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Short Communications

Review

Reviving horizontal area expansion of sunflower (*Helianthus annuus* L.) in rice fallow ecosystems - a relook

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ABSTRACT

Rice is cultivated during *kharif* season in Southeast Asia, but a large chunk remains uncultivated or left fallow in the subsequent season due to several reasons, the major being the water scarcity. Sunflower is cultivated in these rice fallows in the states of Karnataka, Andhra Pradesh, Telangana, Odisha, and West Bengal and to a limited extent in other states. This is an opportunity for horizontal expansion of sunflower area to increase the edible oil production in the country. The initial spurt in area since 1970-71 has experienced a sharp decline in spite of sunflower being one of the most preferred edible oils in the rural, urban and peri-urban households. Unlike the popular *utera* method for pulses, sunflower cultivation needs special attention. Concerted and focused research efforts are needed for fine-tuning the production technology of sunflower under rice fallow. The recent success stories of co-culturing honey bee with sunflower as a community initiative in Nizamabad district of Telangana state need to be extended to other sunflower growing regions of the country. This review critically appraises the rice fallow environments in general, determinants of sunflower production in this fragile eco-system and efforts needed for successful area-cum-production growth of sunflower crop in the country.

Keywords: Drought stress, Low land rice, Microclimate, Rice fallow, Rice stubble, Sunflower, Zero tillage

In order to cope-up with the current consumption level of 19 kg of edible oil per person per year, actual demand is pegged at 25 million tonnes of edible oils, of which 10.50 million tonnes is met from primary (soybean, rapeseed-mustard, groundnut, sunflower, safflower and niger) and secondary sources (oil palm, coconut, rice bran, cotton seed and tree borne oilseeds) and the rest 60%, is met through import i.e. 15 million tonnes (Ministry of Commerce & Industry, 2020). With the rise in edible oil demand and change in oil consumption behaviour which is ostensibly the income elastic, import of edible oil has reached 174% during 2010-20 (www.nfsm.gov.in) and could further escalate. Among the various edible oils imported to India, sunflower oil stood third after palm and soya oils with a share of about 60%, 25% and 12% respectively and contributes to one fifth of the edible oil import basket. The import of crude sunflower oil stood at ₹ 13655 crores during 2018-19 (www.agricoop.gov.in). To cope up with the increasing *per capita* demand of edible oils, horizontal expansion of oilseeds in rice fallows is one of the suitable options. Sunflower is preferred by households due to its attractive colour, and fatty acid profile, and considered as a functional food. The crop is native to America and has spread its roots throughout the world particularly the Eastern Europe and Argentina which together share one-tenth of the world's sunflower production (Adeleke and Babalola, 2020) in the past decades due to its versatile nature for cultivation, particularly its photo-insensitivity (Vasudevan *et al.,* 1998) making it amenable for cultivation throughout the year.

As the majority of the area under oilseeds cultivation is still rainfed (around 75%), there is a significant impact of vagaries of monsoon particularly moisture-deficit stress on the productivity of sunflower during most parts its growing cycle and under rice fallows as well. The strategy for horizontal expansion of sunflower area has zeroed-in on the rice fallow environments, if the constraints are tackled systematically.

Sunflower was first cultivated in the southern part of the country to improve oilseed production in 1970's particularly in Andhra Pradesh, Tamil Nadu and Karnataka. The area under sunflower increased from 1.17 lakh ha in 1970-71 to 2.12 lakh ha in 1995-96, and thereafter the area started dwindling ostensibly due to competitive crops. Within a span of a decade (1970-80) only Karnataka could maintain a steady increase in its area while in Andhra Pradesh and Tamil Nadu sunflower area was declining. In the late 1990s, Karnataka's share to all India was about 38.4 to 45.7 per cent and has risen to 61 per cent in 2005-06 (Singha *et al*., 2014). In Odisha, sunflower is grown on 20000 hectares with a productivity of 1185 kg/ha (GoI, 2017). Karnataka, Odisha and Bihar are the three largest sunflower producing states of the country during 2019-20 (GoI, 2021). Notwithstanding these facts, sunflower area in the country has shrunk to 3 lakh ha in 2020-21.

Rice fallows - a golden opportunity for sunflower area expansion: Rice is cultivated during the *kharif* season in Southeast Asia, but a large chunk of this area (15 million ha) remains uncultivated or left as fallow in the subsequent *rabi*

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or post-rainy season, due to water scarcity (Subbarao *et al*., 2001; Singh *et al*., 2019). This land is regarded as paddy fallow. Of the total paddy fallow area in South and Southeast Asia, about 44 million hectares is in the country (Kumar *et al*., 2018), with a share of 30% area (11.65 million ha) under *kharif* fallow (NAAS, 2013). In addition to this area, there is one more paddy fallow under either paddy-paddy-fallow (summer) or Paddy-fallow (summer), where in the former two paddy crops are taken up in the system with short-medium duration rice cultivars, while in the latter only one medium duration rice coinciding with the post monsoon or northeast monsoon is taken up (Ramesh *et al*., 2019). The National food security mission in its status paper on rice (https://nfsm.gov.in/StatusPaper/Rice2016.pdf) has broadly grouped rice growing regions in the country into five categories (Table 1).

Table 1 Categories of rice growing regions in India

Region	States and preferably the total area	Main season for rice	Condition	Cropping pattern (single/double/triple)	Projected available area for rice fallow crops in the region	Remarks
North-East	Assam, Manipur, Tripura, Megalaya, Mizoram, Nagaland, Arunachal Pradesh	Feb-Jul, Jun-Dec and Dec-Jun	Rainfed	Single	10.42 lakh ha in Assam (Anon 2018)	Basin of Brahmaputra river.
East	Bihar, Chhattisgarh,Jharkhand, Madhya Pradesh, Odisha, Eastern Uttar Pradesh and West Bengal	May-Oct, Jun-Dec or Jan-Jun	Rainfed	Single	3 lakh ha in Bihar, 28.56 lakh ha in Chhattisgarh, 4.75 lakh ha in Jharkhand, 12 lakh ha in West Bengal (Anonymous, 2018) 12.2 lakh ha in Odisha (Jagadev *et al*., 2016)	Basins of Ganga and Mahanadi rivers and has the highest intensity of rice cultivation in the country
North	Haryana, Punjab, Western Uttar Pradesh, Uttarakhand, Himachal Pradesh, and Jammu and Kashmir	May-Nov or Apr-Dec	Rainfed	Single	-	Single crop of rice due to severe winter
West	Gujarat, Maharashtra and Rajasthan	Jun-Dec	Rainfed	Single	-	Rainfed rice
South	Andhra Pradesh, Telangana, Karnataka, Kerala and Tamil Nadu	Mar-Aug	Irrigated/rainfed	Single/ double	14.01 lakh ha in Telangana (Reddy and Reddy, 2017)	Deltaic tracts of Godavari, Krishna and Cauvery rivers and the non-deltaic areas of Tamil Nadu and Andhra Pradesh under irrigated condition in deltaic tracts

North-Eastern region and Eastern region together contribute more than 80 per cent of the paddy fallow area covering the states of Assam, Bihar, Chhattisgarh, Madhya Pradesh, Odisha and West Bengal (Rao *et al.,* 2008). It has also been estimated that rice covering an area of about 26.0 million ha and accounting for 63.3% of the total rice acreage during the *kharif* is available in the Eastern India. Out of which, ~11.7 million ha area remains as rice fallow during the succeeding winter season due to several limitations (Kumar *et al.,* 2019a) in terms of weather and lack of irrigation, etc. In the mono-cropped rice fallows of Odisha (Nayak *et al.,* 2019), sunflower is a preferred crop which occupies 25,000 ha (Mahapatra *et al.,* 2020) and is emerging as an important oilseed crop of the state (Mahapatra *et al.,* 2021a). In the northern region crops which can tolerate chilling injury would fit into this fallow. Sunflower can be a successful crop in the spring season as a sequential crop in the rice-fallow-sunflower cropping system. While western region has limited scope for expansion of sunflower, southern region is the core belt for rice fallow oilseeds *viz.,* sesame and sunflower, to name a few.

Single and double crop rice ecologies: While most of the rice is grown in the *kharif* (wet-season, July-December) as a rainfed crop, rice is also grown in the *rabi* (dry-season, January-June) in many states of India. Approximately 55 per cent of India's rice crop is irrigated (Deep *et al.,* 2018) and majority of these soils is categorized as heavy (clay or clay loams). Such soils, with high water-holding capacity, produce higher rice yields and are suitable for a second crop (Pande *et al.,* 2012). Other than this, alluvial, red, laterite and lateritic, black, saline and alkaline, and peaty and marshy soils are other dominant soil types in which rice is grown (Raychaudhuri *et al.,* 1963) whose utilization by growing oilseeds is basically management driven and the selection of crop and the irrigation infrastructure are the crucial elements.

In Tamil Nadu, the rice fallow is concentrated in the Cauvery deltaic zone as a result of single cropped medium duration rice (Season: Samba; Sowing/planting in August)) and double cropped short duration rice (Season: kuruvai (sowing/planting during June-July) - thaladi/late samba (sowing/planting during September-October) culture. The harvest of samba and thaladi seasons rice falls during January first fortnight to facilitate sowing of rice fallow crops around mid of January (Ramesh *et al.,* 2019).

In coastal Andhra Pradesh, covering the districts of Srikakulam, Vijayanagaram and Visakhapatnam, after long duration rice (140-150 days) which is harvested during November-January depending on the onset of the southwest monsoon the lands are left fallow. Floods are common in this rice culture and hence, flood tolerant rice varieties are preferred in this region. Similar situation prevails in parts of Odisha too. At the time of harvest of rice, the atmospheric temperature remains below 15°C and environmental stress dictates the dates of sowing of sunflower crop as it germinates best at a soil temperature of 21 to 29°C. Temperature and light conditions are very critical for sunflower production (Kingra *et al.,* 2007).

While the residual soil moisture in rice fallow systems endows ample opportunities for expanding oilseeds in this area, lack of provision for a few supplemental irrigations is the key constraint. Cultivation of early to medium duration varieties of rice (Behera *et al.,* 2014) during the *rabi* season to enable farmers grow sunflower on residual moisture in time is a felt need and being short duration in nature, sunflower is an ideal crop for cultivation in the rice fallows.

The rice-fallow soil dynamics: Rice grows under flooded conditions during part or throughout crop growth period. This method of cultivation involves land preparation by puddling followed by transplanting rice seedlings into the puddled soils, and growing of rice in submerged condition until two to three weeks prior to the harvest of the crop (Sahrawat, 2012).

When the soil remains flooded for almost one-fourth of a year in a low land rice-based cropping system, the soil chemistry and microbiology are modified. Flooded soils are devoid of oxygen and two distinct soil layers *viz.,* aerobic top layer and an underlying reduced or anaerobic layer (Reddy, 1982) are formed. This is to tailor the needs of the low land rice crop through modification of the soil redox potential, physical properties and nutrient sources for the soil micro flora. A conservative estimate (Patrick and Reddy, 1976) established that one-fourth of applied nitrogen may be carried forward to the succeeding crop as a residual soil fertility. To be very precise, a considerable portion of applied nitrogen fertilizer to rice system (24.2 to 27.1 kg/ha) remains in the rice soil. In India, the rice crop is fertilized @ 100-150 kg N/ha depending upon the region, soil and other local conditions. Buresh *et al.* (1989) have confirmed that a significant portion of accumulated soil NO_3 may be lost from rice fallows upon the flooding of aerobic soil for rice production. When the flooded rice completes the life cycle, organic and NH_4-N could dominate in the soil over NO_3. Upon fallowing, transmission of aerobic N occurs and NO_3 starts accumulating which might be utilized by the fallow sunflower crop. In the rice fallows, unlike leguminous crops and other oilseeds (Bhaskar and Shivashankar, 1993) sunflower demands additional nutrients to be applied to reap the potential yields and to be remunerative eg. The state of Odisha (Mahapatra *et al*., 2021b).

Ecological considerations for cropping in the rice fallow: Negligible attention has been paid for the utilisation of rice fallows, both in terms of environmental effects and economic value with the sole exception of raising pulses like chickpea, black gram and green gram in the eastern and southern regions as discussed above. Rice fallow systems can have high global warming potential as it emits a lot of N_2O than cropped field (Verma *et al.,* 2006), an issue needing urgent attention for protecting the environment. In the temperate zones of Korea and Japan (Haque *et al.,* 2015), mono paddy cropping systems contribute approximately 30-60 per cent of the annual net global warming potential expressed in terms of greenhouse gas emissions. In these places, paddy fields remain flooded for over 100 days and later they remain fallow under aerobic conditions for over 200 days. Similar analogy may partially hold good for rice belts of Tamil Nadu, Andhra Pradesh and Odisha as well (Ramesh *et al.,* 2019). It has been confirmed that yield-scaled greenhouse gases (YSGHG) emission was highest for rice-fallow-fallow system in West Bengal which can be reduced if the land is properly utilized by making a good trade-off between system productivity and global warming potential GWP through sunflower cultivation in the rice fallows as it registered the highest specific energy and the lowest emission of CO_2 (Ray *et al*., 2020).

Rice fallow sunflower and rice-sunflower cropping systems: Rice fallows are those lands either middle lands or uplands of *kharif* or *rabi* sown rice areas which remained uncropped for the rest of the year as a fallow. Ghosh *et al.* (2012) reported an area of 11.7 m ha after *kharif* rice as fallow in the subsequent *rabi.* In parts of Andhra Pradesh, Telangana and West Bengal, sunflower is raised as a rice fallow crop in a rice-sunflower cropping sequence under zero tillage. In rice fallow sunflower, there is negligible fallow period whereas in rice-sunflower cropping system, the land is thoroughly prepared after rice and the length of the fallow period depends on the local agro-meteorological conditions. Unlike the broadcasting of pulse seeds in the standing rice crop, sunflower cannot be sown in the standing rice crop and needs to be dibbled either manually or mechanically. Sowing sunflower as a sequential crop in rice fallows of Telangana region of Andhra Pradesh (Kumar *et al.,* 2005) or as a zero tillage fallow crop in a clay loam soil at Warangal (Reddy *et al.,* 2010) and sandy loam soils at Bhubaneswar (Patel *et al.,* 2020) was profitable. Practically farmers cultivate sunflower either as a rice fallow crop with zero tillage and rice follow crop with conventional tillage to facilitate sowing and other operations. The interaction of harvesting time of rainy season rice, field moisture condition and temperature at or after harvest of rice determines the success of sunflower.

Determinants of sunflower production

Ecological determinants: Puddling for rice and its effect on the succeeding sunflower: The extensive use of heavy machinery in rice farming brings about numerous benefits through the creation of a compact soil layer particularly to arrest the water loss through percolation and this could have a mixed reactions on the subsequent sunflower in general depending on the soil type. Compaction normally increases the mechanical strength of the soil but excessive use may create soil management problem and can adversely affect plant growth (Raghavan *et al.,* 1977) through tillage and wheel- traffic, that results in a dense soil with poor internal drainage (Bayhan *et al.,* 2002). As a drought tolerant deep rooted crop, in sunflower (Connor and Hall, 1997), the presence of denser soil layers that can reduce both water infiltration in the deeper layers and rooting capacity is against sunflower. It is noted that the inherent characteristics of sunflower *viz*., deep root system, ability to utilize the moisture from deeper soil layers make it an ideal crop in the fallows (Umesh *et al.,* 2020). A decrease in the soil porosity after mechanical operations (Silva *et al.,* 2008) is a common phenomenon.

In the early growth phase of sunflower, soil compaction affected leaf expansion with an impaired leaf area development through slower expansion rates and smaller size of individual leaves (Andrade *et al.,* 1993) wherever zero tillage was practiced for sunflower. The compacted soil could result in sink-limitation with regard to water, nitrogen, and carbon supply modulated by hormonal signals from the roots. Bahyan *et al.* (2002) noticed a decrease in sunflower yield by negatively affecting vegetative growth. Sunflower may suffer due to very poor root penetration (Aboudrare *et al.,* 2006) and to withstand stress conditions (Skoric, 2009). In sunflower, a decrease in root length, root surface, root volume, and root average diameter with a change in root architecture (Scheiner *et al.,* 2012), a reduction of 55% of root length, 67% of root surface, and 42% of root diameter resulting in a decrease of deep root expansion and in an increased lateral growth (Mirleau-Thebaud *et al.,* 2017) was noticed as a result of soil compaction. However, the soil type had a definite bearing on these issues. Since root elongation rate is dependent on the temperature and intercepted photosynthetic photon flux density (Aguirrezabal and Tardieu, 1996), response to available soil water located below the normal rooting depth (Halvorson *et al.,* 1999) is an important criterion for rice fallow sunflower. In contrast to the above, Sessiz *et al.* (2008) could not find any noticeable impact on sunflower for soil compaction in a clay loam soil. Due to soil compaction from the puddled rice, porosity and lack of good drainage system, sunflower could only have limited root distribution especially as shallow root system in rice fallow soils.

Atmospheric temperature: As a rice fallow crop, sunflower is sown during the winter following rice harvest. To utilise the residual nutrients and utilising the moisture after rice harvest, sunflower needs to be seeded in cold, wet soil immediately after rice harvest. The speed of germination is a factor of soil temperature, moisture and oxygen. Grains Research and Development Corporation (GRDC, 2017) has prescribed a soil temperature of 10-12ºC, for satisfactory germination. Under the rice fallow environments of Andhra Pradesh and Odisha, it is predicted that planting into cold soil temperatures may take longer for germination and establishment unless supplemented with irrigation water. It should be kept in mind that the emergence of leaves for any temperature was linear with time in sunflower (Villalobos and Ritchie, 1992). Undisturbed rice stubbles of varying heights under rice fallow systems depending on the height of rice harvest could modify the soil surface characteristics (Cutforth and McConkey, 1997) and the microclimate as well (Bandyopadhyaya *et al.,* 2016). In the northeast India, rice is harvested by leaving at least 1/3rd to 2/3rd of the stem as standing stubbles in the field (Das *et al.,* 2012). Any intervention to modify the microclimate of emerging sunflower would prove beneficial for the crop establishment.

Poor moisture availability, anaerobic conditions and/or drought: Sowing of sunflower seed (dibbling) at optimum soil moisture content in rice fallow fields particularly in the uppermost layer is important since seedling establishment and maintenance of plant population are limiting factors compared to the total soil water content at planting for the yield (Aboudrare *et al.,* 2006). Excess soil moisture content can cause anaerobic environment for seed germination. During the *kharif* season, water table is generally high but as the monsoon rains withdraw, the water table recedes very fast. Even if the crop gets established well by utilizing available soil moisture, lack of winter showers towards flowering stage may create drought conditions leading to crop failure (Kumar *et al.,* 2018). Low moisture content in the soil after rice harvest, fast receding of water table with the advancement of retreating monsoon, and risk of intermittent soil moisture stress towards seed filling stage are a few other constraints for the optimum productivity of fallow crop of sunflower.

Production determinants

Genotype: Sunflower is non- photosensitive which ensures cultivation round the year. Genotypes bred for a particular season may not perform satisfactorily under rice fallow. For eg. KBSH 53 yielded 2161 kg/ha during *kharif* while under rice fallow 1521 kg/ha only at Bengaluru (Sujatha *et al.,* 2016). In most of the states, varieties recommended for non-fallow conditions are cultivated in the rice fallow too. Sunflower is highly sensitive to water logging and a clear relationship has been established (Orchard and Jessop, 1984) between duration of waterlogging and yield, and hence water tolerant strains need to be bred. Notwithstanding this, with respect to yield stage of development seemed to be the key determinant than the duration of waterlogging (Orchard and Jessop, 1984).

The second criterion with regard to genotype is the short duration to escape the unexpected moisture stress at the maturity stage. Notwithstanding this concern, duration need not necessarily be the sole criteria for selection of genotype for rice fallows, instead a genotype with robust root system to extract water from lower layers is equally important. In a typical lowland rice-growing area, Kumar *et al.* (2019b) noticed a fast receding soil moisture in the top 30 cm soil. The deeper soil layers are usually endowed with sufficient soil water. Hence root: shoot ratio can also be considered as an important criteria for recommending of sunflower hybrids for rice fallow ecologies.

The third criterion would be the weed competitive genotype to suppress the weeds since chemical weed management in rice fallows are seldom carried out. In general, weeds have a competitive advantage especially during the initial stages of crop establishment over sunflower in rice fallow due to available soil moisture. Once the sunflower crop gets established, the leaf area covers the ground area and deprives sunlight to the broadleaved weeds.

Nutrient management: Rice fallow technologies have been promoted as, inter alia, banking of the stored soil moisture and the residual nutrients from rice crop. As an oilseed crop, sunflower demands all essential nutrients for optimum production. Wherever, sunflower is sown in rice fallows, the crop is sub optimally fertilized, and consequently the crop suffers due to nutrient stress. Sulphur is an important element for rice fallow oilseeds (Bhaskar *et al.,* 2000) besides other nutrients. Experiments at various AICRP sunflower centres over the past few years have indicated that the rice fallow sunflower crop irrespective of the tillage regime demands more than the blanket recommendation for non-rice fallow crop of sunflower (Meena *et al.,* 2021). In an irrigated well managed lowland rice field with grain yields of 5 to 7 t/ha, fertilizer recovery efficiencies are 30 to 60 per cent, 35 per cent and 15 to 65 per cent for N, P and K (BCI, 2002) implying that the residual nutrients will remain in the soil for utilisation by the succeeding crop. In order to produce 1 tonne of paddy (rough rice), the rice crop absorbs an average of 20 kg N, 11 kg P_2O_5, 30 kg K_2O, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo and 52 kg Si (Roy *et al.,* 2006a). The results of long-term fertilizer experiments conducted with rice-based cropping system at several stations confirm the inadequate nature of so-called 'optimum' fertilizer recommendations (Tiwari, 2002).There exists variation between the amounts of nutrients removed by the upland rice cultivar, and in decreasing order it is N >K > Mg > Ca > P > Fe > Mn > Zn, whereas for the lowland rice cultivar it is K > N > Mg > Ca > P > Mn > Fe > Zn (Sahrawat, 2000) which could determine the nutrient management in the succeeding sunflower crop in turn. The nitrogen lost through ammonia volatilization, runoff, and leaching from the paddy field was 37.2 to 102 kg N/ha, with ammonia volatilization accounting for 69.6% to 83.5% of nitrogen loss (Yang *et al.,* 2013), of which there exists a possibility that the unutilized N leaches to much deeper soil layers as part of the unutilized N (Nishikawa *et al.,* 2014) and that will be available for use by the succeeding crop. But this needs to be quantified for sunflower. This is in jeopardy, if hard pan develops during rice puddling which makes sunflower only a surface feeder.

Removal of straw from the field is widespread in India and hence the depletion of soil K and Si reserves, which has a significant impact on the succeeding fallow crop. In the process, some or all of the nutrients contained in straw may be lost from the rice field (Dobermann and Fairhurst, 2002). In order to produce 1 tonne of yield the sunflower crop absorbs an average of 63.3 kg N, 19.1 kg P_2O_5, 126 kg K_2O, 11.7 kg S, 68.3 kg Ca, 26.7 kg Mg (Roy *et al.,* 2006b). As the fallow sunflower crop is cultivated with minimal nutrient inputs, the nutrient management in rice would have a definite impact on the succeeding sunflower. Sulphur is another important nutrient for sunflower (Veeranagappa *et al.,* 2015) but ignored in fertilizer regimen. Further, the physical condition of soil is poor due to puddled rice and consequently nutrient mobilization is reduced. Zero tillage fertilized with 150% RDF (90:120:90 kg N: P_2O_5: K_2O/ha) could maximize productivity of sunflower hybrid under rice fallow environments of sandy loam soils of Odisha (Mahapatra *et al.,* 2021b). Thus, it is understood that sunflower needs to be fertilised even higher than the RDF for realising optimum productivity (Kalyani *et al.,* 2020). Umesh *et al.* (2020) have confirmed that rice fallow sunflower needs a fertiliser dose of 135:135: 90 kg N: P_2O_5: K_2O/ha, 50% higher than the recommended dose.

Water management

Excess water/flooding: Despite water being a critical ingredient for production, excess water during the crop growing season can result in significant negative effects on crop yield of sunflower. Therefore, water management is very crucial for sunflower as a rice fallow crop since poor water management results in waterlogging at the establishment stage and hampers the establishment, growth and yield of sunflower severely by reducing the availability of oxygen and increased ethylene concentrations in the soil (Yasumoto *et al.,* 2011). Water logging is also known to reduce the root growth leading to other physiological effects (Orchard and So, 1985) besides rapid ethanol synthesis in the roots (Jayasekera *et al.,* 1989). Ultimately, this reduces photosynthesis (Wample and Davis, 1983; Wample and Thornton, 1984) either due to stomatal and/or non-stomatal limitations (Ben *et al.,* 1987; Jayasekera and Boyer, 1990). Short term waterlogging (Orchard and Jessop, 1984; Orchard and So, 1985; Orchard *et al.,* 1986; Jayasekera *et al.* 1989) is widespread in rice fallow sunflower regions (Grassini *et al.* 2007), if not long-term water logging. Although sunflower possess the ability to adapt to waterlogging (Orchard and Jessop, 1984), waterlogging during anthesis (Orchard and Jessop, 1984) and grain filling stages (Grassini *et al.,* 2007) are detrimental than the vegetative stage as it inhibits only leaf expansion (Orchard *et al.,* 1986).

Water stress/drought: While excess water as discussed in the previous section is essentially due to poor water management practices, water stress is conjoint in rice fallow sunflower regions in the country. As a dry season crop of the world, sunflower can resist short periods of water deficit (d' Andria *et al.,* 1995) without noticeable yield penalty with a rider on the stage of water stress (Unger, 1982; Keipp *et al.,* 2020) as it is relatively tolerant to moisture stress (Killi *et al.,* 2017). Owing to its capability of extracting water from deep layers of soil (Chiaranda and Andria, 1994), Rauf (2008) classified sunflower as a low to medium drought sensitive crop making it a suitable candidate for rice fallow since water stress of varying magnitude is very common under these conditions. However, it becomes a yield limiting factor (Ravishankar *et al.,* 1991; Hussain *et al.,* 2017). A reduction in leaf water potential in drought-stressed sunflower plants with increased leaf resistance was noticed by Wample and Thornton (1984) besides photosynthesis. Interestingly, Nezami *et al.* (2008) observed that drought from 4-leaf- stage up to the end of plant growth period did not interfere with leaf production.

Mechanisation related constraints

The efficiency of manual harvesting system by using sickle is a whopping 180 and 200 man hours per hectare to harvest rice (Pande and Devnani, 1984). In the Asian countries, like India, China, Thailand, Vietnam and even in Cambodia the use of combine harvester for paddy harvest is increasing very rapidly to tide over the labour shortage for harvesting of rice which has the multiple advantages and economically attractive. This combines several operations at one go *viz.,* cutting the crop at a desired height from the ground, feeding it into threshing machine, threshing, cleaning, winnowing and transferring directly into a bag with an average post harvesting losses of only about 2.96 per cent of rice yield (Sharanakumar, 2011). This mechanisation although lucrative to rice farmers, the subsequent crop in the sequence faces the onslaught particularly due to excess soil compaction as the normal weight of self-propelled combine harvester is 8200 kg (farmech.dac.gov.in). The compaction is a looming threat for the utilisation of zero tillage rice fallow sunflower.

Opportunities for sunflower cultivation in the rice fallow regions: Opportunities for the successful cultivation of sunflower in the rice fallow with minimal investment need to be explored, particularly where a couple of supplemental irrigations are assured so that optimum yields could be realized. Many growers are reluctant to switch to sunflower in rice fallow because they perceive alternate crops as being more cost-effective despite growing evidence that sunflower can improve profitability as observed in the states of Telangana, West Bengal and Odisha. In spite of the issues stated earlier, the unique adaptation of sunflower to different climatic and soil conditions (Forleo *et al.*, 2018) enhanced its suitability across rice fallow regimes of the country. However, the following research issues needs attention.

Macro level planning

Mapping of rice fallow areas: The information on rice fallow areas are scattered and needs to be consolidated for accurate estimation. The available rice fallow area from various agencies provide only some preliminary information. National Mission on Oilseeds and Oil Palm has also made efforts for bringing additional area under rice fallow with pulses and oilseeds and sunflower is one among the targeted crops. Gumma *et al.* (2016) have estimated that approximately 22.3 M ha of rice-fallow is in South Asia of which 88.3% is in India. Since the fast depletion of the soil residual moisture is the primary obstacle for rice fallow crop (Kumar et al., 2019a), recently the Government of India has made efforts to map the rice fallow areas of the country with satellite image with due consideration to soil water status from Mahalanobis National Crop Forecast Centre, New Delhi under National Food Security Mission.

Success models of rice fallow in selected states: In West Bengal, sunflower is second important oilseed crop after rapeseed-mustard during rabi season. Particularly in Sunderban area, farmers raise sunflower crop as a rabi-summer crop after the harvest of flooded paddy. As the main season autumn rice is harvested during October-November, November 30 sowing date was identified to be ideal for sunflower for getting maximum yield under Gangetic West Bengal condition (Dutta, 2011). The predominant rapeseed-mustard area has shrunken due to short winter spell, delayed sowing and infestation of pest and diseases (Dutta, 2015) and sunflower has wide scope in the state overriding the competing crops mungbean and bhindi. Several farmer groups have modified their land configuration into 3-4 rows of sunflower in a paired row for managing irrigation for sunflower and save irrigation water and labour (Ramesh *et al.,* 2018). Few innovators have initiated village level oil extraction to make the sunflower farming a viable business model.

The relatively short duration with drought tolerance made it a potential crop with limited irrigation water availability (Swain *et al.,* 2019) in Odisha. More and more farmers in Dhenkanal district of Odisha are taking up sunflower cultivation in the wake of frequent depredation of crops by elephants, besides the perennial threats of flood and drought over traditional paddy cultivation in most of coastal Bhadrak district to switch over to sunflower. In the recent past, Begunia block, Khurda district of Odisha has increased the area under rice fallow sesame.

The success of rice fallow sunflower in Nizamabad district of Telangana is linked to water availability in the region. If there is in adequate supply of water for cultivation of second season rice, rice fallow sunflower could occupy major chunk of rice fallow area.

Micro level planning

Conservation agriculture practices: A careful analysis of opportunities for horizontal area expansion of oilseeds has zeroed-in on moisture conservation/resource conservation technologies. It has been acknowledged that zero tillage concept has a wide scope to harness full potential of rice fallow sunflower considering the need to conserve the soil moisture and nutrients. Conservation tillage implies a shift away from strict reliance on control of existing tillage practices and places greater emphasis on environment, soil organic carbon storage, minimizing tillage expenses and so on. Selective rice fallow regime needs an appropriate conservation tillage coupled with fertiliser schedule for a suitable hybrid. This decision making framework, would result in a greater level of productivity with high economic benefit than de facto package of practices for non-rice fallow systems. However, tillage in general had more positive effect on seedling emergence, growth and yield of sunflower than a zero tillage in puddle rice fallows in a sandy clay loam soil (Typic Haplustalf) at Hyderabad (Gurumurthy *et al.,* 2008). Hence conservation agriculture practice are soil and location specific and can't be generalised.

Supplementary irrigation: No matter when the sowing of sunflower as a rice fallow crop is taken up, yield improvement relies heavily on two tactics, the nutrient and irrigation management, of which the lifesaving irrigation at critical crop growth phase, particularly flowering period, is critical. Other water requiring phases are pre-sowing, 20 days after sowing, early bud development, flowering- and seed development.

Co-culturing of honey bees with sunflower: Co-culturing of honey bees with sunflower as a community initiative in the Nizamabad district of Telangana has opened new avenues for the sunflower growers. The erstwhile recommendation of keeping of 4-5 honey bee hives/ha in the sunflower fields to facilitate bee pollination has several pitfalls due to migration of bees during lean period. Hence, the new initiative by a commercial honey entrepreneur wherein several dozens of bee hives are maintained in a particular field to collect honey from the surrounding 2-3 km radius has paid dividends and has to be promoted as a community initiative. This has the twin benefits of honey production as well as enhanced pollination for sunflower productivity.

Research gaps: Despite significant advancements in understanding the agro-meteorology of sunflower at production systems, there remain significant gaps in understanding the relationships between climatic variability and crop yields at finer spatial and temporal scales as the sowing time under rice fallow is a function of the duration of the preceding rice crop. High yielding genotypes of sunflower are too few for cultivation under rice fallow. Research on sunflower genotypes specific to rice fallows, low temperature tolerant and, water logging tolerant strains are needed in addition to drought tolerant cultivars to withstand moisture stress at later stages of crop growth. Besides research with respect to developing suitable genotypes, information on soil health, pest management, mechanization, etc. are also needed. Notwithstanding these issues, a rapid expansion in the sunflower area is on the rise in the states of Telangana, Odisha and West Bengal as a rice fallow crop since availability of water is a serious limitation for the competing vegetable crops.

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High yielding mutants from the introgression lines of groundnut (*Arachis hypogaea* L.)

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ABSTRACT

An effort was made to generate variability for foliar disease resistance and productivity traits in groundnut using induced mutagenesis with gamma rays and ethyl methane sulfate (EMS) in three interspecific derivatives *viz.,* ICGIL 17105, ICGIL 17110, and ICGIL 17112 involving ABK genomes. A large population of M1, M2, M3 and M4 generations were evaluated along with the parents and checks to identify the promising mutants. Germination percentage decreased with an increase in the dosage of mutagen individually and in combination in the M1 generation. Dominant mutants with reduced plant height were observed along with the lethal mutants in the M1 generation. Gamma rays of 300 Gy and 0.3% EMS showed the highest mutagenic frequency and effectiveness for foliar disease resistance [late leaf spot (LLS) and rust] and productivity traits in the M2 generation. Interestingly, mutations were also observed for the taxonomic traits. Evaluation of M3 lines confirmed the superiority of three mutants over the respective parents and the best check (GPBD 4) for foliar disease resistance and pod yield. Superior mutants were checked for the type of allele at late leaf spot (LLS) and rust resistance linked marker loci. Parents and the mutants had the resistant type of allele (like GPBD 4) at all the marker loci (GM1536, GM1954, GM2301, AhTE0498 and AhTE0621). Superior mutants are being evaluated in large plots in the station trial along with the parents and other elite varieties to check their performance towards developing them into commercial varieties.

Keywords: Disease resistance, EMS, Gamma rays, Groundnut, Interspecific derivatives, Productivity

Groundnut is an important legume food and oilseed crop worldwide. It is valued as a rich source of energy contributed by oil (48-50%) and protein (20-40%) in the kernels. It was grown globally on an area of 28.5 million hectares with a production of 46.0 million tons and productivity of 1,647 kg/ha during 2019 (FAOSTAT, 2019). The main objective of groundnut improvement programme continues to be the development of genotypes with high productivity along with resistance to different abiotic and biotic stresses. The effectiveness of the breeding programme depends on the degree of variability within the target traits. Induced mutagenesis has been widely used in groundnut to breed improved varieties (Janila *et al.,* 2013). In addition, the use of wild diploids with diverse genomes, and their derivatives (with cultivated groundnut) could enhance the genetic base of groundnut (Simpson, 2001) by bringing in novel alleles. Also, induced mutagenesis in such derivatives provides an opportunity for the novel alleles to generate new variation. Joshi *et al.* (2019) have demonstrated the successful application of induced mutagenesis among the interspecific derivatives in groundnut where they could generate and identify productive mutants with foliar disease resistance. At ICRISAT, India, a lot of interspecific derivatives have been developed (Sharma *et al.,* 2017). Among them, ICGIL 17110, ICGIL 17105 and ICGIL 17112 (Virginia bunch types) were highly resistant to foliar diseases apart from being productive along with acceptable pod and kernel features. In this study, an effort was made to subject these interspecific derivatives with ABK genomes to induced mutagenesis for improving productivity traits.

