pod, 100 kernel weight, pod and haulm yield were taken at harvest. Kernels collected from all the treatments were analysed for oil content by NMR technique, the protein content by Lowry's method and both are expressed as percentage.

The total number of pods/plant, number of filled pods/plant, pod weight, shelling % and test weight of Asha variety recorded the highest values with the highest level of major nutrients (M_3) and lowest was with M_1. Application of all the four micronutrients (S_6) recorded significantly highest yield attributes than no micronutrient application. Similar results have been reported by Deshmukh *et al.* (1995) and Subramaniyan *et al.* (2001). The highest pod yield was produced with the major nutrients tried 60 N - 80 P_2O_5 - 100 K_2O kg/ha, comparable with 45 N - 60 P_2O_5 - 75 K_2O kg/ha, but significantly higher than with 30 N - 40 P_2O_5 - 50 K_2O kg/ha, which produced the lowest pod yield. Among the micronutrient management practices, significantly the highest pod yield was recorded with S_6, due to efficient translocation of assimilates, particularly for development of pods and involvement of micronutrients in regulatory functions, auxin production, which resulted in increased stature of all the yield attributes leading to higher pod yield (Table 1). The yield increase was up to 48% due to combined application of micro nutrients over control. Saxena *et al.* (2003) reported that pod yield of groundnut could be increased with increasing levels of N and K. The highest haulm yield of groundnut was produced with the highest level of major nutrients tried, and lowest haulm yield with M_1. Application of all the four micronutrients resulted in the highest haulm yield of groundnut, and lowest haulm yield was recorded with no micronutrient application. Revathi *et al.* (1996) reported that combined application of Zn, Fe, Cu, Mn, Ca and Mg increased the pod and haulm yields of groundnut.

Table 1 Effect of major and micronutrients on yield attributes, yields and quality parameters of groundnut

Treatment	Pods/ plant	Filled pods/ plant	100 pod weight (g)	Shelling (%)	Test weight (g)	Pod yield (kg/ha)	Haulm yield (kg/ha)	Protein content (%)	Oil content (%)
Major nutrients ($N-P_2O_5-K_2O$ kg/ha)									
M_1 : 60-80-100	42.7	25.5	121.8	64.91	58.0	1984	3834	32.00	50.42
M_2 : 45-60-75	47.6	29.0	129.0	68.84	61.1	2175	4022	34.32	47.32
M_3 : 30-40-50	49.5	29.8	130.4	69.73	62.2	2244	4094	36.46	43.17
SEm±	0.80	0.262	0.70	0.233	0.670	18.33	46.19	0.04	0.672
CD (P=0.05)	3.2	1.0	2.8	0.92	2.6	72	182	0.19	2.62
Micronutrients									
S_1 : No micronutrient application	37.0	23.8	107.7	63.2	54.8	1742	3594	31.66	45.37
S_2 : $ZnSO_4$ @ 10 kg/ha	50.0	31.1	129.5	69.3	62.4	2383	4235	34.89	48.36
S_3 : Borax @ 5 kg/ha	47.7	29.3	128.8	67.8	59.3	2279	4131	34.84	48.43
S_4 : $FeSO_4$ @ 2.5 kg/ha	46.5	25.8	125.1	67.4	59.0	1808	3660	34.04	47.84
S_5 : $CuSO_4$ @ 5 kg/ha	43.5	25.1	125.	66.9	58.3	2002	3854	33.56	48.21
S_6 : Combined application of all the four micronutrients	54.9	33.4	136.3	71.9	68.7	2592	4426	36.57	43.61
SEm±	1.23	0.652	0.880	0.635	0.868	61.96	71.53	0.06	0.53
CD (P=0.05)	3.3	1.9	2.5	1.8	2.5	118	206	0.18	1.58
M x S interaction									
CD (P=0.05)	6.2	3.3	-	-	4.3	207	-	0.31	-

The highest protein content was recorded with the M_3, since nitrogen forms the principal constituent of protein and protein content is always directly proportional to nitrogen. The increase in protein content is 13.9% and 15.5% respectively with M_3 and S_6. Findings of the present investigation are in agreement with those of Majumdar *et al.* (2001). Combined application of Zn, Fe, Cu and B resulted in high protein in kernel due to involvement of Zn in the synthesis of amino acids, leading to the formation of the protein molecules. Findings of the present investigation are in agreement with those of Krishnappa *et al.* (1994). The highest oil content of groundnut kernel was registered with the lowest level of major nutrients tried (M_1), and low oil content with highest level of major nutrients. The higher oil content in kernel was registered with combined application of Zn, Fe, Cu and B where as lowest was recorded with no micronutrient application which might be due to involvement of boron in catalyzing the metabolism of carbohydrates and Fe and Zn increases enzyme activity and other biological oxidation reactions. Findings of the present investigation are in agreement with those of Moussa *et al.* (1996).

From the experimental results it can be concluded that the post rainy season groundnut could be successfully raised with application of 45-60-75 $N-P_2O_5-K_2O$ kg/ha along with basal application of Zn, B, Fe and Cu in southern agro-climatic zone of Andhra Pradesh.

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Short communication

Integrated weed management in winter season groundnut (*Arachis hypogaea* L.)

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(Received: December, 2010; Revised: December, 2010; Accepted: January, 2011)

ABSTRACT

A field experiment was conducted during the winter season of 2008 to study the effect of different weed management practices on weed control, yield and economics of groundnut (*Arachis hypogaea* L.). The results revealed that hand weeding twice at 20 and 40 days after sowing (DAS), intercultivation (IC) with starweeder at 20 DAS + hand weeding (HW) at 40 DAS, imazethapyr @ 100 g a.i/ha at 20 DAS + HW at 40 DAS, pendimethalin @ 1.0 kg a.i/ha as pre emergence (PE) + HW at 40 DAS and pendimethalin @ 1.0 kg a.i/ha as pre emergence (PE) + imazethapyr @ 100 g a.i/ha at 20 DAS were effective in efficient weed control and in realizing higher pod yield (ranged 1649-1754 kg/ha) and haulm yield (ranged 2400-2439 kg/ha). These treatments resulted in higher weed control efficiency (WCE). Higher B: C ratio was obtained with the pendimethalin as PE + imazethapyr as POE (1.77) followed by pendimethalin as PE + hand weeding at 40 DAS. (1.72).

Key words: Groundnut, Imazethapyr, Intercultivation, Pendimethalin, Quizalofop ethyl, Weed control efficiency

Groundnut (*Arachis hypogaea* L.) is the major oilseed crop of Andhra Pradesh, which has low productivity and high cost of production. Andhra Pradesh produced 5.07 m.t. of groundnut from 2.64 m. ha. with a productivity of 1921 kg/ha during 2008. Weed infestation is considered as one of the critical factors for winter season groundnut production due to the initial slow growth habit of the crop and low temperature during January. Critical period of crop weed competition for groundnut crop was reported to be up to 45 days after sowing (DAS) and weed free environment during this period registered higher pod yield (Rao, 2000). Though hand weeding is recommended for weed control, the labour availability for weeding is scarce and expensive during peak periods of field operations leading to delayed weeding resulting in yield reduction. Hence, use of herbicides is the best alternative for weed control besides being easier, time saving, economical and result in early and effective control of weeds. The lack of herbicide activity for longer periods results in further weed growth that necessitates hand weeding at 25-30 DAS. In such situation, using post-emergence herbicides like imazethapyr or fluazifop-p-butyl or quizalofop-p-ethyl were suggested for weed control at later stages of crop growth. Hence, the present experiment was initiated to find out an effective and economical integrated weed management practice for the winter season groundnut. The experiment was conducted at College Farm, Rajendranagar, ANGRAU during the winter season of 2008. The soil was sandy loam, slightly alkaline in reaction, available soil N, P and K is 252.9, 28.6 and 223 kg/ha respectively. The experiment was laid out in randomized block design with 12 treatments replicated thrice. The treatments details are presented in table 1. The groundnut cultivar, K 134 (Vemana) was sown with spacing of 22.5 cm x10 cm on November 16, 2008 and harvested on March 06, 2009. Fertilizers were applied at 30 kg N, 40 kg P_2O_5 and 50 kg K_2O through urea, single super phosphate and muriate of potash. Altogether eight irrigations were given to the crop at 10 days intervals. Weed count was taken in one m^2 of selected quadrat before the handweeding and intercultivation with star weeder in specified treatments and also same thing followed in all other treatments. The weed control efficiency (WCE) in terms of weed dry weight was worked out based on the following formula.

$$WCE = \frac{DM_C - DM_t}{DM_C} \times 100$$

Where DM_C - Dry weight of weeds in unweeded control
DM_t - Dry weight of weeds in treated plot

Weed flora present in the experimental field consisted of grasses *viz*., *Cynodon dactylon, Digitaria sanguinalis and Dactyloctenium aegyptium and the only sedge observed was Cyperus rotundus. Parthenium hysterophorus, Amaranthus viridis, Amaranthus polygamus, Trianthema portulacastrum, Digera arvensis* and *Legasca mollis* were the broad leaved weeds (BLWs). The results revealed that handweeding (HW) twice at 20 and 40 DAS, intercultivation (IC) at 20 DAS + HW at 40 DAS, pendimethalin @ 1.0 hg a.i/ha as pre-emergence (PE) + HW at 40 DAS, pendimethalin @ 1.0 hg a.i/ha as PE + imazethapyr @ 100 g a.i/ha at 20 DAS and imazethapyr @ 100 g a.i/ha at 20 DAS + HW at 40 DAS were effective against grasses, sedges and broad leaved weeds (BLWs) (Table 1).

Total weed density and weed dry matter was reduced considerably by HW twice at 20 and 40 DAS which was comparable with IC at 20 DAS + HW at 40 DAS and pendimethalin as PE + HW at 40 DAS. Imazethapyr as POE + HW at 40 DAS and pendimethalin as PE + imazethapyr as POE were the next best treatments in reducing weed density and weed drymatter. Maximum weed density and dry matter was associated with control (no weeding) (Table 2). Sasikala (2002) also reported that effective control of grasses and broad leaved weeds with pre-emergence application of pendimethalin followed by imazethapyr as post emergence application.

Hand weeding twice at 20 and 40 DAS, IC at 20 DAS + HW at 40 DAS and pendimethalin as PE + HW at 40 DAS gave higher weed control efficiency during crop growth. The WCE was low due to IC at 20 DAS or post-emergence application of quizalofop-p-ethyl alone at 20 DAS due to poor weeds control.

Significantly higher pod yield (1754 kg/ha) was recorded with HW twice at 20 and 40 DAS which was on par with IC at 20 DAS + HW at 40 DAS (1729 kg/ha) and pendimethalin as PE + HW at 40 DAS (1701 kg/ha). Imazethapyr as POE + HW at 40 DAS (1685 kg/ha) and pendimethalin as PE + imazethapyr as POE (1649 kg/ha) were the next best treatments. Control recorded the lowest pod yield (561 kg/ha) (Table 2).

The highest haulm yield (2439 kg/ha) was recorded with HW twice at 20 and 40 DAS which was on par with IC at 20 DAS + HW at 40 DAS and pendimethalin as PE + HW at 40 DAS. Control (no weeding) recorded the lowest haulm yield (876 kg/ha).

The present study revealed that reduced weed competition at critical stage (20-40 DAS) of groundnut through weed management practices like pendimethalin @ 1.0 kg a.i./ha + imazethapyr @ 100 g a.i./ha at 20 DAS followed by pendimethalin @ 1.0 kg a.i./ha + HW at 40 DAS and IC at 20 DAS + HW at 40 DAS can offer efficient weed control with higher yield in irrigated groundnut during the winter season on sandy loam soils.

Table 1 Effect of integrated weed management practices on weed density (number/m^2) in winter season groundnut

Treatment	Weed density (number/m^2)											
	20 DAS			40 DAS			60 DAS			Harvest		
	Grasses	Sedges	*BLWs	Grasses	Sedges	*BLWs	Grasses	Sedges	*BLWs	Grasses	Sedges	*BLWs
No weeding (control)	8.29 (68)**	7.54 (56)	11.69 (136)	8.53 (72)	8.36 (69)	12.19 (148)	9.04 (81)	9.21 (84)	12.32 (151)	9.64 (93)	9.84 (96)	12.45 (154)
Handweeding (HW) at 20 and 40 days after sowing (DAS)	7.73 (59)	7.26 (52)	11.44 (130)	4.44 (19)	4.22 (17)	4.08 (16)	3.28 (10)	2.22 (4)	3.44 (11)	4.67 (21)	3.45 (11)	4.78 (22)
Intercultivation (IC) with star weeder at 20 DAS	8.11 (65)	7.27 (52)	11.61 (134)	4.64 (21)	4.45 (19)	4.34 (18)	6.62 (43)	6.47 (41)	8.35 (69)	6.77 (45)	9.48 (89)	9.05 (81)
IC + HW at 40 DAS	7.86 (50)	7.12 (50)	11.40 (129)	4.76 (22)	4.65 (21)	4.45 (19)	3.72 (13)	2.2 (4)	3.14 (9)	4.34 (18)	3.72 (13)	5.46 (29)
Pre emergence (PE) application of pendimethalin @ 1.0 kg a.i/ha	5.98 (35)	7.00 (49)	3.24 (10)	6.84 (46)	7.60 (57)	4.76 (22)	6.98 (48)	9.05 (81)	6.07 (36)	5.91 (35)	9.37 (87)	7.34 (53)
Post emergence (POE) application of Imazethapyr @ 100 g a.i/ha at 20 DAS	8.18 (66)	7.41 (54)	11.39 (129)	4.23 (17)	8.23 (67)	4.66 (21)	5.29 (28)	9.16 (83)	5.73 (32)	6.24 (38)	9.58 (91)	6.72 (45)
POE application of Quizalofop-p-ethyl @ 50 g a.i/ha at 20 DAS	7.98 (46)	7.20 (51)	11.65 (135)	1.05 (0.1)	8.29 (68)	11.26 (126)	1.97 (3)	9.04 (81)	11.40 (129)	2.81 (7)	9.69 (93)	11.49 (131)
Pendimethalin as PE + imazethapyr as POE***	5.82 (33)	7.12 (50)	3.58 (12)	3.97 (15)	7.67 (58)	2.80 (7)	4.58 (21)	8.88 (78)	4.45 (19)	5.09 (26)	9.43 (88)	5.65 (31)
Pendimethalin as PE + Quizalofop-p-ethyl as POE***	6.16 (37)	7.20 (51)	3.78 (15)	1.05 (0.1)	7.86 (61)	5.18 (26)	1.97 (3)	8.99 (80)	6.68 (44)	3.15 (9)	9.58 (91)	6.91 (47)
Pendimethalin as PE + HW at 40 DAS	5.90 (34)	7.00 (49)	3.13 (9)	4.34 (18)	8.17 (66)	4.68 (21)	3.59 (12)	2.62 (6)	3.30 (10)	4.11 (16)	3.73 (13)	5.47 (30)
Imazethapyr as POE + HW at 40 DAS	7.92 (62)	7.53 (56)	11.48 (131)	6.61 (43)	7.93 (62)	4.99 (24)	3.71 (13)	2.40 (5)	3.58 (12)	4.45 (19)	3.86 (14)	5.46 (29)
Quizalofop-p-ethyl as POE + HW at 40 DAS	8.05 (64)	7.27 (52)	11.57 (133)	1.05 (0.1)	8.24 (67)	11.83 (139)	2.23 (5)	2.64 (7)	3.31 (11)	3.16 (10)	3.87 (15)	5.47 (30)
SEm ±	0.24	0.27	0.25	0.29	0.28	0.30	0.27	0.23	0.27	0.24	0.19	0.24
CD (P=0.05)	*0.70*	*NS*	*0.74*	*0.85*	*0.84*	*0.90*	*0.79*	*0.67*	*0.80*	*0.72*	*0.56*	*0.70*

* BLWs = broad leaved weeds; ** = original values in parenthesis; *** = post-emergence herbicides applied at 20 DAS

Table 2 Effect of integrated weed management practices on weed control and yield of winter season groundnut

Treatment	Weed drymatter (g/m^2)				Weed control efficiency (%)				Haulm yield (kg/ha)	Pod yield (kg/ha)
	20 DAS	40 DAS	60 DAS	Harvest	20 DAS	40 DAS	60 DAS	Harvest		
No weeding (control)	74.0	96	226	214	-	-	-	-	876	561
Handweeding (HW) at 20 and 40 days after sowing (DAS)	69.0	20	13	33	6.7	79.1	94.2	85.5	2439	1754
Intercultivation (IC) with star weeder at 20 DAS	66.0	27	66	107	1.0	71.9	70.8	50.0	1492	1084
IC + HW at 40 DAS	67.0	28	14	35	9.4	70.8	93.8	84.1	2423	1729
Pre emergence (PE) application of pendimethalin @ 1.0 kg a.i/ha	24.0	36	78	97	67.5	62.5	65.5	54.7	1807	1187
Post emergence (POE) application of Imazethapyr @ 100 g a.i/ha at 20 DAS	70.0	25	50	101	5.4	73.9	77.8	52.8	2018	1242
POE application of Quizalofop-p-ethyl @ 50 g a.i/ha at 20 DAS	68.0	37	87	116	8.1	61.4	61.5	45.8	1602	1141
Pendimethalin as PE + imazethapyr as POE***	22.0	22	37	51	70.3	77.1	83.6	76.1	2418	1649
Pendimethalin as PE + Quizalofop-p-ethyl as POE***	26.0	29	66	78	64.8	69.8	70.8	63.5	2100	1450
Pendimethalin as PE + HW at 40 DAS	23.0	27	16	36	68.9	71.9	92.9	83.2	2417	1701
Imazethapyr as POE + HW at 40 DAS	71.0	37	17	38	4.0	61.4	92.9	83.2	2400	1685
Quizalofop-p-ethyl as POE + HW at 40 DAS	69.0	46	16	40	6.7	52.1	92.9	81.3	2033	1435
SEm ±	3.3	1.8	3.8	4.5	-	-	-	-	41	30
CD (P=0.05)	*9.6*	*5.4*	*11.2*	*13.2*	-	-	-	-	*123*	*89*

***=post-emergence herbicide applied at 20 DAS

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Heterosis for seed yield and its components in Indian mustard (*Brassica juncea* L.)