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MATERIALS AND METHODS

Seeds of ICGIL 17105, ICGIL 17110 and ICGIL 17112 were collected from the germplasm collection at ICRISAT, Hyderabad. Fifty seeds (M0) of these parents were treated with gamma rays (200 Gy and 300 Gy at Bhabha Atomic Research Centre, Mumbai, India) and ethyl methane sulfonate (0.2%, 0.3% and 0.5% at University of Agricultural Sciences, Dharwad) independently and in combinations (Table 1). M1, M2, M3 and M4 generations were grown at IABT Garden (E115) of University of Agricultural Sciences, Dharwad during the rainy season of 2018, 2019, post-rainy season of 2019 and rainy season of 2020, respectively.

M1 generation was raised as single plants with 30 × 10 cm spacing, and the plants were scored for germination percentage (15^{th} day after sowing, DAS), lethality percentage (40 DAS), sterility percentage (50 DAS) and any dominant mutations. The M2 plants were also raised as single plants with 30 × 10 cm spacing, and observed for reaction to late leaf spot (LLS) and rust (at 70, 80 and 90 DAS), number of pods/plant (NPPP) and pod yield/plant (PYPP). Fisher's Z test was performed to check the significant difference between each M1 plant and its parent. Individual M2 plants were harvested separately. M3 generation was raised in lines with 30 × 10 cm spacing in an augmented design including the parents (ICGIL 17110, ICGIL 17105 and ICGIL 17112) and checks (GPBD 4 and G 2-52) in seven blocks. Observations on the morphological traits (botanical varieties), days to 50 per cent flowering (DFF), plant height (PH), pod yield/plant (PYPP), shelling percent (SP), test weight (TW), sound mature kernel weight percentage (SMKP) and pod features (pod beak, reticulation and constriction) were recorded as per the groundnut descriptor (IBPGR/ICRISAT, 1992). Statistical analysis was performed using the agricolae package of R environment. M4 generation was raised in lines with 30 × 10 cm spacing from the progenies of superior mutants from M3. DNA was isolated from these plants using cetyl trimethyl ammonium bromide (CTAB) method (Mace *et al.,* 2003). The plants were subjected for genotyping with the LLS resistance-linked SSR markers (GM1536, GM1954 and GM2301) (Sujay *et al*., 2012), and both LLS and rust resistance-linked *Arachis hypogaea* transposable element (AhTE) markers (AhTE0498 and AhTE0621) (Kolekar *et al.,* 2016). DNA amplification was performed in a 20 µl reaction mixture with an appropriate PCR profile using the Eppendorf Mastercycler® pro and Bio-Rad T100™ Thermal cycler. PCR amplicons were separated on 2% agarose gel.

Table 1 Effect of gamma irradiation and EMS mutagenesis among the interspecific derivatives of groundnut

Treatments	M_1 generation												M_2 generation					
	Germination (%)			Lethality (%)			Sterility (%)			Dwarf dominant mutants			Mutation frequency			Mutagenic effectiveness (%)		
	ICGIL 17105	ICGIL 17110	ICGIL 17112	ICGIL 17105	ICGIL 17110	ICGIL 17112	ICGIL 17105	ICGIL 17110	ICGIL 17112	ICGIL 17105	ICGIL 17110	ICGIL 17112	ICGIL 17105	ICGIL 17110	ICGIL 17112	ICGIL 17105	ICGIL 17110	ICGIL 17112
Control	96	94	92	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
T_1	58	86	82	27.59	23.26	48.78	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
T_2	40	58	80	25.00	27.59	47.50	0	2	0	2	0	0	0.92	0.22	0.02	8.59	2.05	0.19
T_3	34	44	8	17.65	54.55	25.00	0	0	0	0	1	0	0.22	0.02	0.06	6.6.0	0.60	1.80
T_4	28	36	12	42.86	22.22	33.33	0	0	0	0	0	0	0.20	0.06	0.12	4.00	1.20	2.40
T_5	26	0	0	46.15	0.00	0.00	0	0	0	0	0	0	0.66	0.10	0.00	7.92	1.20	0.00
T_6	34	32	0	47.06	31.25	0.00	0	0	0	1	1	0	0.02	0.00	0.00	0.05	0.00	0.00
T_7	18	20	18	55.56	30.00	22.22	0	0	0	0	0	1	0.08	0.00	0.00	0.13	0.00	0.00
T_8	32	10	0	68.75	40.00	0.00	0	0	0	0	1	0	0.06	0.00	0.00	0.06	0.00	0.00
T_9	14	10	10	57.14	20.00	20.00	0	2	0	0	0	4	0.02	0.00	0.00	0.03	0.00	0.00
T_{10}	18	6	0	77.78	33.33	0.00	0	0	0	0	0	0	0.02	0.00	0.00	0.02	0.00	0.00
T_{11}	8	0	0	50.00	0.00	0.00	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00

T1: Gamma rays (200 Gy), T2: Gamma rays (300 Gy), T3: EMS (0.2 %), T4: EMS (0.3%), T5: EMS (0.5%), T6: Gamma rays (200 Gy) EMS (0.2%), T7: Gamma rays (200 Gy) + EMS (0.3%), T8: Gamma rays (200 Gy) + EMS (0.5%), T9: Gamma rays (300 Gy) + EMS (0.2%), T10: Gamma rays (300 Gy) + EMS (0.3%), T11 and Gamma rays (300 Gy) + EMS (0.5%)

RESULTS AND DISCUSSION

Gamma and EMS treated M1 seeds were sown to raise M1 generation. Germination percentage decreased with the increase in the dosage of both gamma and EMS and their combination. Germination percentage was more seriously affected by EMS than by gamma treatment. ICGIL 17110 and ICGIL 17112 showed complete loss of germination with a few treatment combinations of EMS and gamma. Similar trend was also observed for lethality. Drastic reduction in germination with increasing doses of gamma rays (Badigannavar and Murty, 2007), EMS (Muniappan *et al.,* 2016) and their combinations (Kharade *et al.,* 2015) have been reported in groundnut.

A few sterile plants (4 out of 411) were also observed among the M1 plants of ICGIL 17110 as it has been observed in the previous studies (Kavera, 2008; Shanthala, 2011). Dwarf dominant mutants (3-5 out of 411) were observed among each parental line. In groundnut, dominant mutations have been reported for leaf shape (Branch, 2018), seed coat colour (Mondal *et al.,* 2007), lesion mimics (Johal *et al.,* 1995) and plant height (Ashri, 1970; Kavera, 2008; Shanthala, 2011; Joshi *et al.,* 2019).

Individual M1 plants were harvested to collect the M2 seeds. M2 generation was raised by sowing 1,799, 2,508, and 575 M2 seeds from ICGIL 17105, ICGIL 17110 and ICGIL 17112, respectively. Considerable variability was observed for disease resistance and productivity among the M2 plants. The z test could identify the desirable mutants for reaction to LLS and rust, NPPP and PYPP in ICGIL 17105 (206, 216, 180 and 105, respectively), ICGIL 17110 (83, 51, 54 and 76, respectively) and ICGIL 17112 (16, 44, 29 and 8, respectively). Chi-square independence test showed that the parental genotypes (wild types) differed significantly in generating the mutants (results not shown). In total, 111, 20 and 10 mutants showing desirable mutant phenotype for reaction to LLS and rust, NPPP and PYPP were identified in ICGIL 17105, ICGIL 17110 and ICGIL 17112, respectively. Gamma irradiation at 300 Gy showed the highest mutation frequency in ICGIL 17105 (0.92) and ICGIL 17110 (0.22), while 0.3% EMS recorded the highest mutation frequency in ICGIL 17112 (0.12). The same treatments resulted in the highest mutagenic effectiveness of 8.59%, 2.05% and 2.40% in ICGIL 17105, ICGIL 17110 and ICGIL 17112, respectively. In groundnut, both gamma rays and EMS have been successful in generating mutations with a frequency 0.57-3.72 (Manjunath *et al.,* 2020).

The progenies of these 111, 20 and 10 M2 mutants were raised in lines in M3 generation with augmented design, where significant differences were observed for DFF, PH, PYPP, SP, TW and SMKP. Highest PCV and GCV were observed for TW followed by PYPP. The productivity traits were significantly correlated with each other, while they were negatively correlated with DFF. A mutant (ICGIL17105-T7-1-1) of ICGIL 17105 was significantly superior for PYPP, PH and TW over its parent and the best check GPBD 4. Another mutant, ICGIL17105-T4-7-8 was numerically superior over GPBD 4 for PYPP and SP. Among the mutants of ICGIL 17110, the mutant ICGIL17110-T1-9-10 was significantly superior for PYPP, PH and TW over its parent and the best check GPBD 4 (Table 2). However, none of the mutants of ICGIL 17112 was better than the parent or the best check for PYPP.

It was interesting to observe the changes in plant morphological characters leading to change in botanical varieties. All the three parental genotypes belonging to Virginia bunch type (*Arachis hypogaea* ssp. *hypogaea* var. hypogaea) could generate Valencia type (*Arachis hypogaea* ssp. *fastigiata* var. fastigiata) mutants at a low frequency (~0.1). However, a change (~0.1) to Spanish type (*Arachis hypogaea* ssp. *fastigiata* var. vulgaris) was also observed among the mutants of ICGIL 17105. Such taxonomic changes from ssp hypogaea to ssp. fastigiata were observed by Gowda *et al.* (1989) with the EMS (0.5%) mutagenesis in groundnut. Taxonomic changes from ssp. fastigiata to ssp. hypogaea were also observed by Prasad *et al.* (1984) when EMS mutagenesis (0.2%) in a Spanish parent (TMV 2) resulted in the Virginia type mutant (TMV 2-NLM). The results indicate the scope for improving groundnut productivity through mutations in the taxonomic traits.

The three superior mutants (ICGIL17105-T7-1-1, ICGIL17105-T4-7-8 and ICGIL17110-T1-9-10) identified for superior PYPP were of Valencia type with mainstem flowering. ICGIL17105-T4-7-8 and ICGIL17110-T1-9-10 had pod characteristics (pod beak, reticulation and constriction) like that of GPBD 4, while ICGIL17105-T7-1-1 had a slightly prominent pod beak as compared to its parent and GPBD 4 (Fig. 1.).

All the M3 lines were advanced to M4 generation and evaluated for disease (LLS and rust) reaction and pod characteristics. The selected mutants (ICGIL17105-T7-1-1, ICGIL17105-T4-7-8 and ICGIL17110-T1-9-10) were comparable to their parents and GPBD 4 for response to LLS and rust diseases, and they retained the same pod features in M4. When the superior mutants were checked for the allele at LLS and rust resistance linked marker loci, it was observed that the parents and the mutants had the resistant type of allele (like GPBD 4) at all the marker loci (GM1536, GM1954, GM2301, AhTE0498 and AhTE0621) and not the susceptible type of allele (like TAG 24) (Fig. 2.).

Fig. 1. Pod and kernel features of the superior mutants and their parents
1: ICGIL17105, 2: ICGIL17110, 3: GPBD 4 (a released elite variety), 4: ICGIL17105-T7-1-1, 5: ICGIL17105-T4-7-8 and 6: ICGIL 17110-T1-9-10)

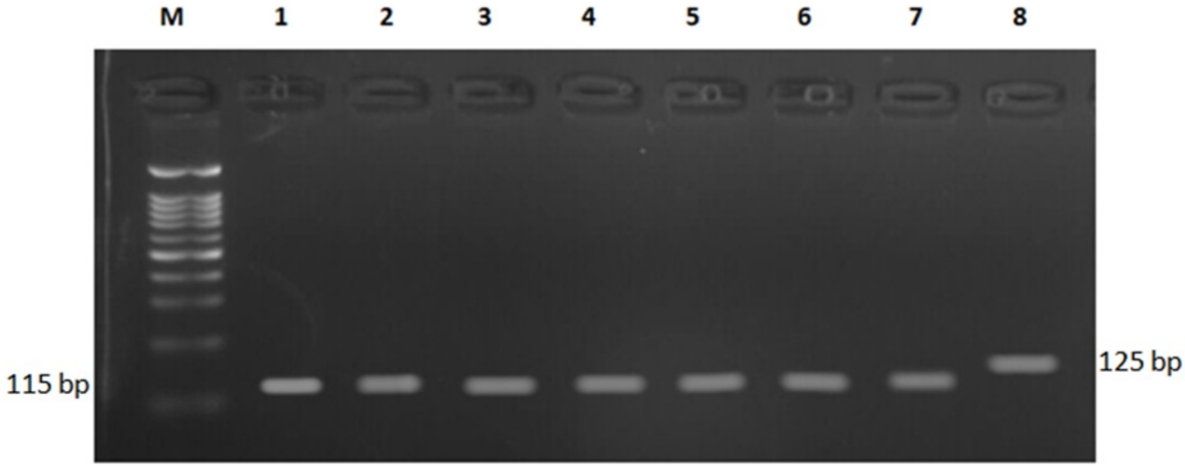

Fig. 2. Amplicon profile of GM1954 among the superior mutants and their parents

M:100 bp DNA ladder, 1: ICGIL17105, 2: ICGIL17110, 3: ICGIL17112, 4: ICGIL17105-T7-1-1, 5: ICGIL17105-T4-7-8, 6: ICGIL 17110-T1-9-10, 7: GPBD 4 and 8: TAG 24

Table 2 Performance of superior M3 mutants of ICGIL 17105, ICGIL 17110 and ICGIL 17112

M3 mutants	DFF	PYPP	TW	SP	PH	SMKP
ICGIL 17105-T7-1-1	34.91	26.10*	46.54*	74.66	29.46*	99.66
ICGIL 17105-T4-7-8	35.31	24.59	46.58	70.51	26.23	79.86
ICGIL 17105-T7-8-9	34.91	21.07	33.93	78.00	26.75	92.46
ICGIL 17105-T1-12-1	35.31	20.84	26.38	55.79	26.42	89.86
ICGIL 17105-T4-9-10	33.91	20.61	47.20	78.43	22.28	98.26
ICGIL 17105-T4-38-1	35.31	20.57	35.54	68.41	24.17	84.86
ICGIL 17105-T11-1-2	34.91	20.20	27.27	72.40	30.13	84.46
ICGIL 17110-T1-9-10	33.11	31.49*	50.83*	73.15	29.97*	92.26
ICGIL 17110-T4-8-6	35.51	24.4	38.98	62.17	32.11	80.86
ICGIL 17110-T4-8-7	34.51	24.28	34.32	60.63	30.26	88.86
ICGIL 17110-T2-9-10	35.91	24.11	48.93	70.81	25.90	90.26
ICGIL 17110-T5-8-4	34.62	23.36	45.93	66.99	27.94	86.26
ICGIL 17112-T2-27-3	35.11	18.78	40.82	69.87	26.37	88.86
ICGIL 17112-T2-37-7	35.23	15.90	30.80	61.27	27.42	82.96
ICGIL 17112-T2-7-1	34.21	15.28	30.70	55.75	28.30	82.86
ICGIL 17105	35.29	20.05	31.23	64.88	23.19	96.43
ICGIL 17110	35.14	27.10	37.97	68.57	23.84	95.00
ICGIL 17112	35.43	20.82	28.50	59.73	22.50	94.57
GPBD 4	34.57	21.66	33.29	65.01	30.91	95.71
SEm ±	0.17	1.61	16.00	15.86	3.43	29.60
CD (5%)	1.34	4.05	12.79	12.73	5.92	17.39

*: Significantly superior than parents. SEm±: Standard error of mean, C.D.: Critical difference, 50% F: Days to 50 per cent flowering, PH: Plant height (cm), PYPP: Pod yield/plant (g), SP: Shelling percentage, TW: Test weight (g), SMKP: Sound mature kernel weight percentage

Such efforts of mutagenesis with gamma rays and EMS in the introgression lines and interspecific derivatives to develop promising mutants have been reported in groundnut (Joshi *et al.,* 2019). The superior mutants developed in this study are being evaluated in large plots in the station trial along with the parents and other elite varieties to check their performance towards developing them into commercial varieties.

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Invigoration of various sized sunflower seeds: an evaluation of germination and seedling quality parameters under different aging conditions

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ABSTRACT

An experiment was conducted at laboratory of Department of Seed Science and Technology, Institute of Agricultural Science, University of Calcutta, West Bengal, India to evaluate the response of various sized sunflower seeds (large, medium, small, composite) to invigoration treatments (control, red chilli powder@ 1g/kg of seed, bleaching powder@ 2 g/kg of seed, aspirin@ 50 mg/kg of seed) under various aging conditions. Results showed that compared to aged seeds, germination and seedling quality parameters of sunflower were best under fresh seeds. Among aging conditions, naturally aged seeds showed less quality deterioration than seeds under accelerated aging. Irrespective of aging and no aging, large sized seeds treated with either red chilli powder or bleaching powder showed good seedling quality. Specifically, freshly harvested large seeds produced vigorous seedling when treated with red chilli powder (vigour index-I: 1833.88, vigour index-II: 2174.52) or bleaching powder (vigour index-I: 1808.76, vigour index-II: 2200.09). Among two aging conditions, seed quality deterioration was better checked and repairing of damage to an extent was done over control when large seeds were treated with powders specially, red chilli powder (vigour index-I: 1079.61, vigour index-II: 1128.59) or bleaching powder (vigour index-I: 1060.07, vigour index-II: 1053.21) under natural aging condition.

Keywords: Aging, Invigoration, Quality, Seed size, Sunflower

Sunflower (*Helianthus annuus* L.) is globally known as an important oilseed crop as it provides 46-52% oil content. Worldwide, sunflower oil is well appreciated for its good quality as it contains very high PUFA content (Rani *et al.,* 2016) and therefore, it is suitable for the people with cardiac issues. Sunflower is also used as decoration material due to its aesthetic beauty. Moreover, sunflower is known to provide oilcakes for improving soil fertility and agricultural productivity. Among the countries of the world, India is a major sunflower producer as it produces 0.19 million tonnes of sunflower from 0.33 million ha of land with a productivity of 590 kg/ha (NFSM, 2018). Karnataka, Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, Maharashtra, Haryana, Punjab, Bihar, Odisha and West Bengal are some important sunflower growing states of India.

Since long, oilseed crops like sunflower hold important places not only in human diet but also in food and other industries. Consistent increase of market price of vegetable oils is very prominent today. Demand and supply gap, interference of middle men, negligence towards oilseed crops, higher dependence on imports to meet the domestic demands are some of the major reasons behind such high price. In order to address supply of the produce of oilseeds at low price under the context of modern day agricultural land shrinkage, productivity of oilseeds requires to be revamped at this hour (Lakshman and Sadakshari, 2018). In order to achieve this, appropriate agro-techniques and package of practises are needed to be implemented.

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Sunflower productivity in India is quite low and declining day by day. One major reason behind such grim situation is poor plant population along with weak seedling growth. Das *et al.* (2020) stated that adequate germination and healthy and vigorous plant stand by addressing seedling mortality are needed to achieve higher productivity of sunflower in India, specially, in West Bengal. For this, care should be paid towards maintenance as well as enhancement of seed quality. In India, seed storage for the next season is a routine practice among the farmers. Various physiological and biochemical changes occur during seed storage. Many scientists have reported that seed quality deteriorates with aging in response to prevailing atmospheric conditions, insect pest and disease attacks, irradiation inside the storage. In order to maintain seed quality as well as to check rapid deterioration of seeds with aging, researchers are trying to formulate several new technologies. One such is seed invigoration. Powdered materials of various compositions (chemicals, crude plant materials, pharmaceutical powders, etc.) are useful in treating seed during storage as it helps to check seed quality deterioration and maintain seed longevity (Bhattacharya *et al.,* 2015; Guha *et al.,* 2012; Basra *et al.,* 2003). Additional care is very much required for sunflower seeds as they contain high oil content (rich in lipids) and deterioration of seed quality is, therefore, a major problem under aging (Balesevic-Tubic *et al.,* 2007). In this regard, invigoration of sunflower seeds with powdered ingredients of various origins and at different doses is a useful option to achieve good germination and vigorous seedling growth. It has been a general fact that different seed sizes respond differently to those powdered ingredients. Earlier, Saha and Mandal (2016) observed the impact of various invigoration treatments on different seed size of sunflower under natural aging condition. With this background, the present study was planned to evaluate germination and seedling quality parameters of various sized sunflower seeds treated with invigoration powdered ingredients under fresh condition as well as natural and accelerated aging conditions.

MATERIALS AND METHODS

The experiment was conducted inside the laboratory of Department of Seed Science and Technology, Institute of Agricultural Science, University of Calcutta, West Bengal, India in 2015 to evaluate the response of various sized sunflower seeds under different aging conditions to invigoration using powdered ingredients. Newly harvested sunflower seeds (variety: Morden) after cleaning and sun drying to a moisture content of 8% were graded visually in to small, medium, large categories along with composites (no grading). Then those different seed categories were treated with 3 invigoration powdered ingredients *viz.,* finely powdered aspirin (active ingredient, ortho acetyl salicylic acid) @ 50 mg/kg of seed, bleaching powder (calcium hypochlorite) @ 2 g/kg of seed and red chilli powder (active ingredient, capsaicin) @ 1g/kg of seed along with control (dry seeds) inside rubber stoppered glass bottles at room temperature (28±1ºC) under favourable conditions.

Performance of seeds treated with invigoration powdered ingredients were thereafter compared among no aging and two aging conditions (natural aging and accelerated aging). Seeds with or without treatment (with various powdered ingredients) were collected in perforated paper packets separately and then those packets were subjected to natural aging in cloth bags under normal room condition for 4 months. For accelerated aging, treated and untreated seeds were collected in paper packets and kept in desiccator. Then, the desiccator containing the seeds was kept in BOD incubator maintaining the 40°C temperature and 98% relative humidity for 16 days. In both the aging, regular shaking of seeds was done without causing any physical damage.

Germination percentage and seedling quality parameters (root length, shoot length, seedling fresh weight, seedling dry weight, vigour index-I and II) were evaluated using the methods prescribed by International Seed Testing Association (ISTA, 2009). Vigour index-I and II were estimated using the following formulas:

Vigour index- I =
Germination percentage × (Root length (cm) + Shoot length (cm))
Vigour index- II =
Germination percentage × Seedling dry weight (mg/seedling)

Data recorded from the experiment were then statistically analysed through OP-STAT online portal (Sheoran *et al.,* 1998) using the methods suggested by Panse and Sukhatme (1985) and treatment means were compared through critical differences (CD) at 5% level of significance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Influence of seed sizes under no aging and aging conditions: Experimental results revealed that germination and seedling quality parameters of sunflower were significantly influenced by the variable seed size under no aging as well as natural and accelerated aging conditions (Tables 1 to 3). Irrespective of no aging, natural aging and accelerated aging, highest germination percentage was observed in case of medium sized seeds which were followed serially by large, composite and small sized seeds. Slightly less water requirement of the medium sized seeds over large ones and thereby, adequate water intrusion in the medium sized seeds might facilitated on high germination percentage. However, germination percentage under large sized seeds was statistically at par with that under medium sized seeds. In fact, large sized seeds performed best with respect to root and shoot lengths, seedling fresh and dry weights, vigour index-I and II. Regarding germination and all the seedling quality parameters, fresh seeds outperformed aged seeds and among two aging conditions, seeds under natural aging produced relatively better germination and seedling quality than the seeds under accelerated aging. Large sized seeds produced germination of 91% (transformed value: 72.39%), 66% (transformed value: 54.29%), and 57% (transformed value: 48.97%), root length of 13.34 cm, 9.73 cm and 8.95 cm, shoot length of 4.81 cm, 4.62 cm and 4.40 cm, seedling fresh weight of 175.9 mg, 117.1 mg and 110.7 mg, seedling dry weight of 22.0 mg, 14.8 mg and 13.2 mg, vigour index-I of 1645.40, 949.45 and 761.65 and vigour index-II of 1996.52, 980.93 and 751.3 under no aging (Table 1), natural aging (Table 2) and accelerated aging (Table 3) conditions, respectively. Impairments of chromosomal and various antioxidant enzymatic activities can be speculated as some of the reasons behind such seed quality deterioration under aging compared to fresh seeds (Kapilan and Thiagarajah, 2015). Specifically, with aging of seeds, production of reactive oxygen species (ROS), lipid peroxidation and leakage of electrolytes might occur (Bhattacharya *et al.,* 2015). Seed germination and physiological activities inside the seeds put great influence on seedling growth and quality (Das *et al.,* 2020). Reduction in germination as well as enzymatic and physiological activities thereby, directly reflect on poor seedling quality parameters under natural and accelerated aging conditions. Large sized seeds impacted positively on quality attributes of sunflower as germination was higher than small ones and quite similar with medium ones. Another possible reason might be the higher food reserves in cotyledons of large sized seeds, which helped in faster and greater root growth (Harper, 1977). Better root growth improved water and nutrient uptakes and thereby, facilitated the photosynthetic activity and ultimately, the overall seedling growth. Similar to the present result, Thiyam *et al.* (2017) in pea, Nagaraju (2001) in sunflower and Chacón *et al.* (1998) in *Cryptocarya alba* also reported best seedling growth from large sized seeds.

Table 1 Response of various sized sunflower seeds to invigoration powdered ingredients under no aging condition

Treatments	Germination percentage*	Root length (cm)	Shoot length (cm)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Vigour index-I	Vigour index-II
Seed sizes							
Composite	89 (70.96)	11.15	4.26	138.2	17.5	1375.60	1562.08
Large	91 (72.39)	13.34	4.81	175.9	22.0	1645.40	1996.52
Medium	91 (73.19)	12.16	4.57	141.3	18.8	1530.56	1714.43
Small	85 (67.59)	10.22	3.78	101.5	15.0	1197.51	1282.86
SE(m)	0.84	0.17	0.04	0.58	0.3	8.99	31.69
C.D.(5%)	2.43	0.51	0.12	1.7	0.8	26.02	91.70
Powdered ingredients							
Control	87 (68.85)	9.70	3.93	125.0	16.8	1184.95	1458.39
Aspirin	88 (70.24)	11.45	4.11	136.6	17.5	1374.66	1550.05
Bleaching powder	92 (73.50)	12.63	4.63	146.6	19.3	1584.01	1768.12
Red chilli powder	90 (71.54)	13.09	4.74	148.7	19.8	1605.45	1779.34
SE (m)	0.84	0.17	0.04	0.58	0.3	8.99	31.69
CD (5%)	2.43	0.51	0.12	1.7	0.8	26.02	91.70

*Data in parenthesis indicates arc sine transformed value of actual germination percentage

Table 2 Response of various sized sunflower seeds to invigoration powdered ingredients under natural aging condition

Treatments	Germination percentage*	Root length (cm)	Shoot length (cm)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Vigour index-I	Vigour index-II
Seed sizes							
Composite	65 (54.02)	7.83	3.93	81.6	12.0	772.69	787.09
Large	66 (54.29)	9.73	4.62	117.1	14.8	949.45	980.93
Medium	68 (55.55)	8.43	4.32	99.3	12.8	868.54	873.09
Small	63 (52.67)	5.72	3.58	71.8	11.6	587.81	733.90
SE(m)	0.55	0.10	0.03	0.90	0.3	6.06	22.77
C.D.(5%)	1.58	0.28	0.09	2.6	0.9	17.53	65.90
Powdered ingredients							
Control	64 (53.00)	6.73	3.68	80.9	11.5	665.26	736.02
Aspirin	65 (53.69)	7.16	3.87	87.0	12.2	718.09	790.46
Bleaching powder	67 (54.98)	8.81	4.42	99.3	13.4	889.35	900.41
Red chilli powder	67 (54.86)	9.02	4.48	102.4	14.2	905.79	948.11
SE (m)	0.55	0.10	0.03	0.90	0.3	6.06	22.77
CD (5%)	1.58	0.28	0.09	2.6	0.9	17.53	65.90

*Data in parenthesis indicates arc sine transformed value of actual germination percentage

Table 3 Response of various sized sunflower seeds to invigoration powdered ingredients under accelerated aging condition

Treatments	Germination percentage*	Root length (cm)	Shoot length (cm)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Vigour index-I	Vigour index-II
Seed sizes							
Composite	56 (48.47)	7.26	3.69	76.0	10.8	615.87	604.3
Large	57 (48.97)	8.95	4.40	110.7	13.2	761.65	751.3
Medium	58 (49.48)	7.71	4.07	93.9	11.9	682.33	689.2
Small	54 (47.42)	5.06	3.33	65.9	10.6	456.17	577.0
SE(m)	0.29	0.06	0.02	0.56	0.3	4.18	20.18
CD (5%)	0.83	0.17	0.07	1.6	0.9	12.09	58.40
Powdered ingredients							
Control	55 (47.68)	6.01	3.43	74.9	10.3	518.11	563.16
Aspirin	56 (48.20)	6.51	3.68	80.9	11.0	568.79	613.35
Bleaching powder	57 (49.28)	8.15	4.17	94.5	12.3	709.19	709.37
Red chilli powder	57 (49.19)	8.31	4.22	96.2	12.8	719.93	735.96
SE(m)	0.29	0.06	0.02	0.56	0.3	4.18	20.18
CD (5%)	0.83	0.17	0.07	1.6	0.9	12.09	58.40

*Data in parenthesis indicates arc sine transformed value of actual germination percentage

Influence of powdered ingredients under no aging and aging conditions: Irrespective of various sizes, invigoration of sunflower seeds with different powdered ingredients exhibited significant influence on germination and seedling quality parameters under no aging as well as natural and accelerated aging conditions (Tables 1 to 3). As compared to control or dry seeds, seed invigoration with powdered ingredients improved germination and seedling quality parameters under both the aging conditions as well as no aging condition (fresh seeds). The highest germination [92 % (transformed value: 73.50 %)] was observed when fresh seeds were treated with bleaching powder. However, seed germination under red chilli powder treatment was statistically at par with it. Besides, maximum root length (13.09 cm), shoot length (4.74 cm), seedling fresh weight (148.7 mg), seedling dry weight (19.8 mg), vigour index-I (1605.45) and vigour index-II (1779.34) were noticed specially under application of red chilli powder in case of fresh seeds over aged seeds (both naturally and accelerated). Among the natural aging and accelerated aging, better seed germination and seed quality parameters were observed in case of naturally aged seeds under application of red chilli powder. In both no aging and aging conditions, seed invigoration with bleaching powder also showed statistical similarity with red chilli powder as it produced root length of 12.63 cm, 8.81 cm and 8.15 cm, shoot length of 4.63 cm, 4.42 cm and 4.17 cm, seedling fresh weight of 146.6 mg, 99.3 mg and 94.5 mg, seedling dry weight of 19.3 mg, 13.4 mg and 12.3 mg, vigour index-I of 1584.01, 889.35 and 709.19 and vigour index-II of 1768.12, 900.41 and 709.37 under no (Table 1), natural (Table 2) and accelerated (Table 3) aging conditions, respectively. Red chilli powder contained capsaicin which possessed antioxidant properties against free radicals (OH° and peroxyl) (Nascimento *et al.*, 2013) and protected seeds to some extent from pathogenic infections under aging conditions (Saha and Mandal, 2016). Moreover, it transferred hydrogen from phenolic hydroxyl group and thereby, acted as potential scavenger of radicals. Besides, inhibitory effects of red chilli powder on lipid peroxidation and electrolyte leakage (Dey and Ghosh, 1993), reduction of aldehyde content (Mandal *et al.,* 2000) and improvement of cell membrane integrity might be some other reasons behind the beneficial effects of red chilli powder on sunflower seeds under both no and aging conditions. Bleaching powder treatment also impacted well on sunflower seeds and seedlings and it might be due to stabilizing capacity of lipid double bonding in seed membrane by the presence of halogen chloride (Rudrapal and Basu, 1981). Farooq *et al.* (2008) and Pryor and Lasswell (1975) further, reported radical scavenging properties of bleaching powder, which probably reflected on high seed and seedling quality in the present study. Similar positive results of bleaching powder treatment on maize and mustard seeds have been reported by Vidyadhar and Singh (2000).

Interaction effect of seed sizes and powdered ingredients under no aging and aging conditions: Apart from their individual effects, both seed size and invigoration powdered ingredients together put statistically significant impact on quality parameters of sunflower under both no aging as well as natural and accelerated aging conditions except germination, seedling dry weight and vigour index-II (Tables 4 to 6). Seed germination and seedling quality parameters were best under no aging condition than the two aging conditions. Irrespective of seed sizes and invigoration powdered ingredients, vigour index-I (Fig. 1) and vigour index-II (Fig. 2) of sunflower seedlings under no aging and aging conditions revealed that best result was observed in fresh seeds which were followed serially by naturally aged seeds and the seeds of accelerated aging. In case of no aging (Table 4), fresh seeds of medium size when treated with bleaching powder germinated to the maximum extent [94 % (transformed value: 75.42%)]. However, large sized fresh seeds treated with red chilli powder produced best quality parameters of seedlings (root length: 15.17 cm, shoot length: 5.10 cm, seedling fresh weight: 183.0 mg, seedling dry weight: 24.0 mg and vigour index-I: 1833.88), which was followed by large sized seeds treated with bleaching powder (root length: 14.73 cm, shoot length: 5.00 cm, seedling fresh weight: 180.0 mg, seedling dry weight: 24.0 mg and vigour index-I: 1808.76). On the other hand, vigour index-II was best observed when large sized fresh seeds were treated with bleaching powder (2200.09). Regarding natural and accelerated aging conditions, similar trend of germination as occurred in fresh seeds was observed. Under natural aging, various sized seed invigoration with powdered ingredients showed better performance than that observed under accelerated aging. Specifically, large sized seeds treated with red chilli powder produced root length of 11.07 cm and 10.33 cm, shoot length of 4.90 cm of 4.70 cm, seedling fresh weight of 123.0 mg and 117.0 mg, seedling dry weight of 16.7 mg and 14.7 mg, vigour index-I of 1079.61 and 870.59 and vigour index-II of 1128.59 and 850.12 in case of natural aging (Table 5) and accelerated aging (Table 6), respectively. Like the fresh seeds, large sized aged seeds treated with bleaching powder also produced good seedling quality parameters both under natural aging (root length: 10.90 cm, shoot length: 4.87 cm, seedling fresh weight: 120.7 mg, seedling dry weight: 15.7 mg, vigour index-I: 1060.07 and vigour index-II: 1053.21) and accelerated aging (root length: 10.17 cm, shoot length: 4.67 cm, seedling fresh weight: 116.3 mg, seedling dry weight: 14.0 mg, vigour index-I: 854.96 and vigour index-II: 807.60) conditions and both large sized fresh and aged seeds treated with either red chilli powder or bleaching powder produced statistically similar quality parameters. Irrespective of aging and no aging conditions, small sized dry sunflower seeds without any treatment (i.e. control) exhibited poorest germination and seedling quality parameters (Tables 4 to 6). Among the two aging practices, accelerated aging caused higher deterioration of seed quality due to exposure to high temperature (40°C) and relative humidity (98%). Under high relative humidity and temperature, seeds probably absorbed high moisture and consequently, high respiration occurred, which finally caused fungal invasion and spoilage (Assefa and Srinivasan, 2016). Besides, chances of cell leachates, increase of electrical conductivity, disintegration of cell membrane, etc. under high relative humidity and temperature might have also triggered seed quality deterioration. Lima *et al.* (2014) also observed severe seed quality deterioration of sunflower in accelerated aging due to exposure to high temperature and relative humidity.

Overall, the study showed the effectiveness of seed invigoration not only in ensuring best germination and seedling quality of fresh seeds but also in checking severe quality deterioration of naturally aged seeds under storage duration of 4 months. Thus, it is concluded that invigoration of large sized seeds with red chilli powder@ 1g/kg of seed or bleaching powder@ 2 g/kg of seed can be recommended as an ideal practice for the sunflower growers for achieving good germination and healthy seedling growth.

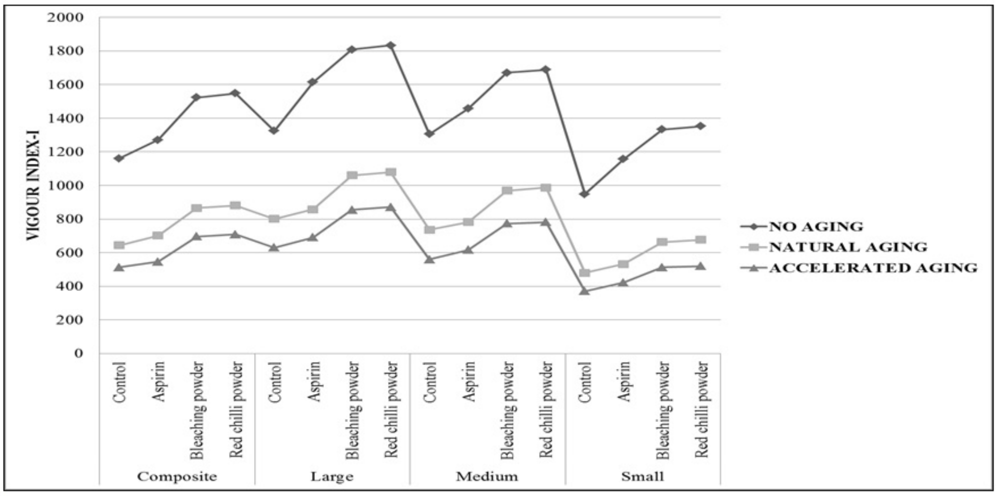

Fig. 1. Interaction effect of seed size and powdered ingredients on vigour index-I of sunflower seedlings under various aging conditions

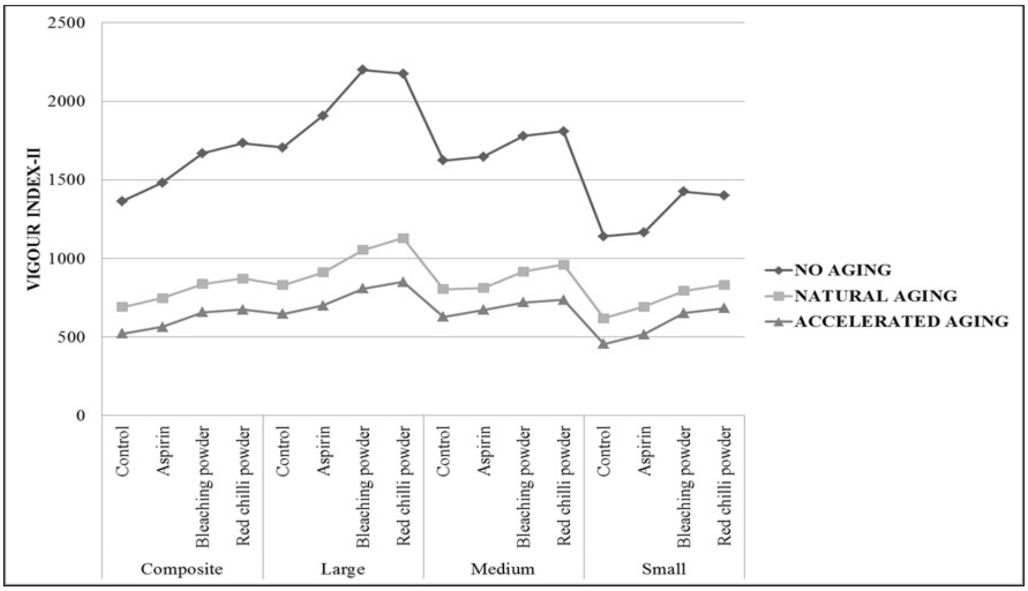

Fig. 2. Interaction effect of seed size and powdered ingredients on vigour index-II of sunflower seedlings under various aging conditions

Table 4 Interaction effect of various sized sunflower seeds and invigoration powdered ingredients on germination and seedling quality under no aging condition

Treatments		Germination percentage*	Root length (cm)	Shoot length (cm)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Vigour index-I	Vigour index-II
Seed sizes × Powdered ingredients								
Composite	Control	85 (67.43)	9.88	3.73	135.0	16.0	1160.73	1364.43
	Aspirin	87 (69.17)	10.75	3.83	136.0	17.0	1270.55	1482.31
	Bleaching powder	93 (74.48)	11.80	4.67	139.7	18.0	1523.22	1667.96
	Red chilli powder	91 (72.75)	12.17	4.80	142.0	19.0	1547.89	1733.63
Large	Control	90 (71.28)	10.30	4.47	168.3	19.0	1325.08	1704.93
	Aspirin	91 (72.71)	13.17	4.67	172.3	21.0	1613.89	1906.55
	Bleaching powder	92 (73.41)	14.73	5.00	180.0	24.0	1808.76	2200.09
	Red chilli powder	91 (72.17)	15.17	5.10	183.0	24.0	1833.88	2174.52
Medium	Control	90 (72.11)	10.24	4.23	114.7	18.0	1305.69	1623.30
	Aspirin	92 (73.26)	11.53	4.40	132.0	18.0	1457.48	1646.39
	Bleaching powder	94 (75.42)	13.10	4.77	157.7	19.0	1670.58	1778.93
	Red chilli powder	90 (71.98)	13.77	4.90	160.7	20.0	1688.47	1809.11
Small	Control	81 (64.59)	8.40	3.30	82.0	14.0	948.29	1140.91
	Aspirin	83 (65.82)	10.37	3.53	106.0	14.0	1156.74	1164.96
	Bleaching powder	89 (70.69)	10.87	4.10	109.0	16.0	1333.47	1425.49
	Red chilli powder	88 (69.27)	11.27	4.18	109.0	16.0	1351.55	1400.10
SEm±		1.68	0.35	0.08	1.16	0.6	17.98	63.37
CD (5%)		NS	1.01	0.24	3.4	NS	52.04	NS

*Data in parenthesis indicates arc sine transformed value of actual germination percentage

Table 5 Interaction effect of various sized sunflower seeds and invigoration powdered ingredients on germination and seedling quality under natural condition

Treatments		Germination percentage*	Root length (cm)	Shoot length (cm)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Vigour index-I	Vigour index-II
Seed sizes × Powdered ingredients								
Composite	Control	63 (52.37)	6.87	3.40	72.0	11.0	644.22	690.49
	Aspirin	64 (53.10)	7.40	3.57	74.0	11.7	701.30	747.51
	Bleaching powder	68 (55.48)	8.40	4.33	88.7	12.3	864.92	838.06
	Red chilli powder	67 (55.14)	8.67	4.43	91.7	13.0	880.33	872.32
Large	Control	64 (53.03)	8.27	4.27	109.7	13.0	800.66	830.58
	Aspirin	65 (53.78)	8.70	4.47	115.0	14.0	857.44	911.32
	Bleaching powder	67 (55.06)	10.90	4.87	120.7	15.7	1060.07	1053.21
	Red chilli powder	68 (55.30)	11.07	4.90	123.0	16.7	1079.61	1128.59
Medium	Control	67 (54.95)	7.01	3.97	88.0	12.0	736.22	804.50
	Aspirin	68 (55.37)	7.41	4.13	91.0	12.0	781.55	811.08
	Bleaching powder	69 (56.01)	9.53	4.57	107.0	13.3	969.42	917.00
	Red chilli powder	69 (55.87)	9.77	4.63	111.0	14.0	986.96	959.78
Small	Control	61 (51.66)	4.77	3.10	54.0	10.0	479.93	618.53
	Aspirin	63 (52.52)	5.13	3.33	68.0	11.0	532.07	691.92
	Bleaching powder	64 (53.37)	6.40	3.93	81.0	12.3	662.99	793.39
	Red chilli powder	64 (53.12)	6.60	3.97	84.0	13.0	676.26	831.76
SEm±		1.10	0.20	0.06	1.8	0.6	12.12	45.54
CD (5%)		NS	0.57	0.17	5.2	NS	35.07	NS

*Data in parenthesis indicates arc sine transformed value of actual germination percentage

Table 6 Interaction effect of various sized sunflower seeds and invigoration powdered ingredients on germination and seedling quality under accelerated aging condition

Treatments		Germination percentage*	Root length (cm)	Shoot length (cm)	Seedling fresh weight (mg)	Seedling dry weight (mg)	Vigour index-I	Vigour index-II
Seed sizes × Powdered ingredients								
Composite	Control	54 (47.24)	6.23	3.27	67.7	9.7	512.15	522.26
	Aspirin	55 (47.63)	6.63	3.37	69.0	10.3	546.10	564.47
	Bleaching powder	58 (49.53)	8.00	4.03	82.7	11.3	696.24	657.30
	Red chilli powder	58 (49.47)	8.17	4.10	84.7	11.7	708.99	673.26
Large	Control	55 (48.11)	7.40	3.97	101.3	11.7	630.27	647.21
	Aspirin	57 (48.87)	7.90	4.27	108.0	12.3	690.79	700.29
	Bleaching powder	58 (49.38)	10.17	4.67	116.3	14.0	854.96	807.60
	Red chilli powder	58 (49.54)	10.33	4.70	117.0	14.7	870.59	850.12
Medium	Control	57 (49.08)	6.22	3.57	81.0	11.0	558.86	628.13
	Aspirin	58 (49.35)	6.77	3.93	84.7	11.7	616.37	672.43
	Bleaching powder	58 (49.82)	8.87	4.37	104.0	12.3	772.89	719.85
	Red chilli powder	58 (49.67)	9.00	4.43	106.0	12.7	781.18	736.37
Small	Control	52 (46.28)	4.20	2.93	49.7	8.7	371.18	455.02
	Aspirin	53 (46.93)	4.73	3.17	62.0	9.7	421.89	516.19
	Bleaching powder	56 (48.38)	5.57	3.60	75.0	11.7	512.67	652.72
	Red chilli powder	55 (48.09)	5.73	3.63	77.0	12.3	518.96	684.10
SEm±		0.57	0.12	0.05	1.12	0.6	8.35	40.36
CD (5%)		NS	0.34	0.13	3.2	NS	24.18	NS

*Data in parenthesis indicates arc sine transformed value of actual germination percentage

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Study of gene action and combining ability for seed yield and yield attributing traits in sunflower (*Helianthus annuus* L.)

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ABSTRACT

Eight CMS lines and seven restorers were crossed in a line x tester fashion to elucidate the information on combining ability for achene yield, yield components and oil content and also to know the nature of gene action involved in inheritance of important traits. A total of 56 crosses were evaluated for 9 different quantitative traits. The analysis of variance revealed the existence of a statistically significant difference between the genotypes used in crossing, which confirmed the differences among selected parents. Among the lines, CMS-853A and CMS-852A exhibited significant *gca* effect for most of the characters studied except autogamy (%) and were found to be the best combiners. Likewise, tester EC-601878 was the best combiner for plant height, head diameter, days to 50% flowering, achene yield, autogamy (%), hull content, volume weight and oil content. Twenty-three crosses showed significant positive *sca* effect for yield. Among the crosses, CMS-103A x EC-601978, CMS-10A x EC-601725, CMS-207A x EC-623023, P-89-1A x EC-623027, CMS-850A x EC-601878 and CMS-853A x EC-623027 exhibited higher positive *sca* effect for yield. Non additive component of the genetic variance was observed for majority of the traits studied.

Keywords: Achene yield, Combining ability, Gene action, Sunflower, Oil content

Sunflower (*Helianthus annuus* L.) is an important oilseed crop in India popularly known as Surajmukhi. The crop is insensitive to day-length and is considered a short duration, requiring about 110 days from planting to harvesting (Putnam *et al.,* 1990; Salunkhe, 1992). Sunflower crop fits well in different types of cropping patterns due to short duration. Sunflower contribution towards attaining self-sufficiency in edible oil as well as to "yellow revolution" has been documented (Mangala Rai, 2002). The main objectives of sunflower breeding programs are the development of productive F1 hybrids with high achene yield and high oil content. The national sunflower hybrid breeding programme was started in early 1980s. Sunflower hybrid breeding was started economically after discovering of CMS by Leclercq in 1969 and restorer line by Kinman in 1970. First sunflower hybrids were produced in US in 1972 and hybrids occupied 80% area in five years (Miller and Fick, 1997). Availability of CMS and fertility restoring sources and highly cross-pollinated nature of sunflower crop has made the exploitation of heterosis possible on commercial scale. In India, the first sunflower hybrid BSH-1 (CMS-234A x RHA-274) was released for commercial cultivation by University of Agricultural Sciences, Bangalore (Seetharam *et al.,* 1980). Since then, 29 hybrids have been released by public sector which are in commercial cultivation (Sujatha *et al.,* 2019). The superiority of hybrids over open pollinated varieties in terms of uniformity, autogamy, productivity, yield stability, oil content and tolerance to pest and diseases shifted the breeding emphasis from population improvement to heterosis breeding. Careful and critical evaluation and selection of parental lines to develop promising hybrids with improved yield potential is of paramount importance in order to improve production and productivity. Combining ability studies elucidates the nature and magnitude of gene action involved in the inheritance of character by providing the information on the two components of variance *viz.,* additive and dominance variances, which are important to decide upon the parents and crosses to be selected for eventual success (Jondhale *et al.,* 2014). The line × tester analysis is one of the efficient methods of evaluating large number of inbred lines as well as providing information on the relative importance of general combining ability and specific combining ability effects for interpreting the genetic basis of important plant traits. Combining ability analysis helps in identification of best parents for further exploitation in breeding programme. The usefulness of a particular cross in exploiting heterosis is judged by the specific combining ability (*SCA*) effect. Based on the combining ability analysis of different characters, higher *SCA* values refer to dominant gene effects and higher *GCA* effects indicate a greater role of additive gene effects controlling these characters. If both the *GCA* and *SCA* values are not significant, epistatic gene effects share an important role in determining these characters (Fehr, 1993). The present investigation was undertaken to select parents with good *gca* effect and crosses with good *sca* effect through line x tester analysis. This study also gives an idea on the nature of gene action involved in inheritance of important quantitative traits. The objective of

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this study was to estimate *GCA* and *SCA* of parents so as to identify superior combiners for high achene yield and yield contributing traits.

MATERIALS AND METHODS

A set of eight cytoplasmic male sterile lines *viz.,* CMS-850A, CMS-852A, CMS-10A, CMS-853A, P-89-1A, CMS-103A, P-2-7-1A, CMS-207A and seven restorers *viz*., EC-601878, EC-623023, EC-623016, EC-623027, EC-601751, EC-601725, EC-623021 were planted during 2014-15 at Nimpith, West Bengal. The seed material was obtained from ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR), Hyderabad and other sunflower AICRP centres. Crossing was performed in line x tester fashion and seeds were harvested separately to study the combining ability analysis. During late *rabi* 2015-16, seven selected exotic collection lines as testers, eight CMS lines, resultant 56 F_1 hybrids along with three checks were sown in a Randomized Block Design (RBD) with two replications. Each entry was raised with two rows in a plot size 3.0 m x 0.6 m by adopting a spacing of 60 cm between rows and 30 cm between plants. Observations were recorded on five randomly selected plants on 9 quantitative characters *viz.,* days to 50 per cent flowering, plant height (cm), head diameter (cm), achene yield (kg/ha), 100 seed weight (g), autogamy (%), hull content (%), volume weight (g/100 ml) and oil content (%). The analysis of variance was computed as per Panse and Sukhatme (1954), for all the characters. Data were further analyzed for general and specific combining abilities, following Line × Tester analysis given by Kempthorne (1957). The significance of *GCA* and *SCA* effects was determined at the 0.05 and 0.01 levels using the t-test.

RESULTS AND DISCUSSION

The analysis of variance for parents and crosses (Table 1) indicated significant differences for all the characters indicating the existence of genetic diversity in the parental material. Mean sum of squares for crosses were also found to be significant for all the traits. The lines, testers and line v/s testers exhibited significant differences among themselves for all characters except 100 seed weight in lines and testers and 100 seed weight and oil content in lines v/s testers. Our results are in conformity with Ortis *et al.* (2005) and Binodh *et al.* (2008). It could be because of the diverse nature of testers and the significant interaction between lines and testers. The parent v/s crosses interactions had non-significant difference for all the characters studied. Similar results have also been reported by Habib *et al.* (2007) and Khan *et al.* (2008). The variance component due to specific combining ability (*sca*) was greater in magnitude than that of general combining ability (*gca*) for all characters indicating predominance of non-additive type of gene action which is in agreement with the findings of Radhika *et al.* (2001), Sakthivel (2001), Varaprasad *et al.* (2006) and Jondhale *et al.* (2014). Additive type of gene action was noticed for plant height only while, additive and non-additive types of gene action was reported for achene yield. Additive gene action was reported for plant height, days to 50% flowering (Bhat *et al.,* 2000) and head diameter (Gvozdenovic *et al.,* 2005).

The general combining ability effects (Table 2) indicated that among the lines, CMS-103A followed by CMS-850A, CMS-852A and CMS-10A possessed genes for earliness as evident from its significant negative highest *gca* effect in desirable direction for days to 50 per cent flowering. Among the testers, EC-623016 followed by EC-601878, EC-601751 and EC-601725 recorded significant negative *gca* effect in desirable direction for days to 50% flowering. Early duration hybrids are required for North India during *rabi* and spring seasons. Hence, above mentioned lines and testers can serve the purpose and can be utilized for development of early hybrids. Dwarf or medium plant height is desirable for sunflower hybrids. Line CMS-103A showed highest significant negative *gca* effect for plant height followed by CMS-850A. These results are in contradiction with the finding of Goksoy *et al.* (2000). These two CMS lines can be exploited for development of medium to dwarf hybrids. Among testers, none of the lines was dwarf. For head diameter, almost all the lines and testers exhibited significant positive *gca* effect except CMS-850A and CMS-103A. Among the female parents, highest positive significant *gca* effect was reported in CMS-853A followed by CMS-852A, P-89-1A and P-2-7-1A for achene yield. Significant positive *gca* effect for achene yield was reported by all the testers while highest was reported by tester EC-601725 followed by EC-623027, EC-623021 and EC-601751.

Higher 100-seed weight contributes to higher seed yield. Among lines, CMS-853A and among testers, EC-623027 and EC-601751 exhibited high *gca* effect in desirable direction for 100 seed weight. For autogamy (%), among lines, only two P-89-1A and CMS-103A showed significant positive *gca* effect while among testers, EC-601878 and EC-623016 exhibited *gca* effect in desirable direction. *GCA* effect in the desirable direction for hull content was reported in CMS-850A and CMS-103A among the lines and among the testers in EC-601878 and EC-623016. Among lines, highest significant negative *gca* effect was reported in CMS-850A followed by CMS-10A, CMS-103A and CMS-207A while among testers, EC-623016 followed by EC-623021, EC-601751 and EC-601878 in desirable direction. For oil content, only EC-601878 exhibited significant positive *gca* effect in desirable direction. These results were in agreement with Ashok *et al.* (2000). In the present study, significant *gca* effect for achene yield was also observed as reported earlier by Radhika *et al.* (2001). Many workers, have reported good general combiners for most of the characters in sunflower (Halaswamy *et al.,* 2004; Manivannan *et al.,* 2005; Tavade *et al.,* 2009). The parents, which are good general combiners for economic traits, may be extensively used in hybridization programmes.

Table 1 Analysis of variance for yield and yield components

Source of variation	d. f.	Days. to 50% flowering	Plant height (cm)	Head diameter (cm)	Autogamy %	100 seed weight (g)	Hull content (%)	Volume weight (g/100 ml)	Achene yield (kg/ha)	Oil content (%)
Location	1	212.46	2978.5**	28.01	176.9	1.182	26.22	39.01	441289.2**	10.58
Repl./Loc	2	27.14	540.8	9.03	26.21	2.887	5.93	19.17	143396.6*	18.21
Line	7	194.04**	9449.0**	25.2**	36.11**	3.522	57.04**	35.63**	1965372.0**	9.49**
Tester	6	74.85**	4816.9**	20.23**	17.35**	0.640	55.80**	14.16**	958346.7**	6.49*
L x T	42	31.86**	510.12**	21.50**	10.51**	0.654	16.30**	13.60**	176794.2**	2.38
L x Loc.	7	0.382	6.92	0.031	0.216	0.004	0.034	0.028	1501.09	0.007
T x Loc.	6	0.360	4.27	0.036	0.199	0.003	0.009	0.033	1278.4	0.004
L x T x LC	42	0.290	2.37	0.026	0.015	0.002	0.054	0.010	752.3	0.005
Error	110	0.002	0.261	0.002	0.029	0.003	0.008	0.006	98.22	0.002
VGCA		3.41	220.6	0.678	0.548	0.047	1.34	0.375	42814.23	0.187
VSCA		15.93	253.76	11.25	5.24	0.83	8.15	6.802	88348.02	1.19
Gene action		Non additive	Additive	Non additive	Non additive	Non additive	Non additive	Non additive	Additive & Non-additive	Non additive

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

Table 2 Estimation of general combining ability effects of male and female parents for yield and yield contributing traits

Name of the parent	Plant height (cm)	Head diameter (cm)	Days to 50% flowering	Achene yield/plant (g)	100 seed weight (g)	Autogamy (%)	Hull content (%)	Volume weight (g/100 ml)	Oil content (%)
Lines									
CMS-850A	-6.25**	-0.22*	-1.82**	- 6.08*	-1.28*	0.35	-0.56*	-0.55*	-0.55*
CMS-852A	8.65**	0.66**	-0.61*	13.27**	1.22*	0.32	0.45*	0.57*	-0.58*
CMS-10A	11.45**	0.45**	-0.55*	5.42	-1.08*	0.41	0.45*	-0.48*	-0.65*
CMS-853A	14.45**	0.81**	0.41**	14.42**	1.62*	0.32	0.41*	0.71*	-0.71*
P-89-1A	9.56**	0.52**	-0.35	10.55**	-1.16*	0.71*	0.49*	0.35*	-0.55*
CMS-103A	-9.87**	-0.26*	-2.31**	-7.42*	-1.56*	0.83*	-0.78*	-0.38*	-0.48*
P-2-7-1A	9.02**	0.46**	-0.29	10.51**	-1.02*	0.65	0.41*	0.47	-0.56*
CMS-207A	7.12*	0.36**	-0.31	8.28*	-1.16*	0.37	0.41*	-0.41*	-0.55*
SEm(±)	2.62	0.14	0.12	3.48	0.05	0.25	0.27	0.31	0.31
Testers									
EC-601878	3.41*	0.81 **	-0.72*	5.08*	-1.18*	0.73*	-0.25*	-0.47*	0.39*
EC-623023	8.85**	0.89**	1.17**	10.08**	-1.18*	-0.25	0.32*	0.55*	-0.37*
EC-623016	8.25**	0.49**	-1.14*	6.27**	-1.42**	0.65*	-0.35*	-1.06**	-1.25**
EC-623027	11.25**	1.58**	1.54**	14.27**	1.22**	0.35	0.25*	1.21**	-0.38**
EC-601751	8.21**	1.17**	-0.72*	10.08**	0.75*	-0.38	0.36*	-0.55*	-0.55*
EC-601725	6.28**	1.09**	-0.55*	14.55**	-1.28*	-0.27	0.25*	0.57*	-1.26**
EC-623021	12.25**	1.60**	0.64*	11.23**	-1.02*	-0.45	-0.40	-1.05**	-1.05**
SEm(±)	4.28	0.21	0.38	1.28	0.07	0.36	0.56	0.41	0.36

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

Table 3 *Per se* performance and corresponding *sca* effect for yield and yield attributing characters

Hybrid combination	Days to 50% flowering		Plant height (cm)		Head diameter (cm)		Achene yield (kg/ha)		Autogamy (%)	
	Per se	*sca*	*Per se*	*sca*	*Per se*	*sca*	*Per se*	*sca*	*Per se*	*sca*
CMS-853A x EC-623027	73	-1.25*	194.5	7.10**	16.4	-0.03	2462	218.0**	87	-0.82*
CMS-853A x EC-623023	75	2.13*	186.5	10.33**	16.0	0.03	2428	212.5**	87	-0.09
CMS-853A x EC-623021	74	0.47	174.0	-4.23*	15.7	-0.09	2292	157.3**	87	-0.67*
CMS-853A x EC-601751	69	-4.95**	158.0	-14.52**	15.4	-0.94*	1861	-411.5**	91	4.06**
CMS-853A x EC-601778	68	0.57	145.0	-11.20**	15.5	1.38*	1575	-202.1**	86	-2.56**
CMS-853A x EC-601725	75	2.13*	192.5	20.03**	16.4	0.147	2278	3.1	87	0.42
CMS-853A x EC-623016	72	-0.09	160.5	-7.50**	15.0	-0.50	2072	22.5	87	-0.34
CMS-852A x EC-623027	76	1.62*	185.0	2.37	15.1	1.02*	2270	-14.1	92	2.02**
CMS-852A x EC-623023	76	2.55*	180.0	3.79	15.4	0.29	2328	69.8**	88	-1.23**
CMS-852A x EC-623021	77	3.34**	184.0	5.30*	15.4	0.10	2272	92.6**	91	1.17**
CMS-852A x EC-601751	72	-1.58*	170.1	-3.00	15.4	0.65*	2284	-44.0*	90	0.45
CMS-852A x EC601878	66	-3.90**	153.0	6.11*	15.0	1.09*	1761	-66.6*	91	0.28
CMS-852A x EC-601725	70	-2.87*	155.0	-16.14**	16.7	0.77*	2072	-243.1**	87	-1.22**
CMS-852A x EC-623016	73	0.84	175.5	6.91*	15.3	1.09*	2306	205.5**	88	-1.48**
CMS-850A x EC-623027	69	0.99	133.0	-0.81	15.2	1.05*	1861	137.3**	91	-0.12
CMS-850A x EC-623023	64	-3.01**	122.5	-0.03	13.8	0.12	1472	-214.4**	91	-0.36
CMS-850A x EC-623021	63	-4.67**	112.0	-12.67**	13.2	-1.26**	1340	-265.8**	90	-1.46**
CMS-850A x EC-601751	69	1.24*	133.0	13.18**	15.4	-1.31**	1861	93.6**	91	0.32
CMS-850A x EC-601878	65	1.92*	92.5	0.66	9.6	2.12**	1500	229.4**	94	1.10**
CMS-850A x EC-601725	69	1.36*	112.0	6.44*	13.7	-0.22	1836	77.0**	91.	1.13**
CMS-850A x EC-623016	68	2.15*	122.5	7.47*	13.3	0.11	1472	-57.1**	91	-0.61*
CMS-103A x EC-623027	67	0.50	138.5	-6.19*	13.5	-0.05	1350	-127.6**	89	-1.41**
CMS-103A x EC-623023	67	0.92*	135.0	1.45	12.7	-0.35	1340	-100.12**	90	-0.15
CMS-103A x EC-623021	66	-0.73	132.0	-3.99	12.7	-0.12	1348	-22.7	90	-0.25
CMS-103A x EC-601751	67	0.25	130.1	-0.50	13.4	-0.06	1472	-42.5*	91	1.53**
CMS-103A x EC-601978	66	3.35**	124.5	19.83**	12.8	1.59**	1533	504.4**	90	-1.15**
CMS-103A x EC-601725	62	-3.50**	120.5	-8.87**	12.2	-1.09*	1232	-268.6**	91	1.85**
CMS-103A x EC-623016	64	0.79	124.0	-1.81	12.7	1.11*	1340	57.1**	90	-0.43
P-2-7-1A x EC-623027	73	1.50*	184.0	8.22**	16.4	0.65*	2094	-6.0	89	-0.24
P-2-7-1A x EC-623023	68	-2.53*	145.5	-18.30**	15.7	0.40*	2192	117.2**	88	-0.48
P-2-7-1A x EC-623021	70	0.78	168.5	7.22*	14.9	0.40*	1872	-26.6	90	1.19**
CP-2-7-1A x EC-601751	76	4.69**	177.5	15.84**	15.8	0.14	2340	90.3**	87	-1.28**
P-2-7-1A x EC-601978	64	-2.59*	137.5	2.54	11.5	-1.84**	1340	-297.1**	90	0.47
P-2-7-1A x EC-601725	68	-2.53*	145.5	-14.66**	15.7	0.16	2192	54.0*	88	0.50
P-2-7-1A x EC-623016	70	0.70	155.5	-1.05	14.9	0.09	1878	-31.7	90	0.77*
CMS-207A x EC-623027	63	-6.54**	142.5	20.87**	14.0	-1.09*	1567	-325.1**	92	2.30**
CMS-207A x EC-623023	73	3.74**	142.5	-9.84**	14.7	0.06	2194	313.8**	88	-1.42**
CMS-207A x EC-623021	70	0.6	167.0	11.65**	14.4	-0.05	1886	90.9**	90	1.45**
CMS-207A x EC-601751	68	-1.87*	145.5	-4.35*	15.7	0.65	1962	16.4	88	-0.77*
CMS-207A x EC-601978	67	1.23*	115.0	8.05**	13.5	0.72	1431	-13.8	90	-0.44
CMS-207A x EC-601725	71	2.27*	172.5	23.23**	14.8	-0.11	2017	77.8**	86	-2.41**
CMS-207A x EC-623016	68	0.55	153.0	7.88*	14.0	-0.18	1547	-159.9**	92	2.30**
P-89-1A x EC-623027	73	1.21*	180.0	12.75**	15.6	0.50*	2218	225.4**	88	-0.97*
P-89-1A x EC-623023	73	1.64*	168.5	12.58**	15.0	0.37	1974	14.9	89	0.27
P-89-1A x EC-623021	71	-1.02*	148.5	-9.31*	14.2	-0.20	1856	-22.6	89	0.17
P-89-1A x EC-601751	71	-1.01*	154.0	1.35	15.1	0.12	2144	109.8**	85	-3.01**
P-89-1A x EC-601978	68	0.58	123.0	-3.35	12.0	-0.69*	1445	-84.8**	91	1.27**
P-89-1A x EC-601725	73	1.64*	148.5	-3.08	15.0	0.13	1960	-61.7**	89	1.25**
P-89-1A x EC-623016	67	-3.05**	136.5	-11.12*	13.9	-0.24	1611	-181.5**	90	1.02**
CMS-10A x EC-623027	72	1.98*	167.5	2.18	15.4	-0.02	1722	-107.8**	88	-0.77
CMS-10A x EC-623023	64	-5.47**	154.0	0.03	14.6	-0.32	1380	-413.8**	92	3.41**
CMS-10AA x EC-623021	71	1.22*	162.5	5.94*	15.2	0.45*	1722	-2.9	8	-0.67
CMS-10A x EC-601751	73	3.23*	142.5	-8.26**	14.7	-0.58*	1967	87.5**	87	-1.31**
CMS-10A x EC-601978	64	-1.60*	119.0	-5.45*	12.8	-0.23	1306	-69.7**	92	1.97**
CMS-10A x EC-601725	70	0.94	156.5	6.33*	15.4	0.18	2240	361.4**	86	-1.50**
CMS-10A x EC-623016	68	0.31	145.5	-0.77	15.0	0.52*	1792	145.2**	87	-1.26**
S.Em(±)	0.11	0.09	0.05	0.04	0.263	0.227	0.162	0.140	6.35	5.50

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

Table 3 *Per se* performance and corresponding *sca* effect for yield and yield attributing characters (contd...)