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(Received: August, 2010; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

Studies on heterosis was carried out using diallel analysis excluding reciprocal comprising seven mustard (*Brassica juncea* L.) parents and their 21 straight F_1 hybrids, with standard check (GM-3). The material was grown in randomized block design with three replications during winter season of 2009 at Main Castor and Mustard Research Station, Sardarkrushinagar (Gujarat). Analysis of variance revealed highly significant difference due to genotypes for all the characters. The differences in the variance due to parents and hybrids were significantly high for all the characters except days to flowering, days to maturity, length of main branch, 1000 seed weight, seed yield/plant and oil content. The range of heterobeltiosis for seed yield/plant was wide (-43.26 % to 61.67%), heterosis over standard parent (GM-3) was manifested by two crosses. The cross combination SKM 0820 x NDCC 28 registered highest heterobeltiosis (61.6%) and over standard parent (79.9 %). Similarly F_1 hybrid IC 385682 x NDR 5-1 stood ranked second for heterosis over better parents (31.67%) and over standard check (40.6 %). As evident from the study, the crosses SKM 0820 x NDCC 28 and IC 385682 x NDR 5-1 could be used to produce biparental progenies to obtain superior segregants which may be handled through pedigree method of breeding.

Key words: Diallel analysis, Heterosis, Heterobeltiosis and Standard heterosis

Mustard (*Brassica juncea* L.) contributes more than 13% to the global production of edible oil. Mustard is largely a self-pollinated crop but certain amount (5-18%) of cross pollination occurs (Labana and Banga, 1984). In mustard breeding programmes, breeding technique of both self and cross pollinated crops are widely used for development of high yielding varieties. These include techniques such as pure line, mass selection, hybridization and recurrent selection. Recently, more emphasis is being placed on heterosis breeding and tissue culture techniques. Heterosis expresses the superiority of F_1 hybrid over its mid parental value in terms of yield and other characters. Exploitation of hybrid vigour has been recognized as an important tool for genetic improvement of yield and may serve as a major fruitful technique to break existing yield barriers. Heterosis in F_1's is suggested for exploitation for hybrid vigour which is important in the present investigation for identification of good combiners of Indian mustard.

The present investigation included seven mustard parents and their 21 straight F_1 hybrids and standard check GM-3. The material was grown in randomized block design with three replications during winter season of 2009 at Main Castor and Mustard Research Station, Sardarkrushinagar (Gujarat). The seven parents (IC 385682, SKM 0820, NDCC 28, RLM 619, NDR 5-1, SKM 0450 and RGN 145) their 21 F_1 hybrids and GM 3 as a standard check were planted in two rows of 5 m length having an inter and intra-row spacing of 45 cm and 15 cm, respectively. Observation were recorded on 5 randomly taken plants from parents and F_1 in each replication for days to flowering, days to maturity, plant height (cm), length of main branch (cm), number of branches/plant, number of siliqua/plant, length of silique (cm), seeds/silique, 1000 seed weight (g), seed yield/plant (g) and oil content (%). Oil content was estimated using NMR. Heterosis was calculated as per formulae used in estimation of heterosis over better parent (Fonseca and Patterson, 1968) and heterosis over standard check (Meredith and Bridge, 1972)

Analysis of variance (Table 1) revealed highly significant differences due to genotypes for all the characters. Significantly high amount of variance indicated that genetic variability was sufficiently high in the population of parents and hybrids. The variance due to genotypes was further partitioned into parents, hybrids and parents v/s hybrids for all the traits. The differences in the variance due to parents and hybrids were significantly high for all the characters except days to flowering, days to maturity, length of main branch, 1000 seed weight, seed yield/plant and oil content. The variance for parents significantly differed out from that of hybrids for plant height and seeds/siliquae. The difference among crosses may be due to better combination of genes derived from the genetically diverse parents in respect of seed yield and its components.

The heterosis was estimated as per cent increase or decrease in F_1 value over better parents value (heterobeltiosis) and over standard check (GM-3) for seed

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yield and its components. The heterosis for six characters are presented in table 2. The results revealed that none of the crosses were found significant in desirable direction for days to flowering and days to maturity over better parent and standard check. The cross combination IC 385682 x NDR 5-1 recorded highest positive and significant heterobeltiosis (28.1%) for number of branches/plant. While cross IC 385682 x NDCC 28 recorded significant and positive heterobeltiosis (13.4%) and standard heterosis (29.6%) for 1000 seed weight. The crosses IC 385682 x NDR 5-1 (26.6%), IC 385682 x SKM-0450 (26.7 %) and IC 385682 x RGN 145 (27.2%) were found positive and significant standard heterosis for 1000 seed weight.

The range of heterobeltiosis for seed yield/plant was wide (-43.26 % to 61.67%). Similarly heterosis over standard check (GM-3) was manifested by two crosses. The cross combination SKM 0820 x NDCC 28 registered highest heterobeltiosis (61.6%) and over standard check (79.9%) while F_1 hybrid IC 385682 x NDR 5-1 stood ranked second for heterosis over better parents (31.7%) and over standard check (40.6%). These findings are accordance with Singh *et al.* (2003) and Prajapati *et al.* (2009).

As evident from the study, the crosses SKM 0820 x NDCC 28 and IC 385682 x NDR 5-1 could be used to produce biparental progenies to obtain superior segregants which may be handled through pedigree method of breeding as suggested by Sohan Ram (2009).

Table 1 Mean squares for various characters in mustard

Source	d.f.	Days to flowering	Days to maturity	Plant height	Length of main branch	Number of branches/ plant	Number of siliquae/ plant	Length of siliquae	Seeds/ siliqua	1000 seed weight	Seed yield/ plant	Oil (%)
Replications	2	3.47	5.33	719.54*	51.09	1.12	169.74	0.02	2.19	0.14	24.88	0.39
Treatments	27	14.38*	79.89	546.41**	100.34*	7.45**	2641.90**	0.23**	2.04**	0.44**	911.51	3.06
Parents	6	8.42	87.21	864.39**	93.73	8.97**	2679.11*	0.33**	5.06**	0.19	927.24	3.89
Hybrids	20	16.85*	81.64	453.56**	104.52*	7.36**	2714.61**	0.19**	0.89	0.52**	951.95	2.62
Parent vs. hybrid	1	0.70	1.02	495.60	56.57	0.003	964.48	0.17	6.85*	0.33	8.43	6.71
Error	54	8.11	90.52	179.19	54.48	2.50	1108.86	0.05	0.96	0.09	128.59	2.02
SEm±		1.64	5.49	7.73	4.26	0.91	19.22	0.13	0.57	0.17	6.55	0.81

*,** Significant at 5% and 1% levels, respectively

Table 2 Heterosis over better parent (BP) and standard check GM-3 (SC) of six characters in mustard

Parents	Days to flowering		Days to maturity		Number of branches/ plant		1000 seed weight (g)		Seed yield/plant (g)		Oil (%)	
	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
IC 385682 x SKM 820	-0.77	-2.87	4.91	-0.61	15.79	19.51	11.75	27.71*	21.17	35.04*	0.55	-1.67
IC 385682 x NDCC 28	0.55	-3.32	0.6	-1.77	-19.42*	-3.70	13.42*	29.62*	-36.19**	-27.19	-1.97	-4.14
IC 385682 x RLM 619	1.41	-2.65	-0.6	-2.94	-19.17*	-4.20	7.17	22.48	-0.22	14.65	-0.48	-2.67
IC 385682 x NDR5-1	-7.61	-7.83	1.19	-1.19	28.06*	13.83	10.75	26.57*	31.67*	40.58*	-0.73	-2.92
IC 385682 x SKM 0450	-4.71	-4.07	0.89	-1.48	0.00	-0.25	10.83	26.67*	1.05	7.89	0.15	-2.06
IC 385682 x RGN 145	8.54	3.22	1.49	-1.19	-20.35*	-11.11	8.27	27.24*	-35.7**	-7.41	-1.18	-3.36
SKM 0820 x NDCC 28	-1.64	-5.43	15.9*	10.14	-2.48	16.54	-1.75	12.29	7.62	22.79	1.02	-1.21
SKM 0820 x RLM 619	-0.86	-4.83	-0.92	-5.84	-38.33**	-26.91	-15.83*	-3.81	-33.01**	-23.02	1.2	-1.04
SKM 0820 x NDR 5-1	-1.63	-4.60	1.22	-3.81	4.29	8.15	-0.33	13.90	61.6**	79.94**	-0.85	-3.03
SKM 0820 x SKM 0450	4.34	1.19	3.06	-2.06	-9.05	-5.68	-7.33	5.90	-10.55	-0.40	-0.26	-2.47
SKM 0820 x RGN 145	-1.58	-6.41	3.36	-1.77	6.19	18.52	-11.18	4.38	-14.37	23.30	0.94	-1.29
NDCC 28 x RLM 619	5.32	-2.42	12.68	10.43	-14.17	13.58	-8.31	0.76	-23.98	28.64	-4.84	-10.12
NDCC 28 x NDR 5-1	13.1*	1.41	1.77	0.26	-13.54	-8.40	0.28	3.43	-28.98*	-30.24	4.87	-8.49
NDCC 28 x SKM 0450	2.48	9.98	-3.54	-3.52	-7.71	8.89	-13.09*	1.62	-8.09	-14.58	0.34	-5.13
NDCC 28 x RGN 145	-4.43	-7.68	1.79	-1.19	-5.83	4.69	-3.48	2.57	-2.51	21.26	0.99	-7.51
RLM 619 x NDR 5-1	-0.7	-4.45	-1.46	-1.48	-9.17	16.54	-10.00	10.48	-12.93	-0.91	-2.78	-6.75
RLM 619 x SKM 0450	-4.19	-3.25	-0.88	-1.48	2.50	5.68	-19.92**	-1.52	-7.2	5.60	0.52	-7.64
RLM 619 x RGN 145	5.93	-6.41	2.09	-2.06	-15.83	27.41	-14.51*	-4.19	-37.15**	17.70	-1.1	-1.06
NDR 5-1 x SKM 0450	2.65	-2.57	-1.46	-1.48	6.44	-0.25	-7.75	3.90	-21.5	-43.51	-1.37	-7.66
NDR 5-1 x RGN 145	17.87**	16.00	11.94	-2.35	-15.04	-1.73	-8.91	9.33	-43.26**	-15.75	0.13	-5.41
IC 385682 x RGN 145	2.29	-6.63	2.39	-1.48	-1.99	13.33	-9.64	4.10	-28.95**	-15.70	-1.77	-3.14
CD (P=0.05)	4.66	4.66	15.57	15.57	2.59	2.59	0.48	0.48	18.54	18.54	2.32	2.32
CD (P=0.01)	6.21	6.21	20.74	20.74	3.45	3.45	0.45	0.45	24.72	24.72	3.10	3.10

*,** Significant at 5% and 1% levels, respectively

BP= Better parent and SC= Standard check (GM 3)

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Effect of organic and inorganic sources of nutrients, gypsum and thiourea on productivity of Indian mustard (*Brassica juncea* L.)

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(Received: May, 2010; Revised: September, 2010; Accepted: May, 2011)

ABSTRACT

A field experiment was conducted at Udaipur to study the effect of nutrient sources, gypsum and thiourea on the growth and yield of mustard (*Brassica juncea* L.). The results indicated that, application of inorganic sources (60 kg N + 40 kg P_2O_5/ha) significantly recorded higher crop growth, seed and stover yield. Application of gypsum at 250 kg/ha and foliar application of thiourea (1000 mg/l) recorded significantly higher growth, seed and stover yields over lower doses/control.

Key words: Growth parameters, Mustard, Thiourea, Yield

Oilseeds form the second largest commodity after cereals in India of which rapeseed and mustard (*Brassica juncea* L.) occupies second largest group. Among agronomic factors known to augment crop production, adequate crop nutrition through fertilization is considered as one of the most productive inputs. In recent years, the use of agrochemicals as growth regulators, growth stimulants and growth promoting substances to modify various metabolic or physiological processes inside plant system resulted in increasing the crop yield. Therefore, the present study was undertaken to ascertain the response of mustard to different organic and inorganic sources of nutrients, gypsum and application of thiourea.

A field experiment was undertaken during the winter season of 2006 at Rajasthan College of Agriculture, Udaipur. The experiment consisted of three sources of nutrients (inorganic sources) (60 kg N + 40 kg P_2O_5/ha), FYM 10 t/ha + inorganic sources, poultry manures 5 t/ha + inorganic sources), three models of gypsum (250 kg/ha) application (control, full dose of gypsum at sowing and 50% at sowing + 50% at 35 days after sowing (DAS) and two levels of plant growth regulator (control and thiourea application at 1000 mg/l during pre-flowering stage) making 18 treatment combinations. The experiment was laid out in factorial randomized block design and replicated three times.

The soil of the experimental field was clay loam in texture, slightly alkaline in reaction (pH 8.10) and calcareous in nature, high in organic carbon content (0.76%), medium in available nitrogen (284.2 kg/ha) and phosphorus (20.4 kg/ha) and rich in potassium (292.8 kg/ha). Mustard variety, Pusa Jaikisan (Bio 902) was sown at 30 cm x 10 cm @ 5.0 kg seed/ha. The crop was sown on November 5, 2006 and harvested on March 8, 2007 when siliqua attained physiological maturity. Drymatter, leaf area index (LAI), crop growth rate (CGR), chlorophyll content, test weight and seed yield were recorded.