Hybrid combination	100 seed weight (g)		Hull content (%)		Volume weight (g/100 ml)		Oil content (%)	
	Per se	*sca*	*Per se*	*sca*	*Per se*	*Sca*	*Per se*	*sca*
CMS-853A x EC-623027	6.1	0.52**	32.1	1.60**	42.8	-0.17	35.7	-0.57
CMS-853 A x EC-623023	5.9	0.56**	29.8	0.03	43.0	0.05	35.6	-0.62
CMS-853A x EC-623021	5.6	-0.17	27.8	-1.93**	43.7	1.86*	36.4	0.39
CMS-853A x EC-601751	5.3	-0.23*	27.3	-1.98**	42.6	-0.78*	36.8	1.00*
CMS-853A x EC-601778	5.4	-0.31*	24.8	-1.93**	45.3	1.21*	37.4	0.30
CMS-853A x EC-601725	5.5	-0.10	33.1	2.62**	40.0	-3.03**	35.2	-1.00*
CMS-853A x EC-623016	5.5	0.27*	31.9	1.60**	43.8	0.85*	37.2	0.50
CMS-852A x EC-623027	4.9	0.18	29.8	-1.10**	40.0	-1.93*	35.8	-0.41
CMS-852A x EC-623023	4.6	-0.24*	34.6	4.45**	43.2	1.31*	36.1	-0.06
CMS-852A x EC-623021	5.0	-0.24*	29.8	-0.31	40.0	-0.83*	35.8	0.15
CMS-852A x EC-601751	4.8	-0.25*	31.1	1.37**	41.6	-0.75*	36.4	0.66
CMS-852A x EC601878	5.1	-0.08	27.3	0.19	42.6	-0.46	36.8	-0.27
CMS-852A x EC-601725	5.5	0.46**	31.9	1.02*	43.8	1.88*	37.2	1.09*
CMS-852A x EC-623016	5.8	0.53**	25.2	-5.53**	42.7	0.78*	35.8	-0.86*
CMS-850A x EC-623027	5.1	0.23*	27.3	-2.30**	42.6	0.26	36.8	0.56
CMS-850A x EC-623023	4.5	-0.10	30.9	6.17**	43.6	1.27*	38.4	1.14*
CMS-850A x EC-623021	4.8	-0.18	29.0	0.15	42.2	0.96*	37.2	0.13
CMS-850A x EC-601751	5.1	0.26*	27.3	-1.08**	42.6	-0.16	36.8	-0.08
CMS-850A x EC-601878	5.0	0.05	27.8	1.97**	39.7	-3.82**	37.0	-1.21*
CMS-850A x EC-601725	5.1	0.27	27.3	-2.23**	42.6	0.21	37.2	-0.06
CMS-850 x EC-623016	4.5	-0.53**	30.9	1.50**	43.6	1.28*	38.4	0.64
CMS-103A x EC-623027	5.1	0.10	34.4	3.88**	43.2	-0.19	38.7	1.13*
CMS-103A x EC-623023	4.8	0.02	29.0	-0.87*	42.2	-1.22*	37.2	-0.34
CMS-103A x EC-623021	4.8	-0.36*	29.0	-0.78*	42.2	-0.11	37.2	-0.14
CMS-103A x EC-601751	5.1	0.08	30.3	0.92*	42.6	-1.23*	36.8	-0.35
CMS-103A x EC-601978	5.7	0.59**	23.6	-3.18**	48.5	4.03**	38.4	-0.03
CMS-103A x EC-601725	4.7	-0.29*	29.8	-0.65*	43.4	-0.03	38.1	0.60
CMS-103A x EC-623016	5.1	-0.14	31.0	0.68	42.2	-1.23*	37.2	-0.85*
P-2-7-1A x EC-623027	5.1	-0.61**	34.4	0.59*	43.2	0.03	37.0	-0.32
P-2-7-1A x EC-623023	5.4	-0.09	32.5	-0.68*	43.5	0.33	37.6	0.35
P-2-7-1A x EC-623021	6.6	0.85**	33.6	1.34**	42.4	-0.14	37.8	0.60
CP-2-7-1A x EC-601751	5.5	-0.21*	31.9	-0.74**	42.6	-0.01	35.2	-1.65*
P-2-7-1A x EC-601978	5.3	-0.52**	30.8	0.84**	45.6	1.29*	38.7	0.58
P-2-7-1A x EC-601725	5.4	-0.30*	32.5	-1.32**	43.5	0.29	37.6	0.38
P-2-7-1A x EC-623016	6.8	0.87**	33.6	-0.03	42.4	0.80*	37.8	0.05
CMS-207A x EC-623027	4.7	-0.11	32.6	-0.59*	39.6	-0.39	39.0	1.33*
CMS-207A x EC-623023	4.4	-0.17	29.3	-3.16**	39.9	-0.10	36.4	-1.27*
CMS-207A x EC-623021	5.0	0.02	33.8	1.38**	38.0	0.89*	37.5	0.07
CMS-207A x EC-601751	5.4	0.61**	32.5	0.48*	43.5	3.15**	37.6	0.38
CMS-207A x EC-601978	5.2	0.33*	31.9	2.48**	39.2	1.94*	38.5	-0.03
CMS-207A x EC-601725	4.8	0.02	33.1	-0.02	40.0	0.03	36.8	-0.85*
CMS-207A x EC-623016	4.3	-0.70**	32.4	-0.59*	40.2	0.20	38.5	0..38
P-89-1A x EC-623027	4.5	-0.30*	30.9	0.80**	45.1	2.93**	37.6	0.29
P-89-1A x EC-623023	4.6	0.05	31.6	0.58*	39.7	-2.53**	36.8	-0.49
P-89-1A A x EC-623021	4.8	-0.10	31.6	0.62*	39.7	-1.42*	36.8	-0.28
P-89-1A x EC-601751	5.1	0.36*	30.6	0.12	45.5	2.92**	37.4	0.56
P-89-1A x EC-601978	5.0	0.10	25.8	-2.08**	45.2	1.88*	38.8	0.66
P-89-1A x EC-601725	4.6	-0.16	31.6	-0.06	39.7	-2.56**	36.8	-0.47
P-89-1A x EC-623016	5.1	0.09	33.1	1.62**	41.0	-1.23*	37.5	-0.27
CMS-10A x EC-623027	5.4	0.34*	30.6	-1.27**	40.8	-0.54	36.5	-0.89*
CMS-10A x EC-623023	4.8	-0.02	29.0	-2.34**	42.2	0.88*	38.6	1.31*
CMS-10A x EC-623021	5.4	0.21*	30.7	-0.48*	40.8	0.57	36.5	-0.63
CMS-10A x EC-601751	4.4	-0.64**	31.6	0.90**	39.6	-2.15*	36.4	-0.52
CMS-10A x EC-601978	5.0	-0.16	29.8	1.70**	40.3	-2.18*	38.2	0.01
CMS-10A x EC-601725	5.1	0.10	32.5	0.65*	44.6	3.27*	37.6	0.31
CMS-10A x EC-623016	5.4	0.15	32.5	0.75*	41.5	0.15	38.2	0.41

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

The *sca* effect showed that none of the single crosses showed maximum *sca* effect in desirable direction for all the characters (Table 3). Hybrid combination CMS-207A x EC-623027 followed by P-2-7-1A x EC-623023 exhibited highest *sca* effect for days to 50% flowering and plant height, while CMS-850A x EC-601878 for head diameter. These results are in accordance with the findings of Sharma *et al.* (2003); Gvozdenovic *et al.* (2005); Hladni *et al.* (2006). Significant *sca* effect in desirable direction for hull content was reported in CMS-852A x EC-623016 and for volume weight in CMS-103A x EC-601978. Twenty-three crosses were noticed significant positive *sca* effect for achene yield. Among these crosses, CMS-103A x EC-601978, CMS-10A x EC-601725, CMS-207A x EC-623023, P-89-1A x EC-623027, CMS-850A x EC-601878, CMS-853A x EC-623027 and CMS-853A x EC-623023 showed highest positive *sca* effect for seed yield . Four crosses exhibited significant positive *sca* effect for oil percent and highest was reported in the cross CMS-10A x EC-623023. These characters might be due to non-additive gene action indicating that heterosis breeding may be rewarding in sunflower. These results are in conformity with the earlier findings of Patil *et al.* (2007), Binodh *et al.* (2008), Asif *et al.* (2013), Archana *et al.* (2018), Tyagi *et al.* (2020) and Haddadan *et al.* (2020). In the majority of the crosses, high *sca* effect was due to low x low, high x low and low x high combining parents which further substantiated the operation of non-additive gene action for the characters studied.

From the present investigation it could be concluded that almost all the characters studied were governed by non-additive gene action except a few. Six parents, CMS-853A, CMS-852A, EC-623027, EC-601751, EC-623023 and EC-601725 had significant positive *gca* effect for seed yield and other yield contributing traits. The new combinations, CMS-103A x EC-601978, CMS-10A x EC-601725, CMS-207A x EC-623023, P-89-1A x EC-623027, CMS-850A x EC-601878, CMS-853A x EC-623027 and CMS-853A x EC-623023 may be used in the production of more heterotic hybrids as well as for enhancing seed yield/hectare.

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Study on combining ability for seed yield and its attributing traits in sunflower (*Helianthus annuus* L.)

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ABSTRACT

Six CMS lines and nine restorers of sunflower were used in a Line × Tester mating design at Zonal Agricultural Research Station, Bengaluru to determine the combining ability and mode of gene action. The traits studied were days to 50 % flowering, plant height, head diameter, stem diameter, seed yield/plant, 100 seed weight, volume weight and oil content. The *gca* and *sca* effects were not significant for all the traits. The SCA variance were greater than GCA variance for the traits *viz.,* plant height, head diameter, seed yield/plant, stem diameter and 100 seed weight, which showed greater manifestation of non-additive gene action. Among the CMS line, BCB-43A and among the testers, LTRR-822, RHA-95C-1 and RHA-95C-2 were good general combiners for most of the traits. The cross combinations BCB-171A × RHA 95C-2, BCB-44A × RHA-92, BCB-44A × RHA-95C-1, BCB-43A × GKVK-2 and BCB-170A × LTRR-822 showed higher sca for seed yield/plant.

Keywords: Combining ability, *GCA*, *SCA*, Sunflower

Sunflower (*Helianthus annuus* L.) belongs to the family Compositae. It is now one of the world's leading edible oilseed crops. Sunflower was first domesticated in central part of the United States of America. Sunflower is an all season crop, cultivated throughout the world, having its origin in USA. It was introduced to India during 1969, as an oilseed crop. Later, in 1972, Indians started its cultivation on commercial scale, employing Russian open-pollinated varieties namely, EC 69874 (Armaverts), EC 68414 (Perdovik), EC 68413 (Vniimk) and EC 68415 (Armavirskii). Sunflower is known to consist of up to 40 to 45 per cent oil content. The oil is valuable due to the high concentration of polyunsaturated fatty acids (PUFAs), which include high content of oleic and linoleic acids.

Sunflower is a cross pollinated crop with predominantly hybrids being used for commercial production. The development of heterosis lead to identification of pollination control systems like cytoplasm nuclear genetic male sterility system. First ever CGMS system was derived from an interspecific cross among Helianthus petiolaris Nutt and cultivated sunflower *H. annuus* (Leclercq, 1969) which is now generally known as PET 1 CGMS system. The first CGMS-based sunflower hybrid, BSH-1 was evolved and declared for commercial production during 1980 in India (Seetharam *et al.*, 1980). The demand of sunflower oil is continuously increasing in our country mainly because of its high smoke point and high concentration of polyunsaturated fatty acid but dismally, the productivity of India is lower than other countries like Italy, USA and Russia.

This can be inflated through practicing better cultivation and by developing favorable hybrids. One of the most productive methods to inflate the yield is the utilization of heterosis by using two genetically different lines. The interpretation of heterotic hybrid is based on the combining abilities of its parents (Kadkol *et al.,* 1984). Therefore, combining ability analysis is of special significance to identify parental lines and to develop good hybrids/synthetics/composites. Earlier studies led to the selection of inbreds with high gca and predominance of non-additive gene action for seed yield and its components. Patil *et al.,* (2012) reported that to test combining ability the line × tester analysis has been widely used. The study of combining ability helps to gain the information about the magnitude and the nature of gene action involved namely additive variance and non-additive variance, which assist in selection of parents and crosses for fruitful hybrid development.

The present study was undertaken to assess the combining ability of male sterile and fertility restorer lines and the relationship of *per se* performance of inbreds with their gca effects for yield and its components, which will be useful in selecting parents for production of superior hybrids.

MATERIALS AND METHODS

Materials for the study comprised of six cytoplasmic male sterility lines derived from two different sources i.e. *Helianthus annuus* (BCB-43A, BCB-44A and BCB-170A) and Helianthus argophyllus (BCB-171A, BCB-166A and BCB-42A), nine testers (multi-headed) *viz.,* LTRR-822, RHA 6D-1, RHA-95C-1, RHA-92, RHA 60-P, RHA-95C-2, RHA-93, GKVK-2 and RHA-378 and two standard checks *viz.,* KBSH-44 (National check) and KBSH-53 (Local check). Diverse CMS lines, the testers and check hybrids were procured from the AICRP on sunflower, UAS, GKVK,

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Bengaluru. All the six CMS lines and nine inbred lines were sown in the field to effect crossing in a Line × Tester fashion (Kempthorne, 1957) in order to obtain F1's during summer 2019. Staggered sowing of all CMS lines and restorer lines were carried out to ensure synchronized flowering with all lines for crossing. A day prior to opening of first ray floret all the heads of CMS lines and testers were covered with cloth bags in order to prevent undesirable pollination. Pollen from the inbred lines was collected separately in petri dishes with the help of camel hair brush and applied to the flowers of female lines using brushes during morning hours. The pollination was repeated for five to six days in each of the combination to ensure sufficient seed set and simultaneously all inbreds were sib pollinated.

The developed 54 crosses along with two standard checks *viz.,* KBSH-44 and KBSH-53 and parents were assessed in separate trial of RCBD with two replications in late *kharif* 2019-20 at the experimental plots of the Zonal Agricultural Research Station, UAS, GKVK, Bengaluru. The data were recorded on morphological and physiological traits viz., days to 50% flowering (days), plant height (cm), head diameter (cm), stem girth (cm), 100 seed weight (g), volume weight (g/100ml), seed yield/plant (g) and oil content (%).The mean values of the inbred lines and F1 hybrids were used to calculate the values of the combining abilities and assess the gene effects for morpho-physiological and yield traits using the line × tester method.

RESULTS AND DISCUSSION

The analysis of variance of combining ability showed that the variance due to crosses was found highly significant for all the traits. The variance due to lines were significant for plant height, stem diameter and volume weight whereas testers were significant for all the traits except head diameter, stem diameter and seed yield/plant and Line × Tester interaction variance was highly significant for all the traits which specifies the presence of dominance variance between hybrids (Table 1). Per se performances of parents (Table 2) indicated that among the six lines, BCB-166 and BCB-170 and RHA 6D-1, RHA-95C-1 and RHA-378 among the nine testers, showed superior performance for majority of the traits.

Combining ability analysis helps the breeder in selecting desirable parents for exploitation in breeding programme. The concept of combining ability as a measure of gene action was proposed by Sprague and Tatum (1942). Use of general combining ability (*gca*) effects of the parents is the important criteria for selection. Generally the parents with high *per se* may not-transmit their superiority in their progenies. The assessment of general combining ability forms the basis to select parents for hybridization and this has been adopted in many reports (Mohan Rao, 2001; Gangappa *et al.,* 2007; Nandini, 2013; Budihal, 2017; Divya, 2018; Niharika, 2019) in sunflower.

General and specific combining ability effects help to identify good parents and hybrids, respectively. The perusal of *gca* effects of 15 parents (6 CMS lines and 9 restorers) for eight traits (Table 3) indicated that the BCB-43 showed good general combiner for majority of the traits *viz.,* plant height, volume weight and seed yield/plant. Among the restorers, RHA-95C-1 was good general combiner for head diameter, seed yield/plant, volume weight and 100 seed weight. Similar results of RHA-95C-1 being good general combiner for numerous traits has been earlier reported (Mohan Rao, 2001; Gangappa *et al.,* 2007; Nandini, 2013; Sunitha, 2015). Among the testers, LTRR-822 was good general combiner for head diameter, seed yield/plant and oil content, and RHA-95C-2 was good general combiner for plant height and oil content exhibiting significant *gca* effects in positive direction. All these testers can be utilized for development of better hybrids and also in conventional breeding programme.

The relationship of per se performance of inbreds and gca effects of inbreds are presented in Fig. 1 for all the traits tested. Among these eight traits, none of the traits except stem diameter showed *per se* performance of lines as a good measure for their *gca* effects.

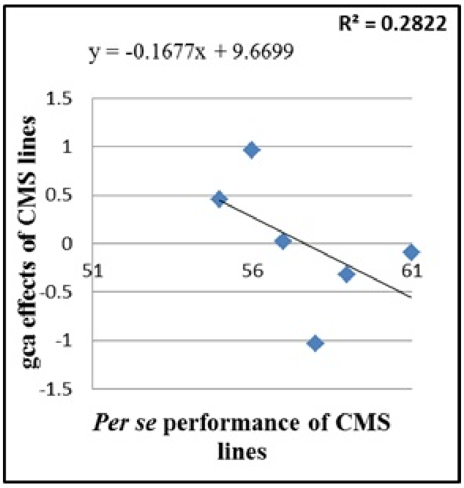
Specific combining ability is very important estimate for determining the suitability of F_1. In this study, out of 54 hybrids none of the crosses was a desirable specific combiner for all the traits. Similar results were observed by Mohan Rao (2001) and Meena *et al.* (2013). It was interesting fascinating to note that the top five hybrids namely, BCB-171A × RHA-95C-2, BCB-44A × RHA-92, BCB-44A × RHA-95C-1, BCB-43A × GKVK-2 and BCB-170A × LTRR-822 recorded highest sca effects for seed yield/plant (Table 4). The mean performance of hybrids was compared with checks which indicated that these hybrids were better performed over the checks for most of the traits.

For all the traits under study, parents with high × high or high × low or low × low gca effects suggesting high output of these crosses due to additive and dominance gene interactions were involved in the crosses with significant sca effects in the desirable direction. The ideal cross combination to be exploited is one which shows high magnitude of *sca* in addition to *gca* in both or at least in one of the parents.

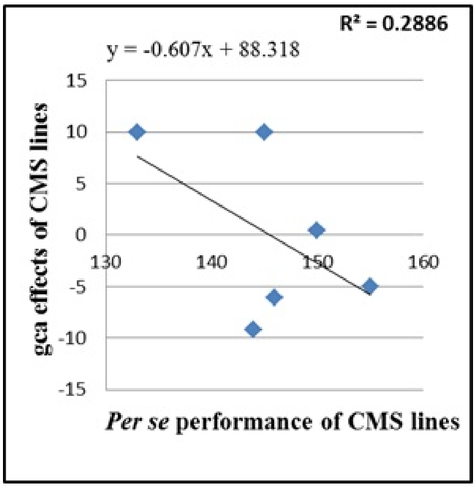
The best five hybrids, BCB-171A × RHA 95C-2, BCB-44A × RHA-92, BCB-44A × RHA 95C-1, BCB-43A × GKVK-2 and BCB-170A × LTRR-822 for seed yield/plant with high significant *sca* effects were identified. The line, BCB-43A was good general combiner for seed yield/plant. Three testers, LTRR-822, RHA-95C-1 and RHA-95C-2 were found to be best general combiners for seed yield and other yield contributing traits. These four parents can be utilized in heterosis breeding programme.

Table 1 Analysis of variance for combining ability

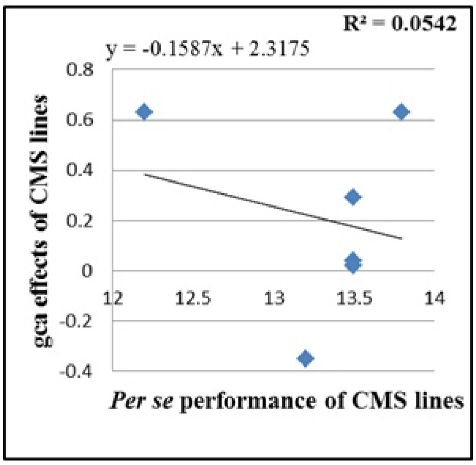
Source of variation	DF	Mean sum of squares							
		Days to 50% flowering	Plant height (cm)	Head diameter (cm)	Stem girth (cm)	Seed yield/ plant (g)	100 seed weight (g)	Volume weight (g/100ml)	Oil content (%)
Replication	1	3.00	43.51	0.81	0.01	8.59	0.42*	18.96	0.97
Crosses	53	7.92**	389.97**	3.56**	0.11**	56.37**	0.47**	21.82**	6.73**
Line effect	5	8.34	1238.16**	3.63	0.27*	43.58	0.37	92.61**	1.41
Tester effect	8	28.96**	886.89**	4.98	0.07	52.61	1.21**	30.48*	31.02**
Line × Tester effect	40	3.65**	184.56**	3.32**	0.09**	58.71**	0.34**	11.24*	2.54*
Error	53	0.89	19.31	0.64	0.03	7.29	0.10	6.55	1.97



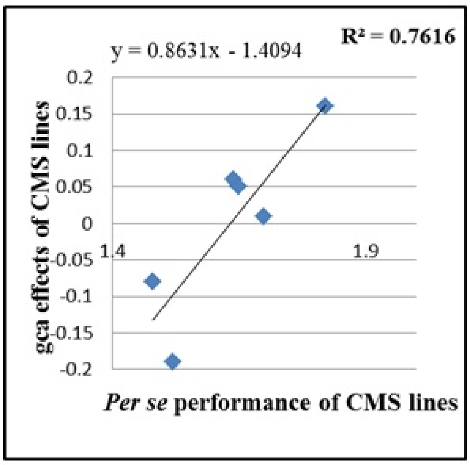
Days to 50% flowering



Plant height (cm)



Head diameter (cm)



Stem girth (cm)

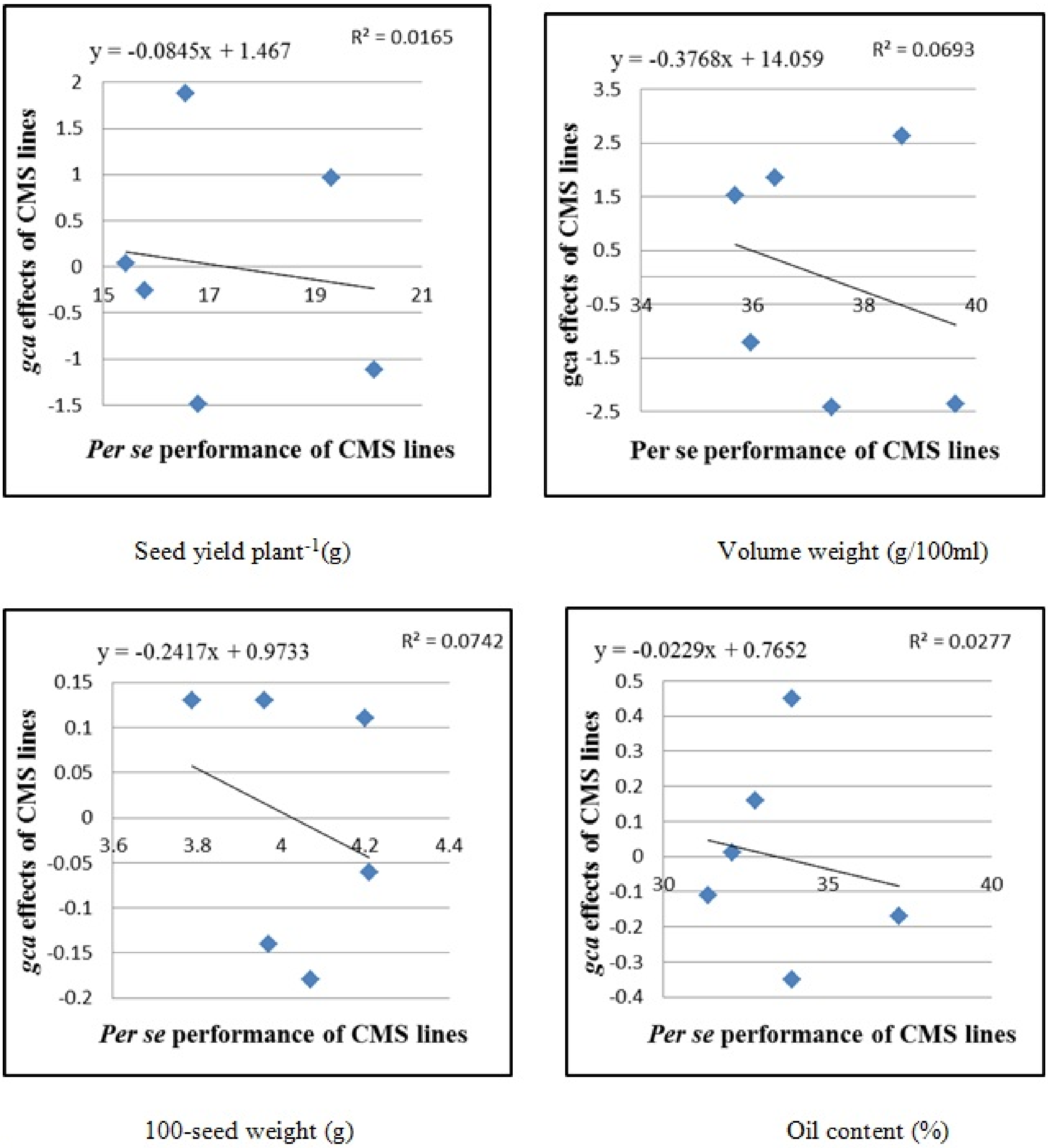


Fig. 1. Correlation between *per se* performance of diverse CMS lines with their corresponding gca effects for yield and its attributing traits

Results obtained identified BCB-43, RHA-92 and RHA 95C-1 as inbred lines with high (H) overall *gca* effects and BCB-44, RHA 95C-2 and GKVK-2 as lines with low overall *gca* effects for most of the characters. These lines can be further utilized as parents in future heterosis breeding programme. The hybrid combinations BCB-43A × GKVK-2, BCB-44A × RHA-92 and BCB-44A × RHA- 95C-1 with high specific combining ability for seed yield/plant and oil content over the national check KBSH-44 need to be established for their superiority by extensive testing in station and multi-location trials over the years.

Table 2 Mean performance of parental lines for seed yield and its components

Lines	Days to 50% flowering	Plant height (cm)	Head diameter (cm)	Stem girth (cm)	Seed yield/plant (g)	Volume weight (g/100ml)	100 seed weight (g)	Oil content (%)
BCB-42	59	150	13.80	1.52	15.8	35.98	3.97	32.1
BCB-43	56	144	14.00	1.48	16.56	36.41	3.79	31.38
BCB-166	55	133	13.20	1.7	16.8	38.68	4.21	37.18
BCB-44	61	145	13.50	1.64	15.45	35.7	4.2	33.91
BCB171	58	146	13.50	1.65	19.31	39.65	3.96	32.81
BCB-170	57	155	15.20	1.82	20.12	37.42	4.07	33.91
Mean	57.66	145.5	13.37	1.64	17.34	37.37	4.03	33.54
CD at P=0.05	3.57	13.4	0.76	0.32	2.85	6.38	0.55	3.03
CD at P=0.01	5.61	21.03	1.19	0.49	4.47	10.01	0.86	4.76
Testers								
LTRR-822	64	110.1	13.4	1.68	16.5	34.6	3.61	35.22
RHA-6D-1	65	111.4	12.4	1.86	18.2	38.75	3.87	37.02
RHA-95-C-1	64	139.4	15.2	1.92	20.5	37.8	3.29	35.56
RHA-92	60	80.5	12.6	1.65	10.8	35.5	3.51	33.03
RCR-60 P	58	136	12.5	1.62	11.7	37.1	4.61	31.33
RHA-95-C-2	60	92	11.5	1.62	15.6	40.1	4.48	36.17
RHA-93	58	71	14.5	1.71	10.5	38.62	3.64	35.62
GKVK-2	55	82.5	10.5	1.76	10.5	40.6	3.39	34.75
RHA-378	55	109.5	11.5	1.84	16.5	38	5.08	38.41
Mean	59.89	103.6	12.68	1.74	14.53	37.89	3.94	35.23
CD at P=0.05	4.89	5.21	2.03	0.16	3.1	3.22	1.02	3.13
CD at P=0.01	7.11	7.58	2.96	0.24	4.51	4.68	1.48	4.55

Table 3 Estimates of gca effects of lines and testers

Lines	Days to 50% flowering	Plant height (cm)	Head diameter (cm)	Stem girth (cm)	Seed yield/plant (g)	Volume weight (g/100ml)	100 seed weight (g)	Oil content (%)
BCB-42	-0.32	0.44	0.63 **	-0.19 **	-0.26	-1.22 *	-0.14	0.01*
BCB-43	0.96**	-9.20 **	0.04	-0.08 *	1.88 **	1.86**	0.13	-0.11
BCB-166	0.46	9.93 **	-0.35	0.01	-1.49 *	2.63 **	-0.06	-0.17
BCB-44	-0.09	9.93 **	0.29	0.06	0.04	1.53*	0.11	0.45
BCB171	-1.04 **	-6.11 **	0.02	0.05	0.96	-2.37 **	0.13	0.16*
BCB-170	0.02	-4.97**	0.63 **	0.16**	-1.12	--2.42*	-0.18*	-0.35
S. Em±	0.29	1	0.22	0.36	0.59	-0.14	0.08	0.32
CD at P=0.05	0.58	2.01	0.43	0.07	1.19	0.13	0.16	0.65
CD at P=0.01	0.77	2.68	0.58	0.09	1.58	-0.06	0.21	0.86
Testers								
LTRR-822	0.77*	1.19	0.84**	0.03	3.15**	-1.67*	-0.01	1.03*
RHA-6D-1	2.19**	9.53**	-1.05**	0.13**	-2.23**	-0.16	-0.51**	2.12**
RHA-95-C-1	1.19**	11.86**	0.63*	0.04	1.34*	2.16**	0.39**	0.29
RHA-92	-0.32	-13.94**	-0.92**	-0.11*	-0.41	-0.73	-0.28*	-1.57**
RCR-60 P	-1.07**	-0.51	0.42	-0.08	-1.82*	-1.24	-0.25*	-3.34**
RHA-95-C-2	1.77**	-3.74**	0.08	-0.01	-2.33**	1.19	0.06	0.86*
RHA-93	-0.57	-9.42**	0.17	-0.09	0.63	-0.77	-0.13	0.18
GKVK-2	-1.89**	-2.41	-0.25	0.03	1.32	2.62**	0.22*	-0.28
RHA-378	-2.07**	7.43**	0.08	0.05	0.35	-1.4	0.45**	0.68
Mean	0.35	1.23	0.26	0.04	0.73	0.74	0.09	0.39
CD at P=0.05	0.71	2.46	0.53	0.09	1.45	1.48	0.19	0.79
CD at P=0.01	0.95	3.28	0.7	0.12	1.94	1.96	0.25	1.05

* Significant at P=0.05 ** Significant at P=0.01

Table 4 The top five combinations based on specific combining ability for seed yield/plant (g)

Hybrid combination	*sca*	Seed yield/ plant (g)	Maturity group	Days to 50% flowering	Plant height (cm)	Head diameter (cm)	Stem girth (cm)	100 seed weight (g)	Volume weight (g/100ml)	Oil content (%)
BCB-171A × RHA 95C-2	11.05**	30.70	MID LATE	57	168.6	17.72	1.89	4.46	41.21	35.27
BCB-44A × RHA-92	10.60**	32.09	LATE	59	170.7	15.30	2.06	3.47	38.74	34.28
BCB-44A × RHA 95C-1	9.08**	31.35	MID LATE	56	186.2	16.12	1.92	4.48	40.69	36.56
BCB-43A × GKVK-2	8.74**	32.30	EARLY	53	168.4	17.51	1.95	4.24	46.13	35.33
BCB-170A × LTRR-822	8.08**	30.93	LATE	59	152.6	14.72	1.94	3.94	36.65	36.90
KBSH-44 (NC)		26.72	LATE	63	205	15.3	2.19	6.51	45.29	32.3
KBSH-53 (LC)		27.05	LATE	65	221	15.5	2.16	5.46	38.38	35.9
S. Em±	1.75	1.91		0.66	3.20	0.57	0.12	0.23	1.81	0.99
CD at P=0.05	3.51	5.41		1.88	9.09	1.60	0.33	0.65	5.13	2.82
CD at P=0.01	4.67	7.21		2.51	12.11	2.13	0.44	0.86	6.84	3.75

*Significant at P=0.05; **Significant at P=0.01

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Studies on heterosis for seed yield and its component traits in castor (*Ricinus communis* L.) hybrids suitable for Odisha state

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ABSTRACT

The experimental material consisted of 40 entries which included two pistillate lines (DPC-23 and M-571) and 12 monoecious lines (DCS-64, DCS-86, DCS-102, DCS-105, DCS-107, DCS-108, DCS-109, DCS-110, DCS-112, DCS-118, DCS-119, DCS-123), their resultant 24 hybrids developed through a line x tester mating design and two check hybrids (DCH-177 and DCH-519). These entries were tested in a randomized block design with three replications at AICRP centre on Castor, Bhawanipatna, Odisha over three years (2014-15 to 2016-17) during *kharif* season. Considering *per se* performance of hybrids, eleven hybrids recorded higher seed yield per plant than the check hybrid DCH-177 of which four hybrids *viz.,* M-571 x DCS-110 (102.8 g/plant), M-571 x DCS-112 (100.6 g/plant), M-571 x DCS-105 (93.8 g/plant) and DPC-23 x DCS-110 (93.4g/plant) had high per se performance along with significant positive heterobeltiosis and standard heterosis for seed yield. The range of heterosis over better parent varied from -25 to 31.6%, while over standard check, it ranged from -30.1 to 24.3 %. The cross M-571 x DCS-110 depicted significantly the highest and positive heterobeltiosis (31.6%), standard heterosis (24.3 %) as well as the highest seed yield per plant (102.8g). Other cross combinations *viz.,* M-571 x DCS-112, M-571 x DCS-105 and DPC-23 x DCS-110 were with significant and positive heterobeltiosis (28.7%, 20.1% and 24.0%, respectively), standard heterosis (21.6, 13.4 and 13.0%, respectively) and *per se* performance (100.6, 93.8 and 93.4 g/plant, respectively). The expression of heterotic response over better parents and standard check indicated the real superiority of the hybrids which could be exploited further through multilocational testing over different environments for judging their importance from the commercial point of view.

Keywords: Castor, Heterosis, Heterobeltiosis, Standard heterosis

Castor (*Ricinus communis* L.) is one commercially important non-edible oilseed crop in the dicotyledonous angiosperm family 'Euphorbiaceae' having chromosome number 2n=20. Castor is generally distributed in the tropical, sub-tropical and warm temperate zones (Weiss, 2000). It is believed to have originated in Egypt, Ethiopian region of tropical East Africa and India. Subsequently it spread to China, Brazil, Thailand, Argentina, USA, etc. (Anjani, 2012). The Ethiopian-East African region is considered to be the most probable site of origin because of presence of high diversity in Ethiopia (Moshkin, 1986). In India, it is known from very early days and is referred in Susruta Samhita written over 2000 years ago (Gangaiah, 2005). Its monoecious nature favours cross-pollination up to the extent of 50 per cent. Castor is a perennial crop but grown as an annual crop for economic purpose. The phenomenon of heterosis has proved to be the most important genetic tool in enhancing the yield of self as well as cross pollinated species in general and castor in particular. With the availability of cent per cent pistillate lines in castor, exploitation of heterosis or hybrid vigour has become commercially feasible and economical (Gopani *et al.,* 1968; Lavanya and Chandramohan, 2003; Patted *et al.,* 2016; Jalu *et al.,* 2017). It is a quick and convenient way of combining desirable characters which has assumed greater significance in the production of F_1 hybrids. The aim of heterosis analysis is to find out the best combination of crosses giving high degree of useful heterosis and characterization of hybrids for commercial exploitation.

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MATERIALS AND METHODS

The experimental material consisted of 40 entries which included two pistillate lines (DPC-23 and M-571) and 12 monoecious lines (DCS-64, DCS-86, DCS-102, DCS-105, DCS-107, DCS-108, DCS-109, DCS-110, DCS-112, DCS-118, DCS-119, DCS-123), their resultant 24 hybrids developed through line x tester mating design and two check hybrids (DCH-177 and DCH-519). These 40 entries were tested in a randomized block design with three replications at AICRP on Castor, Regional Research and Technology Transfer Station, Bhawanipatna over three years during *kharif* seasons of 2014-15 [Date of sowing (D/S) - 29.07.2014], 2015-16 (D/S - 11.08.2015) and 2016-17 (D/S - 17.08.2016). The soil type of the research station is vertisol with clay loam texture having pH range of 6.8 to 7.2. The climate of the zone is hot and sub-humid with mean annual rainfall of 1330.5 mm. Each entry was grown in two rows of 6.0 m length at a spacing of 90 cm x 60 cm. FYM @ 5t/ha was applied during final land preparation. A basal fertilizer dose of 20:40:20 kg N-P_2O_5-K_2O/ha was applied at the time of sowing. Top dressing of 20kg N/ha and earthing up was done after 1st hoeing and weeding operation. Need based plant protection measures were taken as and when required.

Five competitive plants were selected randomly from each entry in each replication for the purpose of recording observations on different characters *viz.,* plant height up to primary spike (cm), number of nodes up to primary spike, total length of primary spike (cm), effective length of primary spike (cm), number of effective spikes/plant, number of capsules in primary spike, 100-seed weight (g) and seed yield per plant (g). Days to 50% flowering of primary spike and days to maturity of primary spike were recorded on plot basis. The mean values for different characters were recorded in all the three years of experimentation i.e. during 2014-15, 2015-16 and 2016-17 and the pooled mean values were subjected to statistical analysis. Pooled analysis of variance for experimental design was performed to test the significance of difference among the genotypes for all the characters as per the method suggested by Panse and Sukhatme (1985). Heterobeltiosis was estimated as per the procedure given by Fonseca and Patterson (1968) using mean values for various characters over better parents. Standard heterosis i.e. superiority of F_1 over best check hybrid DCH-177 was estimated for various characters as per the formula given by Meredith and Bridge (1972).

RESULTS AND DISCUSSION

The pooled analysis of variance revealed significant mean squares for environments, parents, hybrids (Crosses) and parents vs. hybrids for all the 10 characters studied (Table 1). The results suggested that significant differences existed among parents and hybrids for all the 10 characters over environments, which indicated existence of considerable genetic variability among parents and hybrids with regard to all the characters studied. Mean square due to parents v/s hybrids were also highly significant over environments for all the traits. This suggested the presence of heterosis in the material for all the characters. Mean square due to genotypes and their interaction with environments were also highly significant.

In the present study, heterosis over better parent (heterobeltiosis i.e. H1) and over best standard check hybrid DCH-177 (standard heterosis i.e. H2) was estimated. Several crosses exhibited conspicuous level of heterobeltiosis and standard heterosis for different characters which are presented in Table 2. Range of heterosis as well as number of crosses exhibiting significant positive as well as negative heterobeltiosis and standard heterosis are presented in Table 3.

Since earliness in flowering and maturity is desirable, the hybrids showing negative heterosis for these two traits are of immense value in breeding. Twenty three hybrids with significant negative heterobeltiosis for days to 50% flowering and maturity were noticed and they are of immense value as early maturing castor hybrids are highly preferred to fit into multiple cropping pattern (Table 2 and 3). Standard heterosis was significantly negative for days to 50% flowering in four crosses *viz.,* DPC-23 x DCS-102 (-7.3%), DPC-23 x DCS-105 (-6.8%), DPC-23 x DCS-64 (-4.7%) and DPC-23 x DCS-109 (-3.4%). Three hybrids *viz.,* DPC-23 x DCS-64 (-8.1%), DPC-23 x DCS-105 (-7.9%) and DPC-23 x DCS-102 (-7.6%) with significant negative standard heterosis for days to maturity could be promoted as early maturing hybrids. Significant and desirable (negative) heterosis for days to flowering and days to maturity of primary raceme was reported by Patel *et al.* (2015) and Delvadiya *et al.* (2018).

Table 1a Pooled analysis of variance for the experimental design over three years for different characters in castor (2014-15 to 2016-17)

Source	df	DFF	DM	PH	NN
Environments	2	64.6**	716.4**	13593.0**	164.2**
Genotypes	37	328.9**	799.7**	1570.2**	64.6**
Parents	13	454.7**	1209.5**	1726.4**	98.0**
Hybrids	23	181.5**	462.4**	1489.0**	37.3**
Parent vs Hybrids	1	2084.3**	3228.8**	1404.4**	258.1**
Genotypes x Environment	74	7.2**	31.1**	120.5**	1.8**
Parents x Environment	26	2.3	10.9**	112.2**	1.3**
Hybrids x Environment	46	10.2**	26.9**	120.8**	2.0**
Parent vs Hybrids x Environment	2	2.9	391.0**	222.6**	5.5**
Error	222	2.0	5.2	29.8	0.6

DFF- Days to 50% flowering of primary raceme, DM-Days to maturity of primary spike, PH-Plant height upto primary spike, NN-Number of nodes up to primary spike

Table 1b Pooled analysis of variance for the experimental design over three years for different characters in castor (2014-15 to 2016-17)

Source	df	TLPS	ELPS	NES	NCP	100-seed wt.	Seed yield/plant
Environments	2	2145.0**	2179.5**	7.4**	3898.1**	62.1**	25008.8**
Genotypes	37	200.5**	269.9**	2.0**	339.7**	167.0**	2091.6**
Parents	13	146.0**	200.0**	2.6**	392.1**	278.7**	1611.0**
Hybrids	23	189.00**	253.0**	1.3**	294.1**	108.7**	1454.2**
Parent vs Hybrids	1	1172.8**	1567.2**	9.0**	708.4**	56.7**	23000.1**
Genotypes x Environment	74	24.4**	23.8**	0.3**	49.6**	4.0**	254.3**
Parents x Environment	26	16.9	17.2	0.2	31.9**	0.9	159.7
Hybrids x Environment	46	23.2**	22.7**	0.3**	58.3**	5.6**	238.1**
Parent vs Hybrids x Environment	2	151.2**	135.6**	1.0	79.1**	5.2**	1858.3**
Error	222	12.5	11.6	0.1	16.4	0.7	126.5

TLPS - Total length of primary spike, ELPS - Effective length of primary spike, NES - Number of effective spikes/plant, NCP - Number of capsules in primary spike

Table 2 Per cent heterobeltiosis (H1) and standard heterosis (H2) for days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary spike and number of nodes up to primary spike (pooled over three years)

Genotype/Cross	Days to 50 % flowering of primary raceme		Days to maturity of primary spike		Plant height up to primary spike		Number of nodes up to primary spike	
	H1	H2	H1	H2	H1	H2	H1	H2
DPC-23 x DCS-64	-6.2 **	-4.7 **	-11.5 **	-8.1 **	-3.7	-12.9 **	-6.3 *	-13.1 **
DPC-23 x DCS-86	-25.4 **	2.6	-8.0 **	7.7 **	-23.5 **	-14.3 **	-31.3 **	-13.4 **
DPC-23 x DCS-102	-15.2 **	-7.3 **	-13.7 **	-7.6 **	-10.2 **	-28.3 **	-19.9 **	-21.9 **
DPC-23 x DCS-105	-22.2 **	-6.8 **	-17.2 **	-7.9 **	-26.8 **	-27.6 **	-28.1 **	-22.9 **
DPC-23 x DCS-107	-16.2 **	10.7 **	-6.6 **	11.0 **	-6.2 *	-8.1 **	-15.8 **	-0.2
DPC-23 x DCS-108	-6.4 **	2.9	-3.4 **	4.3 **	5.1	-22.8 **	-12.2 **	-17.5 **
DPC-23 x DCS-109	-18.3 **	-3.4 *	-8.5 **	2.5 *	-11.0 **	-18.4 **	-10.0 **	-12.9 **
DPC-23 x DCS-110	-7.5 **	9.1 **	-0.6	11.4 **	13.4 **	-6.6 *	-5.2 *	-10.0 **
DPC-23 x DCS-112	-15.3 **	8.3 **	-6.8 **	11.4 **	-11.6 **	-10.8 **	-27.1 **	-8.2 **
DPC-23 x DCS-118	-18.1 **	9.9 **	-7.9 **	6.0 **	-11.9 **	-4.7	-22.6 **	-5.2 *
DPC-23 x DCS-119	-12.1 **	19.8 **	-5.0 **	13.6 **	-6.0 *	1.7	-18.2 **	4.2
DPC-23 x DCS-123	-25.9 **	15.9 **	-22.1 **	7.9 **	-17.3 **	-5.0	-38.4 **	0.5
M-571 x DCS-64	-17.9 **	14.6 **	-9.4 **	5.8 **	-0.2	-9.7 **	-24.2 **	-2.8
M-571 x DCS-86	-11.9 **	23.0 **	-3.3 **	13.2 **	2.0	14.3 **	-11.0 **	14.1 **
M-571 x DCS-102	-23.5 **	6.8 **	-10.6 **	4.3 **	28.7 **	2.8	-16.1 **	7.6 **
M-571 x DCS-105	-16.4 **	16.7 **	-7.5 **	8.0 **	7.3 *	6.1 *	-17.6 **	5.7 *
M-571 x DCS-107	-12.7 **	21.9 **	-10.4 **	6.5 **	10.1 **	7.8 **	-8.2 **	17.7 **
M-571 x DCS-108	-14.9 **	18.8 **	-5.1 **	10.7 **	43.8 **	5.6	-20.0 **	2.5
M-571 x DCS-109	-16.0 **	17.2 **	-5.1 **	10.7 **	5.1	-3.6	-20.4 **	2.1
M-571 x DCS-110	-18.1 **	14.3 **	-4.2 **	11.8 **	26.8 **	4.5	-19.6 **	3.1
M-571 x DCS-112	-9.9 **	25.8 **	-7.5 **	10.5 **	7.0 *	8.0 **	-12.3 **	12.5 **
M-571 x DCS-118	-12.1 **	22.7 **	-2.8 **	13.5 **	11.9 **	21.0 **	-7.2 **	19.0 **
M-571 x DCS-119	-14.4 **	19.5 **	-4.3 **	14.4 **	10.3 **	19.3 **	-9.0 **	16.6 **
M-571 x DCS-123	-16.8 **	30.0 **	-16.9 **	15.2 **	6.5 *	22.5 **	-21.3 **	28.4 **

H2 has been estimated over best check hybrid DCH-177

Table 2 contd. Per cent heterobeltiosis (H1) and standard heterosis (H2) for total length of primary spike, effective length of primary spike, number of effective spikes/plant, number of capsules in primary spike , 100- seed weight and seed yield/plant (pooled over three years)

Genotype/Cross	Total length of primary spike		Effective length of primary spike		Number of effective spikes/plant		Number of capsules in primary spike		100-seed weight		Seed yield/plant	
	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
DPC-23 x DCS-64	15.7 **	-7.1	15.7 **	-7.1	-11.8 *	4.1	6.6	-6.7	-7.3 **	-18.6 **	-7.7	-20.8 **
DPC-23 x DCS-86	8.1	-13.2 **	1.0	-18.9 **	10.7	9.8	-11.6 **	-22.8 **	-3.3 **	11.0 **	22.6 **	5.1
DPC-23 x DCS-102	-12.8 **	-19.3**	-12.2 **	-20.5 **	-9.9	-10.7	-19.0 **	-7.3	-5.0 **	-11.3 **	-24.4 **	-30.1 **
DPC-23 x DCS-105	-20.7 **	-25.4 **	-21.4 **	-26.0 **	11.6	10.7	-26.4 **	-26.7 **	-14.0 **	-10.1 **	-15.7 *	-23.3 **
DPC-23 x DCS-107	26.1 **	2.8	27.9 **	2.7	-31.4 **	-32.0 **	20.0 **	6.0	-4.2 **	8.4 **	3.6	-11.2
DPC-23 x DCS-108	20.8 **	-3.0	20.2 **	-3.5	10.7	9.9	4.2	-4.0	-7.7 **	-18.9 **	13.2	-3.0
DPC-23 x DCS-109	-5.1	0.2	-5.1	0.2	-28.1 **	-28.7 **	-8.5 *	6.0	-3.7 **	2.0	-5.5	-16.5 *
DPC-23 x DCS-110	14.1 **	12.6 **	14.1 **	12.6 **	-8.3	-9.0	5.7	17.6 **	4.2 **	9.8 **	24.0 **	13.0 *
DPC-23 x DCS-112	1.2	-18.4 **	-3.0	-22.2 **	-12.4	-13.1 *	11.4 **	-0.5	-0.8	7.1 **	20.7 **	3.5
DPC-23 x DCS-118	16.1 **	-6.8	11.9 *	-10.2 *	-19.8 **	-20.5 **	15.6 **	1.0	9.0 **	-4.3 **	-1.1	-15.2 *
DPC-23 x DCS-119	34.9 **	10.5 *	37.7 **	10.5 **	-22.3 **	-22.9 **	20.6 **	5.4	-0.4	3.9 **	7.21	-8.1
DPC-23 x DCS-123	3.4	-12.3 **	-9.6	-27.4 **	2.5	1.6	-5.6	1.0	-16.3 **	6.9 **	28.5 **	10.2
M-571 x DCS-64	-9.4 *	-11.6 **	-1.0	-11.6 **	3.5	22.1 **	-5.6	-7.9 *	-33.3 **	-28.6 **	-25.0 **	-29.2 **
M-571 x DCS-86	-9.3 *	-11.5 **	-0.9	-11.5 **	-5.4	-13.9 *	1.1	-1.4	1.3	16.2 **	12.2	6.1
M-571 x DCS-102	3.6	1.1	11.6 **	0.9	15.5 *	-2.5	-2.8	11.3 **	-16.9 **	-11.1 **	-13.4	-18.2 **
M-571 x DCS-105	7.1	4.5	11.0 *	4.5	5.4	-4.1	8.5 *	8.2 *	-1.4	5.5 **	20.1 **	13.4 *
M-571 x DCS-107	-7.8	-10.1 *	0.7	-10.1 *	-14	-29.5 **	4.3	1.7	-5.7 **	6.7 **	-8.9	-14.0 *
M-571 x DCS-108	21.5 **	18.5 **	32.8 **	18.5 **	10.1	-1.6	22.4 **	19.4 **	-24.5 **	-19.2 **	8.0	2.0
M-571 x DCS-109	1.8	7.5	1.1	6.8	12	-8.2	-11.5 **	2.5	1.8	8.9 **	11.5	5.4
M-571 x DCS-110	14.9 **	13.3**	14.9 **	13.3 **	7	-12.3	-2.7	8.3 *	11.6 **	19.4 **	31.6 **	24.3 **
M-571 x DCS-112	-3.6	-5.9	5.4	-5.9	19.0 *	-2.5	22.5 **	19.5 **	3.5 **	11.7 **	28.7 **	21.6 **
M-571 x DCS-118	-11.9 **	-14.1 **	-11.9 **	-21.4 **	6	-13.1 *	-4.7	-7.0	-4.8 **	1.8	-3.6	-8.9
M-571 x DCS-119	-6.7	-9.0 *	2.0	-9.0 *	20.0 *	-1.5	-7.4	-9.7 *	5.8 **	13.2 **	7.1	1.2
M-571 x DCS-123	-10.2 *	-12.4 **	-8.1	-18.0 **	-10	-26.2 **	-6.6	-0.2	-14.0 **	9.8 **	-11.5	-16.4 *

H2 has been estimated over best check hybrid DCH-177

Castor is traditionally grown in Odisha on river banks as tall, perennial plant types where crop management for plant protection, manual picking is very labour intensive leading to over drying, shattering and loss of yield. The present study identified nine hybrids with significant negative heterobeltiosis and standard heterosis for plant height up to primary spike. The hybrid DPC-23 x DCS-102 (-28.3%) followed by DPC-23 x DCS-105 (-27.6%), DPC-23 x DCS-108 (-22.8%) and DPC-23 x DCS-109 (-18.4%) with significant negative standard heterosis for plant height can be considered for promoting short to medium height hybrids in traditional castor growing areas of Odisha state. Significant and negative heterosis for plant height up to primary spike has also been reported earlier by Patel *et al.* (2015) and Delvadiya *et al.* (2018).

The standard heterosis (H2) for seed yield/plant ranged from -30.1 % (DPC-23 x DCS-102) to 24.3 % (M-571 x DCS-110). Four hybrids *viz.,* M-571 x DCS-110 (24.3 %), M-571 x DCS-112 (21.6 %), M-571 x DCS-105 (13.4 %) and DPC-23 x DCS-110 (13.0 %) exhibited significant positive heterosis over the best check hybrid DCH-177. High heterosis for seed yield in castor has also been reported by Lavanya and Chandramohan (2003), Lavanya *et al.* (2006), Patel and Pathak (2006), Sridhar *et al.* (2009), Barad *et al.* (2009), Chaudhari *et al.* (2011), Chaudhari and Patel (2014), Makani *et al.* (2015), Sapovadiya *et al.* (2015), Patted *et al.* (2016) and Jalu *et al.* (2017).

Considering the *per se* performance of hybrids, four hybrids *viz.,* M-571 x DCS-110 (102.8g), M-571 x DCS-112 (100.6g), M-571 x DCS-105 (93.8g) and DPC-23 x DCS-110 (93.4g) had significant positive heterobeltiosis and standard heterosis for seed yield/plant when compared with the check hybrid DCH 177 (82.7 g) (Table 4). These crosses also manifested the significant positive standard heterosis for important yield contributing traits like total length of primary spike, effective length of primary spike, number of capsules in primary spike and hundred seed weight in the cross M-571 x DCS-110, number of capsules in primary spike and hundred seed weight in the hybrid M-571 x DCS-112 and M-571 x DCS-105. Similarly the hybrid DPC-23 x DCS-110 exhibited significant standard heterosis in desired direction for the traits like plant height up to primary spike, number of nodes up to primary spike, total length of primary spike, effective length of primary spike, number of capsules in primary spike and hundred seed weight. This emphasized that high degree of heterosis for seed yield might be attributed to the heterosis observed for these component characters. This corroborates the findings of Sridhar *et al.*

(2009), Sodavadiya (2010), Sapovadiya *et al.* (2015), Makani *et al.* (2015) and Patted *et al.* (2016). The cross M-571 x DCS-110 depicted significantly the highest and positive heterobeltiosis (31.6 %), standard heterosis (24.3 %) as well as the highest seed yield/ plant (102.8 g). Three other hybrids *viz*., M-571 x DCS-112 , M-571 x DCS-105 and DPC-23 x DCS-110 were the other promising crosses exhibiting significant and positive heterobeltiosis (28.7%, 20.1% and 24.0%, respectively), standard heterosis (21.6%, 13.4% and 13.0%, respectively) and *per se* performance (100.6 g/plant, 93.8 g/plant and 93.4 g/plant, respectively). In such cases, expression of heterotic response over better parent and standard check indicated the superiority of hybrids from the commercial point of view.

Thus, considerable heterobeltiosis and standard heterosis observed for seed yield and other associated characters suggested the presence of large genetic diversity among the parents and existence of desirable heterosis in the materials studied. Four hybrids *viz.,* M-571 x DCS-110, M-571 x DCS-112, M-571 x DCS-105 and DPC-23 x DCS-110 appeared to be the most suitable cross combinations for exploitation in practical plant breeding programme in castor, as they exhibited significant and positive heterobeltiosis over their respective better parents and standard heterosis over the best check hybrid DCH-177. Such crosses could be exploited further through multilocational testing over different environments for judging their importance from the commercial point of view.

Table 3 Magnitude of heterobeltiosis (H1) and standard heterosis (H2) over environments for various characters in castor

Characters	Pooled mean	Desirable aspect	Range (%)		Number of crosses with significant heterosis			
			H1	H2	H1		H2	
					Positive	Negative	Positive	Negative
Days to 50 % flowering of primary raceme	49.6	Early	-25.8 to -6.2	-7.3 to 30.0	-	24	18	4
Days to maturity of primary spike	115.5	Early	-22.1 to -0.6	-8.1 to 15.2	-	23	21	3
Plant height up to primary spike (cm)	85.9	Dwarf	-26.6 to 43.8	-28.3 to 22.5	10	9	7	10
Number of nodes up to primary spike	15.7	Low	-38.4 to -5.2	-22.9 to 28.4	-	24	8	9
Total length of primary spike (cm)	37.1	Longer	-20.7 to 34.9	-25.4 to 18.5	8	6	4	11
Effective length of primary spike (cm)	36.2	Longer	-21.4 to 37.7	-27.4 to 18.5	10	3	4	12
Number of effective spikes/plant	2.4	More	-31.4 to 20.0	-32.0 to 22.1	3	5	1	9
Number of capsules in primary spike	49.5	More	-26.4 to 22.5	-26.7 to 19.5	7	3	6	4
100- seed weight (g)	26.8g	High	-33.3 to 11.6	-28.6 to 19.4	5	14	14	8
Seed yield per plant (g)	73.1g	High	-25.0 to 31.6	-30.1 to 24.3	7	3	4	9

Table 4 The best performing hybrids for seed yield per plant along with heterobeltiosis (H1), standard heterosis (H2) and standard heterosis for component characters in castor

Hybrid (Cross combination)	Seed yield/plant(g)	Heterosis (%)		Significant desirable standard heterosis for component traits
	per se	H1	H2	
M-571 x DCS-110	102.8	31.6 **	24.3 **	Total length of primary spike, Effective length of primary spike, Number of capsules in primary spike, 100- seed weight
M-571 x DCS-112	100.6	28.7 **	21.6 **	Number of capsules in primary spike, 100- seed weight
M-571 x DCS-105	93.8	20.1 **	13.4 *	Number of capsules in primary spike, 100- seed weight
DPC-23 x DCS-110	93.4	24.0 **	13.0 *	Plant height up to primary spike, Number of nodes up to primary spike, Total length of primary spike Effective length of primary spike Number of capsules in primary spike, 100- seed weight
DCH-177(Check)	82.7			

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Evaluation of water-stress tolerance in soybean using NDVI, gas exchange and morphological traits

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ABSTRACT

A field experiment was conducted during 2017 and 2018 under drought stress (DS) and non-stress conditions (IR) to identify drought tolerant soybean accessions as well as agronomic and physiological traits contributing to drought stress tolerance. Sixty-four soybean accessions including released varieties, genetic stocks and five check varieties were sown in an augmented design. The traits contributing to total biomass *viz*., plant height, number of pods, number of branches, shoot-root dry weight at vegetative stage, and NDVI at vegetative as well as pod filling stage were associated with water-stress tolerance in soybean. Physiological traits *viz*., relative leaf water content (RWC), normalized vegetative index (NDVI) and chlorophyll index were higher in non-stressed crop. Similarly, higher activities of the gas exchange traits *viz*., photosynthetic rate (Pn), stomata conductance (Gs), intercellular CO_2 concentration (Ci) and transpiration rate (Tr) were observed under non stress condition. On the basis of minimum yield reduction under stress and drought tolerance indices the soybean accessions RSC 10-46, TAMS 98-21, EC 241780, MACS 1281, HARDEE, MAUS 612, DS 9814, MACS 1460 and KDS 753 were observed as water stress tolerant while, EC 241695, LEE 54, MACS 1370, CAT 3466, PK 1029, VLS 75, AGS 228 and AMS 1002 were observed as water stress sensitive. These findings were confirmed by the cumulative rank due to drought tolerance indices such as stress susceptibility index (SSI), stress tolerance index (STI), tolerance (TOL), yield index (YI), drought resistance index (DRI), yield stability index (YSI), stress susceptibility percentage (SSPI), drought tolerance efficiency (DTE) and modified stress tolerance index (MSTI) as well as cluster analysis using drought tolerance indices, hence, could be useful in soybean improvement for water-stress tolerance.

Keywords: Morpho-physiological traits, Soybean, Water-stress tolerance, Yield

Soybean [*Glycine max* (L.) Merrill] is known as a wonder bean and is a valuable agricultural commodity as it has multiple uses in the daily livelihood of human beings. It has gained meritorious status among the oilseeds and pulses as it has various commercial and industrial uses in addition to food and feed due to its high protein content (38-40%) and edible oil content (18-22%). Soybean has its identity as the most produced oilseed and affordable source of protein around the world with 56% and 69% share in global oil production and world protein concentrate, respectively. Among oilseed crops, soybean has the largest area under cultivation (Singh, 2010). As compared to other oilseeds, soybean showed highest growth rate (10.51%) of area under cultivation during last two decades (Lokesh and Dandoti, 2017). In India, soybean has become a predominant rainy season oilseed crop grown under rainfed agro-ecosystem. In India 10.60 million ha area is under soybean cultivation with annual production of 10.98 million ton and 1036 kg/ha productivity (FAO STAT, 2017). Although, significant increase is achieved in potential productivity of soybean through painstaking efforts by the breeders, the actual average productivity attained at farmers' field is merely about 40% of the potential productivity (Venkateswarlu and Prasad, 2012) and there exists a large yield gap for soybean and other oilseed crops (Sharma, 2018). Constraints to optimum productivity of soybean include the rainfed cultivation coupled with the erratic behaviour of monsoon, heat and moisture stress at critical growth stages, and biotic interferences to crop growth (Agarwal *et al.,* 2013). Indian climate is divided into twenty-one agro-climatic zones with diverse climatic conditions that affect the production and productivity of the crops grown in the geographical region. Precipitation is one of the major climatic factors which determine the yield of rainfed crops like soybean. Insufficient, erratic/irregular, and uneven rains received during the soybean crop growth period hinder the yield due to the unavailability of soil moisture during critical growth, development and reproductive stages. Occurrence of drought at one or the other stage of crop growth is attributed as one of the major factors responsible for the low productivity and year to year variation in yield of soybean (Bhatia *et al.,* 2014, Zipper *et al.*, 2016). Long dry spell up to 10-20 days results in reduction in yield or complete failure of crop in severe drought conditions. Soybean crop is very sensitive to water deficit at different growth stages. Water stress is reported to reduce germination and vigour of soybean crop through the reduction in weight/seed and deterioration of seed quality

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(Dornbos and Mullen, 1991). Similarly, drought stress significantly decreases the soybean seed yield, plant height, seed index, biomass production, stem diameter and the number of matured pods as the soil water depletion occurs (Mirakhori *et al.*, 2009). Drought stress in late vegetative stages may cause significant yield losses, up to 40% in the bad year with very low rains, and a reduction of seed quality in soybean (Sulieman and Tran, 2012). Stress during reproductive stage has a higher effect on yield than the drought stress before flowering (Kpoghomou *et al.*, 1990). Westgate and Peterson (1993) showed that the earliest stages of pod development, mainly ovary expansion, were most susceptible to drought stress. Besides agronomic traits, water stress also alters the physiological activities such as photosynthesis, transpiration, stomata opening, osmoregulation, and CO_2 concentration in leaf tissue of the crop plant (Zhang *et al.*, 2016; Mokter *et al.*, 2014). Soybean genotypes which can give optimum yield under water-stressed conditions need to be identified and using them in breeding programme to develop drought tolerant varieties is a necessity. Similarly, identification of morpho-physiological traits associated with water-stress tolerance is essential to improve the productivity and sustainability of soybean. The present study was undertaken with the objective of identifying water-stress tolerant soybean genotypes which can be used for further improvement of soybean for sustainable production, and also to assess the associated agro-physiological traits related to water stress tolerance.

MATERIALS AND METHODS

Field experiments were conducted at experimental farm of MACS-Agharkar Research Institute, Pune (M.S.), India (latitude18°14' N, longitude75°21' E and an altitude of 548.6 m above mean sea level) during two consecutive years 2017 and 2018 from June to October. The experimental site was typically rainfed with 596 mm and 379 mm total rainfall received during crop growth period (June to October) of rainy season 2017 and 2018, respectively. Average minimum and maximum temperature during 2017-18 and 2018-19 growing season was 21.93°C & 31.32°C and 20.94°C & 30.46°C; respectively (Fig. 1). Soil of the experimental plot belongs to the order Vertisol with slight alkaline pH (7.4) and medium in organic carbon (0.42%). Intermediate levels of N (298 kg/ha) and P_2O_5 (18.87 kg/ha) were available in the soil, whereas, amount of K_2O in the soil was on higher side (331 kg/ha). Sixty-four soybean accessions including released varieties, genetic stocks and five checks (Table 1) developed at various agro ecological regions of India were sown in augmented complete block design (ACBD) in each of the water treatment. The checks were replicated four times and assigned randomly. Seeds were sown in 3 m x 2 rows with 45 cm spacing between two rows and about 5 cm spacing between the two plants. Field experiments were conducted with two water treatments i.e. normal irrigation (non-stress) and water-stress condition. The experiment with water stress treatment was sown in rainout shelter to facilitate inducing the water stress to growing crop by means of closing roofs at the time of rain. Optimum isolation distance was maintained between irrigated and water stress treatments considering percolation of water. Water stress treatment was given to the crop by withholding the rain and irrigation water at V3 (seedling stage) vegetative stage and at reproductive stage R5 to R6. Experiment with normal irrigation (non-stressed) was supplied with two irrigations at different growth stages. The soil moisture content from stressed and non-stressed experiments was derived using the gravimetric method by Black (1965) as: Soil moisture % = {[(Wt. of wet soil + tare) - (Wt. of dry soil + tare)]/ (Wt. of dry soil + tare) - (tare)} × 100. The soil moisture content under water-stress during vegetative and reproductive stages was lower than that of non-stressed plots. The range of soil moisture in non-stressed plot was 39.05-41.37% while under stress induced plots it was 9.99-12.00% (Table 2).

Data was recorded from five randomly selected plants on various morpho-agronomic traits *viz.,* number of branches/plant, dry matter/plant, height/plant, number of pods/plant, seed yield/plot and root and shoot dry weight (at 50% flowering). Roots along with nodules were obtained from soil using core method given by Fenta *et al.* (2014). Relative water content (RWC) of leaves was determined according to Turner (1981) as: RWC = (FW - DW) / (SW - DW) × 100 where, FW is leaf fresh weight, SW is the turgid weight of leaves after soaking in water for four hour at room temperature (approx. 20°C) and DW is dry weight of leaves after drying at 85°C for three days. Half of the third (from the top) fully expanded leaf was used for determination of the RWC and gas exchange parameters *viz.,* photosynthetic rate (Pn), stomatal conductance (Gs), transpiration rate (Tr), CO_2 concentration (Ci) of leaves were recorded using portable Infrared Gas Analyzer (LICOR 6400 XT) at 50% flowering of respective genotype, for which fully expanded leaf in the top was used. Chlorophyll index of leaves was recorded using Chlorophyll meter SPAD-502 (Minolta, Japan) and normalized difference vegetation index (NDVI) was measured using NDVI Field Scout CM 1000 at 30, 45 and 60 days after sowing (DAS).

Nine drought tolerance indices including Stress susceptibility index (SSI), Stress tolerance index (STI), Tolerance (TOL), Yield index (YI), Drought resistance index (DRI), Yield stability index (YSI), Stress susceptibility percentage (SSPI), Drought tolerance efficiency (DTE) and modified stress tolerance index (MSTI) (Fischer and Maurer, 1978; Fischer and Wood, 1981; Fischer *et al.,* 1998; Fernandez, 1992; Rosielle and Hamblin, 1981; Bouslama and Schapaugh, 1984; Moosavi *et al.,* 2008; Farshadfar and Sutka, 2002) were calculated as follows:

a) $SSI = (1 - (Y_s/Y_p))/(1 - (\bar{Y}_s/\bar{Y}_p))$

b) $STI = (Y_s \times Y_p)/(\bar{Y}_p^2)$

c) $TOL = Y_p - Y_s$

d) $YI = (Y_s)/(\bar{Y}_s)$

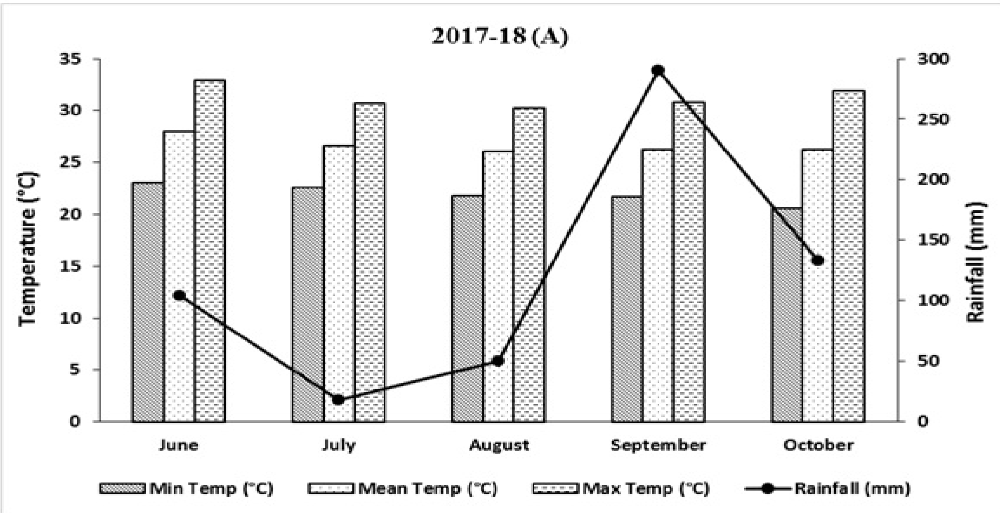
e) $DRI = (Y_s \times (Y_s/Y_p))/\bar{Y}_s$

f) $YSI = Y_s/Y_p$

g) $SSPI = (Y_p - Y_s/2(\bar{Y}_p)) \times 100$

h) $DTE (\%) = (Ys / Yp) \times 100$

i) $MSTI = KiSTI$, $K_1 = (Y_p)^2 / (\bar{Y}_p)^2$ and $K_2 = (Y_s)^2 / (\bar{Y}_s)^2$



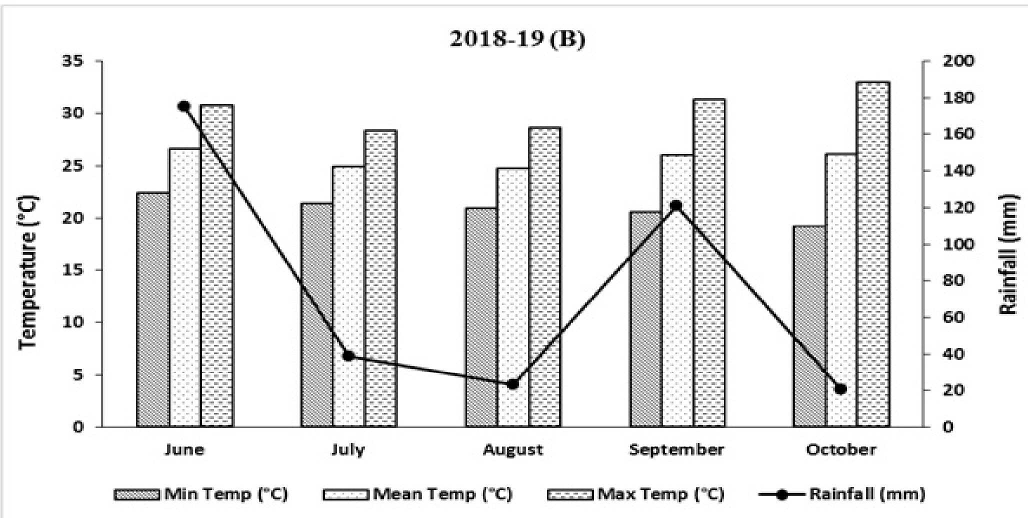


Fig. 1. Rainfall and temperature during crop growing period 2017-18 (A) and 2018-19 (B)