The drymatter accumulation at 30, 60, 90 DAS and at harvest, LAI at 30, 60 and 90 DAS, CGR at 30-60 and 60-90 DAS, chlorophyll content at 45 DAS, test weight, seed and stover yield of mustard were significantly higher with application of inorganic sources of nutrients (60 kg N + 40 kg P_2O_5/ha) over FYM 10 t/ha + inorganic sources and poultry manure 5 t/ha + inorganic sources (Table 1). Application of organic sources along with inorganic sources were found at par with each other for these parameters (except chlorophyll content at 45 DAS). The corresponding per cent increase were in the order of 12.7, 9.9, 6.0, 7.6, 8.4, 8.3, 8.2, 8.6, 9.7, 9.5, 12.1, 10.0, 8.4 and 7.5, respectively with the application of inorganic sources over FYM 10 t/ha + inorganic sources only. In general, overall improvement in crop growth under optimum nutrition involving combination of N and P_2O_5 seems to be on account of their potential role in modifying soil and plant environment conducive for better development of plant growth. Nitrogen is considered as essential in synthesis of chlorophyll and amino acids while, phosphorus improved various metabolic and physiological processes. It has been well emphasized that various nutrient elements and their combined use have significant role to play in enhanced growth in terms of drymatter by virtue of their impact on morphological and photosynthetic components of growth along with higher accumulation of nutrients.

Application of gypsum at 250 kg/ha at both the levels (i.e., full dose at sowing and 50% at sowing + 50% at 35 DAS) recorded significantly higher growth parameters, yield attribute (test weight) and yield over control. There was an improvement of 6.7, 20.5, 6.2 and 15.4% in seed and stover yield due to application of gypsum over full dose of gypsum at sowing and control, respectively. Overall improvement in growth characters of mustard plant *vis-a-vis* seed yield owing to S application was well documented (Singh and Meena, 2004). Sulphur enhanced cell multiplication, elongation and expansion, imparts a deep colour to leaves due to better chlorophyll synthesis, resulting in greater amounts of drymatter in comparison to sulphur deficient plant.

Foliar application of thiourea (1000 mg/l) at pre-flowering stage recorded significantly higher drymatter accumulation at 60 and 90 DAS and at harvest, LAI at 60 and 90 DAS, CGR at 60-90 DAS, test weight and seed and stover yield over control. The per cent increase in these parameters was found to be 12.4, 10.7, 12.5, 14.5, 14.0, 9.1, 14.4, 14.5 and 9.9, respectively. Thiourea application stimulates the photosynthetic carbon mechanism and hence, might have increased canopy photosynthesis (Sahu *et al.*, 1993). The significant improvement in reproductive efficiency of crop, suggest profound influence of thiourea in efficient translocation of photosynthates towards sink resulting in increased number of siliqua/plant, number of seeds/siliqua and test weight and these improved yield attributes cumulatively led to increased seed yield.

Table 1 Effect of organic and inorganic sources of nutrients, gypsum application and thiourea on mustard

Treatment	Drymatter accumulation (g/plant) at				Leaf area index			Crop growth rate		Chlorophyll content at 45 DAS (mg/g fresh weight of leaf)	Test weight (g)	Yield (kg/ha)	
	30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	30-60 DAS	60-90 DAS			Seed	Stover
Source of nutrient													
Inorganic sources	1.87	25.09	44.28	56.17	1.43	2.90	4.05	23.22	20.19	1.138	4.40	2020	4751
FYM 10 t/ha + inorganic sources	1.66	22.82	41.77	52.21	1.32	2.68	3.73	21.16	18.44	1.015	4.00	1864	4481
Poultry manure 5 t/ha + inorganic sources	1.72	23.77	42.19	52.69	1.31	2.65	3.71	22.05	17.98	1.068	4.18	1848	4487
CD (P=0.05)	0.106	1.346	2.121	3:077	0.047	0.171	0.252	1.329	1.582	0.024	0.25	101	252
Gypsum (250 kg/ha)													
Without gypsum	1.58	21.20	39.36	48.88	1.24	2.46	3.44	19.63	17.76	0.897	3.77	1719	4200
Full dose at sowing time	1.83	24.22	43.35	54.44	1.40	2.79	3.89	22.39	18.73	1.108	4.21	1941	4584
50% at sowing + 50% at 35 DAS	1.84	26.26	45.52	57.74	1.43	2.98	4.16	24.42	20.12	1.217	4.59	2072	4870
CD (P=0.05)	0.106	1.346	2.121	3.077	0.047	0.171	0.252	1.329	1.582	0.024	0.25	101	252
Plant growth regulator													
Control (water spray)	1.75	22.50	40.58	50.52	1.35	2.56	3.58	21.75	18.02	1.073	3.90	1781	4336
Thiourea at 1000 mg/l	1.75	25.29	44.91	56.85	1.37	2.93	4.08	22.53	19.66	1.075	4.48	2040	4767
CD (P=0.05)	NS	1.099	1.732	2.512	NS	0.140	0.206	NS	1.291	NS	0.20	82	206

LAI = Leaf area index; CGR = Crop growth rate; DAS = Days after sowing

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Short communication

Assessment of proper stage of harvesting in Indian mustard (*Brassica juncea* L.)

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(Received: May, 2010; Revised: January, 2011; Accepted: February, 2011)

ABSTRACT

Appropriate stages of harvest were determined on the basis of highest seed weight, oil content, protein content, seed germination and seed vigour for 40 different varieties of Indian mustard (*Brassica juncea* L.). It was observed that moisture content in fresh seeds varied from 20 to 25% at harvest. Morphological indicators recorded in terms of percentage of green/yellow siliqua colour indicated that proper harvest stage coincided with more than 70% yellowish siliquae.

Key words: Germination, Harvest stage, Indian mustard, Seed weight

Indian mustard (*Brassica juncea* L.) is the major oilseed crop in India. The uses of high-quality seeds are essential for good stand, establishment and yield of any crop. Earlier researchers have reported that seed of some crops attain maximum viability and vigour at physiological maturity (PM) (Dhawan and Mainawatee, 1992, Varshney *et al.*, 2001). Identification of harvesting maturity (HM) is important to avoid shattering losses and to obtain good quality seed. Delouche (1980) defined HM, as when seed moisture content is low enough to allow effective threshing with a mechanical harvester. However, it was felt useful to confirm these indicators and to study comprehensively the proper stage of HM based on other parameters. No confirmatory reports are published about the proper stage of harvesting of Indian mustard cultivars. Hence, this experiment was laid out with objective of assessment of proper stage of harvesting in Indian mustard cultivars and establishing the morphological indicators.

The experimental material comprised of 40 varieties of Indian mustard and conducted at Directorate of Rapeseed Mustard Research, Sewar, Bharatpur, Rajasthan. Varieties were evaluated in split plot design with three replications keeping six harvesting dates at one week interval starting form 104 days after sowing, as main plot and 40 varieties of Indian mustard as sub plot. The blocks were divided into six main plots and 40 varieties of Indian mustard were randomized within each main plot. Each variety was grown in single row plot of 5m length and spacing between row-to-row and plant-to-plant were maintained at 45 cm and 10 cm, respectively. Observations were recorded for seed weight (g), moisture content in fresh seed (%), protein content (%), oil content (%), germination per cent, root length (cm) and shoot length (cm) of seven days old seedlings on the seeds harvested from five plants at different harvesting dates.

Criteria for ascertaining the appropriate harvesting stage was followed considering the stage when seed weight, oil and protein content of a variety reaches to its peak and the germination is more than 85%. Oil and protein content were considered to determine the right stage of harvesting since the basic outputs in Indian mustard are seed yield and oil content and the germination is the most important parameter to assess the seed quality. It is expected that after seed weight reaches to its peak, there will be no further gain in seed yield, oil and protein content. The plants were harvested from each variety at six different harvesting stages namely 104, 111, 118, 125, 132 and 139 days after sowing.

Analysis of variance revealed the presence of significant variation at different harvesting stages for seed weight, moisture content in fresh seed, protein content, oil content, germination %, root length and shoot length. Similarly the significant variation was observed among varieties for all the seven traits. Interaction between harvesting stage and varieties was also significant for all the traits except root length. The presence of significant interaction indicated that the varieties had varied response for these traits hence the harvesting stages can't be generalized and are being discussed variety wise. The 1000 seed weight, in general showed an increase from earliest harvesting stage at 104 days up to 125 days. The moisture content of the fresh seed declined gradually from 33.3% (at 104 days) to 16.7% (at 139 days). Protein content had shown increase up to 118 days while, the oil content had increased up to 125 days indicating there by that synthesis of protein had occurred earlier than oil content. The germination percent of the seed was tested after drying and storage of the seed for two months to avoid the effect of dormancy. Maurya (2002) reported dormancy of 4 to 8 weeks in Indian mustard. The germination % in general increased up to 132 days in present material.

Table 1 Mean values of seven traits under different harvesting dates in Indian mustard

Harvesting days	1000 seed weight (g)	Moisture content (%)	Protein content (%)	Oil content (%)	Germination (%)	Shoot length (cm)	Root length (cm)
104	3.1	33.3	19.3	36.6	17.1	3.4	5.3
111	3.8*	29.6*	20.3*	38.9*	46.9*	5.8*	8.8*
118	4.2*	26.7*	21.1*	39.8*	75.7*	7.2*	11.0*
125	4.4*	23.8*	21.2	40.4*	87.8*	7.3	14.0*
132	4.4	20.1*	21.2	40.5	95.0*	7.5	12.4
139	4.4	16.7*	21.0*	40.5	96.5	7.4	12.5
CD (P=0.05)	0.11	0.5	0.70	0.5	2.4	0.3	1.2

* indicate significantly higher/lower estimate for the respective trait than that of earliest harvesting date.

Table 2 Appropriate stages (in days) of 40 Indian mustard varieties for 1000 seed weight, oil content, protein content and germination percentage

Variety	Test weight	Protein content	Oil content	Germination percentage	Rec. stage of harvesting*
ACN Satabdi	111	111	111	111	111
CS-52	125	111	104	125	125
CS-54	118	118	111	118	118
Geeta (RB 9901)	125	118	111	118	125
GM-1	118	118	118	118	118
GM-2	125	118	118	125	125
GM-3	118	111	111	125	125
JM-2	125	125	125	125	125
JM-3	118	118	118	125	125
Kanti	111	104	118	118	118
Kranti	118	118	118	132	132
Krishna	125	118	118	125	125
Laxmi (RH 8812)	118	111	111	125	125
Maya	118	118	118	118	118
NDRE-4	104	104	104	104	104
Narendra rai (NDR-8501)	118	118	118	132	132
PBR-91	125	125	118	125	125
PBR-97	125	125	118	132	132
Pusa Agrani (Sej-2)	111	104	104	118	118
Pusa Bahar	118	118	118	125	125
Pusa Bold	125	125	118	125	125
Pusa Jagannath (VSL 5)	125	118	111	125	125
Pusa Jai Kisan (Bio-902)	118	111	118	125	125
Pusa Krishma (LES-39)	111	111	111	132	132
Pusa Mahak (JD-6)	118	118	118	125	125
Rajat (PCR-7)	118	118	111	125	125
RGN 13	118	118	111	118	118
RGN 48	118	111	111	125	125
RH-30	125	125	118	125	125
RH-819	118	118	118	125	125
RL-1359	125	118	118	139	139
Sanjucta Asech	104	111	104	111	111
Saurabh (RH-8113)	125	125	125	132	132
Swarn jyoti (RH-9801)	118	118	111	125	125
TM-2	118	111	118	118	118
TM-4	111	111	118	111	118
Urvashi (RK-9501)	111	118	118	118	118
Vaibhav	111	111	118	118	118
Varuna (T 59)	125	118	118	125	125
Vasundhra (RH-9304)	111	118	111	125	125

* recommended stage of harvesting (in days after sowing)

The root and shoot length had shown increase up to 125 and 118 days, respectively (Table 1). Varieties also had considerable variability for seed weight, moisture content of fresh seed, oil content, protein content and germination %. Considering the significant interaction between harvesting stage and varieties, the appropriate harvesting stages were found varying on the basis of criteria established for this purpose. The different stages at which seed weight, oil content and protein content were at plateau and germination was more than 85% have been summarized in table 2. Accordingly the right harvest stages in terms of days after sowing were established and presented in table 2.

The morphological indicators, which were recorded as percent green/yellow coloured siliquae, were taken into consideration to establish the morphological indicators for appropriate harvesting stage. It was found that right harvest stage which was established on the basis of criteria followed in present investigation was coinciding with 70 or higher percentage of yellow coloured siliquae on the plants hence this can be concluded that the stage when 70 or more percentage of siliquae turn to be yellow is the appropriate stage for harvest on the basis of morphological appearance. The change of colour as an morphological indicator for harvesting stage has been reported by Varshney *et al.* (2001) in Indian mustard. In general, the moisture content at right harvest stage of the variety ranged from 20 to 25%.

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Short communication

G. Til 4 : A white seeded high yielding early maturing sesame (*Sesamum indicum* L.) variety suitable for North Saurashtra region of Gujarat

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(Received: July, 2010; Revised: March, 2011; Accepted: April, 2011)

ABSTRACT

White seeded sesame (*Sesamum indicum* L.) variety G.Til 4 was found suitable for cultivation in North Saurashtra Region of Gujarat. This variety showed yield increment of 18.3% and 10.8% over G.Til 2 and G.Til 3, respectively. G.Til 4 is at least 5 days earlier than both the checks.

Key words: Early maturity, G.Til 4, Higher yield, White seeded sesame

Among the oilseeds, sesame (*Sesamum indicum* L.) seeds are a good source of quality oil, i.e., around 50% of its total mass. India occupies first position in both sesame production and sesame export worldwide (Anonymous, 2008). Among the sesame growing states, Gujarat contributes 28.6% to total sesame production in the country. The state has a great potential for sesame production for domestic and export markets but the yield of this valuable crop is relatively low especially in rainy season due to lack of improved varieties as well as resistance to diseases and pests of economic importance. In Gujarat, summer is the favourable season with three times higher production than in rainy season due to assured irrigation and very low incidence of diseases and pests. Three white seeded high yielding varieties, namely G.Til 1, G.Til 2 and G.Til 3 are under cultivation in the state. G.Til 3 is the recently released variety having bolder seed size and showing low incidence of gallfly and mites (Monpara *et al.*, 2008).

Apart from high yield, early maturity is another desirable trait as it may protect the crop from various biotic and abiotic stresses. Considering the advantages of short duration varieties of sesame for rainfed production system of the region, breeding efforts were initiated at the Agricultural Research Station, Amreli. A cross was attempted between G.Til 1 and RT 125 in the rainy season. G.Til 1 is a white seeded variety released for commercial cultivation in Gujarat and RT 125 is a drought tolerant variety which was developed in Rajasthan.

The segregating material was handled through pedigree method and early maturing lines with more than one capsule per axil were selected. Preliminary field level screening of advanced generations showed encouraging yields thus demonstrating a potential for selection of lines suitable for short growing season. The selected line was tested and evaluated as AT 159 for its production potential in the rainy season of 2006 through 2009 at different locations of the North Saurashtra Agro-climatic Region, a semi-arid region with an average rainfall of 580 mm. AT 159 along with other test entries and checks were evaluated in randomized block design with four replications in different categories of trials, i.e., PET (Preliminary Evaluation Trial), SSVT (Small Scale Varietal Trial) and LSVT (Large Scale Varietal Trial). All these trials consisted of plots with variable rows (3 for PET, 4 for SSVT and 6 for LSVT) of 5.0 m length. Seeds were hand drilled in rows spaced 45 cm apart and the crop was thinned at 15-20 days after germination keeping plant to plant distance of 10 cm. All agronomic practices were followed for growing a good crop.

On the basis of seed yield data recorded from the experiments being conducted at different locations of North Saurashtra Region during rainy season 2006 through 2009 including AT 159 and two checks *viz.*, G.Til 2 and G.Til 3 (Table 1), it was observed that the AT 159 performed better and produced mean seed yield (average of 9 trials) of 770 kg/ha as against 651 kg/ha of G.Til 2 and 695 kg/ha of G.Til 3. Thus, yield advantage of AT 159 was 18.3 % and 10.8% higher over check variety G.Til 2 and G.Til 3, respectively was recorded. Similarly, it gave higher per day oil production to the tune of 26.24% and 16.28% over G.Til 2 and G.Til 3, respectively.

Examination of characteristic features of AT 159 and two check varieties (Table 2) indicated that AT 159 had distinct morphological characteristics for easy identification. AT 159 and G.Til 2 have medium sized capsule which arises more than one per axil, while G.Til 3 possessed long capsule which arises singly per axil. Capsules are glabrous in AT 159 and G.Til 3, while hairy in G. Til 2. Leaf arrangement was alternate in AT 159 as compared to opposite in both the checks. So far earliness is concerned; AT 159 showed 2 to 3 days early flowering and 5 to 6 days early maturity than both the checks. It has relatively short plant stature with higher number of productive capsules/plant. The genotype has shining white seed colour suitable for export purpose.

The variety AT 159 was also screened for reaction to major pests and diseases under field conditions during two rainy seasons. Per cent disease index (PDI) calculated on the basis of 0 - 5 scale (0 by resistance, 5 by most susceptible) for leaf spot disease was comparatively less in this genotype (7.78) compared to the checks G. Til2 and G.Til 3 (19.6 and 14.6, respectively). Incidence of other diseases and pests was similar to that of both the checks.

Gujarat state released this entry of sesame as G.Til 4 for *commercial cultivation in* North Saurashtra region on the basis of its consistent superior performance under rainfed condition and early maturity. G.Til 4 has been registered (IC 584256) and conserved under long term storage at NBPGR, New Delhi.

Table 1 Yield performance of AT 159 (G. Til 4) and checks G. Til 2 and G. Til 3 in various locations of North Saurashtra region

Year	Location	Yield (kg/ha)			CD (P=0.05)	CV (%)
		AT 159	G.TIL 2(C)	G.TIL 3(C)		
2006	Amreli	511	534	540	82	14.7
	Dhari	Experiment failed				
	Mean	511	534	540		
	% Increase over		-4.31	-5.37		
2007	Amreli	1563	1404	1343	149	7.5
	Dhari	513	401	451	61	8.8
	Mean	1038	903	897		
	% Increase over		14.95	15.72		
2008	Amreli	727	611	722	104	11.9
	Jamnagar	345	405	423	58	11.5
	Targhadia	512	374	355	103	17.6
	Nanakandhsar*	301	311	273	29	8.2
	Mean	528	463	500		
	% Increase over		14.04	5.60		
2009	Amreli	739	624	615	68	7.8
	Targhadia	1210	773	1117	206	18.9
	Jamnagar	812	735	692	170	16.2
	Nanakandhsar*	364	271	379	77	27.7
	Mean	920	711	808		
	% Increase over		29.40	13.86		
	Over all mean of 9 trials	770	651	695		
	% Increase over		18.28	10.79		

* Data not included in calculating mean due to below state average

Table 2 Characteristic features of AT 159 (G. Til 4) and two checks

Character	AT 159	G.Til 2 (C)	GTil-3 (C)
Branching pattern	Branched	Branched	Branched
Leaf arrangement	Alternate	Opposite	Opposite
Stem hairiness	Glabrous	Hairy	Glabrous
Flower colour	Purplish white	Purplish white	Purplish white
Corolla hairiness	Sparsely hairy	Sparsely hairy	Sparsely hairy
Density of capsule hairiness	Glabrous	Hairy	Glabrous
Capsule shape	Narrow oblong	Narrow oblong	Broad oblong
Capsule/leaf exil	More than one	More than one	One
Capsule arrangement	Multi- alternate	Multi- opposite	Single- opposite
Seed colour	White	White	White
Capsule length	Medium	Medium	Long
Days to 50 % flowering	41	44	43
Days to Maturity	81	87	86
Primary branches/plant	2.4	2.7	2.2
Capsules/plant	57	54	54
Plant height (cm)	87	93	96
1000 seed wt (g)	2.80	2.90	3.13
Oil content (%)	48.1	48.4	48.6

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Short communication

Identification of restorers for diverse CMS sources in sunflower (*Helianthus annuus* L.)

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(Received: January, 2010; Revised: January, 2011; Accepted: February, 2011)

ABSTRACT

Three cytoplasmic male sterile lines of sunflower (*Helianthus annuus* L.) each belonging to a different cytoplasmic source. PET1 (ARM 243A), CMS PF (FMS 850A) and CMS I (IMS 850A) were crossed with 40 inbreds to identify fertility restorer lines for each CMS source. Most of the lines restored fertility for classical petiolaris cytoplasm PET1. Only a few could restore fertility on new CMS sources. Out of 40 inbreds tested, 22 were found to be restorers for CMS PET1 while others behaved as maintainers. Only two inbreds could restore fertility and remaining 38 inbreds behaved as maintainers for CMS PF. Three inbreds were effective restorers, five inbreds exhibited segregation and rest of 32 inbreds were maintainers for CMS I. Only one elite inbred could restore fertility on PET 1, CMS PF and CMS I cytoplasm. A few effective restorers were identified for the CMS sources, which can be exploited in developing hybrids with better heterosis possessing alternate cytoplasm.

Key words: CMS source, Maintainer, Restorer, Sunflower

Commercial cultivation of sunflower (*Helianthus annuus* L.) was started in India during 1972 with the introduction of four open pollinated varieties. The discovery of cytoplasmic male sterility in sunflower by Leclercq (1969) in France and subsequent identification of genes for fertility restoration by Kinman (1970) in USA have resulted in the development of hybrids for commercial cultivation. Sunflower breeders have extensively exploited the heterosis on the *Helianthus petiolaris* (PET-1) source of male sterility by utilizing few fertility restorers. Such type of dependency on a single source of male sterility could lead to narrow genetic base leading to a potential risk and high degree of genetic vulnerability in hybrid sunflower cultivation which can predispose the crop for some unforeseen situations of biotic and abiotic stresses in future years. Hence, diversification of CMS sources is inevitable in heterosis breeding which will add flexibility and nuclear diversity to breeding programmes. Fortunately, several new sources of cytoplasmic male sterility have been reported by Whelan (1980). The newly developed CMS sources for broadening of genetic base of cytoplasm have revealed polymorphisms in the mitochondrial DNA (Crouzillat *et al.*, 1994). But using these diverse CMS sources, hybrids could not be developed because of the non-availability of effective restorers. In view of the limitation, an attempt was made to identify restorers for the newly developed CMS sources.

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Three diverse CMS sources (lines) *viz.*, ARM 243A from *Helianthus petiolaris* (PET 1), FMS 850 A from *H. petiolaris* ssp *fallax* (PF) and IMS 850A from *H. lenticularis* (CMS I) and 40 parental inbreds of diverse genetic background were obtained from Directorate of Oilseeds Research (DOR), Hyderabad.

Twenty rows each of the three cytoplasmic male sterile lines and two rows each of the 40 inbreds were planted in separate blocks during winter season 2007, with a spacing of 60 cm between rows and 30 cm between plants. A row length of 4.5 m was maintained. Staggered sowings of male parents, twice at weekly interval, was done to synchronize the flowering and recommended agronomic practices were followed.

The heads of male sterile lines and the inbreds were covered with cloth bags at the ray floret stage i.e., just before the commencement of flower opening. The three different CMS sources were crossed to all the 40 inbreds in a line x tester method. Crossing was done by collecting pollen from the inbreds in a petridish with the aid of a small brush which was applied on five florets each of the corresponding CMS lines between 8 to 11 am and the procedure repeated till the opening of all disc florets. Precautions were taken to avoid possible contamination. F_1 seeds from each of the 120 crosses were collected separately at maturity for assessing the fertility restoration of the 40 inbreds on the three CMS lines.

The identification of inbred behaviour with respect to maintenance and restoration of the cytoplasmic male sterile sources of sunflower involved in the present study was conducted during the rainy season of, 2008 at Research Farm, Hyderabad. F_1 seeds from the 120 crosses were planted in an unreplicated trial. Each entry was sown in a single row of 4 m length with a spacing of 60 cm x 30 cm. At anthesis stage, plants were classified as male fertile/male sterile based on anther dehiscence and pollen shedding. Pollen fertility was also confirmed in the laboratory using 1% acetocaramine staining (Chaudhary *et al.*, 1981).

The maintainer/restorer reaction of the inbreds for different CMS sources has been presented in table 1. In general, most of the inbreds tested behaved as maintainers for the new CMS sources. Even the identified effective restorers of the traditional PET-1 cytoplasm behaved mostly as maintainers. Results indicated that out of 40 test inbreds, 22 were found to be restorers for the traditional PET-1 cytoplasm, while remaining behaved as maintainers. Two inbreds *viz.*, R-17 and LTRR 5 acted as restorers for PF (FMS 850A) cytoplasm, while 38 inbreds behaved as maintainers. For CMS I (IMS 850 A) cytoplasm, three inbreds i.e., GP-290-5-3, LTRR 5 and GP-322-1 were found to be good restorers whereas five inbreds (PS 3035, 95-C1, PS 1027, GP1-69 and R-587) showed segregation and the rest behaved as maintainers. Similar results of differences in fertility restoring genes for different CMS backgrounds have been reported by Dudhe *et al.* (2009). It could be noted that 19 inbred lines, which acted as restorers for the traditional PET 1 cytoplasm behaved as maintainers for PF and CMS I sources.

Table 1 Maintainer/restorer reaction of different inbred lines in the background of three CMS lines (three sources)

Inbred	PET-I	CMS PF	CMS I
	ARM 243A	FMS 850A	IMS 850A
RHA-859	R	M	M
RHA-6D-1R	R	M	M
RHA-274	R	M	M
RHA-341	R	M	M
PS-3035	M	M	S
R-296	M	M	M
P-356R	R	M	M
3376R	R	M	M
GP-290-5-3	M	M	R
PKV101R	R	M	M
LRHA P2	R	M	M
R-17	R	R	M
LTRR-5	R	R	R
R-288	R	M	M
NDR-7	R	M	M
P-69R	R	M	M
NDOL-2	M	M	M
95-C1	R	M	S
P-70R	R	M	M
R-297	R	M	M
R-273	R	M	M
PS-1027	M	M	S
R-649	R	M	M
R-356	M	M	M
RES-834-1	R	M	M
NDR-4	M	M	M
NDLR-1	R	M	M
GP1-69	M	M	S
R-587	M	M	S
GP-322-1	M	M	R
R-271	M	M	M
GP-33E-4-2	M	M	M
GP-2158-4	M	M	M
R-298	R	M	M
GP2-2086	M	M	M
GP2-1217	M	M	M
GP-472-5-5	M	M	M
R-272-1	R	M	M
GP-2166-5	M	M	M
GP-325-3	M	M	M

R=Restorer; M=Maintainer; S=Segregation

Only one elite inbred LTRR 5 restored fertility in all the three CMS lines and acted as common restorer, this indicated that though CMS lines were different by cytoplasmic background, the fertility restoring gene could be same. The inbred LTRR-5 may be tried with other CMS lines from each source to confirm its universal restoration. Such source is likely to be exploited for isolation of R genes and using them for development of transgenics. While 12 inbreds acted as common maintainers for all the three CMS sources, suggesting the absence of fertility restoration genes in these inbreds. The restorer for one CMS source behaved as maintainer for other source and *vice-versa,* confirming the diversity among the CMS sources and possessing different mechanisms of male sterility. Kukosh (1981) reported that inbreds were found to carry Rf genes and can restore fertility with CMS lines developed with diverse cytoplasmic background. The inbred lines restoring fertility to different forms of CMS sources were found to be most useful in practical breeding programmes.

Four inbreds *viz.*, PS-035, PS-1027, GP-69 and R-587 acted as partial restorer for CMS-I cytoplasm and behaved as maintainers for PET-1 and PF cytoplasm. It is evident from present investigation that few inbreds behaved differently with the three cytoplasmic backgrounds in respect of maintainer and restorer behaviour suggesting the presence of modifying genes influencing the fertility restoration, resulting in partial fertility (Rukmini Devi *et al.*, 2006; Dudhe *et al.*, 2009). The inbred line 95-C1 behaved as partial restorer on CMS I cytoplasm, acted as fertility restorer for PET-1 cytoplasm and behaved as maintainer for PF cytoplasm. Similarly, Thrinadh Kumar (1999) reported that, the inbred line DRS-3 restored fertility in CMS 7-1A and DCMS-6 while maintaining sterility in DCMS-1. Hence, the inbred line 95-C1 is to be studied further for its ability to differentiate between the three CMS sources and the restorer genes in it. Inbred R-17 acted as fertility restorer for PET-1 and PF cytoplasm and behaved as maintainer for CMS I cytoplasm.

These CMS lines can be safely included in the breeding programme to broaden the genetic base of cytoplasmic male sterility in sunflower to avoid the possible risk of susceptibility. The restorers identified will help in exploitation of new CMS sources for hybrid development with better heterosis and diversity of cytoplasm in sunflower. The identified maintainers after testing for their combining ability and agronomic performance will be converted into new cytoplasmic male sterile lines and may be used in sunflower breeding programmes for developing diverse hybrids with better heterosis and resistance to disease and insect pests.

ACKNOWLEDGEMENTS

The authors are thankful to the Directorate of Oilseeds Research, Indian Council of Agricultural Research, Hyderabad, India, for providing the germplasm and extending necessary facilities.

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Short communication

Genotype x environment interaction and stability analysis in castor (*Ricinus communis* L.)

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(Received: July., 2010; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

The genotype x environment interactions were substantial for all the characters of castor (*Ricinus communis* L.) except days to 50% flowering and oil content. The linear components were accounted for major portion of total G x E interactions for all the traits except total length of main raceme, effective length of main raceme and oil content. Among parents, DCS-89 and JI-353 and among hybrids, Geeta x PCS-124, Geeta x DCS-89, JI-353 x DCS-89, Geeta x JI-353 and JI-244 x PCS-124 were the best due to their good stability coupled with high seed yield/plant. Good stability of these superior genotypes for seed yield/plant were synchronized with their stability for yield attributes.

Key words: Castor, G x E interaction, Stability analysis

Genotype and its interaction with prevailing environment is the basic factor determining the final yield. The genotype x environment interaction is particularly important in the expression of quantitative characters, which are controlled by polygenes and are greatly modified by environmental influences. The existence of interaction between genotype and environment was recognized by Fisher and Mackenzie (1923). Better understanding of the relative contribution of cultivars, environments and their interaction as a source of variation could potentially help breeder to develop cultivars with more stable performance as the phenotypic performance of a genotype is not necessarily the same under diverse ecological conditions (Solomon *et al.*, 2008). Therefore, the present study was carried out to identify the superior castor (*Ricinus communis* L.) hybrids for seed yield and component traits suitable for diverse agroclimatic conditions. Identification of stable hybrids will definitely help to enhance the productivity of the castor.

The experimental material consisted of 56 genotypes *viz.*, 10 inbred lines/varieties of castor used as parental lines, 45 F_1 generations of crosses among them using diallel mating design excluding reciprocals and GCH-6 as a standard check. The experimental material was grown in a randomized block design with three replications over three different environments. The environments were created by sowing at three dates i.e., 15 June, 15 July and 15 August during the rainy season of 2008. In each experiment, every entry was accommodated to the plot of one row of 7.2 m length. The rows were spaced at 90 cm apart; keeping plant-to-plant distance of 60 cm. Recommended package of practices were adopted to raise the crop under irrigated conditions. Observations on seed yield and other component traits *viz.*, days to flowering and maturity of main raceme, plant height up to main raceme(cm), nodes up to main raceme, total and effective length of main raceme(cm), number of effective branches/plant, number of capsules/spike, 100 seed weight(g), shelling outturn(%) and oil content(%) were recorded on five randomly selected competitive plants. The mean values were subjected to statistical analysis and the stability analysis was also done Eberhart and Russel (1966).

The analysis of variance revealed significant differences among genotypes for all the traits (Table 1), it indicating presence of sufficient variability in the materials. Significant mean square due to environments indicated differences among environments used. The combined environment and genotype x environment interaction was also significant for seed yield and other traits. Partitioning of genotype x environment interaction into linear and non-linear components revealed the significance of both the components. Higher magnitude of linear component for all the traits suggested that G x E interaction for these attributes was predictable. The present findings were in agreement with those obtained by Patel (2001) for seed yield. However, Manivel and Hussain (2000) and Solanki and Joshi (2003) reported higher magnitude of non-linear component for seed yield in castor.