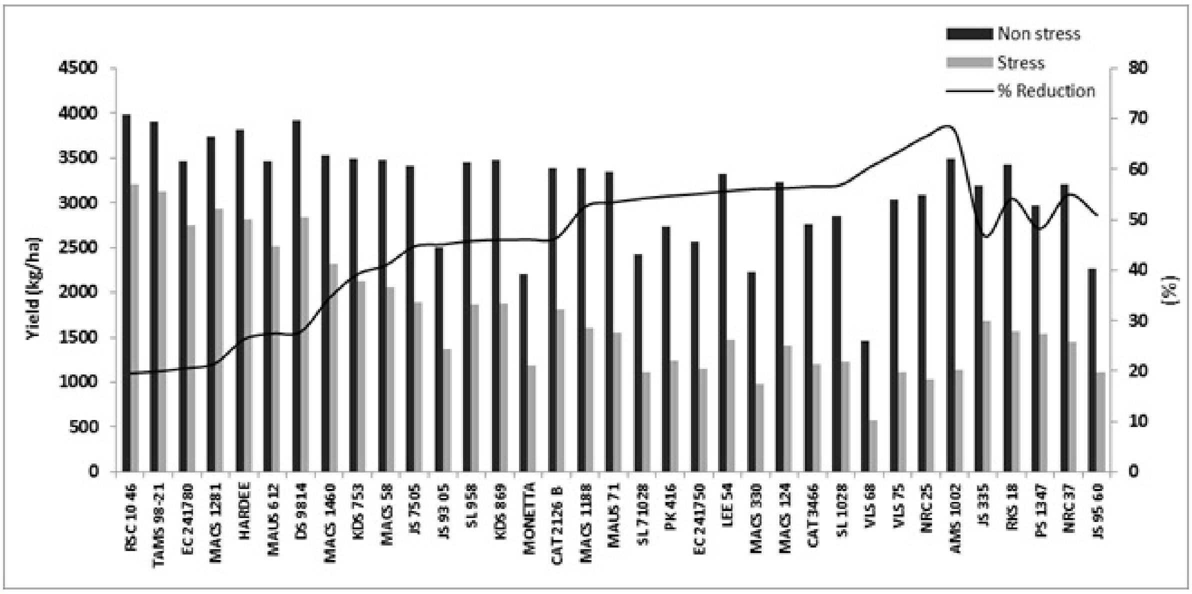


Fig. 2. Average yield reduction (percent) under stress and non-stress condition in soybean accessions over two years of testing (2017-18 and 2018-19)

Table 1 Pedigree of the soybean genotypes used for evaluation of water-stress tolerance

Genotype	Pedigree	Genotype	Pedigree
KDS 753	JS 93-05 X EC 241780	MAUS 47	PS-73-7 X Hark
HARDEE	D 49-772 X Improved pelican	KDS 344	JS 335 X EC 241780
MACS 1460	RKS 24 X JS 9560	CAT 489A	Exotic Collection
RSC 10-46	Bragg X JS 335	SL 71028	Breeding Line
SL 958	SL 525 X SL 706	MACS 1407	MAUS 144 X MACS 450
KDS 869	JS 335 X EC 538800	PK 472	HARDEE X Punjab-1
EC 15971	Exotic Collection	MACS 450	Bragg X MACS 111
EC 251501	Exotic Collection	JS 20-34	JS 98-63 X PK 768
MACS 57	JS-2 X Improved pelican	EC 241695	Exotic Collection
PK 416	UPSM 534 X S 38	PS 1556	(PA 1042 X MACS 5450) X (PS 1024 X PS 1241)
CAT 1979B	Indigenous collection	AGS 228	Exotic Collection
VLS 75	EC 361362 X VHC 3022	DSB 23-2	JS 335 x EC 241780
EC 241750	Exotic Collection	MACS 1370	DSb 5 X JS 335
CAT 3468	Exotic Collection	LEE 54	Exotic Collection
SL 1028	PK 1223 X SL (E) 4	MACS 330	Indigenous collection
CAT 2122A	Exotic Collection	DS 9814	Bragg x DS 93-MM-39
PK 1027	Exotic Collection	MAUS 612	MAUS 71 X HLM 501563
MACS 124	JS-2 X Improved pelican	JS 7505	Breeding Line
MACS 13	Hampton X EC 7034	CAT 3466	Exotic Collection
CAT 3293	Exotic Collection	PK 1029	PK 262 X PK 317
MACS 1281	JS (SH) 9301 X MACS 13	MAUS 61	Pb-1 X DS 87-14
CAT 2126B	Exotic Collection	MACS 58	JS-2 X Improved pelican
JS 93-05	Secondary selection from PS 73-22	CAT 3339	Exotic Collection
MAUS 71	JS71-05 X JS 87-38	DSB 28-3	JS 93-05 X EC 241780
EC 538828	Exotic Collection	EC 109563	Exotic Collection
LEE 95	Exotic Collection	VLS 68	Breeding Line
EC 241780	Exotic Collection	MAUS 2	Selection from SH 84-14
DSB 21	JS 335 X EC 241778	JS (SH) 93-37	Breeding Line
AMS 1002	Mutant of JS 93-05	AGS 38	Exotic Collection
MACS 1188	JS (SH) 9301 X MACS 450	JS 95-60*	Secondary selection from PS 73-22
MONETTA	Introduction from university of Nanjing, China, 1927 and from V5A (EC2587)	JS 335*	JS 78-77 X JS 71-05
TAMS 98-21	Exotic Collection	NRC 37*	JS 72-44 X Punjab 1
PK 1042	Bragg X PK 416	PS 1347*	PK 472 X PK 1024
EC 241309	Exotic Collection	RKS 18*	MAUS 450 X MONETTA
NRC 25	Breeding Line		

*Checks used

Table 2 Mean soil moisture content under water-stress and non-stressed conditions during 2017-18 and 2018-19

Year	Growth stage	Water treatment	Soil Moisture (%)
2017-18	Late vegetative stage	Normal irrigation	21.31
		Water-stressed	11.69
	Reproductive stage (anthesis)	Normal irrigation	19.74
		Water-stressed	9.68
2018-19	Late vegetative stage	Normal irrigation	20.06
		Water-stressed	12.33
	Reproductive stage (anthesis)	Normal irrigation	19.31
		Water-stressed	10.31

In the above formulas, Ys and Yp represent yield under stress and non-stress conditions for each cultivar, respectively, whereas, Y̌s and Y̌p represent yield mean in stress and non-stress conditions for all cultivars, respectively.

The data were subjected to analysis of variance followed by LSD tests for means comparisons using ACBD-R software (Rodríguez *et al.,* 2017). Descriptive statistical analysis was performed with SPSS software (Version 9.0 IBM, India). To categorize the cultivars into drought (water) stress tolerant and drought (water) stress sensitive, percent reduction in yield was calculated using formula: % Reduction in Yield = {[Yield (Normal irrigation) - Yield (Drought stress)] / Yield (Normal irrigation)} × 100.

Pearson's correlation and principal component analysis were used to test association between morphological, agronomic and physiological traits. Multiple regression analysis was conducted by step-wise adding and removing variables to estimate contribution of various traits to yield under normal and water-stress conditions. Cluster analysis was performed using SPSS by ward method to test association between different drought indices with yield under both the water regimes.

RESULTS AND DISCUSSION

Effect of water stress on soybean yield: Mean grain yield of the soybean accessions across the years showed that the higher grain yield was registered in RSC 10-46, TAMS 98-21, MACS 1281, DS 9814, HARDEE, EC 241780, MAUS 612 and MACS 1460, while the lower yield was in VLS 68, CAT 3468, EC 538828, CAT 1979 B, VLS 75, AMS 1002 and JS 20-34 under stress condition. The details of descriptive statistics of the different morpho-physiological traits over two years are given in Table 3. Pooled analysis of data across the years was carried out and the analysis of variance showed that the mean squares due to genotype including the checks were highly significant (P=0.01) for grain yield (Table 4) under both the water regimes.

The results revealed that the soybean accessions grown under water stress condition produced lower seed yield than the non-stressed condition for both the years 2017 and 2018 (Table 5). On an average the yield decline of 713 to 1855 kg/ha was observed under stress condition as compared to non-stress. The average soybean seed yield was significantly higher (3056 kg/ha) in non-stressed crop plants over water-stressed (1557 kg/ha). An average of 41% and 57% yield reduction was noticed in 2017 and 2018, respectively, under water-stressed conditions compared to normal irrigated conditions. The grain yields ranged from 1464 to 3988 kg/ha under non-stress condition while 581 to 3210 kg/ha under water-stressed condition. Percent reduction in yield was lower in accessions RSC 10-46, TAMS 98-21, EC 241780, MACS 1281, HARDEE, MAUS 612, DS 9814, MACS 1460 and KDS 753 than rest of soybean genotypes and checks. On the basis of minimum yield reduction due to exposure to water-stress these soybean genotypes were found tolerant to water-stress. Accessions EC 241695, LEE 54, MACS 1370, CAT 3466, PK 1029, VLS 75, AGS 228 and AMS 1002 were observed sensitive to drought as the percent reduction in yield was high (Fig. 2). From the results of the present study it was observed that unavailability of optimum moisture retards plant growth, flower development, seed formation and many biochemical processes in soybean plants which subsequently results in reduction in seed yield (Sepanlo *et al.*, 2014, Mimi *et al.*, 2017, Chowdhury *et al.,* 2016, Jumrani and Bhatia, 2019). Water stress during the vegetative, reproductive (flowering) and pod filling stage usually reduces seed yield as a result of fewer pods and seeds/unit area (Manavalan *et al.,* 2009). In this study, RSC 10-46, TAMS 98-21, MACS 1281, EC 241780, DS 9814, HARDEE and MAUS 612 were tolerant to water stress during vegetative and reproductive stage.

Phenotypic correlations, association and contribution of traits to water-stress tolerance: Plant height at 60 DAS, plant height at harvesting and NDVI at 60 DAS showed significant correlation with yield under normal as well as drought conditions in both the years of testing, 2017 and 2018 (Table 6). Number of branches, root dry weight, shoot dry weight (at 50% flowering), and NDVI at 45 DAS showed significant positive correlation with yield under water-stressed condition in both the years. In 2017, RWC at flowering stage, NDVI at 30 DAS and SPAD at 45 DAS showed significant correlation with yield under drought conditions, whereas, dry matter at all stages showed significant correlation with yield under normal as well as drought condition. In 2018, average number of branches, root dry weight, shoot dry weight and NDVI at 45 DAS showed significant correlation with yield under drought condition. Agronomic and physiological traits which exhibit consistent association with yield under water stress shall be the most reliable traits to improve water stress tolerance in soybean. Average number of pods, number of branches, and plant height showed positive correlation with yield in the present study, which is in agreement with earlier reports (Fenta *et al.,* 2014; Sepanlo *et al.,* 2014; Mimi *et al.,* 2017; Chowdhury *et al.,* 2016; Jumrani and Bhatia, 2019; Aung *et al.,* 2011).

Principal component analysis showed that PC1 and PC2 contributed 18.83% and 11.84% to the total variation under water stress condition, whereas, PC1 and PC2 contributes 13.56% and 11.68% to the total variation under normal irrigation treatment in 2017 (Fig. 3). In 2018, under drought stress treatment PC1 and PC2 contributes 16.28% and 12.67% to the total variation and similarly under normal irrigation treatment PC1 and PC2 contributes 14.80% and 13.86% to the total variation. The acute angles between vectors showed that number of pods, number of branches and plant height at 60 days were positively associated with yield in both years under normal irrigated and drought stress treatment (Fig. 3). Dry matter at 45 DAS showed positive association with yield in both treatments in 2017. Dry matter at 60 DAS, NDVI at 60 DAS, number of lateral roots and shoot dry weight showed positive association with yield under normal irrigation treatment in 2017, whereas, plant height at harvesting, 100 seed weight and NDVI at 30 and 45 DAS showed positive association with yield under drought stress treatment. SPAD at 60 DAS showed negative association with yield under drought stress treatment in 2017. Plant height at 30 DAS, transpiration rate and carbon assimilation rate showed negative association with yield under normal irrigation treatment (Fig.3). PCA and multiple regression analysis also confirmed plant height, biomass measured by dry weight at various stages, and pods/plant as vital contributors to grain yield under different water regimes. In 2018, NDVI at 30, 45 and 60 DAS, SPAD at 60 DAS, plant height at 60 DAS, number of branches, RWC at flowering stage and plant height at harvesting showed positive association with yield under both treatments. Root parameters such as root length, root dry weight, root nodule dry weight as well as shoot dry weight, dry matter at 30 and 45 DAS showed positive association with yield under water stressed condition. Photosynthesis rate and carbon assimilation rate showed negative association with yield under both water stress and normal irrigation treatment. NDVI at 30 DAS and 45 DAS, the indicators of shoot biomass at 30 and 45 days after sowing, also showed significant association with yield under water-stress conditions. NDVI was found useful to differentiate soybean cultivars with contrasting response to water-stress (Crusiol *et al.,* 2017), although the study was conducted with limited number of cultivars. Water-stress showed significant decrease in root and shoot biomass at vegetative stage in our study as reported earlier in soybean by Fenta *et al.* (2014) and Thu *et al.* (2014). Root dry weight and shoot dry weight at vegetative stage also showed significant correlation with yield under water-stress. Root nodule weight also showed significant contribution to yield under water-stress. Therefore, root architecture and shoot biomass at vegetative stage can be used as reliable phenotypic traits for selection of soybean accession tolerant to water-stress, as reported earlier by Fenta *et al.* (2014). Overall, our results showed that the traits contributing to total biomass such as plant height, number of pods, number of branches, shoot-root dry weight at vegetative stage, and NDVI at vegetative as well as pod filling stage were associated with water-stress tolerance in soybean. Multiple regression analysis was used to determine the relationship between response variable (yield) and explanatory variables such as plant height at 60 DAS, carbon assimilation rate (Ci), number of pods, plant dry matter at 30 and 60 DAS, NDVI at 30 and 60 DAS, and SPAD at 60 DAS (Table 7). In 2017, plant height at 60 DAS, Ci and plant dry matter at 30 DAS explained 15.9%, 21.6% and 26.7% variation in yield, respectively, under normal irrigation treatment. Similarly, dry matter at 60 DAS and NDVI at 30 DAS explained 11.8% and 18.3% variation in yield, respectively, under drought stress treatment. In 2018, 27.5%, 37.1%, 43.7% and 48.4% variation in yield under normal irrigation treatment was explained by changes in plant height at 60 DAS, number of pods, SPAD at 60 DAS and NDVI at 60 DAS, respectively whereas, 14.3%, 21.2% and 26% variation in yield under drought stress treatment was explained by changes in plant height at 60 DAS, number of pods and root nodules, respectively.

Effect of drought stress on physiological traits of soybean: Relative water content (RWC) of the leaves during water stress treatments had shown significant decrease compared to non-stressed crop (Fig. 4). Previous studies supported that the leaves of soybean subjected to drought stress exhibit large reduction in RWC (Zhang *et al.,* 2016). Normalized vegetative index (NDVI) and Chlorophyll index (SPAD value) recorded in both the water regimes showed that, the crop with non-stress had higher values for both the traits (Fig. 5). Range of the SPAD and NDVI under stress condition during 45 DAS was 32.50 to 44.85 and 0.83 to

0.92, respectively. Photosynthetic rate (Pn), stomata conductance (Gs), intercellular CO2 concentration (Ci) and transpiration rate (Tr) evaluated in stressed and non-stressed crop are represented in Fig. 6 and 7. Higher activities of the physiological traits were observed under non stress condition. Drop in photosynthetic rate was seen with the water stress in stressed crop as compared to non-stressed crop. On an average, photosynthetic rate, stomata conductance, transpiration rate and CO_2 concentration in non-stressed crop was 18.56 μmols/m^2/s, 0.250 mol/m^2/s, 5.00 mol/cm^2/s and 277.14 μmol/mol, respectively and in stressed crop it was 16.82 μmols/m^2/s, 0.200 mol/m^2/s, 4.04 mol/cm^2/s and 251.24 μmol/mol, respectively. The reduction in RWC and photosynthetic performance of leaves might be due to reduced availability of water which was reported earlier by Mokter *et al.* (2014) and Zhang *et al.* (2016). Chlorophyll content (SPAD value) also showed reduction under drought stress compared to non-stress condition.

Yield based drought tolerance indices: Drought tolerance indices were determined on the basis of yield under water-stressed and non-stressed conditions (Table 8). RSC 10-46, TAMS 98-21, HARDEE, MACS 1281 and EC 241780 were identified as the most tolerant accessions based on lower values of stress susceptibility index (SSI), tolerance (TOL) and stress susceptibility percent index (SSPI). These accessions showed higher yield under non stress and stressed condition than rest of the accessions and checks. Values for stress tolerance index (STI), yield index (YI), drought resistance index (DRI), yield stability index (YSI), modified stress tolerance index (K1&K2 STI) and drought tolerance efficiency (DTE) were higher in soybean genotypes RSC 10-46, TAMS 98-21, HARDEE and MACS 1281, which suggested the tolerance capacity of these genotypes under the limited supply of water. Highest drought tolerance efficiency (DTE) was observed in RSC 10-46 (80.48%) followed by TAMS 98-21 (80.06%), EC 241780 (79.42%) and MACS 1281 (78.45%). Drought tolerance indices determined on the basis of the yield obtained under both water regimes are useful to categorize genotypes on the basis of their yield response to water-stress. In the present study RSC 10-46, TAMS 98-21, HARDEE, MACS 1281 and EC 241780 showed low SSI, TOL and SSPI as compared to rest of the genotypes. Similarly, these genotypes have recorded higher STI, YI, DRI, YSI, DTE and K1&K2 STI.

Table 3 Average, minimum, maximum, standard deviation and variance of various morpho-physiological traits in soybean accessions under irrigated and water-stressed conditions over two years of testing

Trait	Non stress condition					Water-stress condition				
	Min.	Max.	Avg.	S.D.	Var.	Min.	Max.	Avg.	S.D.	Var.
Plant height at 60 days (cm)	20	61	44	9	74	19	62	39	8	72
Plant height at harvest (cm)	20	91	45	12	152	19	80	41	11	111
Avg. number of pods	16.2	63.1	40.8	8.3	69.1	11.2	57.1	29.1	7.2	52.4
Avg. number of branches	1.4	5.4	3.4	0.8	0.6	0.7	4.6	2.8	0.7	0.5
Dry matter at 30 days (g)	1.3	4.2	2.7	0.6	0.3	1.3	3.4	2.0	0.4	0.2
Dry matter at 45 days (g)	6.9	23.0	14.0	2.8	8.1	4.4	15.2	8.6	2.3	5.2
Dry matter at 60 days (g)	14.5	45.3	25.2	5.6	31.4	11.3	37.7	19.9	5.5	30.1
RWC vegetative stage	53.3	78.1	66.6	5.7	32.9	50.8	75.2	63.5	4.9	23.8
RWC flowering stage	61.0	81.2	72.7	3.7	13.9	50.5	73.3	63.8	3.9	15.0
Root nodule fresh weight (g)	0.40	2.70	1.13	0.40	0.16	0.23	1.10	0.62	0.23	0.05
Root nodule dry weight (g)	0.11	0.73	0.34	0.13	0.02	0.04	0.50	0.20	0.09	0.01
Root length (cm)	6.6	23.4	14.0	3.3	10.6	7.1	21.4	13.8	2.9	8.3
Root dry weight (g)	0.29	168.71	2.80	18.32	335.73	0.25	0.82	0.52	0.13	0.02
Number of lateral roots	3.0	9.5	6.0	1.3	1.8	2.0	9.0	5.3	1.4	2.0
Shoot dry weight (g)	2.90	14.70	6.77	2.10	4.40	1.70	8.55	4.57	1.38	1.91
Yield (q/h)	1464	3988	3056	536	287425	581	3210	1557	515	264849
100 Seed weight (g)	7	25	14	2	5	6	22	14	3	6
NDVI at 30 DAS	0.68	0.90	0.78	0.05	0.00	0.62	0.90	0.83	0.05	0.00
NDVI at 45 DAS	0.66	0.96	0.92	0.03	0.00	0.74	0.95	0.89	0.03	0.00
NDVI at 60 DAS	0.73	0.95	0.91	0.03	0.00	0.65	0.94	0.89	0.05	0.00
SPAD at 30 DAS	25.3	41.4	32.3	3.0	9.2	28.6	38.9	34.0	2.4	5.8
SPAD at 45 DAS	25.1	48.1	39.5	4.3	18.4	32.3	46.6	39.0	3.1	9.8
SPAD at 60 DAS	23.2	49.9	43.9	3.5	12.1	27.2	45.8	41.5	2.8	8.1
Photosynthetic rate (μmols/m^2/s)	11.1	24.4	18.7	2.9	8.3	7.2	19.1	13.2	2.8	7.6
Stomatal conductance (mol/m^2/s)	0.16	0.54	0.34	0.10	0.01	0.06	0.42	0.20	0.06	0.00
CO2 concentration (μmol/mol)	231	325	285	19	369	153	309	243	30	926
Transpiration rate (mol/cm^2/s)	3.4	7.1	5.5	0.8	0.6	2.0	6.1	3.7	0.8	0.6

Table 4 Mean square values for seed yield among sixty-eight soybean genotypes under non stress and stress condition

Sources of variation	Non stress condition				Stress condition			
	df	MS	F value	P	df	MS	F value	P
Blocks	3	204675.6	4.507		3	665319.6	30.952	
Entries	68	333783.7	7.350	0.0003	68	290126.5	13.497	0.0004
Checks	4	804337.1	17.711	0.001	4	192142.5	8.938	0.001
Genotypes	63	315615.5	6.95	0.004	63	328184.9	15.268	0.01
Checks x Genotypes	1	-403829	-8.892		1	-1715617	-79.815	
Error	12	45412.29			12	21494.93		

Table 5 Yield (kg/ha) response of soybean genotypes under water-stressed and non-stressed condition

Genotypes	2017			2018		
	Irrigated condition	Water-stress condition	% Reduction	Irrigated condition	Water-stress condition	% Reduction
RSC 10 46	3889	3404	12.5	4087	3015	26.2
TAMS 98-21	3795	3464	8.7	4010	2785	30.5
MACS 1281	3530	3006	14.8	3935	2850	27.6
DS 9814	3948	3281	16.9	3900	2388	38.8
HARDEE	3667	2948	19.6	3970	2682	32.4
EC 241780	3067	2650	13.6	3861	2852	26.1
MAUS 612	3048	2578	15.4	3879	2450	36.8
MACS 1460	3204	2178	32.0	3851	2450	36.4
KDS 753	3185	2281	28.4	3801	1969	48.2
MACS 58	3341	1956	41.5	3877	2484	35.9
JS 7505	3526	2022	42.7	3293	1750	46.9
KDS 869	3507	2130	39.3	3448	1627	52.8
SL 958	3626	2215	38.9	3262	1520	53.4
CAT 2126B	3052	1341	56.1	3716	2288	38.4
JS 335*	3096	1784	42.4	3273	1267	61.3
RKS 18*	3322	2109	36.5	3528	1218	65.5
PS 1347*	2431	1726	29.0	3505	1289	63.2
NRC 37*	3220	1923	40.3	3193	1163	63.6
JS 95 60*	2059	1252	39.2	2462	969	60.6
Mean	2884	1764		3247	1388	
LSD	1413	919		596	635	

* checks

Ranking method: It may be contradictory to identify the drought tolerant genotypes based on any one of the tolerance indices (Table 9). Hence, rank (R), mean rank (R-) and standard deviation (SDR) of ranks of all drought tolerance criteria were calculated and mean rank and standard deviation were used to identify most desirable drought tolerant soybean genotypes. Considering all these indices, genotype RSC 10-46, TAMS 98-21, MACS 1281 and HARDEE showed the best mean rank and lowest standard deviation of the rank among all the genotypes, and hence these were identified as most drought tolerant (Table 9). On similar basis, EC 241780, DS 9814 and MAUS 612 were identified as moderately drought tolerant and rest of the genotypes as drought. Mean rank and standard deviation of the tolerance indices was found to be useful for prediction of stress tolerant genotype in wheat, maize and Brassica species (Farshadfar *et al.,* 2012 a, b; Naghavi *et al.,* 2013; Khalili *et al.,* 2012; Aliakbari *et al.,* 2014).

Cluster analysis: The cluster analysis based on different tolerance indices could classify the soybean accessions into two categories as water-stress tolerant and sensitive (Fig. 8). The analysis showed that the accessions in tolerant group such as RSC 10-46, TAMS 98-21, MACS 1281, HARDEE, EC 241780, DS 9814, MACS 1460, and MAUS 612 had highest Yp, Ys, STI, DRI, YSI, DTE, K1STI and K2STI values. This group was considered to be the most suitable group for both the conditions i.e. non stress and stress environment. The second group containing rest of the genotypes and checks had high SSI value and intermediate values of the rest indices, thus were less tolerant to drought (Naghavi *et al.,* 2013). The results of the cluster analysis showed that the drought tolerance indices, except SSI, are useful to identify the soybean accessions suitable for water-stressed conditions. On the basis of minimum yield reduction under stress and drought tolerance indices soybean accessions RSC 10-46, TAMS 98-21, EC 241780, MACS 1281, HARDEE, MAUS 612, DS 9814, MACS 1460 and KDS 753 were identified as water stress tolerant. These findings were confirmed by the cumulative rank due to drought tolerance indices and cluster analysis using drought tolerance indices, hence, could be useful in soybean improvement for water-stress tolerance.

Table 6 Phenotypic correlation of measured traits with yield under water-stressed and non-stressed condition

Trait	2017		2018	
	Yield (Normal)	Yield (Drought)	Yield (Normal)	Yield (Drought)
Plant height at 60 days	0.395**	0.429**	0.524**	0.379**
Plant height at harvest	0.377**	0.308**	0.488**	0.351**
Avg. number of pods	0.294**	0.142	0.375**	0.322**
Avg. number of branches	0.163	0.219*	0.16	0.288**
Dry matter at 30 days	0.233*	0.314**	-	-
Dry matter at 45 days	0.240*	0.276*	-0.257*	0.14
Dry matter at 60 days	0.234*	0.343**	-	-
Root nodule fresh weight	-	-	-0.235*	-0.108
Root nodule dry weight	-	-	-0.241*	-0.156
Root dry weight	-0.013	0.215*	-0.013	0.218*
Root length	0.043	0.236*	-	-
Shoot dry weight	0.073	0.256*	-0.21	0.279*
RWC of leaves at flowering stage	0.057	0.286**	0.403**	0.152
NDVI at 30DAS	-0.108	0.293**	-	-
NDVI at 45DAS	0.018	0.303**	0.021	0.282**
NDVI at 60DAS	0.349**	0.251*	0.348**	0.231*
SPAD at 45DAS	-0.189	-0.244*	-0.292**	-0.181
SPAD at 60DAS	-	-	0.494**	0.205

** & * Significant at 1% and 5% levels of probability, respectively

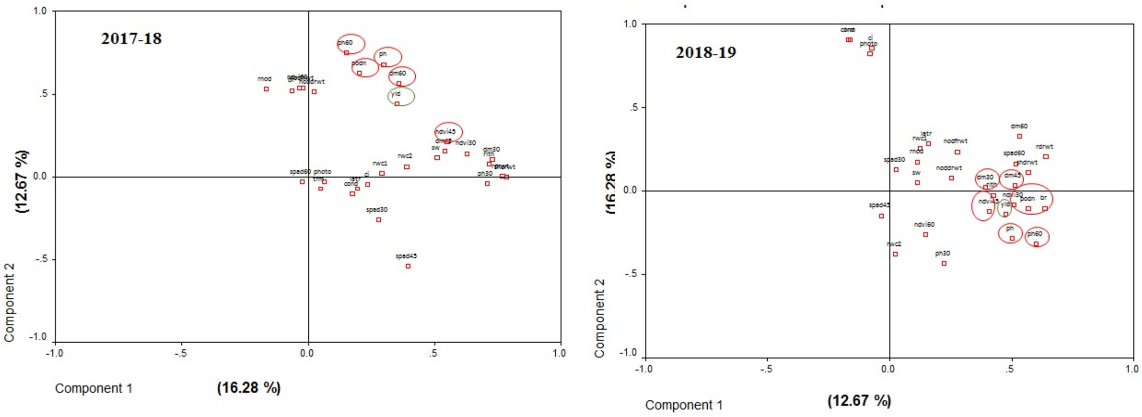


Fig. 3. Principal component analysis showing traits associated with grain yield in soybean under water stress conditions in 2017-18 and 2018-19 season

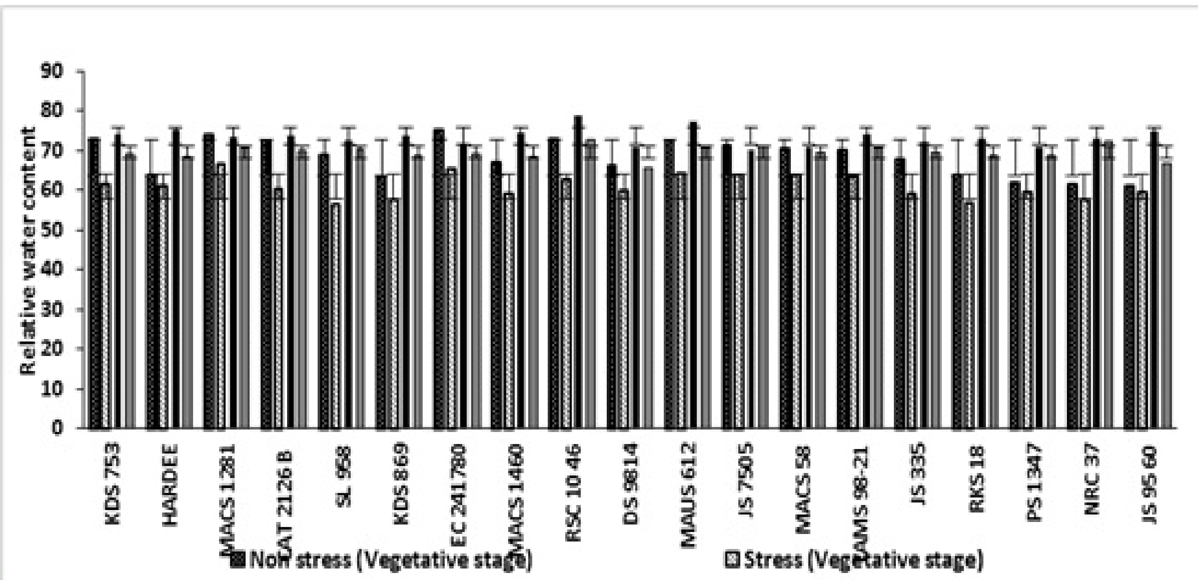


Fig. 4. Relative water content (RWC) of leaves under both water regimes stress during vegetative stage

Table 7 Multiple regression of yield with morphological and physiological parameters of soybean under non-stress and water-stressed condition

Components	R^2
2017- Non stress condition	
Yield= -681.473 + 23.182 (PH at 60 DAS) + 6.711 (Ci) + 335.741 (DM at 30 DAS)	
PH at 60 DAS	0.159
Ci	0.216
DM at 30 DAS	0.267
2017- Stress condition	
Yield= -94.907 + 65.372 (DM at 60 DAS) + 1647.332 (NDVI at 30 DAS)	
DM at 60 DAS	0.118
NDVI at 30 DAS	0.183
2018- Non stress condition	
Yield= -3419.06 + 25.297 (PH at 60 DAS) + 11.386 (Pods/ Plant) + 35.497 (SPAD at 60 DAS) + 3844.241 (NDVI at 60 DAS)	
PH at 60 DAS	0.275
Pods/plant	0.371
SPAD at 60 DAS	0.437
NDVI at 60 DAS	0.484
2018- Stress condition	
Yield= 292.936 + 22.119 (PH at 60 DAS) + 19.503 (Pods/plant) + 17.001 (Root nodules)	
PH at 60 DAS	0.143
Pods/plant	0.212
Root nodules	0.260

PH: Plant height, DM: Dry matter, Ci: CO2 concentration

Table 8 Seed yield and drought tolerance indices of soybean genotypes and check varieties in response to water-stress and non-stressed condition

Treatment	YP	YS	SSI	STI	TOL	YI	DRI	YSI	SSPI	DTE	K1STI	K2STI
KDS 753	3493	2125	0.80	0.79	1368	1.36	0.83	0.61	22.38	60.83	1.31	1.86
HARDEE	3819	2815	0.54	1.15	1004	1.81	1.33	0.74	16.42	73.72	1.56	3.27
MACS 1281	3733	2928	0.44	1.17	805	1.88	1.48	0.78	13.16	78.45	1.49	3.54
CAT 2126 B	3384	1815	0.95	0.66	1569	1.17	0.62	0.54	25.68	53.62	1.23	1.36
SL 958	3444	1868	0.93	0.69	1577	1.20	0.65	0.54	25.80	54.22	1.27	1.44
KDS 869	3478	1878	0.94	0.70	1599	1.21	0.65	0.54	26.16	54.01	1.29	1.46
EC 241780	3464	2751	0.42	1.02	713	1.77	1.40	0.79	11.67	79.42	1.28	3.12
MACS 1460	3528	2314	0.70	0.87	1214	1.49	0.97	0.66	19.85	65.60	1.33	2.21
RSC 10 46	3988	3210	0.40	1.37	779	2.06	1.66	0.80	12.74	80.48	1.70	4.25
DS 9814	3924	2835	0.57	1.19	1090	1.82	1.32	0.72	17.83	72.23	1.65	3.31
MAUS 612	3464	2514	0.56	0.93	950	1.61	1.17	0.73	15.54	72.59	1.28	2.61
JS 7505	3410	1886	0.91	0.69	1524	1.21	0.67	0.55	24.93	55.32	1.24	1.47
MACS 58	3479	2053	0.84	0.76	1426	1.32	0.78	0.59	23.33	59.01	1.30	1.74
TAMS 98-21	3903	3125	0.41	1.31	778	2.01	1.61	0.80	12.73	80.06	1.63	4.03
NRC 37	3206	1444	1.12	0.50	1762	0.93	0.43	0.45	28.83	45.05	1.10	0.88
JS 335	3184	1688	0.95	0.57	1496	1.08	0.58	0.53	24.48	53.01	1.09	1.18
JS 95-60	2261	1110	1.04	0.27	1151	0.71	0.35	0.49	18.82	49.11	0.55	0.51
RKS 18	3425	1570	1.10	0.57	1854	1.01	0.47	0.46	30.34	45.85	1.26	1.02
PS 1347	2968	1537	0.98	0.49	1431	0.99	0.51	0.52	23.42	51.78	0.95	0.98

YP: Yield under non-stressed conditions, YS: Yield under water-stressed condition, SSI: Stress susceptibility index, STI: Stress tolerance index, TOL: Tolerance, YI: Yield index, DRI: Drought resistance index, YSI: Yield stability index, SSPI: Stress susceptibility percentage index, DTE: Drought tolerance efficiency and K1&2 STI: Modified stress tolerance index

Table 9 Rank (R), rank mean (R-) and standard deviation of ranks (SDR) of drought tolerance indices