Phenotypic stability of the genotypes was measured by three parameters *viz.*, mean performance over environments (x), regression coefficient (bi) and deviation from regression (s^2di). The data showed that as many as 17 genotypes (2 parents and 15 hybrids) were found to be stable for seed

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yield/plant, which expressed high seed yield/plant, non-significant linear (bi) and non-linear components (s^2di). These hybrids were also found to be stable for important yield components, 15 hybrids for total and effective length of main raceme each, 24 hybrids for effective branches/plant, 14 hybrids for capsules/spike and 22 hybrids for 100 seed weight were observed to be stable.

Table 1 Analysis of variance for stability parameters for seed yield and its components

Source of variation	d.f.	Days to flowering of main raceme	Days to maturity of main raceme	Plant height up to main raceme (cm)	No. of nodes up to main raceme	Total length of main raceme (cm)	Effective length of main raceme (cm)	Effective branches/ plant	No. of capsules on main raceme	Shelling outturn (%)	100 seed weight (g)	Oil content (%)	Seed yield/plant (g)
Genotype	54	48.14**	76.50**	657.31**	14.81**	186.98**	181.33**	9.71**	482.29**	7.90**	19.75**	1.04**	794.71**
Environment + (G x E)	110	1.93**	11.78**	3.99**	1.62**	2.62**	2.63**	0.56**	23.96**	1.66**	1.49**	0.05	101.63**
Environment (E)	2	65.01*	102.52**	177.86**	55.85**	77.03**	77.03**	14.40**	761.88**	45.92**	6.81**	0.07	3211.69**
G x E	108	0.78	10.13*	0.83**	0.63**	1.27**	1.28**	0.30*	10.54**	0.86**	1.39**	0.05	45.08**
Environment (linear)	1	130.02**	205.03**	355.73**	111.70**	154.07**	154.05**	28.80**	1523.76**	91.84**	13.63**	0.15	6423.38**
G x E (linear)	54	1.01*	14.01**	1.23**	1.02**	1.53	1.51	0.40**	16.59**	1.26**	2.53**	0.03	73.54**
Pooled deviation	55	*0.55**	*6.13***	*0.42**	*0.24*	*0.98***	*1.04***	*0.20*	*4.40***	*0.45**	*0.26*	*0.07*	*16.33***
Pooled error	324	0.47	3.07	0.30	0.95	0.47	0.65	0.48	2.09	0.28	0.69	0.14	9.36

* and ** indicates significant at P=0.05 and P=0.01 levels, respectively

Table 2 Stable parents and hybrids (top ten) identified on the basis of high mean for seed yield/plant and stability parameters

	Parents/Hybrids	Seed yield/plant (g)	bi	S^2di	Stable for component traits
Parents	*DCS-89*	*152.67*	*1.01*	*-24.00*	*DF, DM, Pht, ND, TL, EL, EB++, Sh, SW, Oil*
	JI-353	149.00	0.52	-22.70	DF, DM, Pht, ND, TL, EL, Cap, Sh, SW, Oil
Hybrids	Geeta x PCS-124	168.33	1.30	-23.90	DF, DM, Pht, TL, EL , EB, Cap, Sh, SW, Oil
	Geeta x DCS-89	165.33	1.26	-23.70	DF+, DM, Pht+, ND, TL+, EL, Cap, Sh, SW, Oil
	JI-353 x DCS-89	165.00	1.48	-22.50	DF, Pht, ND, TL, EL, EB, Cap, Sh, SW, Oil
	Geeta x JI-353	163.00	1.93	-22.80	DF, DM, Pht, ND, TL, EL, Cap, Sh, SW, Oil
	JI-244 x PCS-124	160.11	1.90	-15.20	DF, Pht, ND, EB, Cap, Sh, Oil
	JI-342 x DCS-89	160.00	2.58	-21.20	DF, DM, Pht, ND, TL, EL+, EB, Cap, SW, Oil
	JI-357 x PCS-124+	155.67	2.37	-23.90	DF, DM, Pht, ND, TL, EL, EB+, Sh, SW
	JI-342 x JI-353	151.67	1.25	-23.70	DF, DM, Pht, ND, TL, EL, EB, Sh, SW, Oil
	JI-353 x JI-357	150.67	0.05	-6.70	DF, Pht, ND, TL, EL, EB, Cap, Sh+, SW++, Oil
	JI-244 x JI-353	150.56	0.32	5.30	DF, DM, Pht, ND, TL, EL, EB, Sh+, SW, Oil
Environment mean		137.72			
SEm ±		2.90			

+ and ++ indicates stability for favourable and unfavorable environments, respectively

DF = Days to 50% flowering, DM = Days to maturity, Pht = Plant height up to main raceme, ND = Number of nodes up to main raceme, TL = Total length of main raceme, EL = Effective length of main raceme, EB = Number of effective branches/plant, Cap = Number of capsules on main raceme, Sh = Shelling outturn, SW = 100-seed weight, Oil = Oil content

The data also revealed that 3 hybrids JI-244 x JI-342, JI-244 x DCS-89 and JI-357 x PCS-124 were found to be stable under favourable environments having high seed yield/plant, significant regression coefficient (b>1) and non-significant deviation from regression. The top ten high yielding and stable hybrids were listed in table 2 along with high yielding and stable parent DCS-89 and JI-353. It is evident that, these hybrids had high seed yield/plant along with high stability for most of the component traits evaluated. The top ranking hybrid Geeta x PCS-124 recorded stability for days to flowering and maturity of main raceme, plant height up to main raceme, total and effective length of main raceme, effective branches/plant, number of capsules on main raceme, 100 seed weight and oil content whereas, for shelling outturn this hybrid was stable under better environment. All hybrids were stable for higher number (10) of component traits except JI-244 x PCS-124 and JI-357 x PCS-124. Among 45 hybrids, the hybrids JI-244 x JI-342, JI-244 x DCS-89 and JI-357 x PCS-124 were found stable for seed yield/plant under better environmental conditions (Table 2). The hybrid Geeta x PCS-124 registered stability for different traits under better and poor environments. The genotypes which are specially adapted for better or poor environments are due to adaptive plasticity or individual adaptability. The genotype may create different phenotypes in different environments, each of which being better adapted for the situation. This type of behaviour has been well documented in literature.

The mean yield of each genotype depends on particular sample of agronomic practices used for study. It is therefore, suggested that in order to identify suitable genotypes, actual testing over a wide range of environments including poor and good ones would be advantageous; while making selection, attention should be paid to the phenotypic stability of characters directly related to seed yield, particularly number of capsules on main raceme, number of effective branches/plant, total and effective length of main raceme and 100 seed weight, so as to achieve the maximum stability for seed yield/plant in castor.

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Short communication

Evaluation of heterosis for yield and its components in castor (*Ricinus communis* L.)

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(Received: July., 2010; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

Heterosis was studied in a set of 10 x 10 diallel crosses involving 45 F_1s and 10 parents in castor (*Ricinus communis* L.), over better parent and standard check, GCH-6. Among 45 hybrids, DCS-89 x PCS-124, JI-353 x PCS-124 and Geeta x PCS-124 recorded the significant and positive (desirable) heterosis over GCH-6. The cross SKP-42 x JI-371 followed by DCS-89 x PCS-124 and SKP-42 x JI-338 recorded the highest heterobeltiosis for seed yield/plant. The high heterosis for yield in these hybrids was mainly due to high heterosis in one or more of yield component traits.

Key words: Castor, Heterosis, Yield

Castor (*Ricinus communis* L.) is a highly cross pollinated crop in which most of the cultivars have been developed by hybridization followed by selection. The exploitation of heterosis has been an important breeding tool in castor, which became feasible due to availability of stable pistillate lines (Gopani *et al.*, 1968). In Gujarat, real break through in castor production has come with the development and release of hybrids for commercial cultivation. Still there is potential for further enhancement of yield level of castor through genetic improvement. The selection of suitable parents is important for the development of better hybrids. For this, it is always essential to evaluate available promising lines in their hybrid combinations for yield and yield attributing characters (Giriraj *et al.*, 1973). An experiment was laid out to identify the most promising heterotic cross combinations developed in diallel fashion.

The experimental material consisted of 56 genotypes *viz.*, ten inbred lines/varieties of castor used as parental lines, 45 F_1 generations of crosses among them using diallel mating design excluding reciprocals and GCH-6 as standard check. The experimental material was grown in a randomized block design with three replications over three different environments. The environments were created by three dates of sowing i.e., 15 June, 15 July and 15 August during the rainy season of 2008. In each experiment, every entry was accommodated to the plot of one row of 7.2 m. length. The rows were spaced 90 cm apart; keeping plant to plant distance of 60 cm. Recommended package of practices were adopted to raise the crop under irrigated condition. Observations on seed yield and other component traits *viz.*, days to flowering and maturity of main raceme, plant height upto main raceme (cm), nodes upto main raceme, total and effective length of main raceme (cm), effective branches/plant, number of capsules on main raceme, 100 seed weight (g), shelling outturn (%) and oil content (%) were recorded on five randomly selected competitive plants. The mean values were statistically analyzed for heterosis (Fonseca and Patterson, 1968).

Analysis of variance for seed yield and its components in pooled over environments is given in table 1. In present study, the range of most of the characters was wider in the crosses than their parents (Table 2). The extent of heterosis for seed yield ranged from -16.22% to 19.03% over better parent and -28.72% to 12.17% over standard check GCH-6. Out of 45 crosses, 12 over better parent and 3 over GCH-6 exhibited significant positive heterosis for seed yield. Lavanya and Chandramohan (2003), Golakia *et al.* (2004) and Patel and Pathak, (2006) reported similar results for heterosis in seed yield. For oil content, the cross combination SKP-42 x JI-371 recorded significant positive heterosis over better parent. None of the crosses recorded significant positive heterosis over GCH-6 for oil content and 100 seed weight. Absence of heterosis for oil content and 100 seed weight were attributed to the fact that these characters is predominantly governed by additive gene action. The most promising hybrids DCS-89 x PCS-124, JI-353 x PCS-124 and Geeta x PCS-124 (Table 3) manifested significant and desirable heterosis over standard check GCH-6 for all important yield contributing characters *viz.*, effective branches/plant, total and effective length of main raceme, number of capsules on main raceme. This emphasized that high degree of standard heterosis for seed yield/plant might be due to the heterosis observed for important yield

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component traits. High association of heterosis between these characters and seed yield/plant in castor have also been earlier reported by Joshi *et al.* (2001), Thakker *et al.* (2005) and Golakia *et al.* (2008).

Table 1 Analysis of variance for seed yield and its components in pooled over environments

Source of *variation*	d.f.	Days to flowering of main raceme	Days to maturity of main raceme	Plant height up *to main* raceme (cm)	No. of nodes up to main raceme	Total length of *main* raceme (cm)	Effective length of *main* raceme (cm)	Effective branches/ plant	No. of capsules on main raceme	Shelling outturn (%)	100 seed weight (g)	Oil content (%)	Seed yield/ plant (g)
Environments (E)	2	196.12**	308.29**	512.03**	163.46**	221.10**	221.13**	42.44**	2263.22**	139.24**	20.04**	20.32**	9385.46**
Genotypes (G)	54	146.79**	223.65**	2007.72**	45.25**	569.95**	552.53**	29.65**	1445.88**	24.15**	58.64**	3.14**	2369.12**
Parents (P)	9	149.42**	455.53**	4532.49**	82.99**	1122.62**	1070.33**	37.84**	2876.10**	26.28**	105.41**	5.14**	3825.44**
Hybrids (H)	44	148.80**	179.50**	1533.96**	38.53**	430.22**	417.93**	28.36**	1184.20**	23.67**	50.32**	2.79**	1903.18**
P vs. H	1	34.94	79.19**	130.43**	1.01	1744.04**	1814.64**	12.75**	87.90*	25.96**	3.76*	0.73	9763.52**
G x E	108	2.26	30.80**	2.42	1.93*	3.83**	3.87**	0.93*	32.14**	2.58*	4.26**	0.15	137.30**
P x E	18	2.41	1.04	3.95	0.67	1.51	1.70	2.02	16.03*	1.54	11.49*	0.05	76.48*
H x E	88	2.27*	37.58**	2.14*	2.17	4.34	4.36	0.73	36.14**	2.72	2.80*	0.17	150.26**
P vs. H x E	2	0.35	0.92	0.97	2.50	1.82	2.00	0.08	1.17	5.80	3.40	0.14	114.36
Error	324	10.85	9.14	10.50	1.88	1.23	1.44	0.38	15.47	2.49	2.11	0.43	71.31

* and ** indicates *significant at PO=0.05 and P=0.01 levels, respectively*

Table 2 Range of heterosis and number of significant crosses in desirable direction for seed yield and twelve component characters pooled over environments

Character	Range				No. of significant crosses in desirable direction	
	Mean		Heterosis over			
	Parents	Hybrids	Better parent	Standard check	Better parent	Standard check
Days to flowering of main raceme	54.11 – 68.89	48.56 - 68.56	-16.60 – 1.89	-18.62 – 14.71	6	3
Days to maturity of *main* raceme	103.67 – 129.22	108.22 - 125.11	-9.67 – 6.88	-1.02 – 14.43	19	5
Plant height up to main raceme (cm)	41.44 – 123.56	41.56 – 109.22	-22.18 – 20.17	-36.18 – 67.75	12	18
Number of nodes up to main raceme	12.33 – 23.00	12.11 – 22.56	-30.92 – 14.56	-28.76 – 32.68	10	4
Total length of main raceme (cm)	31.78 – 55.22	37.67 – 68.33	-32.42 – 38.47	-24.83 – 36.36	24	12
Effective length of main raceme (cm)	31.78 – 54.22	17.00 – 68.33	-32.42 – 38.47	-24.83 – 36.36	23	12
Effective branches/plant	6.33 – 12.89	6.56 – 16.00	-38.79 – 45.36	-31.40 – 67.36	10	11
No. of capsules on main raceme	39.00 – 97.00	36.33 – 109.33	-48.45 – 26.35	-48.99 – 53.51	10	7
Shelling outturn (%)	61.19 – 65.44	62.16 – 68.58	-6.30 – 3.69	-3.54 – 6.41	0	4
100 seed weight (g)	25.19 – 37.74	27.63 – 37.33	-17.32 – 28.01	-22.37 – 4.88	4	0
Oil content (%)	47.48 – 49.76	47.72 – 50.06	-3.15 – 2.46	-2.72 – 2.05	1	0
Seed yield/plant (g)	95.78 – 154.78	110.56 – 174.00	-16.22 – 19.03	-28.72 – 12.17	12	3

Table 3 Heterosis (%) over standard check, GCH-6 of the best three crosses selected for seed yield along with *per se* performance (parenthesis) (Pooled over environments)

Cross	Days to *flowering of* main raceme	Days to maturity of main raceme	Plant height *up to main* raceme (cm)	No. of nodes up to main raceme	Total length of main raceme (cm)	Effective length of main raceme (cm)	Effective branches/ plant	No. of capsules on main raceme	Shelling *outturn (%)*	100 seed *weight (g)*	Oil content *(%)*	Seed yield/plant (g)
DCS-89 x PCS-124	10.99** (66.22)	9.65** (119.89)	-17.41** (53.78)	3.27 (17.56)	-2.88 (48.66)	-2.88 (48.66)	63.91** (15.67)	16.21 (59.66)	-0.18 (64.33)	4.88 (37.33)	2.05 (50.06)	12.17* (174.00)
JI-353 x PCS-124	6.15 (63.33)	7.22** (117.22)	-10.07* (58.56)	-3.27 (16.44)	36.36** (68.33)	36.36** (68.33)	62.65** (15.55)	22.38* (68.00)	-2.04 (63.13)	-20.34 (28.35)	1.73 ()49.91	8.95* (169.00)
Geeta x PCS-124	4.66 (62.44)	0.41 (109.78)	5.97 (69.00)	22.68** (22.56)	19.51** .(60.22)	17.52** (58.89)	46.44** (14.00)	53.51** (109.33)	-2.56 (62.80)	-22.37 (27.63)	-0.08 (49.02)	8.52* (168.33)

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Short communication

Quality hybrid seed production in castor (*Ricinus communis* L.)

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(Received: September, 2010; Revised: December, 2010; Accepted: February, 2011)

ABSTRACT

In the present study, parental lines of castor (*Ricinus communis* L.) hybrid, DCH-177 i.e., DPC-9 (female line) and DCS-9 (male line) were sown in 3:1 ratio at three different dates to study the influence of environment and growth regulators on sex expression and hybrid seed quality. The dates of sowing showed significant effect on sex expression. September and October sown crop reduced ISF maintaining more number of stable pistillate plants besides high genetic purity and better seed quality. Effect of growth regulators indicated that GA3 promoted ISF while ethrel suppressed the ISF.

Key words: Castor, Ethrel, GA_3, Sex expression

Castor (*Ricinus communis* L.) is an ancient oilseed crop of the world. India is one of the principal producers of castor cultivated in an area of about 0.74 m.ha with a production of 0.79 m.t. Andhra Pradesh is an important castor growing state in rainfed situations and occupies an area of 0.27 m.ha with a production of 0.10 m.t and productivity of 387 kg/ha (Damodaram and Hegde, 2005).

Sex expression in castor is highly influenced by environmental factors like high day temperature, photoperiod, fertility, age of plant, nutrition, etc. (Shifriss, 1960). Such higher susceptibility to environmental factor leads to high sex variants in pistillate lines which creates problem in hybrid seed production.

Occurrence of interspersed staminate flowers (ISF) cause a serious problem in maintaining genetic purity of the hybrid seed. Regulation of ISF by exogenous application of hormones will be of great importance in order to obtain quality hybrid seed. Hence, the present study was taken up to study: (I) the effect of growth regulators on expression of pistillate/staminate flowers and (ii) to find out the influence of environment on sex expression, genetic purity status and quality seed production.

The experiment was carried out to study the influence of exogenous application of chemicals *viz.*, GA_3 and ethrel on sex expression in pistillate line, DPC-9. The parental lines i.e., DPC-9 and DCS-9 were sown in a ratio of 3:1 at monthly intervals in September (15th), October (15th) and November (15th), 2006 in randomized block design at Seed Research and Technology Centre, Rajendranagar with three replications. The chemicals were sprayed as per the doses (Table 1) on the female parental line in each plot at 28 and 45 days after sowing in all monthly intervals. In addition to GA_3 and ethrel, water spray and manual removal of interspersed staminate flowers on seed parent was also imposed.

Recommended package of practices were adopted to grow the crop. The field was uniformly fertilized @ 40 kg N, 40 kg P_2O_5 and 20 kg K_2O/ha. A spacing of 90 cm x 60 cm was adopted. The observations were recorded on number of plants, plant height (cm), the number of ISF in different spike orders i.e., primary, secondary and tertiary, pistillate plant population (%), number of pistillate plants with ISF, length and weight of primary spike, number of capsules/plant, 100 seed weight and seed yield.

Seed quality parameters *viz.*, germination %, total seedling length (cm), seedling vigour index and field emergence index were also recorded. Hundred seeds from each treatment in four replications were subjected to germination test following between paper method. On 10th day, germination % was calculated as per the following formula:

$$\text{Germination \%} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds}} \times 100$$

Ten seedlings from each replication of germination test were selected and root and shoot length was recorded. These seedlings were dried in hot air oven at 80°C for four days and dry weight was expressed in grams (Abdul Baki and Anderson, 1973).

Seedling vigour index on length basis =

Seed germination % x Seedling length (cm)

Seedling vigour index on dry weight basis =

Seed germination % x Seedling dry weight (g)

Field emergence index was recorded on alternate days from 7 to 14 days after sowing in all the treatments. The rate of emergence was determined as per the formula suggested by Baskin (1998).

Grow out test (GOT) was conducted with the seed obtained from primary spike for testing the genetic purity status of the hybrid produced in different environments. In each treatment not less than 400 plants are maintained in all the replications for assessing genetic purity. The observations were made from vegetative phase to reproductive phase. The labeling of the off-types was continued from vegetative phase to reproductive phase, based on morphological characters as per the DUS guidelines. At the end of all the observations, total plant population and off-types were recorded and computed for genetic purity assessment.

The results indicated that occurrence of ISF on primary, secondary and tertiary spike was influenced by dates of sowing. November sown seed parent resulted in more number of ISF compared to September and October sown crop. Similar findings were reported by Lakshmamma *et al.* (2002) and Lavanya (2002). ISF production was more during November as compared to September and October sown crops which might be due to more heliothermal units (HTU) and less number of growing degree days (GDD) during November month. A mean maximum temperature of 31-32°C promote ISF, while low temperatures result in fully female recemes (Ankineedu *et al.*, 1968). The influence of chemical treatments on sex expression revealed that GA_3 @ 100, 200 and 300 mg/l promoted ISF in pistillate parents. Such effect was high during November sown crop. Second order spike recorded more number of ISF with application of 100 ppm GA_3 (Table 1). As the sexual differentiation is closely associated with hormonal and genetic constituents, the realisation of ISF depends on a combination of endogenous and environmental factors. Masculinization by GA_3 was associated with increased growth rate i.e., stem elongation (Khrayanin and Chailakhyan, 1988). Promotion of ISF flowers by exogenous application of GA_3 might be due to reduction of growth inhibitor levels of ethylene and abscissic acid (ABA). Irrespective of dates of sowing, ethrel @ 0.1%, 0.05% and 0.01% were effective which reduced the number of ISF and enhanced the number of pistillate flowers (Table 1). Similar findings were also reported by several researchers in castor (Ramesh *et al.*, 2000; Gopala Krishnamurthy *et al.*, 2003).

October sown seed parent had maximum number of pistillate plants (90.2) followed by September sowing (87.4), while minimum was observed in November (84.5). Production of less number of ISF during October, September months resulted in occurrence of more pistillate plants (Table 1). Similar findings were also reported by Gopala Krishnamurthy *et al.* (2003). Irrespective of the dates of sowing, ethrel treatments had profound influence on maintenance of pistillate plants whereas GA_3 had failed to maintain stable pistillate plants. Similar results were also reported by Lakshmamma *et al.* (2002) and Ramesh *et al.* (2000). In general, GA_3 has tendency to promote male flowers and *vice versa* with ethrel. So, maintenance of pistillate lines might be due to hormonal balance between growth promoters and inhibitors.

In castor, short to medium plant height is desirable since it allows intercultural operations, spraying and harvesting without difficulty. In the present study, September sown crop recorded minimum height and October sown crop recorded maximum plant height. Among the treatments, GA_3 had increased the plant height compared to the other treatments. As GA_3 has tendency to increase internodal length, it increased plant height at all concentrations.

Dates of sowing had significant impact on length of primary spike of the seed parent. There was an increase in length of primary spike in October sown crop (38.9 cm) and minimum spike length was observed in November sown crop (35.6 cm) (Table 2). Among all the treatments, ethrel @ 0.1% recorded maximum spike length (41.5 cm). Minimum spike length (32.9 cm) was recorded with control.

Dates of sowing had also significant impact on weight of primary spike and number of capsules of the seed parent. There was increase in weight of primary spike and number of capsules (55.1) in October sown crop and minimum spike weight and capsules (48.2) was observed in November sown crop. Among all the treatments, ethrel @ 0.1% recorded maximum values (58.3 capsules).

Dates of sowing and treatments have significantly influenced 100 seed weight (Table 2). Among different dates of sowing, maximum 100 seed weight was recorded in October sown crop (26.6 g). Ethrel treatment improved the 100 seed weight. Ethephone might have caused a high degree of femaleness in castor and consequently increased the number of seed output and heavy seeds.

Seed yield (100 g/plant) was maximum in September sown crop as climatic conditions were congenial for production of more pistillate whorls, good seed setting and seed weight (Table 2). It was in agreement with the findings of Kanwar and Bhuvaneshwari (2004) while minimum seed yield (70.8 g/plant) was recorded in November sown crop due to more number of ISF. Treatments had significant impact on seed yield of the seed parent. Ethrel at all concentrations increased the seed yield (69 to 72 g/plant) when compared to control (69.7 g/plant) and other treatments (78.3 to 86.5 g/plant). Increase in seed yield on ethrel spray might be due to more number of pistillate plants and less ISF, effective seed setting, more number of capsules/spike and more seed weight.

Germination % was significantly influenced by dates of sowing. High germination % was recorded by the seeds obtained from October sowing followed by September sowing. The influence of treatments on germination % was found significant where ethrel @ 0.1% recorded high germination %. Both ethrel and GA_3 treatments improved germination % over control, which might be due to activation of enzymes controlling the germination in the developing seed. In addition, they also improved the quality of seed in terms of high germination and vigour.

The vigour parameters *viz.*, field emergence index, root length, shoot length and drymatter production of seedling were almost in the order of preference that were evaluated for seed germination, which could be attributed to the reserve food materials utilized at the time of germination as indicated by the 100 seed weight (Table 3). Similar results due to difference in time of sowing were reported by Ranganayaki (2001). Seed vigour was maximum in the hybrid seed obtained from October sowing (168.7) followed by September sown crop (148.7). Ethrel treatment has improved the seed vigour over the other treatments (Table 4). Similar results were reported by Krishnan and Rao (2005).

Hybrid seed obtained from September (90.2) and October sown (88.1) crop recorded above certification standard genetic purity because of less number of ISF on pistillate parent (Table 2). The genetic purity of castor hybrid when hybrid seed production was taken up during November was found to be sub-standard (83.2%) due to more number of ISF with less number of pistillate plants of seed parent which resulted in selfed plants.

Table 1 Effect of dates of sowing and treatments on number of ISF in different spike orders of castor

Treatment	Primary spike				Secondary spike				Tertiary spike				Pistillate plant population (%)			
	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean
GA_3 @ 100 mg/l	15.0	16.0	20.5	17.2	17.5	19.3	23.5	20.1	10.0	11.0	13.0	11.3	80.5	86.5	80.2	82.4
GA_3 @ 200 mg/l	13.0	17.0	19.0	16.3	11.0	13.0	18.0	14.0	8.0	8.5	9.2	8.6	86.3	89.5	80.5	85.4
GA_3 @ 300 mg/l	10.5	15.0	17.8	14.4	9.0	10.5	13.2	10.9	7.0	7.2	6.9	7.0	91.3	93.6	81.2	88.7
Ethrel @ 0.1%	3.6	3.2	2.5	3.1	3.0	2.6	2.1	2.6	2.3	2.5	1.8	2.2	95.8	96.5	90.5	94.3
Ethrel @ 0.05%	3.8	3.4	2.9	3.4	3.3	2.8	2.0	2.7	1.5	1.9	1.6	1.7	94.5	97.3	90.4	94.1
Ethrel @ 0.01%	4.6	4.2	5.3	4.7	4.2	3.6	3.0	3.6	2.4	2.0	2.1	2.2	90.6	92.0	89.0	90.5
Water spray	4.5	5.0	5.2	4.9	4.5	3.5	3.1	3.7	3.8	2.6	2.0	2.8	86.0	89.5	85.0	86.8
Manual removal of ISF	6.0	4.8	5.9	5.6	5.2	4.3	3.6	4.4	4.2	3.7	3.1	3.7	81.5	84.0	82.0	82.5
Control	5.0	4.3	6.0	5.1	4.8	4.2	3.5	4.2	3.6	4.1	5.0	4.2	80.5	83.0	81.5	81.7
Mean	7.3	8.1	9.5	8.3	6.9	7.1	8.0	7.3	4.8	4.8	5.0	4.9	87.4	90.2	84.5	87.4
	F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2	
SEm±	0.32	0.51	0.81		0.4	0.56	0.98		0.26	0.39	0.53		0.40	0.62	1.11	
CD (P=0.05)	0.68	0.96	1.61		0.81	0.91	1.92		0.48	0.71	0.89		0.81	1.30	2.21	

F_1 = Dates of sowing; F_2 = Treatments

Table 2 Effect of dates of sowing and treatments on yield and yield components and genetic purity of castor

Treatment	Length of primary spike				No. of capsules				100 seed weight (g)				Seed yield (g/plant)				Grow out test			
	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean
GA_3 @ 100 mg/l	40.6	41.9	36.0	39.5	49.3	65.2	47.8	54.1	24.9	26.5	24.5	25.3	99.2	81.0	76.0	85.5	83.5	78.0	65.0	75.5
GA_3 @ 200 mg/l	40.7	42.0	38.0	40.2	54.1	60.0	56.0	56.7	28.3	30.4	26.5	28.4	95.9	88.0	70.0	84.7	85.0	79.5	63.0	75.8
GA_3 @ 300 mg/l	32.0	38.3	39.5	36.6	45.4	49.2	46.0	46.9	18.8	20.5	24.7	21.3	107	81.0	71.0	86.5	87.2	81.2	66.5	78.3
Ethrel @ 0.1%	42.3	43.1	39.0	41.5	60.5	61.5	53.0	58.3	30.4	31.2	23.8	28.5	113	86.0	72.0	90.5	97.0	93.8	93.8	94.9
Ethrel @ 0.05%	32.8	36.1	36.8	35.2	50.8	56.6	51.0	52.8	23.8	25.5	22.5	23.9	107	83.0	70.5	87.1	94.6	94.0	94.0	94.2
Ethrel @ 0.01%	30.9	38.8	35.5	35.1	46.2	51.1	47.0	48.1	25.3	27.6	24.5	25.8	114	81.0	69.0	87.9	92.5	93.5	93.5	93.2
Water spray	34.9	36.0	32.0	34.3	52.8	55.1	46.0	51.3	25.8	28.0	26.0	26.6	96.6	68.0	71.0	78.5	90.8	92.0	92.0	91.1
Manual removal of ISF	35.5	37.2	34.0	35.6	48.8	49.0	44.0	47.3	25.7	27.0	23.0	25.2	95.8	69.0	70.0	78.3	91.2	91.0	91.0	90.0
Control	32.3	36.5	30.0	32.9	47.0	48.0	43.0	46.0	22.2	23.0	21.0	22.1	74.2	67.0	68.0	69.7	90.0	90.0	90.0	90.0
Mean	35.8	38.9	35.6	36.8	50.5	55.1	48.2	51.3	25.0	26.6	24.1	25.2	100	78.3	70.8	83.2	90.2	88.1	83.2	87.2
	F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2	
SEm±	0.13	0.19	0.29		0.19	0.24	0.22		0.17	0.29	0.52		0.82	1.27	2.22		0.86	1.41	5.51	
CD (P=0.05)	0.19	0.28	0.53		0.31	0.43	0.43		0.28	0.49	1.06		1.63	2.49	4.44		1.71	2.68	4.68	

F_1 = Dates of sowing; F_2 = Treatments

Table 3 Effect of dates of sowing and treatments on seed quality parameters

Treatment	Seedling vigour index on dry weight basis				Field emergence index			
	Sep.	Oct.	Nov.	Mean	Sep.	Oct.	Nov.	Mean
GA_3 @ 100 mg/l	60.0	139.0	102.0	100.0	7.8	8.1	7.7	7.9
GA_3 @ 200 mg/l	171.2	188.0	136.8	165.3	9.2	9.4	8.3	9.0
GA_3 @ 300 mg/l	180.7	194.0	147.0	173.7	8.7	8.9	7.8	8.5
Ethrel @ 0.1%	178.8	193.0	133.0	168.2	8.3	8.6	8.0	8.3
Ethrel @ 0.05%	168.5	176.0	139.2	161.2	8.6	9.2	7.9	8.6
Ethrel @ 0.01%	160.6	172.0	143.2	158.6	8.3	8.6	8.0	8.3
Water spray	152.7	163.0	126.7	147.5	8.0	8.3	7.6	8.0
Manual removal of ISF	139.4	158.0	125.7	141.0	7.6	7.8	7.1	7.5
Control	126.2	136.0	108.3	123.5	7.2	7.6	7.0	7.3
Mean	148.7	168.7	129.0	148.8	8.2	8.5	7.7	8.1
	F_1	F_2	F_1xF_2		F_1	F_2	F_1xF_2	
SEm±	0.86	0.93	1.34		0.05	0.14	0.31	
CD (P=0.05)	1.86	2.17	3.36		0.11	0.26	0.49	

Irrespective of dates of sowing, female plants with ISF were observed indicating the involvement of some inherent factors in sex expression which created problems during hybrid seed production leading to more amount of selfed seed in hybrid seed lots, resulting in low genetic purity. Suppression of ISF is essential for obtaining better quality seed with high genetic purity which has to be manipulated either by growth regulators or dates of sowing.