Genotypes	Yp	Sp	SSI	STI	TOL	YI	DRI	YSI	SSP	DTE	K1STI	K2STI	R-	SDR
KDS 753	7	9	9	9	10	9	9	9	10	9	7	9	8.83	0.94
HARDEE	4	5	5	5	6	5	5	5	6	5	4	5	5.00	0.60
MACS 1281	5	3	4	4	4	3	3	4	4	4	5	3	3.83	0.72
CAT 2126 B	15	14	14	14	15	14	14	14	15	14	15	14	14.33	0.49
SL 958	12	13	12	12	16	13	13	12	16	12	12	13	13.00	1.48
KDS 869	9	12	13	11	17	12	12	13	17	13	9	12	12.50	2.50
EC 241780	10	6	3	6	1	6	4	3	1	3	10	6	4.92	3.00
MACS 1460	6	8	8	8	9	8	8	8	9	8	6	8	7.83	0.94
RSC 10 46	1	1	1	1	3	1	1	1	3	1	1	1	1.33	0.78
DS 9814	2	4	7	3	7	4	6	7	7	7	2	4	5.00	2.04
MAUS 612	11	7	6	7	5	7	7	6	5	6	11	7	7.08	1.98
JS 7505	14	11	11	13	14	11	11	11	14	11	14	11	12.17	1.47
MACS 58	8	10	10	10	11	10	10	10	11	10	8	10	9.83	0.94
TAMS 98-21	3	2	2	2	2	2	2	2	2	2	3	2	2.17	0.39
NRC 37	16	18	19	17	18	18	18	19	18	19	16	18	17.83	1.03
JS 335	17	15	15	16	13	15	15	15	13	15	17	15	15.08	1.24
JS 95-60	19	19	17	19	8	19	19	17	8	17	19	19	16.67	4.14
RKS 18	13	16	18	15	19	16	17	18	19	18	13	16	16.50	2.07
PS 1347	18	17	16	18	12	17	16	16	12	16	18	17	16.08	2.07

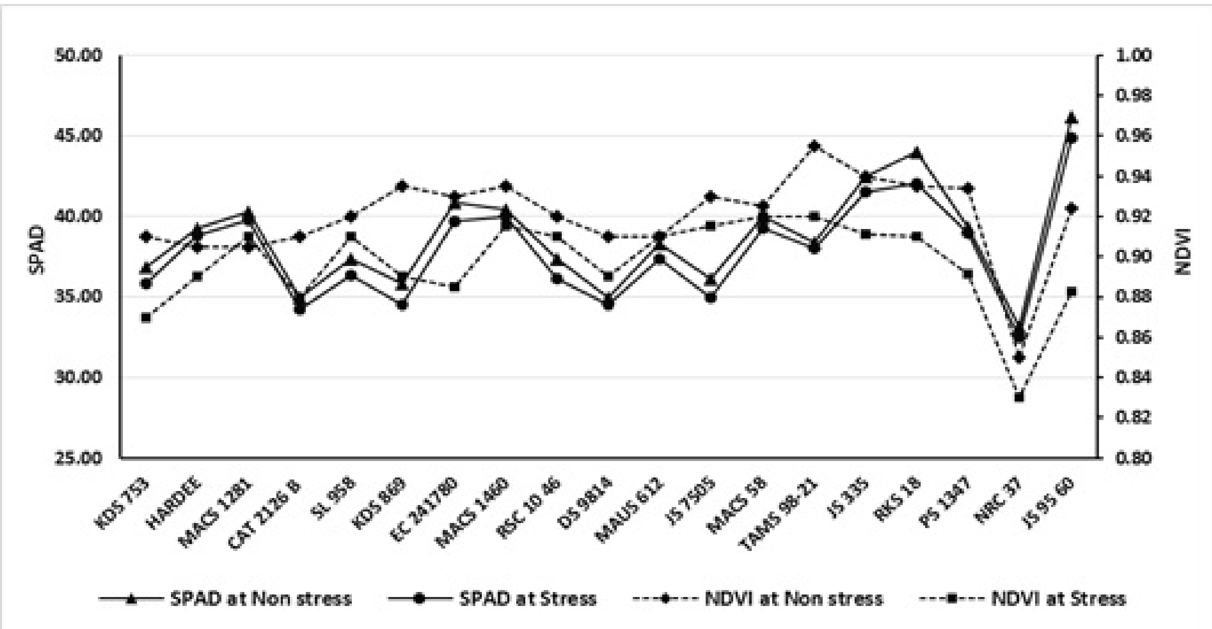


Fig. 5. Normalized difference vegetative index (NDVI) and Chlorophyll content (SPAD) in soybean at 45 DAS under both water regimes

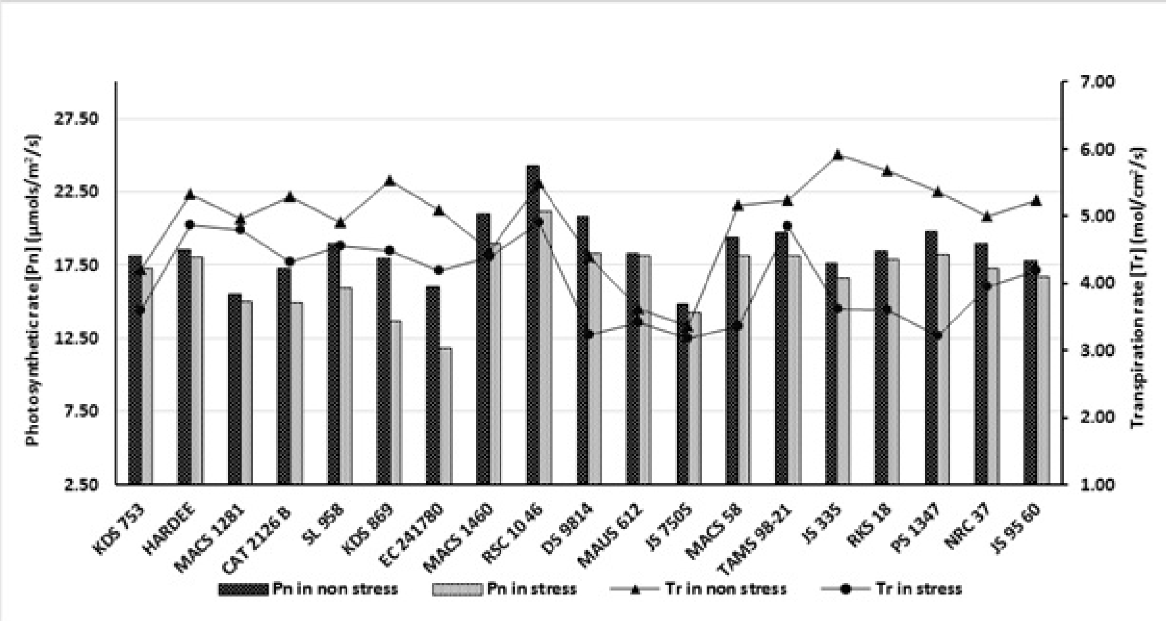


Fig. 6. Influence of water-stress on mean photosynthetic rate (Pn) and mean transpiration rate (Tr) of soybean leaves under both water regimes during 2017-18 and 2018-19

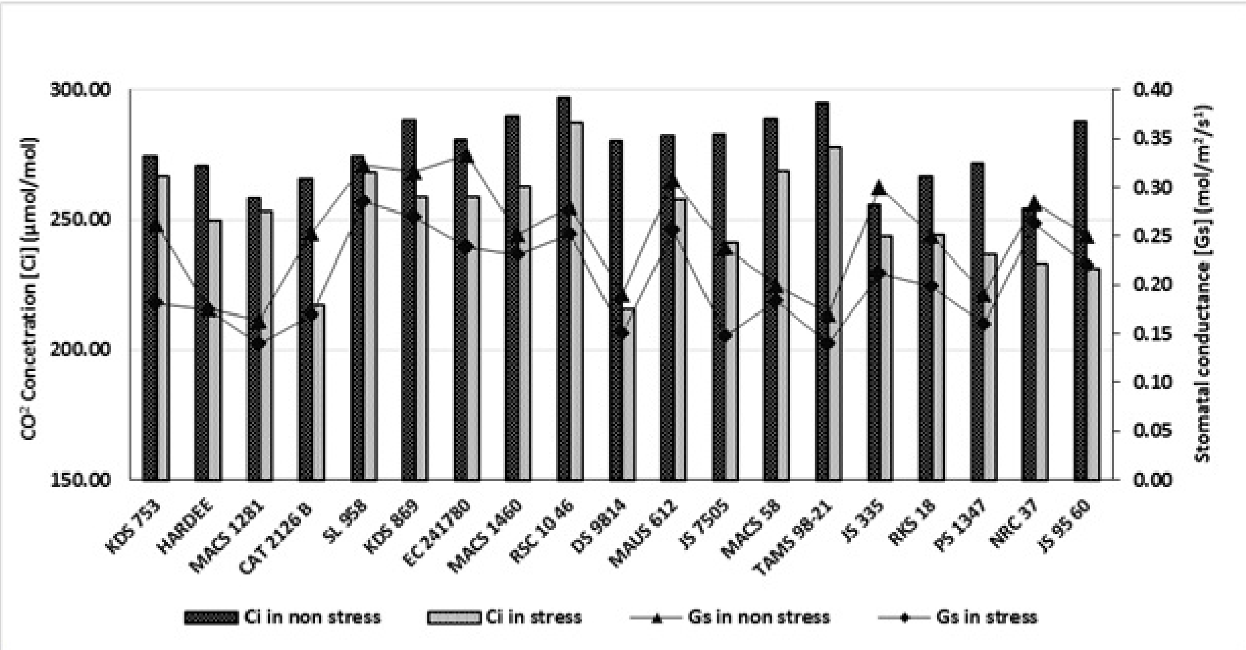


Fig.7. Influence of water-stress on mean CO2 concentration (Ci) and mean stomatal conductance (Gs) of soybean leaves during 2017-18 and 2018-19

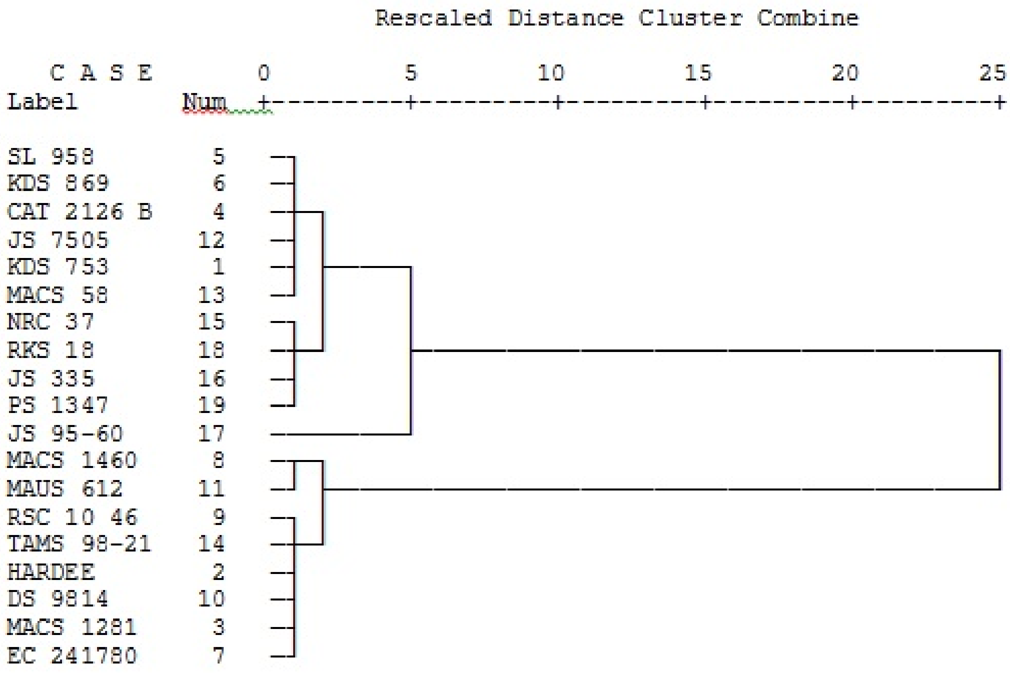


Fig. 8. Dendrogram using ward method showing classification of cultivars based on resistance/tolerance indices

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Effect of super absorbent polymer on drought mitigation, and enhancing productivity and profitability of Indian mustard (*Brassica juncea* L.)

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ABSTRACT

Under the current scenario of increasing demand of edible oil and dwindling irrigation water supply, the development of drought mitigation strategies is the need of the hour to increase productivity and profitability of the Indian mustard (*Brassica juncea* L.). A field experiment was conducted to evaluate the field efficacy of the superabsorbent polymer (SAP: Pusa hydrogel) and its application rates 0, 1.5, 2.5 and 5.0 kg/ha under moisture stress and normal moisture conditions in a factorial randomized complete block design and replicated thrice. The SCMR, dry matter accumulation, 1000-seed weight, oil and biological yields, economic indicators of the Indian mustard and also the soil available N, P and S contents were reduced ($p = 0.05$) under moisture stress regime, but improved considerably with the use of SAP. Across the moisture regimes, the maximum oil yield (1.12 t/ha), biological yield (9.24 t/ha), harvest index (29.12 %), gross returns (₹ 116140/ha), net returns (₹ 74790/ha), B: C ratio (1.81) and economic efficiency (₹ 519.4/ha/day) were recorded with SAP @ 5.0 kg/ha. SAP @ 2.5 to 5.0 kg/ha improved oil yield and net returns by 3 % (0.04 t//ha) and 2 % (₹ 1980/ha), respectively under normal moisture regime, while under moisture stress these parameters were increased by 13% (0.12 t/ha) and 14% (₹ 8280/ha), respectively. Further, under moisture stress, the maximum B:C ratio (1.66) was recorded with 5.0 kg SAP/ha, while it was the maximum (2.05) with 2.5 kg SAP/ha under the normal moisture regime. Across the moisture regimes, SAP @ 5.0 kg/ha, being on par with 2.5 kg SAP/ha improved the soil organic carbon, available N, P, K and S by 29.27, 13.61, 14.10, 11.95 and 25.01%, respectively over the control. Thus, 5.0 kg SAP/ha under moisture stress and 2.5 kg SAP/ha under normal moisture condition can be recommended for increasing yield, profit, saving water and better soil health in Indian mustard.

Keywords: Indian mustard, Moisture stress, Oil yield, Profitability, Soil physico-chemical properties, Superabsorbent polymer

Indian mustard (*Brassica juncea* L.) is the major winter oilseed crop of India. Nearly, 70% of its area cultivated in Rajasthan, Haryana and Uttar Pradesh is mostly under rainfed conditions. During the year of 2018-19 in India, the oilseed brassica (rapeseed and mustard) production recorded the highest ever production of 9.3 mt from 6.1 mha acreage with all-time highest average productivity of 1511 kg/ha till the year 2019-20. These crops share nearly 24% area and 27% production of total oilseeds in the country. It contributes more than 33% of vegetable oil production and plays a crucial role in meeting the edible oil requirements of the country. However, the production of domestic edible oils (10.52 mt) was not found sufficient to meet the Nation's growing edible oil demand which is being met through imports worth ₹ 75000 crores during 2017-18. During the last five years, the total domestic demand has increased from 19.82 mt in 2012-13 to 25.88 mt in 2017-18. The situation will be more challenging with escalating consumption of edible oils up to 2030 with the ever-increasing population (Jat *et al.*, 2019).

Mustard is predominantly grown in Rajasthan either under rainfed or limited irrigations. The crop recurrently faces drought like situations during critical crop growth periods (Rathore *et al.,* 2014). This leads to poor seed and oil yields (Rathore *et al.,* 2019; Choudhary *et al.,* 2019). Thus, it is imperative to identify avenues of sustaining productivity while minimizing the impact of water stress during active crop growth period. Use of chemicals for the in-situ conservation and efficient utilization of the available soil moisture in root zone will certainly help in increasing the productivity of crop under the limited supply of water.

Superabsorbent polymers (SAPs) like hydrogel are promising option to exploit the existing water use in soil for the field and horticultural crops (Kolhapure *et al.,* 2016; Tian *et al.,* 2019). Pusa hydrogel is a semi-synthetic, cross linked, derivatized cellulose-graft-anionic superabsorbent polymer (IARI, 2012). It absorbs a minimum of 350 times of its dry weight in pure water and gradually releases it. Field experiments conducted in different crops in India revealed that use of hydrogel could be helpful in conserving soil moisture and improving crop productivity significantly (IARI, 2012; Jakhar *et al.,* 2017; Rathore *et al.,* 2017; Singh *et al.,* 2018; Rathore *et al.,* 2019; Choudhary *et al.,* 2021).

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Superabsorbent polymers are not only used for water saving in irrigation, but they also have tremendous potential to improve physico-chemical and biological properties of the soil (Kalhapure *et al.,* 2016). Studies have shown that SAP can improve soil structure (Yang *et al.,* 2021), organic carbon and chemical properties and nutrient use efficiency (Tian *et al.,* 2019). The higher water storage capacity, irrigation water productivity and yield with SAPs improves profitability (Montesano *et al.,* 2015; Kalhapure *et al.,* 2016). Jat *et al.* (2018) reported that application of hydrogel @ 5.0 kg/ha had not only improved the mustard yield but also improved the production efficiency (15.0 kg/ha/day) and water productivity (8.46 kg ha/mm). However, the efficacy of SAP should be evaluated as per the growing area and crop to exploit its potential benefits. Therefore, keeping the facts in view, the present study was executed with the objectives 1) to standardize the application rate of SAP, 2) to assess the efficacy of SAP in mitigating the effect of moisture stress in terms of productivity and profitability, and 3) to study the response of SAP on soil physico-chemical properties in Indian mustard.

MATERIALS AND METHODS

Soil and weather: The study was conducted at ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur (27°12'8.9" N, 77°27'18.8" E and 170 m above mean sea level) during rabi season (October to March) of 2018-19. The experimental clay loam soil had 0.43 % organic carbon, 237.2 kg $KMnO_4$ oxidizable N/ha, 19.8 kg 0.5 N $NaHCO_3$ extractable P/ha, 175.6 kg 1.0 N NH_4OAc exchangeable K/ha, 8.1 pH and 0.61 dS/m EC at initiation of the study. During the crop season, the daily values of the maximum and minimum temperature, maximum and minimum relative humidity, bright sunshine hours and wind velocity ranged between 15-34.8 °C, 0.4-21.8°C, 70.5-97.3 %, 45.3-89.4 %, 0-10 hours/day and 0-7.6 km/hr, respectively. Total rainfall received during the crop period was 37.4 mm. The distribution of rainfall and other weather parameters during the crop growing period have been presented in Fig. 1.

Treatment details and crop culture: The eight treatment combinations consisting four levels of superabsorbent polymer (SAP; Pusa hydrogel; 0, 1.5, 2.5 and 5.0 kg/ha) and two moisture regimes (normal moisture and moisture stress) were allotted in a factorial randomized block design and replicated thrice. SAP was drilled in furrows while sowing of the Indian mustard crop (var. DRMRIJ 31) with a tractor drawn seed-cum-fertilizer drill machine.

Crop was sown on 22 October 2018 in lines at 30 cm row-to-row distance using 5 kg seeds/ha. Gap filling and thinning operations were performed and a planting geometry of 30 cm × 10 cm was kept to maintain the optimum plant population. The recommended doses 80:40:40:40:5:1 kg/ha of $N:P_2O_5:K_2O:S:Zn:B$ were uniformly applied to all the treatments through urea, SSP, MOP, zinc sulphate and borax fertilizers. Half dose of N and full dose of P, K and other nutrients were applied as basal at the time of sowing, while remaining 50% dose of N was top dressed after first irrigation. To ensure a good crop establishment, 1st irrigation was applied uniformly in the all the treatments at 33 days after sowing (DAS). Moisture stress regime was created by with-holding the 2nd irrigation i.e. second irrigation was applied only to the treatments of normal moisture regime at reproductive stage of crop after 70 DAS. Under normal moisture regime crop received 192.1 mm water through two irrigations and rainfall, while under moisture stress regime it received only 132.1 mm water through one irrigation and rainfall. Other recommended crop management practices were followed to harvest a good crop.

Growth and yield: The SCMR values that represent the chlorophyll or relative N content in intact mustard leaves were measured at 45 and 75 DAS using a SPAD 502 Chlorophyll Meter. Standard methods were employed to record the observations on dry matter accumulation and 1000-seed weight. The crop was harvested on 15 March from 4.5 m × 3.0 m net plot area. The harvested produce was left in the field for few days for proper sun drying and then weighed for total biomass which was adjusted at 12 % moisture content. The produce was threshed manually and seeds were cleaned. The final seed and biological yields were recorded in kg/plot and then expressed as t/ha. The ratio of grain yield and biological yield was multiplied by 100 and expressed in percent to derive the values of harvest index. The oil content in the seed was determined with near infrared reflectance spectroscopy (NIRS, Model FOSS 6500) by using non-destructive method of oil estimation as suggested by Alexander *et al.* (1967) using equation developed for mustard samples. Accordingly, the oil yield was calculated by multiplying the oil content in the seed sample of each treatment with its respective seed yield and expressed in t/ha.

Soil properties: Soil physico-chemical parameters were recorded at the end of the experiment. Electrical conductivity (EC, dS/m) and pH (1:2.5; soil: water ratio) were estimated by following the methods as suggested by Piper (1950). Soil samples collected from individual plots were separated for content of organic carbon by wet digestion method, available nitrogen by alkaline $KMnO_4$ method, available phosphorous by 0.5 M sodium bicarbonate extraction method, available potassium by flame photometry method and available S by turbidimetric method using the spectrophotometer (Prasad *et al.,* 2006).

Economics: The economics of cultivation was worked out on the basis of prevailing market price of produce and cost of inputs. Net returns were estimated by deducting the total cost of cultivation from gross returns, and benefit: cost (B:C) ratio was calculated by dividing net returns with total of fixed and variable costs. Price/kg of seed, stover and Superabsorbent polymer were ₹ 42, ₹ 0.50 and ₹ 1200 during 2018-19. The ratio of net returns and crop growing period was expressed in terms of economic efficiency.

Statistical analysis: The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique for a factorial randomized block design using SAS package (ver. 9.3). The results have been presented at 5% level significance (p = 0.05).

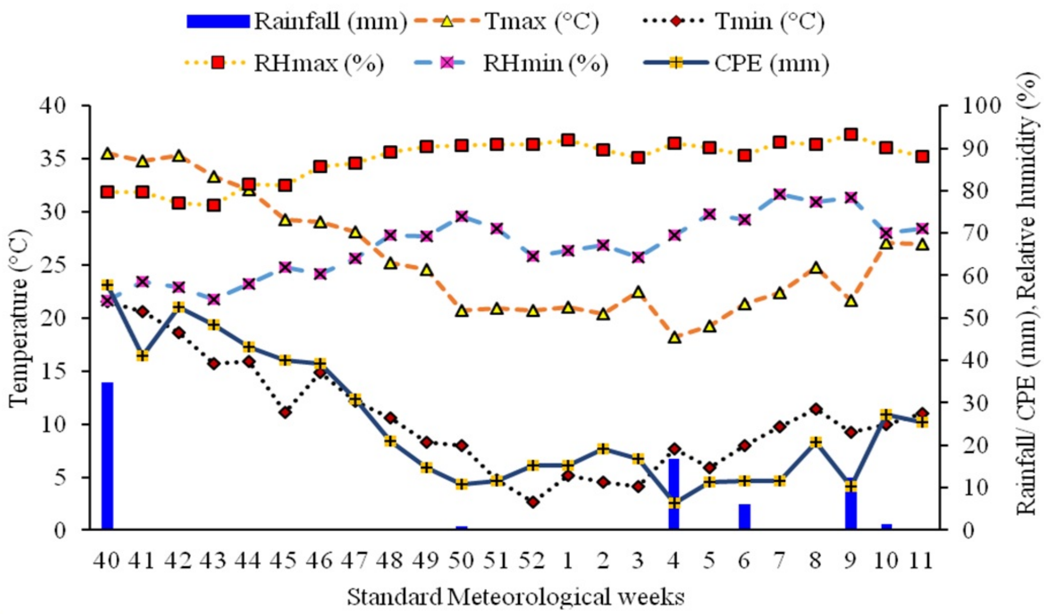

Fig. 1. Weather conditions during the crop growing period in 2018-19

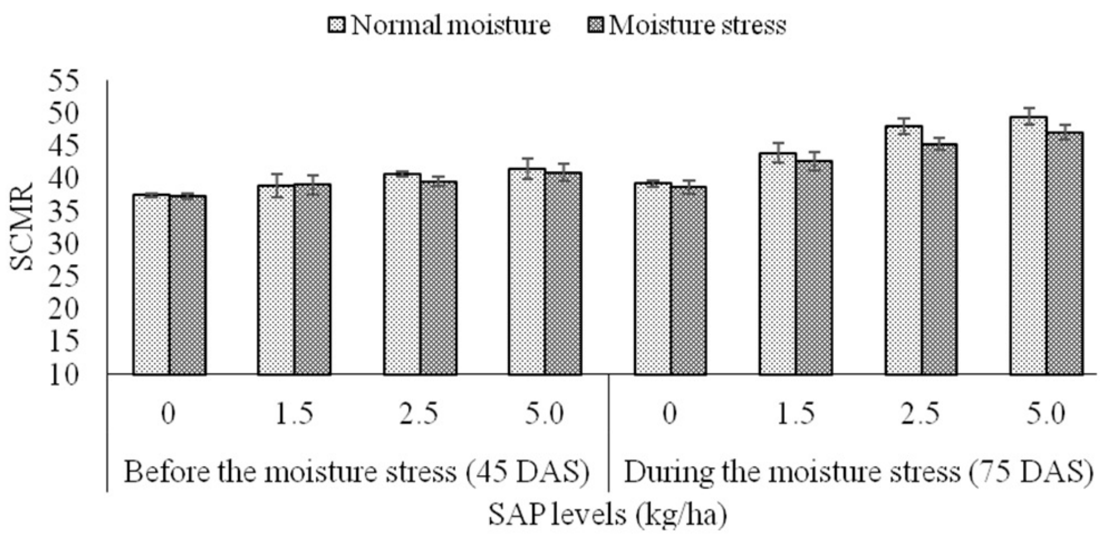

Fig. 2. Effect of soil moisture regimes and superabsorbent polymer levels on SPAD-chlorophyll meter reading (SCMR) of mustard

RESULTS AND DISCUSSION

Plant growth and yield attributes: The SCMR which indicates the chlorophyll or relative N content in leaves and over all crop health of the crop varied significantly at 75 DAS due to different soil moisture regimes and SAP levels, though it did not differ at 45 DAS (Fig. 2). At 75 DAS, SCMR was recorded higher (7.24%) under normal moisture than the moisture stress regime. Among the SAP levels, the maximum SCMR (48.3) was recorded with 5.0 kg SAP/ha though on par with 2.5 kg SAP/ha but significantly higher than the control and 1.5 kg SAP/ha levels. The limited supply of water and thereby nutrients might have resulted in lower SCMR under the moisture stress. SAP can absorb water 350 times of its dry weight and gradually release the same during the water stress in the soil (IARI, 2012). Dry matter accumulation (DMA) and also the 1000-seed weight in mustard reduced significantly by 11.70 and 5.10%, respectively due to moisture stress compared to normal moisture regime (Table 1). The maximum values of the DMA (118.6 g/plant) and 1000-seed weight (6.22 g) were recorded with 5.0 kg SAP/ha though on par with 2.5 kg SAP/ha but significantly higher over the other. Increase in DMA and 1000-seed weight with the SAP might be due to improved water supply which provided a congenial growth environment for cell elongation, cell turgidity, opening of stomata and finally the partitioning of photosynthates efficiently to the sink (Chauhan *et al.,* 2002). Further. higher 1000-seed weight might be also due to the better availability of nutrients along with a better translocation of photosynthates from source to sink which in turn helped in higher accumulation of photosynthates in the seeds with the application of irrigation and SAP (Yadav *et al.,* 2010; Singh *et al.,* 2018).

Biological yield and harvest index: The maximum biological yield (9.20 t/ha) was recorded under normal moisture regime, which was higher by 12.74% over the moisture stress regime (Table 1). Among the SAP levels, the maximum biological yield (9.24 t/ha) was recorded with 5.0 kg SAP/ha though on par with 2.5 kg SAP/ha but significantly higher by 9.09-14.36% than rest of the SAP levels. This indicates that the SAP alleviated the impact of moisture stress by way of maintaining optimal water supply and thus, increased the yield of mustard. Harvest index was recorded higher under normal moisture (28.64%) compared to under moisture stress regime (26.97%). The maximum harvest index was recorded with 5.0 kg SAP/ha (29.12%) which was on par with 2.5 kg SAP/ha but significantly higher than rest of the SAP levels. Comparatively higher values of the growth and yield attributing characters led to significant improvement in the biological yield and harvest index of mustard under normal moisture over the moisture stress regime. Singh *et al.* (2018) reported that application of irrigation increased the biological yield and its components significantly over no irrigation. SAP application increased the biological yield and harvest index significantly over the control through optimal supply of water. Consequently, availability of adequate moisture to plants might have resulted in production of more photosynthates, helping in translocation of more photosynthates to the seeds and thus, improved these agronomic traits (Moghadam *et al.,* 2009). Choudhary *et al.* (2019) have reported that the seed, stover and biological yields decreased significantly by 11, 7 and 8%, respectively due to moisture stress but compensated with the use of SAP either alone or in combinations with plant bio-regulators.

Oil content and its yield: Oil content in seed did not differ significantly by the moisture regimes, but it was influenced significantly with the SAP levels (Table 1). The maximum oil content was recorded with 5.0 kg SAP/ha (41.55%) which was on par with other levels of SAP but significantly increased by 3.67% over the control. The highest oil yield was obviously obtained under normal moisture regime (1.09 t/ha), which was higher by 21.11% over the moisture stress regime (Fig. 3). Jat *et al.* (2018) also have reported that the optimal irrigation (0.7-0.8 IW/CPE) applied to mustard resulted the higher oil content and oil yields than deficit irrigations (0.6 IW/CPE). In the present study, maximum decrease in oil yield due to moisture stress was recorded at the control and lower levels of SAP (₹ 2.5 kg SAP/ha) which ranged between 16.94 to 19.98%, while the least decrease in oil yield was recorded with 5.0 kg SAP/ha (12.10%). This indicated that application of SAP (5.0 kg/ha) reduced the oil yield loss due to moisture stress. Averaged across the moisture regimes, the maximum oil yield was recorded with 5.0 kg SAP/ha (1.12 t/ha), being on par with 2.5 kg SAP/ha but significantly higher by 30.23 and 15.46% over the control and 1.5 kg SAP/ha, respectively (Fig. 3). SAP @ 2.5 to 5.0 kg/ha improved oil yield 3% (0.04 t/ha) under normal moisture regime, while under moisture stress increased by 13% (0.12 t/ha). This suggests that the application of 5.0 kg SAP/ha under moisture stress and 2.5 kg SAP/ha under normal moisture regime was beneficial in enhancing the oil yield of mustard. Comparatively higher oil content and seed yields led to significant increase in the oil yield of the mustard at higher levels of SAP. Jat *et al.* (2018) reported that the oil yield was significantly improved with 5.0 kg/ha hydrogel over the 2.5 kg/ha and the control. However, in contrary to this, Singh *et al.* (2018) reported that the application of irrigation and hydrogel could not influence the oil content in seeds significantly.

Soil physico-chemical properties: Different soil moisture regimes were found to influence the available N, P and S in soil significantly, and EC, pH, organic carbon and available K non-significantly (Table 2). Under normal moisture regime, available N, P and S increased significantly by 6.21, 7.88 and 9.37%, respectively over the moisture stress regime. These soil chemical parameters were also influenced significantly due to different SAP levels, except EC and pH (Table 2). The maximum soil organic carbon (0.53%), available N (247.9 kg/ha), available P (21.6 kg/ha), available K (192.1 kg/ha) and available S (22.5 kg/ha) were observed with 5.0 kg SAP/ha, being on par with 2.5 kg SAP/ha but significantly higher by 29.27, 13.61, 14.10, 11.95 and 25.01%, respectively over the control. This indicates that availability of nutrients increased with increase in supply of water either due to irrigation or SAP. Bhaskar *et al.* (2012) and Rathore *et al.* (2019) have also reported that hydrogel appreciably enhanced water storage in the soil, it's readily availability and thereby meet the crop water requirement under water-stress conditions. Jakhar *et al.* (2017) have also reported a significant improvement in soil available N, P and K contents in maize-mustard cropping system with hydrogel under zero tillage. The SAP (hydrogel) might have improved the soil physical properties, i.e. porosity, soil permeability, infiltration rate with increasing water holding capacity of soil (Bhaskar *et al.,* 2012).

Table 1 Effect of soil moisture regimes and superabsorbent polymer levels on growth, yield attributes and yield of mustard

Treatment	Dry matter accumulation (g/plant)	1000-seed weight (g)	Biological yield (t/ha)	Harvest index (%)	Oil content in seed (%)
A. Soil moisture regimes					
Normal moisture	110.3	6.08	9.20	28.6	41.2
Moisture stress	98.5	5.77	8.16	27.0	41.1
SEm±	2.92	0.07	0.11	0.35	0.23
LSD ($p \leq 0.05$)	8.86	0.21	0.32	1.05	NS
B. SAP levels (kg/ha)					
0.0	90.0	5.61	8.08	26.5	40.1
1.5	100.1	5.82	8.47	27.6	41.5
2.5	109.1	6.04	8.91	28.1	41.5
5.0	118.6	6.22	9.24	29.1	41.6
SEm±	4.13	0.10	0.15	0.49	0.33
LSD ($p \leq 0.05$)	12.54	0.30	0.46	1.49	1.00

Table 2 Effect of soil moisture regimes and superabsorbent polymer levels on soil properties (0-15 cm soil depth) at harvest of mustard

Treatment	Electrical conductivity (dS/m)	pH	Organic carbon (%)	Available nutrients (kg/ha)			
				N	P	K	S
Soil moisture regimes							
Normal moisture	0.58	8.11	0.49	242.9	21.23	185.7	21.24
Moisture stress	0.60	8.10	0.44	228.7	19.68	180.2	19.42
SEm±	0.02	0.07	0.02	3.21	0.27	2.98	0.56
LSD ($p \leq 0.05$)	NS	NS	NS	9.73	0.82	NS	1.71
SAP levels (kg/ha)							
0.0	0.59	8.09	0.41	218.2	18.93	171.6	17.99
1.5	0.60	8.07	0.44	234.8	20.00	180.5	19.50
2.5	0.61	8.11	0.48	242.4	21.30	187.7	21.34
5.0	0.58	8.16	0.53	247.9	21.60	192.1	22.49
SEm±	0.03	0.10	0.03	4.54	0.38	4.21	0.80
LSD ($p \leq 0.05$)	NS	NS	0.09	13.76	1.16	12.77	2.41

Economic indicators: The maximum cost of cultivation (₹ 38810/ha) was reported under normal moisture regime which was 3.48% less under the moisture stress regime due to saving of cost of one irrigation (Table 3). Normal moisture regime resulted in the higher values of gross returns, net returns, B:C ratio as well as economic efficiency to the tune of 19.27, 29.41, 25.32 and 29.43%, respectively over the moisture stress regimes. Among the SAP levels, the maximum values of gross returns (₹ 116140/ha), net returns (₹ 74790/ha), B:C ratio (1.81) and economic efficiency (₹ 519.4/ha/day) were obtained with 5.0 kg SAP/ha, being on par with 2.5 kg SAP/ha but significantly higher by 16.20-24.85, 21.08-30.00, 11.73-11.73 and 21.13-30.05%, respectively over the control (Table 3). Under moisture stress regime, the maximum B:C ratio (1.66) was recorded with 5.0 kg SAP/ha, while it was the maximum (2.05) with 2.5 kg SAP/ha under the normal moisture regime. Moreover, the net returns improved by ₹ 1980 /ha (2%) and ₹ 8280/ha (14%) with increase in SAP level from 2.5 to 5.0 kg/ha under normal moisture and moisture stress regimes, respectively which might be due to the role of SAP in conserving and supply of moisture during the stress period and thereby increasing the yields as well as net returns under moisture stress regime. Thus, the significant increase in economic indicators was due to increase in yields of the mustard which was driven by supply of water mainly through irrigation and supplemented by the SAP, though response of SAP was observed greater under moisture stress than the normal moisture regime. Rathore *et al.* (2019) also reported that the highest net returns could be obtained with scheduling of irrigation at 0.8 IW/CPE + hydrogel (SAP). Profitability index was also recorded higher with SAP. Further, the higher water storage capacity, irrigation water productivity and yields with SAP improves profitability (Rathore *et al.,* 2014; Montesano *et al.,* 2015; Kalhapure *et al.,* 2016). Jat *et al.* (2018) have reported that application of 5.0 kg/ha hydrogel significantly increased the gross returns over the 2.5 kg/ha hydrogel and without hydrogel. It gave higher gross returns (₹ 3673 to 6251/ha) and production efficiency (4.89 to 7.91%) over the 2.5 kg/ha hydrogel and without hydrogel.