Hybrid seed obtained from GA_3 sprayed plots recorded very low (75.5 to 78.3%) genetic purity. This could be due to production of more number of ISF during seed production. Ethrel has resulted in seed with high standard genetic purity (93.2 to 94.9) due to suppression of ISF and maintenance of pistillate plants. Hybrid seed obtained from control plots (90.0) also had above certification standard genetic purity because of congenial climatic factors.

From the present study it is concluded that September and October sown crop reduced ISF maintaining more number of stable pistillate plants besides high genetic purity and better seed quality indicating that September-October sowings were congenial for quality hybrid seed production. GA_3 promoted ISF while ethrel suppressed the ISF. Ethrel @ 0.1% is recommended for production of better quality hybrid seed. Though manual removal of ISF in seed parent also resulted in high genetic purity and good seed quality it is not feasible when the crop is raised over a large area.

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Analysis of genetic divergence in safflower (*Carthamus tinctorius* L.)

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(Received: February, 2010; Revised: April, 2011; Accepted: May, 2011)

ABSTRACT

Fifty safflower (*Carthamus tinctorius* L.) genotypes were evaluated for 10 seed yield and yield attributing characters to study the genetic diversity existing among them by using Mahalanobis D^2 statistics. The genotypes were grouped into eight clusters. The maximum inter-cluster distance was observed between cluster II and cluster VIII (712.48), while the least distance was noticed between clusters V and VI (101.89). Among the ten characters evaluated, days to 50% flowering, seed yield/plant and diameter of main capitulum were important since they together contributed 82.2% towards the total divergence. Genotypes from cluster II and cluster VIII could be involved as parents in hybridization programme to exploit heterotic combinations and release good recombinants for future breeding programmes.

Key words: D^2 statistics, Genetic divergence, Safflower

Safflower (*Carthamus tinctorius* L.) is an important oilseed crop which is also used in the manufacture of carthamin dye. There exists abundant variability among the safflower germplasm collections for various traits which need to be harnessed for breeding high yielding varieties. However, the proper and precise utilization of these lines in breeding programmes depends on their characterization for qualitative and quantitative traits. The success of any hybridization programme depends upon the choice of parents of diverse origin. The importance of selection of parents on the basis of genetic distance to get heterotic effect in F_1 generation and higher frequency of better segregants in subsequent generations has been reported by earlier researchers in oilseed crops like groundnut (Sangha, 1973), sesamum (Trehan *et al.*, 1975), *rai* (Yadav *et al.*, 1973) and linseed (Pyasi, 2000). Multivariate analysis is an important biometrical technique for quantifying the degree of divergence among different genotypes. Mahalanobis's D^2 statistics (1936) as described by Rao (1952) has been successfully used by plant breeders in different crops for isolating genetically diverse genotypes. In the present study, an attempt has been made to utilize this useful technique for selection of parents for hybridization in safflower breeding programme.

The experimental material comprised of 46 safflower germplasm accessions and four released varieties *viz.*, Bhima, Manjira, JSI-7 and A-1 as checks. The experiment was conducted at the College Farm, College of Agriculture of Acharya N.G. Ranga Agricultural University, Rajendranagar, during the winter season of 2008. The experiment was laid out in a randomized block design with three replications. Each germplasm accession was represented by two rows of 3m length. The spacing between two successive rows was 45cm and between plants in a row was 20cm. The data was recorded on five randomly selected plants of each germplasm accession for seed yield and yield attributing traits *viz.*, days to 50% flowering, plant height (cm), diameter of main capitulum (mm), number of effective capitula/plant, number of filled seeds in main capitulum, 100 seed weight (g), biological yield (g), hull content (%) and seed yield/plant. Mahalanobis's D^2 technique as described by Rao (1952) was used to classify the 50 genotypes of safflower into different clusters on the basis of genetic diversity existing in them.

Through multivariate analysis, the 50 genotypes based on D^2 values were grouped into eight clusters (Table 1). The composition of different clusters varied from 2 to 13 genotypes. Cluster I comprised of 13 genotypes followed by cluster III which consisted of 11 genotypes. Clusters IV and VIII consisted of three genotypes each. The remaining clusters *viz.*, V, VI and VII had six genotypes each and cluster II had two genotypes. The average intra-cluster distance (Table 2) revealed that the genetic diversity among genotypes in cluster VII was minimum (60.78) followed by cluster VI (63.47). The maximum intra-cluster distance (91.73) was observed in cluster II, hence selection within this cluster might be carried out on the basis of highest mean for the desirable traits. The relative divergence of each cluster from other clusters (inter-cluster distance) indicated high order of divergence between cluster II and cluster VIII (712.48) followed by that between cluster I and cluster VIII (645.33). Hence, selection of parents from these clusters for hybridization programme would help create novel recombinants with maximum hybrid vigour. Hybridization between genetically distant genotypes to generate promising breeding material has been suggested by Sankarapandian *et al.* (1996).

There was a wide range of variation in the cluster mean values for most of the characters under study (Table 3). Cluster IV had highest mean values for plant height, diameter of main capitulum and 100 seed weight. Cluster VIII recorded highest mean values for number of filled seeds in main capitulum, biological yield/plant and seed yield/plant. The contribution of individual characters towards the divergence (Table 4) indicated that days to 50% flowering contributed maximum (53.31%) towards diversity followed by seed yield/plant (17.06%), diameter of main capitulum (11.84%), biological yield (8.41%), number of filled seeds in main capitulum (3.02%), plant height (2.69%), number of effective capitula/plant (1.63%), oil content (1.14%), 100 seed weight (0.49%) and hull content (0.41%). Thus, three characters, days to 50% flowering, seed yield/plant and diameter of main capitulum were important since they together contributed 82.21% towards the total divergence. In sunflower, Narsaiah (1995) reported that seed yield and plant height are the important contributing characters to total divergence.

Crosses involving divergent parents are likely to yield desirable recombinants. Based on the information generated in this study, the genotypes GMU-2021 and GMU-2282 forming cluster II when crossed with genotypes GMU-3130, GMU-3144 and GMU-3146 of cluster VIII (exhibiting maximum inter-cluster distance) are expected to give rise to promising segregants for seed yield and hence may be used in future breeding programmes for improvement of yield in safflower.

Table 1 Distribution of germplasm lines of safflower into different clusters by Mahalanobis's D^2 technique

Cluster No.	No. of genotypes	*Germplasm accession numbers*
I	13	GMU 2014, 2015, 2171,2172, 2173, 2134, 2039, 2177, 2325, 2336, 2285, 2272, 2274
II	2	GMU-2021, 2282
III	11	GMU 2046, 2048, 2129, 2133, 2286, 2318, 2320, 2358, 2357, Bhima, Manjira
IV	3	GMU 2328, 2368, A-1
V	6	GMU 2276, 2312, 2322, 2342, 2347, 2353
VI	6	GMU 2276, 2312, 2322, 2342, 2347, 2353
VII	6	GMU 2364, 2367, 3142, 3150, 3454, JSI-7
VIII	3	GMU 3130, 3144, 3146

Table 2 Average intra (bold) and inter-cluster distances of safflower genotypes through Euclidean cluster distances

	I	II	III	IV	V	VI	VII	VIII
I	**65.05**	151.26	373.26	350.00	497.59	538.05	328.93	645.33
II		**91.73**	179.30	246.19	294.59	345.96	277.05	712.48
III			**77.18**	124.78	158.96	147.70	181.00	531.06
IV				**88.31**	242.86	166.27	129.73	349.92
V					**78.70**	101.89	180.23	466.55
VI						**63.47**	122.93	318.64
VII							**60.78**	219.60
VIII								**86.00**

Table 3 Cluster means for ten characters of 50 safflower genotypes

Cluster	Days to 50% flowering	Plant height (cm)	No. of effective capitula/ plant	Diameter of main capitulum (mm)	No. of filled seeds in main capitulum	100 seed weight (g)	Biological yield/plant (g)	Hull content (%)	Oil content (%)	Seed yield/ plant (g)
I	91.75	86.70	20.12	21.85	18.56	5.26	56.20	36.55	23.16	17.11
II	86.00	82.56	16.17	21.63	16.10	4.96	41.84	34.80	24.87	12.85
III	78.88	86.64	18.78	23.36	18.45	5.40	47.16	37.04	23.10	14.58
IV	80.33	92.71	17.32	25.05	18.59	5.96	60.18	43.40	24.41	17.14
V	75.83	80.66	18.19	19.43	19.01	5.56	58.83	36.06	22.82	17.30
VI	74.50	80.77	18.57	21.78	17.46	5.18	68.02	39.92	23.21	20.87
VII	79.94	87.53	22.36	21.98	19.58	4.78	72.24	49.37	23.35	21.91
VIII	79.22	88.26	18.51	22.88	24.55	5.54	105.51	46.51	23.68	34.34
Mean	81.84	85.64	19.25	22.14	18.84	5.31	60.49	39.48	23.31	18.47

Table 4 Contribution of different characters towards genetic divergence (D^2) among 50 genotypes of safflower

Character	No. of times ranked first	% contribution towards divergence
Days to 50 % flowering	653	53.31
Plant height (cm)	33	2.69
No. of effective capitula/plant	20	1.63
Diameter of main capitulum (mm)	145	11.84
No. of filled seeds in main capitulum	37	3.02
100 seed weight (g)	6	0.49
Biological yield/plant (g)	103	8.41
Hull content (%)	5	0.41
Oil content (%)	14	1.14
Seed yield/plant (g)	209	17.06

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Character association and path analysis in safflower (*Carthamus tinctorius* L.)

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(Received: February, 2009; Revised: February, 2010; Accepted: March, 2011)

ABSTRACT

Sixty safflower (*Carthamus tinctorius* L.) accessions and four checks were evaluated for eight quantitative traits in a simple lattice (8x8) design with two replications. Correlation studies revealed positively significant relationships between seed yield and number of filled seeds in main capitulum, diameter of main capitulum, oil content and days to 50% flowering. Diameter of main capitulum exhibited highly significant and positive correlation with number of filled seeds in main capitulum and oil content. Number of filled seeds in main capitulum recorded the highest direct effect on seed yield, which was followed by 100 seed weight and oil content. Number of filled seeds in main capitulum also recorded the highest direct effect on seed yield hence this trait can be considered as the most important one for the improvement of seed yield in safflower.

Key words: Correlation, Direct effects, Path coefficient, Safflower

Selection is one of the principal tools of crop improvement. The effectiveness of selection for a particular trait depends upon the extent of direct or indirect effects of the trait on seed yield. Therefore, knowledge of interactions among the characters is very essential to determine the extent and nature of relationship between yield and its contributing characters. The present study has been undertaken with the objective of estimating the phenotypic correlation between different quantitative traits and carrying out path coefficient analysis to estimate the direct and indirect contribution of component traits on seed yield in safflower (*Carthamus tinctorius* L.).

The experimental material consisted of 60 exotic germplasm accessions and four cultivated check varieties obtained from safflower germplasm management unit (GMU) of the Directorate of Oilseeds Research (DOR), Hyderabad. The experimental material was laid out in a simple lattice (8x8) design with two replications at College Farm, College of Agriculture, Acharya N.G. Ranga Agricultural University, Hyderabad. Each genotype was sown in three rows of 2m length with a spacing of 45 cm x 20 cm. Recommended agronomic practices and prophylactic measures were adopted for growing a good crop.

Data were recorded for 8 quantitative traits on 10 competitive plants over two replications and mean values were used for analysis. The phenotypic correlation coefficients were calculated by working out the variance components of each character and the covariance components for each pair of characters using the formula suggested by Al-Jibouri *et al.* (1979). The direct and indirect effects were estimated by taking seed yield as the dependent variable, using path coefficient analysis suggested by Wright (1921) and elaborated by Dewey and Lu (1959).

Positive significant relationships were found between seed yield and number of filled seeds in main capitulum (0.840), diameter of main capitulum (0.407), oil content (0.340) and days to 50% flowering (0.220) (Table 1). Of these, similar results for the trait-number of filled seeds in main capitulum were also reported by Bagheri *et al.* (2001), Diwakar *et al.* (2006) and Mahasi *et al.* (2006). Among the component traits, days to 50% flowering was significantly and positively associated with plant height (0.583), diameter of main capitulum (0.535), oil content (0.260) and number of filled seeds in main capitulum (0.222). Plant height exhibited a significant and positive correlation with diameter of main capitulum (0.413), oil content (0.270) and number of filled seeds in main capitulum (0.233). Diameter of main capitulum indicated a highly significant positive association with number of filled seeds in main capitulum (0.348) and oil content (0.306). Number of filled seeds in main capitulum exhibited a highly significant positive association with oil content (0.303), however it recorded a significant negative correlation with 100 seed weight (-0.314). This indicates that selection for maximum diameter of main capitula can result in improvement of seed yield since the trait number of filled seeds in main capitulum exhibited a highly positive correlation with seed yield.

The interrelationship between different traits especially the direct and indirect effects of different traits were estimated by path coefficient analysis in respect of seed

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yield. The results revealed that number of filled seeds in main capitulum had the highest direct effect on seed yield (0.848) which was followed by 100 seed weight (0.154), oil content (0.108), diameter of main capitulum (0.095) and number of effective capitula/plant (0.026) (Table 2). Days to 50% flowering (-0.035) and plant height (0.064) recorded negative direct effects on seed yield/plant. These results are in agreement with the findings of Patil (1998) and Diwakar *et al.* (2006). Number of filled seeds in main capitulum recorded a high positive correlation and highest direct effect on seed yield and can be considered the most important trait for improvement of seed yield in safflower.

Table 1 Estimates of phenotypic correlation coefficients between seed yield and its contributing characters

Character	Days to 50% flowering	Plant height (cm)	No. of effective capitula/ plant	Diameter of main capitulum (mm)	No. of filled seeds in main capitulum	100 seed weight (g)	Oil content (%)	Seed yield/plant (g)
Days to 50% flowering	1.000	0.583**	-0.103	0.535**	0.222*	0.178*	0.260**	0.220**
Plant height (cm)		1.000	0.105	0.413**	0.233**	-0.042	0.270**	0.178*
No. of effective capitula/plant			1.000	-0.138	-0.069	-0.091	-0.004	-0.063
Diameter of main capitulum (mm)				1.000	0.348**	0.210*	0.306**	0.407**
No. of filled seeds in main capitulum					1.000	-0.314**	0.303**	0.840**
100 seed weight (g)						1.000	-0.121	-0.112
Oil content (%)							1.000	0.349**
Seed yield/plant								1.000

* = Significant at 5% level; ** = Significant at 1% level

Table 2 Estimates of path coefficients between seed yield and its contributing characters

Character	Days to 50% flowering	Plant height (cm)	No. of effective capitula/plant	Diameter of main capitulum (mm)	No. of filled seeds in main capitulum	100 seed weight (g)	Oil content (%)	Seed yield/ plant (r)
Days to 50% flowering	-0.035	-0.037	-0.002	0.051	0.188	0.027	0.028	0.220*
Plant height (cm)	-0.020	-0.064	0.002	0.039	0.198	-0.006	0.029	0.178*
No. of effective capitula/plant	0.003	-0.006	0.026	-0.013	-0.058	-0.014	-0.005	-0.063
Diameter of main capitulum (mm)	-0.018	-0.026	-0.003	0.095	0.295	0.032	0.033	0.407**
No. of filled seeds in main capitulum	-0.007	-0.014	-0.001	0.033	0.848	-0.048	0.032	0.840**
100 seed weight (g)	-0.006	0.002	-0.002	0.020	-0.266	0.154	-0.013	-0.112
Oil content (%)	-0.009	-0.017	-0.001	0.029	0.257	-0.018	0.108	0.349**

Diagonal values (Bold) indicate direct effects; Residual value = 0.455; *=Significant at 5% level; **=Significant at 1% level

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Short communication

Effect of integrated nutrient management in safflower (*Carthamus tinctorius* L.) under lateritic soils of West Bengal

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(Received: November, 2010; Revised: December, 2010; Accepted: February, 2011)

ABSTRACT

A field experiment was conducted with safflower (*Carthamus tinctorius* L.) variety A-1 during the winter season of 2006 in red and lateritic soils of West Bengal. The experiment consists of eight treatments which was laid out in randomised block design (RBD) and replicated thrice. Integration of organic (vermicompost) and biofertilizer (*Azotobacter*) with the different inorganic recommended dose (RD) performed the best in terms of growth attributes, yield attributes, seed yield and stover yield of safflower. Combination of 75% RD + 25% N as vermicompost + *Azotobacter* is the best treatments.

Key words: Nutrient management, Safflower, Seed yield

India occupies premier position in the world in terms of total acreage of safflower (*Carthamus tinctorius* L.) (4.3 lakh ha) with an average productivity of 465 kg/ha. The crop is cultivated primarily for its seed which yields edible oil. The safflower crop is usually grown in the winter season as a rainfed crop on residual soil moisture. Poor crop management under input starved conditions is the most important reason for low yield/ha. Under optimum soil moisture condition and management levels, responses to nitrogen (N) was found to be around 60 kg/ha. The phosphate (P) requirement of safflower is moderate. Seed oil content increases with an increased P rates when applied along with 60 kg N/ha (Zaman, 1988). Integrated nutrient supply and management system aimed at sustainable crop production by the combined use of inorganic fertilizers and biofertilisers to promote the inherent nutrient supplying capacity of the soil are imperative.

A field experiment was carried out under red and lateritic soil of Agricultural Research Farm of Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, West Bengal during winter season of 2006. The soil was sandy loam with pH 5.8, organic carbon 0.32 %, available N 252.4 kg/ha, available P_2O_5 50.4 kg/ha and available K_2O 172.6 kg/ha. The experiment was laid out in randomised block design where each treatment was replicated thrice. There were eight treatments (Table 1). Nitrogen, phosphorus and potassium were applied as urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. Vermicompost, SSP, MOP and 3/4th of urea according to treatment doses was applied as basal and rest 1/4th urea was applied as top dressing at 60 days after sowing (DAS). Biofertilizer, *Azotobacter* was applied at 30 DAS. The crop was sown in the month of December, 2006 and irrigation was given just after sowing to ensure good germination. The safflower variety Annigeri - I was sown and a spacing of 45 cm x 15 cm was maintained. In addition to the irrigation at sowing, the crop received two more irrigations at 30 and 85 DAS. All other package of practices were followed as per the recommendations. The crop was harvested at 133 DAS. Seed yield and other yield parameters were computed.

The growth parameters like plant height, leaf area index (LAI) at 120 DAS and crop growth rate (CGR), net assimilation rate (NAR) between 90-120 DAS are presented in the table 1. At 120 DAS, the highest plant height of 63.4 cm was recorded in the treatment F_7 which was significantly higher than all other treatments. Higher plant height were recorded in the F_4. It was closely followed by the application of F_8. The lowest plant height was observed in F_3. From the different fertility levels, it was indicated that combination of organic fertilizer with inorganic fertilizer had a special effect on plant height. Similar finding was recorded by Das Reddy *et al.* (2001) where green manuring by sunhemp resulted greatest average plant height (68.5cm) of safflower.

The highest value of LAI at 120 DAS (0.75) was recorded in F_7 which was statistically at par with that observed in F_8 and F_4. The lowest value (0.49) was recorded in treatment F_3. Among the treatments, combined application of vermicompost and *Azotobacter* was found to perform the best at different crop growth stages which may be attributed to mineralization of plant nutrients in higher amounts resulting in more availability of plant nutrients.

Between 90-120 DAS, the highest CGR of 5.63 g/m^2/day was recorded in the treatment F_7 which was significantly higher than all other treatments. It was closely followed by

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the application of F_4, F_8 and F_1. The lowest crop growth rate was observed in the treatment F_3. However, the highest NAR values (5.35 g/m^2/day) during 90-120 DAS were recorded in F_3.

At harvest, the data on number of capitula/plant, number of seeds/capitula were statistically analysed and presented in table 1. The highest number of capitula (14.3) was recorded in treatment F_7. It was closely followed by F_4. The use of different recommended levels with the combination of vermicompost and biofertilizer performed the best in terms of number of capitula/plant also which may be due to mineralization of plant nutrients in higher amounts resulting in more available and in adequate quantity. The lowest number of capitula/plant was recorded in F_3. The highest number of seeds/capitula (24.0) was obtained in F_7 and was significant among the other treatments tested. The lowest number of seeds/capitula was observed in F_3.

Seed yield, stover yield and harvest index of safflower were presented in table 1. The highest seed yield (441.3 kg/ha) was recorded in F_7 which was statistically at par with the seed yield of F_4 and was significantly higher than all other treatments. It might be attributed to production of higher magnitudes of yield attributing characters (*viz.*, capitula/plant, seeds/plant and test weight). It may due to supply of nutrient in an integrated manner which leads to soil and crop sustainability by balanced application of nutrients, as they also supply adequate micronutrients for the crop needs which is also a prerequisite to increase fertilizer use efficiency (Singh and Chauhan, 1999). Similar finding was also reported by Mishra *et al.* (2006) where maximum seed yield was obtained with the residual effect of 75% recommended nitrogen + 25% N as cow dung urine. The application of F_1 and F_8 showed at par values in terms of seed yield (kg/ha).The lowest seed yield was recorded in F_3 treatment.

The highest stover yield (1450 kg/ha) was recorded in F_7 treatment. The highest stover yield was closely followed by F_4 and F_1. The treatments F_2, F_5 and F_6 were at par in stover yield. The lowest stover yield (845 kg/ha) was recorded in F_3 treatment.

Among the treatments, F_7 recorded the highest harvest index (23.3) followed by F_4 (22.3). The treatments F_1 and F_5 were at par in terms of harvest index. The lowest harvest index (17.6) was recorded in F_3. Combination of inorganic, organic and biofertilzer treatments was found to perform the best in terms of seed yield, stover yield and harvest index. This might be due to mineralization of plant nutrient in higher amounts resulting in more availability of plant nutrients.

From the experimental finding it is concluded that, among the treatments, use of 75% RD + 25% N as vermicompost + *Azotobacter* (F_7) showed the better performance with regards to growth and yield attributes, seed and stover yield of safflower in red and lateritic soils of West Bengal.

Table 1 *Effect of integrated nutrient management levels on growth and yield components of safflower*

Treatment	Plant height (cm) at 120 DAS	LAI at 120 DAS	CGR at 90-120 DAS	NAR at 90-120 DAS	No. of capitula/ plant	No. of seeds/ capitula	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
F_1- 100 %RD(40:40:20)	59.3	0.63	4.98	5.17	11.7	21.66	326	1222	20.9
F_2- 75% RD	54.2	0.57	4.61	5.14	9.3	20.00	284	1047	19.4
F_3- 50% RD (20:20:10)	51.3	0.49	4.11	5.35	7.7	19.66	231	845.0	17.6
F_4- 75% RD (30:30:15) +25%N(vermicompost)	62.3	0.69	5.22	4.75	13.0	22.66	391	1357	22.3
F_5- 50% RD (20:20:10)+50% N(vermicompost)	53.6	0.65	4.79	4.99	11.0	20.66	253	1082	19.2
F_6- 100 %RD(40:40:20) + *Azotobacter*	58.9	0.61	4.65	5.05	10.3	20.66	276	1027	18.9
F_7- 75% RD (30:30:15) +25%N (vermicompost) +*Azotobacter*	63.4	0.75	5.63	4.71	14.3	24.00	441	1450	23.3
F_8- 50% RD (20:20:10)+50% N(vermicompost)+ *Azotobacter*	60.5	0.66	5.11	5.18	11.7	21.00	322	1123.0	21.0
SEm ±	0.9	0.03	0.08	0.16	0.8	0.84	17	55.2	0.6
CD (P=0.05)	2.7	0.09	0.24	0.48	2.4	2.54	54	167.2	1.8
CV (%)	2.5	5.88	2.83	5.82	12.7	6.85	9	8.	5.0

RD = Recommended dose

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Short communication

Stability analysis for seed yield in linseed (*Linum usitatissimum* L.) under rainfed conditions

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(Received: September. 2010; Revised: March. 2011; Accepted: May, 2011)

ABSTRACT

Stability of eight linseed (*Linum usitatissimum* L.) genotypes for seed yield and oil content (%) was studied. The variance for individual and pooled environments showed that mean sum of squares due to genotypes was non-significant for seed yield and oil content. The non-significant genotype and environment interaction was observed for both the characters. Environment (linear) interaction component was significant for seed yield and non-significant for oil content. The variance due to pooled deviation (non linear) was highly significant for seed yield and oil content. Varieties T-397 and R4116 were stable for seed yield. The genotypes R4115 and T397 were found stable for oil content.

Key words: Linseed, Oil, Stability, Yield

The presence of genotype x environment interaction (g x e) poses a serious problem in selection of genotypes of any crop species as the estimates of genetic variance are biased. Since, linseed (*Linum usitatissimum* L.) is grown under rainfed conditions in Bastar plateau zone of Chhattisgarh, the yield levels suffer due to highly fluctuating environments. Inadequate information is available on adaptability of linseed genotypes to seasonal and environmental variations. Hence, the present investigation was undertaken to determine genotype x environmental interaction, stability parameters, identify the stable and responsive genotype (s) with respect to seed yield and oil content in linseed. Presence of large amount of genotype x environmental interaction nullifies selection of lines based on mean performance under a particular environment. Therefore, emphasis should be given on stable performance of a line over different environments (Yadav *et al.*, 2002).

The present study was undertaken with eight linseed genotypes namely R-4113, R-4114, R-4115, R-4116, R-4116 along with released varieties T-397, R-552 and IA-32. These were tested for three consecutive years (2007-08, 2008-09, 2009-10) at research field of Shaheed Gundadhur College of Agriculture and Research Station, Jagdalpur, Chhattisgarh. The experiment was conducted under rainfed conditions and a randomized block design with three replications was adopted. The plot size was 10 rows of 5 m length each, spaced at 30cm apart. Seeds were sown in second fortnight of October. Statistical analysis was performed on the basis of mean value of each plot pooled over 3 years. The stability analysis was done using model suggested by Eberhart and Russel (1966).

The analyses of variance for individual and pooled environments showed that mean sum of squares due to genotypes were non-significant for both the characters (Table 1). The analysis indicated that genotype interacted strongly with the environment.

Non-significant differences among genotypes were observed for seed yield (kg/ha) and oil content (%). The non-significant genotype x environment interaction was also recorded for all the studied characters by Adunga and Labuschange (2004)

Environment (linear) interaction component was significant for seed yield (kg/ha) and non-significant for oil content (%).The variance due to pooled deviation (non linear) was highly significant for both the characters.

The mean, regression coefficient (bi) and deviation from regression (S2di) for seed yield (kg/ha.) and oil content (%) are presented in table 2.

In the present investigation, the magnitude of regression coefficient (bi) and deviation from regression varied from genotype to genotype. The first group consisting the genotypes which have high mean value, bi is equal to unity and S2di non significantly deviated from zero were considerable as stable genotypes over all the environments studied.

The variety T-397 was stable for oil content (%).The genotypes which are showing high mean value than over all mean but exhibiting above average stability with bi >1 comes under the second group, indicated that they were highly sensitive to environmental conditions. The genotypes T-397 and R-4116 stable for seed yield.

The third group consisting the varieties /genotypes, which are showing high mean value than the population mean and exhibiting below average in stability with bi <1, indicating that these genotypes were least sensitive to environmental conditions. Genotype R-4115 (oil yield %) comes under third group. Hence, adapted for poor environment as suggested by Adunga and Labuschange (2004).

Table 1 Pooled analysis of variance (mean square) for seed yield (kg/ha) and oil content (%) in linseed

Source of variation	d.f.	Seed yield (kg/ha)	Oil content (%)
Genotype	7	15426.71	3.60
Environment	2	343520.74**	3.54
G x E	14	12618.74	10.53
Environment (linear)	1	687041.49**	7.08
G x E (linear)	7	13435.79	7.83
Pooled deviation	8	10326.48**	11.57 **
Pooled error	42	2065.71	0.44

*,** significant at 5% and 1% levels, respectively

Table 2 Estimates of different stability parameters for seed yield (kg/ha) and oil content (%) in linseed

Genotype	Seed yield (kg/ha)			Oil content (%)		
	($\bar{x}$)	bi	S^2di	($\bar{x}$)	bi	S^2di
R-4113	593.00	0.91	9435.4*	37.32	0.92	2.38*
R-4114	525.81	1.15	3267.2	36.96	2.88	10.40**
R-4115	513.40	1.16	-1668.4	36.94	- 1.35	0.85
R-4116	596.00	1.28	1834.2	34.28	2.24	25.87**
R-4119	582.91	0.73	11192.6*	36.16	2.01	16.13**
T-397	670.00	1.62	6352.9	36.95	- 5.03	0.20
R-552	427.60	0.32	3409.7	36.41	1.64	21.45**
IA-32	570.32	0.78	31662.3**	34.87	4.67	11.79**
Mean	559.90	1.0		36.24	1.0	
SEm±	71.9	0.3			3.6	

*,** significant at 5% and 1% levels, respectively

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BOOK REVIEW

Compendium of Plant Virus, Phytoplasma and viroid diseases research in India (1903 - 2008)

The authors has painstakingly collected a large pool of references from multiple sources of reviews and also through personal contact and requests made and carefully sorted all the publications in the theme areas of plant virus, phtoplasma and virod diseases that are present in India. The compilation presented the publications on the subject theme starting from 1903-2008. The book has been arranged in five major parts: glimpses of plant virus research in India, listing of plant viruses, phtoplasma and virod diseases reported from India, References, host pathogen Index and Author's Index.

Authors have expressed their source of inspiration for such work as "Bibliography of plant viruses and Index to Research" by Helen Pandy published in 1976. It is not understandable why and how the authors choose the period 1903-2008. A question automatically will arise in the mind of readers why it was not from 1900-2008? One more deviation from the normal book publication is absence of "Contents" in the book. Similarly book accommodated the photographs of some of the Scientists responsible for progress of plant virus research in India which do not reflect the authors thoughtful inclusion of names. Some of them in the list are still struggling to establish themselves in the field and figuring them in the list does not really pay the respect to the stalwarts.

Notwithstanding these deviations, the book will be very useful to the students and researchers in the field of virology. However, high price of the book (₹1200/-) may come in the way of those who wants to include it in their personal library.

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OBITUARY

Dr. Santosh Kumar, Breeder (Castor), Zonal Agril. Research Station, Kumhrawand Farm, Jagdalpur-494 005, Bastar, Chattisgarh passed away in a massive bomb blast. Dr. Kumar has been instrumental in coordinating castor research in AICRP (Castor) Centre at Jagdalpur. His contributions for the improvement of castor research are commendable. The Indian Society of Oilseeds Research convey their heartfelt condolences to the bereaved family.

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Printed & Published by General Secretary on behalf of The Indian Society of Oilseeds Research,
Directorate of Oilseeds Research, Rajendranagar, Hyderabad-500 030, India,
Ph : (040) 24016141/24015345; Fax : (040) 24017969
Web site: http://www.isor.org.in; E-mail: oilseedsociety@gmail.com
Computer Typesetting : **Sasi Graphics**, Rajendranagar, Hyderabad Printed by **M/s Progressive Press Pvt. Ltd**, Hyderabad