Table 3 Effect of soil moisture regimes and superabsorbent polymer levels on economics of mustard

Soil moisture regimes	SAP levels (kg/ha)				Mean
	0.0	1.5	2.5	5.0	
Cost of cultivation (10^3 ₹/ha)					
Normal moisture	36.18	37.93	39.10	42.02	38.81
Moisture stress	34.84	36.59	37.76	40.68	37.46
Mean	35.51	37.26	38.43	41.35	
Gross returns (10^3 ₹/ha)					
Normal moisture	101.29	110.44	119.26	124.16	113.78
Moisture stress	84.76	91.79	96.92	108.13	95.40
Mean	93.02	101.11	108.09	116.14	
	A. Soil moisture regimes		B. SAP levels (kg/ha)		A × B
SEm±	2.31		3.26		4.61
LSD ($p \leq 0.05$)	6.99		9.89		NS
Net returns (10^3 ₹/ha)					
Normal moisture	65.11	72.51	80.16	82.14	74.98
Moisture stress	49.93	55.20	59.17	67.45	57.94
Mean	57.52	63.86	69.66	74.79	
	A. Soil moisture regimes		B. SAP levels (kg/ha)		A × B
SEm±	1.79		2.54		3.59
LSD ($p \leq 0.05$)	5.44		7.70		NS
B:C ratio					
Normal moisture	1.80	1.91	2.05	1.95	1.93
Moisture stress	1.43	1.51	1.57	1.66	1.54
Mean	1.62	1.71	1.81	1.81	
	A. Soil moisture regimes		B. SAP levels (kg/ha)		A × B
SEm±	0.02		0.04		0.05
LSD ($p \leq 0.05$)	0.08		0.11		NS
Economic efficiency ((₹/ha/day)					
Normal moisture	452.2	503.5	556.7	570.4	520.7
Moisture stress	346.7	383.4	410.9	468.4	402.3
Mean	399.4	443.4	483.8	519.4	
	A. Soil moisture regimes		B. SAP levels (kg/ha)		A × B
SEm±	12.46		17.63		24.93
LSD ($p \leq 0.05$)	37.80		53.46		NS

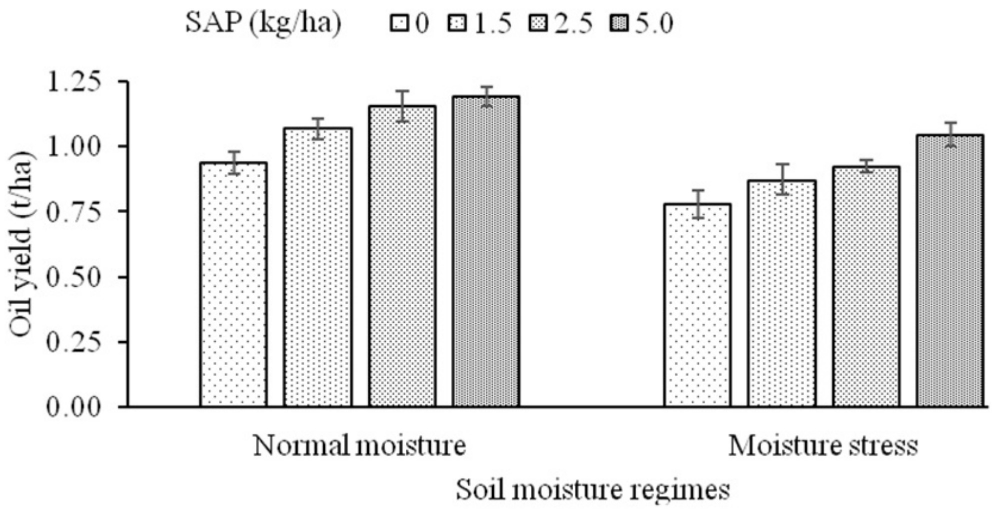

Fig. 3. Effect of soil moisture regimes and superabsorbent polymer levels on oil yield of mustard

The study highlighted that under limited irrigation water, superabsorbent polymer (Pusa hydrogel) can be a viable option to achieve higher productivity, oil yield and profitability of Indian mustard alleviating the negative effect of drought under semi-arid fragile ecologies. Thus, the study suggests that application of 5.0 kg SAP/ha under moisture stress and 2.5 kg SAP/ha under normal moisture condition could be beneficial in enhancing the productivity, profitability and economic efficiency of the Indian mustard. A marginal yield reduction due to moisture stress could be compensated with improved soil properties and saving of water with the use of SAP in Indian mustard.

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Drought tolerant and physiologically efficient genetic resources for rainfed castor (*Ricinus communis* L.)

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ABSTRACT

Six identified germplasm accessions (RG 111, RG 298, RG 1437, RG 1494, RG 1826, RG 2797) with good root volume, dry weight and low drought susceptibility index (low DSI) along with two checks (48-1, DCH-519) were screened to understand their performance under rainfed conditions during *kharif* 2014 and 2015. Secondary spikes were produced only during 2015 in RG 2797. Germplasm lines *viz.,* RG 298 and RG 1826 produced tertiary spikes during both years. RG 111, RG 1437 and RG 1494 recorded tertiary seed yield during 2015 only. Pooled mean seed yield data showed higher primary seed yield in RG 1494 and RG 2797. Secondary seed yield was higher in RG 1437 followed by RG 298 and RG 1494. Tertiary seed yield was more in RG 1826 and RG 298. Among the genotypes studied, RG 1494 (101 g/pl.) followed by RG 1826 (96 g/pl.) and RG 298 (91 g/pl.) with significantly higher total seed yield (pooled average of two years) showed better performance. RG 298 and RG 1826 recorded high harvest index (HI) of 36.1% and 42.6% respectively. RG 1494 recorded significantly higher stem and leaf weight at harvest but with low HI (31.3%) compared to RG 298 and RG 1826, which indicated the stay green trait of this genotype. Genotypes, RG 1494, RG 298 and RG 1826 with good root growth, high seed yield under rainfed conditions and with drought tolerance could be used in breeding programs.

Keywords: Castor, Drought tolerance, *Kharif*, Rainfed

Castor is grown in an area of 7.51 lakh hectares with a production of 11.96 lakh tonnes and an average productivity of 1593 kg/ha in India (DAC&FW, 2019). It is an indeterminate crop with forced annuality and considered as a drought tolerant species. The crop is grown mostly in *kharif* under rainfed conditions on sandy loam soils of South India in general and Andhra Pradesh and Telangana in particular and as irrigated crop in North India. The average productivity of castor in Andhra Pradesh or Telangana is not exceeding 450 kg/ha primarily due to low and chequered distribution of rainfall and prolonged mid or terminal dry spells, while, it goes up to 2000 kg/ha in Gujarat. The main reason is that, as the crop is grown in *kharif*, amount and distribution of rainfall vary in different years exposing the crop to intermittent drought stress during rainy season and terminal drought stress in the post rainy season.

Drought stress may coincide with critical phenological stages i.e. flowering/maturity of either one or more than one of the three spike orders *viz*., primaries, secondaries or tertiaries, more so with the later order spikes due to cessation of monsoon season by that time. Contribution from different spike orders differ with duration of the crop and occurrence of stress.

There is a dire need to develop genotypes with drought tolerance, to yield better even during severe drought years and achieve maximum yield during normal rainfall years. The basic advantage in taking yield as selection criteria is that it integrates all additive traits of many underlying mechanisms of drought tolerance (Kambiranda *et al.*, 2011). Root as a water mining tool plays a major role in drought tolerance by maintaining the plant water status. The root traits such as biomass, length, density and depth have been proposed as the main drought avoidance traits to contribute to seed yield under terminal drought environments (Turner *et al.*, 2001; Reddy and Venkateshwarlu, 1971). Root volume, root dry weight, leaf area index (LAI) and stem girth showed strong positive correlation with TDM (Lakshmamma and Lakshmi Prayaga, 2010). High heritability of HI coupled with the weak response to environmental variation (Hay, 1995) makes it suitable as a major trait for imparting yield stability under stress. Success in selecting for high yield under drought requires a simultaneous selection for both crop growth rates and HI.

In previous studies conducted at IIOR, germplasm with good root growth (in root structure) and drought tolerance (based on the field studies carried out during late *rabi* by imposing drought stress from 30-90 DAS) were selected. These selected germplasm were sown in *kharif* for two years (2014 and 2015) to evaluate their performance in terms of TDM, seed yield and HI under rainfed conditions without irrigation.

MATERIALS AND METHODS

During previous studies at IIOR, germplasm accessions were screened in specially constructed root structures (Lakshmamma *et al.*, 2010; 2013) and selected lines with better root traits were screened for drought tolerance by

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imposing drought stress form 30-90 DAS and best lines with good seed yield under stress and with low drought susceptibility index (DSI) were identified (Lakshmamma *et al*., 2017) (Table1). Among them, six germplasm accessions with good root growth in terms of root volume, root dry weight and known drought tolerance along with two checks i.e. 48-1 (a popular variety), DCH-519 (a released hybrid) were grown under rainfed conditions for two years during *kharif*, 2014 and 2015 with three replications in RBD. Five rows per each replication were sown with a spacing of 90 X 60 cm at Narkhoda research farm, ICAR-IIOR, Hyderabad. Seed rate followed was 2 kg/acre. Soil of this farm was red sandy loam with less water holding capacity. Recommended dose of fertilizers [60 kg N (30 kg basal and 30 kg at 30 DAS), 40 kg P_2O_5] was applied. One irrigation was given after sowing for better germination (both years) as plant stand is important to evaluate the performance of genotypes. Rainfall (mm), evaporation (mm) and sunshine hours during crop growth (2014 and 2015) are presented in Fig. 1 and 2.

In 2014, crop was sown on 14th July, 2014. An amount of 21.2 mm rainfall received from 1st to 14th July in 4 spells with 10.8 mm rain on 14th July. On 16th July, 17 mm rainfall was received. Later, on 24th July field was irrigated to get good germination. A total of 337.1 mm rainfall received during crop growth period. All genotypes matured by 126 days except RG 2797 which took 149 days for harvesting of secondary spikes. Highest rainfall was received during 35th week. In 2015, Crop was sown on 3rd July, 2015 with rainfall of 4 mm on 1st July, 12 mm on 2nd July. Then one irrigation was given on 6th July, 2015. A total of 255.8 mm rainfall was received during crop growth. All genotypes matured by 128 days. During this year, though total rainfall received was less during crop growth, no prolonged dry spells were there in the crop season except for two short dry spells from Sept. (18th Sept.-10th Oct. i.e. 23 days) till harvest (12th Oct.-8th Nov. i.e. 28 days) which had reduced the growth duration by one week. The data on crop growth, TDM at primary harvesting, TDM at final harvest, spike characters and seed yield of different spike orders were recorded. RBD analysis was done for individual years for all characters. As the data showed homogeneity of variance in both the years, pooled analysis over two years for seed yield of different spike orders (primary, secondary, tertiary), total seed yield and HI was carried out using SAS 9.3. (SAS Institute, Cary NC).

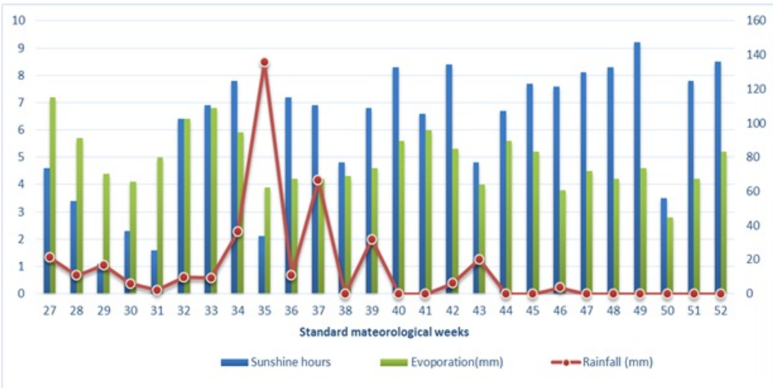

Fig. 1. Distribution of weather parameters during crop growth period (2014)

Table 1 Per plant root growth, dry matter and seed yield of the studied genotypes with drought stress during previous experiments at IIOR, Hyderabad

Genotypes	Root volume (cm3)	Root dry weight (g)	LAI	TDM (g)	Imposition of drought stress from 30-90DAS in field			
					Seed Yield (g/plant) in		% reduction in Seed yield in stress	DSI
					Control	Stress		
RG 111	404	68.4	2.76	503	141.4	109.3	22.7	0.65
RG 298	255	38.1	2.8	281	128	86	32	0.96
RG 1437	355	63.5	2.78	448	80.5	60.2	18.0	0.50
RG 1494	310	122.0	2.54	465	95.4	79.0	17.1	0.49
RG 1826	269	51.6	4.30	427	114.8	114.6	0.2	0.01
RG 2797	263	47.9	2.69	312	118.6	95.3	19.6	0.54
Checks								
48-1	355	57.8	2.54	452	109.8	70.9	35.4	1.07
DCH-519	-	-	-	-	158.6	102.9	35.1	1.06

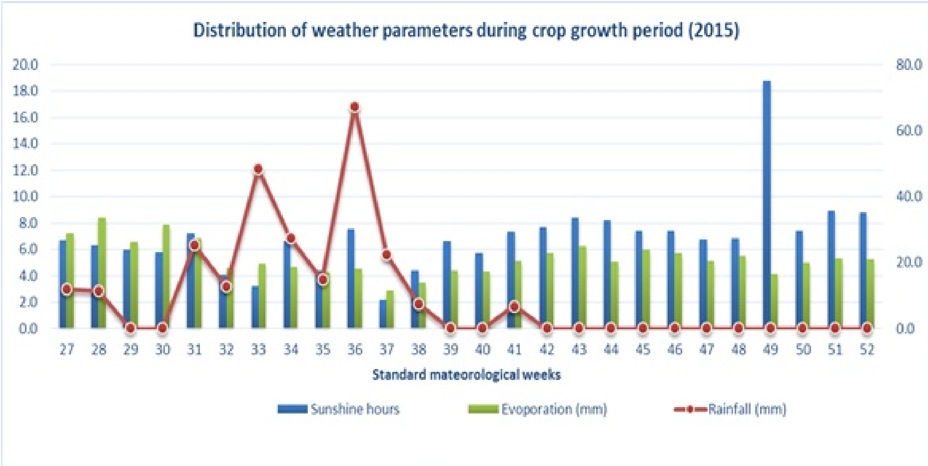

Fig. 2. Distribution of weather parameters during crop growth period (2015)

Table 2 Morphological traits at harvest and crop duration of studied germplasm during two years

Genotypes	Plant height (cm)			Node number on primary stem			Number of secondary branches			Number. of tertiary branches			Stem girth (mm)			Duration (days)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
48-1	138.6	111.9	125.3	14	15	15	3	2	3	4	4	4	28.80	26.3	27.6	119	111	115
RG 111	139.9	111.9	125.9	16	16	16	3	3	3	3	4	4	26.10	25.6	25.9	118	128	123
RG 298	77.7	61.4	69.6	12	12	12	3	3	3	4	4	4	26.40	23.7	25.1	126	113	120
RG 1437	190.4	83.9	137.2	17	11	14	2	2	2	3	3	3	28.09	24.8	26.4	119	117	118
RG 1494	101.1	111.3	106.2	11	13	12	2	2	2	3	3	3	24.14	26.6	25.4	109	115	112
RG 1826	71.4	73.3	72.4	10	11	11	2	2	2	3	3	3	24.27	22.3	23.3	122	112	117
RG 2797	223.2	138.7	181.0	20	18	19	2	2	2	0	0	0	33.23	32.1	32.7	149	124	137
DCH-519	138.9	103.7	121.3	15	14	15	2	2	2	3	3	3	25.03	24.3	24.7	119	106	113
Mean	135.2	99.5	117.4	14	14	14	3	3	3	3	3	3	27.01	25.7	26.4	123	116	119
SEm(±)	5.8	5.65		1	0.45		0	0.24		0	0.41		1.33	0.91				
CD(0.05)	17.5	16.7		3	1.3		1	0.7		1	1.2		4.02	2.7				
CV(%)	7.4	9.1		10	5.6		12	16.2		18	21		8.50	6.1				

RESULTS AND DISCUSSION

Morphological traits: Crop was lanky due to continuous rainfall and more cloudy days (5 days) from 29th August to 2nd September in 1st year (mean plant height of 135.2cm). Genotypes RG 298 and RG 1826 were dwarf with an average height of 70-72 cm and with low node number (11-12). Stem girth was more in RG 2797 and lowest in RG 1826 (Table 2). On an average, 3 secondary and 3 tertiary branches were produced. RG 2797, a long duration germplasm line, did not produce tertiary branches and the crop was forced harvested by 137 DAS.

Crop duration: Except RG 2797, all other genotypes matured in 112-128 days after sowing (DAS). RG 2797, a long duration genotype had initiated secondary spikes by 110-120 DAS and was force harvested by 137 DAS (Table 2). Though, all genotypes produced tertiary branches except RG2797, tertiary spike formation and seed yield was recorded only in RG 298 and RG 1826 during both the years. In 2014, there was rainfall till November and crop was harvested on 16th November, 2014 with an average duration of 123 days. But during 2015, average crop duration was reduced by one week (123 days in 2014 and 116 days in 2015) as there were two dry spells from September (18th Sept - 10th Oct, i.e., for 23 days) till harvest (12th Oct-8th Nov i.e. for 28 days).

TDM at primary harvesting: During 2014, the crop put forth more vegetative growth due to heavy rainfall of 144.1 mm in August and 123.6 mm in September, out of which 139 mm was received from 26th August to 1st September, 2014.

Except RG 298, all genotypes along with checks recorded higher stem dry weight and were on par (Table 3). Leaf dry weight was not significant and total spike weight at this stage was significantly higher in RG 1494 and TDM was on par in all genotypes except RG 298 with less TDM. In 2nd year (2015), stem weight was significantly higher and on par in RG 1494, RG 2797. RG 298, RG 1826 recorded less stem dry weight. Significantly higher leaf dry weight was recorded in RG 1494 followed by RG 2797. RG 111 and RG 298 recorded lowest spike weight and RG 1494 and RG 2797 recorded significantly higher TDM compared to all other genotypes studied (Table 3). Mean data of two years showed higher stem, leaf, spike dry weight and TDM in RG 1494.

Primary spike characters: On an average, primary spike matured by 93 DAS. RG 298 and RG 1826 matured earlier (84 DAS) than other genotypes and RG 2797 was late and took >100 days for maturity of primary spike (data not presented). RG 2797, RG 1494 recorded significantly higher effective spike length (ESL), capsule number and spike weight/plant (Table 4) during both years, but lower than DCH-519. Mean seed yield (pooled analysis) of primary was higher in RG 1494, RG 2797 and were on par with DCH-519. Mean primary seed size (test weight) was more in RG 1437, RG 1826, and RG 2797.

Table 3 Total dry matter (TDM) at primary harvesting during two years (g/plant)

Genotypes	Stem weight			Leaf weight			Total spike weight			TDM		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
48-1	205.9	108.1	157.0	28.6	34.5	31.6	150.3	71.9	111.1	384.8	214.5	299.7
RG 111	163.5	110.8	137.2	32.3	44.0	38.2	105.5	48.1	76.8	301.3	202.8	252.1
RG 298	86.5	66.4	76.5	17.3	25.5	21.4	99.3	47.6	73.5	203.0	139.5	171.3
RG 1437	161.4	92.9	127.2	43.0	41.3	42.2	111.4	107.7	109.6	315.8	241.9	278.9
RG 1494	151.0	160.5	155.8	28.6	76.8	52.7	191.8	142.4	167.1	371.4	379.6	375.5
RG 1826	221.0	79.3	150.2	18.4	20.6	19.5	119	104.7	111.9	358.5	204.5	281.5
RG 2797	164.9	160.7	162.8	33.1	54.3	43.7	108.1	113.7	110.9	306.1	328.6	317.4
DCH-519	167.8	92.4	130.1	29.0	38.4	33.7	204.6	138.7	171.7	401.4	269.4	335.4
Mean	165.3	108.9	137.1	28.8	41.9	35.4	136.3	96.9	116.6	330.3	247.6	289.0
SEm(±)	23.5	5.67		7.6	3.92					30.3	10.34	
CD(0.05)	71.4	16.7		NS	11.5					92.0	30.6	
CV(%)	24.7	8.6		45.4	15.7					15.9	7.2	

Table 4 Primary spike characters of genotypes studied during two years

Genotypes	Effective spike length (cm)/spike			Capsule No./spike			Total spike weight (g/plant)			Seed yield (g/plant)			Test weight (g)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
48-1	41.4	41.3	41.4	44	45	45	48.2	53.5	50.9	28.8	32.5	30.7	26.40	27.85	27.13
RG 111	30.3	28.3	29.3	31	31	31	32.9	37.6	35.3	16.2	20.3	18.3	23.31	27.52	25.42
RG 298	25.6	25.3	25.5	28	30	29	34.1	28.7	31.4	22.6	14.2	18.4	25.77	25.33	25.55
RG 1437	35.1	30.1	32.6	34	33	34	40.9	48.2	44.6	23.5	28.9	26.2	25.61	32.61	29.11
RG 1494	36.9	38.4	37.7	58	76	67	58.2	91.6	74.9	31.9	51.8	41.9	18.48	22.14	20.31
RG 1826	23.6	28.2	25.9	26	36	31	32.1	40.6	36.4	23.7	25.1	24.4	27.09	28.37	27.73
RG 2797	44.7	41.6	43.2	59	59	59	76.1	98.4	87.3	34.4	48.0	41.2	24.60	30.05	27.33
DCH-519	59.1	50.9	55.0	63	59	61	73.1	76.2	74.7	39.8	38.4	39.1	22.74	24.20	23.47
Mean	36.6	35.5	36.3	43	46	45	50.3	59.4	54.4	28.0	32.4	30.2	24.24	27.25	25.76
SEm(±)	23.34	1.98		4	3.06		6.2	3.48		3.2	2.14	1.89	1.08	0.69	
CD(0.05)	7.1	5.9		13	9.0		18.9	10.3		9.6	6.3	5.48	3.28	2.0	
CV(%)	11.1	9.9		18	11.5		21.4	10.4		19.6	11.9	15.32	7.72	4.5	

Table 5 Secondary spike characters of genotypes studied during two years

Genotypes	Spike number/plant			Effective spike length (cm)/spike			Capsule No./spike			Total spike weight (g/plant)			Seed yield (g/plant)			Test weight (g)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
48-1	4	2	3	27.8	20.7	24.3	29	19	24	113.0	49.5	81.3	66.5	31.4	49.0	26.77	27.0	26.89
RG 111	3	3	3	18.9	15.9	17.4	21	16	19	79.4	53.1	66.3	47.2	29.8	38.5	26.93	26.3	26.62
RG 298	4	3	4	22.1	17.5	19.8	23	20	22	84.1	50.8	67.5	51.8	31.5	41.7	23.77	22.4	23.09
RG 1437	3	3	3	22.2	17.2	19.7	27	19	23	76.8	76.8	76.8	45.2	48.5	46.9	24.33	31.7	28.02
RG 1494	3	3	3	24.4	21.7	23.1	34	20	27	87.9	73.9	80.9	44.6	37.1	40.9	19.13	25.8	22.47
RG 1826	3	2	3	23.2	17.2	20.2	19	17	18	52.1	44.5	48.3	35.0	30.6	32.8	25.40	27.1	26.25
RG 2797	2	2	2	0	29.3	14.7	0	43	36	0.0	112.9	56.5	0.0	44.4	22.2	0.00	21.6	21.6
DCH-519	3	2	3	25.6	33.2	29.4	26	30	28	84.5	74.3	79.4	45.5	40.5	43.0	22.18	23.7	22.94
Mean	3	2.5	3	23	21.6	22.5	26	23	25	72	67.0	69.6	42	36.7	39.3	21	25.7	24.74
SEm(±)	0	0.20		1.5	1.11		2	1.61		6.0	2.84		4.2	3.52	2.6	0.64	1.66	
CD(0.05)	NS	0.6		4.6	3.3		6	4.7		18.2	8.4		12.8	10.4	7.55	1.95	4.9	
CV(%)	21	13.4		11.2	9.8		13	12.9		14.4	8.0		17.4	17.9	16.21	5.28	11.6	

Secondary spike characters: Early maturity of secondaries was noticed in RG 298 and RG 1826 (101 DAS) (data not presented). During 1st year, though, there was secondary branch production, no spike formation was seen in RG 2797. Differences were not significant for ESL except RG 111 which produced smaller spikes. RG 1494 recorded higher capsule number and all others were on par. Spike weight was also on par among the studied genotypes except in RG 1826 which recorded lower spike weight while the check variety 48-1 recorded significantly higher spike weight. Seed yield of all other genotypes was on par except RG 1826 which was lower and check 48-1 recorded significantly higher seed weight than all other genotypes. Mean 100 seed weight of RG 1494 was significantly less and other genotypes were on par except RG 2797 in which no secondary seed yield was recorded (Table 5).

Data recorded during 2015 showed significantly higher ESL and capsule number in RG 2797, but spike matured late (124 DAS) compared to other genotypes. Spike weight was very high in RG 2797 (112.9 g/pl) followed by RG 1437, RG 1494 but seed yield was higher in RG 1437 which was on par with RG 2797, DCH-519. RG 1437 recorded significantly higher test weight and on par with RG 1826 and 48-1. Average pooled secondary seed yield was more in RG 1437 and was on par with RG 298, RG 1494 and checks.

Tertiary spike characters: Tertiary branches produced during two years in all genotypes except RG 2797. But spikes were produced only in RG 298 and RG 1826 during 1st year. During 2nd year, tertiary spikes were produced in RG 111, RG 298, RG 1437, RG 1494 and RG 1826. Among them, spike weight and seed yield was higher in RG 1494 followed by RG 1437, RG 111 (Table 6). Average seed yield of both years showed more tertiary seed yield in RG 1826 and RG 298.

Total seed yield: Mean seed yield from the study (pooled analysis) showed higher primary seed yield in RG 1494, and RG 2797 which were on par with DCH-519. Secondary seed yield was higher in RG 1437 and was on par with RG 298, RG 1494 and checks. Average seed yield of both years showed more tertiary seed yield in RG 1826 and RG 298.Total seed yield was significantly higher in RG 1494 (101g/pl.) followed by RG 1826 (96g/pl.) and RG 298 (91 g/pl.) which showed better performance of these genotypes in rainfed conditions (Table 7) though, other genotypes also showed drought tolerance under field conditions during previous years of experimentation by withholding irrigation from 30-90 DAS (Table 1).

TDM at final harvesting: In 2014, RG 2797, RG 1437 recorded significantly higher stem dry weight. Leaf dry weight was more in RG 2797 followed by RG1437 and TDM was more in RG 2797 which was on par with RG 1437, but seed yield was more in RG 298, RG 1826. In 2015, stem weight was significantly higher and on par in RG 1494, RG 2797. RG 2797 recorded significantly higher leaf weight at harvest and was on par with RG 1494. TDM at harvest was also more and on par in RG 1494 and RG 2797. Pooled mean TDM at harvest was significantly higher in RG2797 followed by RG 1494 (Table 8).

Harvest Index (HI): During 1st year, RG 298, RG 1826 recorded significantly higher HI (≥45%) followed by all other genotypes which were on par except RG 1437, RG 2797 (23%, 11% respectively). During 2nd year, RG 1826, RG 1437 showed 39% HI and all other genotypes recorded up to 30% HI and were on par except RG 2797 with 22% HI. Mean of two years showed significantly high HI of 42.6% in RG 1826 followed by RG 298 with 36.1%. All other genotypes were on par with ≤30% HI except RG 2797 which has recorded low HI of 16.6 % (Table 7).

For crops grown in dry environments, high potential growth rate and efficient use of available water are desirable traits. Tall and lanky plants with more stem dry weight at 90 DAS were seen in 1st year due to more rain during August and recorded more stem weight even at harvest. But, in 2nd year, due to less amount of rainfall, crop did not put forth excess TDM and due to short dry spells during October, the crop duration and TDM at harvest was reduced. In RG 2797, secondary branches produced during both years but spike formation and seed yield was recorded only during 2nd year. Though there was tertiary branch production in both the years, only RG 298, RG 1826 produced tertiary spikes in both years and RG 111, RG 1437, RG 1494 produced tertiary spikes and seed yield only in 2nd year. This might be due to heavy rain during August in 1st year that gave rise to more vegetative growth in terms of plant height and branch production and as the rainfall receded in October, the branches did not give rise to spikes or no seed formation was seen. In 2nd year, as vegetative growth was restricted, less spike production and seed yield recorded in many genotypes. Similar observations have been reported by Arunachalam and Kannan (2012) in groundnut where intermittent dryness during cropping period reduced the biomass production, development of matured pods and pod yield. Mean total seed yield was significantly higher in RG 1494 followed by RG 1826 and RG 298. RG 298, RG 1826 also recorded high HI of >36.0% due to early growth and tertiary seed yield followed by RG 1494 (31.3%). If fallen leaf weight (17% of TDM as reported by Lakshmamma *et al.,* 2017) is included in TDM, HI values will be less (±30.0%) than the reported values. Among the genotypes studied, RG 298 and RG 1826 were dwarf with early maturity (84 DAS for primary spike maturity) and also with tertiary seed yield. Early maturity helps in avoiding terminal drought due to SW monsoon cessation. RG 2797 recorded higher TDM during both the years with high stem weight at harvest and recorded low HI values compared to other genotypes. More leaf weight in RG 2797 could be due to its long duration. Perhaps, this genotype would have yielded more if the duration was extended.

High heritability of HI coupled with weak response to environmental variation (Hay, 1995) makes it suitable as a major trait for improving yield stability under stress. The greatest challenge to using HI directly in breeding programs is its often observed negative linkage with shoot biomass (Scully and Wallace, 1990) and maturity duration (Krishnamurthy *et al.*, 2010). The genotypes with high HI (RG 298, RG 1826) also recorded moderate TDM with short duration. Among the good yield and high HI genotypes, RG 1494 recorded significantly higher stem, leaf weight at harvest but with low HI (31.3%) compared to RG 298 and RG 1826, and this showed the stay green trait of this genotype and if partitioning efficiency is increased by improving the mobilization of stem reserves, it can be an excellent source for drought tolerance. It recorded <20% reduction in seed yield with low drought susceptibility index (DSI) of <0.5 (Table 1) with very good compensation of primary yield by producing more secondary and tertiary seed yield with high SCMR when screened for drought tolerance (Lakshmamma *et al.*, 2017). The genotypes with less DSI (<1) can be considered as drought tolerant. But low DSI values of a genotype could be due to less yield production under well-watered conditions rather than an indication of its ability to tolerate water stress. Therefore, the stress tolerant genotypes defined as per DSI, need not necessarily have high yield potential (Karaba *et al.*, 2011). But, the selected genotypes in this study also recorded good seed yield apart from low DSI values. Selection for best yields often ensures indirect selection for harvest index but HI alone may lead to selection of entries with a poor biomass potential (Wallace *et al.*, 1993). If that improved harvest index is a result of increased partitioning duration, this may not be the best adaptation strategy to produce higher under terminal drought. Hence, the selected genotypes should have moderate TDM, high seed yield and HI to be included in breeding programs. Several physiological, morphological and phenological traits may play a significant role in crop adaptation to drought stress during soil drying (Serraj *et al.*, 2004). Root traits play a major role in drought tolerance under terminal drought environments. In terms of root architecture, both prolific root systems extracting more of the water in upper soil layers and longer root systems extracting soil moisture from deeper soil layers are important for maintaining yield under terminal drought (Turner *et al.*, 2001). All the studied genotypes recorded good root growth characters *viz*., root volume, dry weight (Table 1) and also recorded low DSI values when screened in field by imposing drought stress from 30-90 DAS (Lakshmamma *et al.*, 2010; 2013; 2017).

Our experiments revealed that during the 1st year of trial, except RG 111, all other genotypes recorded higher TDM but seed yield and harvest index were more in RG 298, RG 1826 (> 110 g/plant and >45% respectively), and during the 2nd year, TDM at harvest was significantly higher and on par in RG 1494, RG 2797 but RG 1437, RG 1494 recorded more seed yield (> 110 g/plant) and RG 1437, RG 1826 recorded high HI (≥39%). Hence, RG 1494, RG 298 and RG 1826 with good root growth, high seed yield under rainfed conditions and with drought tolerance could be used in breeding programs. Further evaluation of identified lines in varied rainfed environments is required to exploit the drought potential of these lines for climate smart agriculture.

Table 6 Tertiary spike characters of genotypes studied during two years

Genotypes	Spike number/ plant			Effective spike length (cm)/spike			Capsule No./ spike			Total spike weight /plant			Seed yield (g/plant)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
48-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RG 111	0	3	2	0	10.8	5.4	0	10	5	0	60.9	30.5	0	30.5	15.3
RG 298	4	3	4	14.3	11.5	12.9	18	14	16	77.1	34.6	55.9	40.9	20.5	30.7
RG 1437	0	4	2	0	13.7	6.9	0	13	7	0	57.3	28.7	0	33.3	16.7
RG 1494	0	4	2	0	13.9	7.0	0	19	10	0	70.7	35.4	0	36.6	18.3
RG 1826	6	2	4	15.9	13.7	14.8	16	14	15	116.9	38.0	77.5	51.8	23.7	37.8
RG 2797	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DCH-519	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	1.3	2.0	1.8	15.1	8.0	5.9	4	9	7	24.3	32.7	28.5	11.6	18.1	14.9
SEm(±)		0.23						0.64			2.32			1.98	2.13
CD(0.05)		0.7						1.9			9.8			5.8	6.18
CV(%)		29.1						17.3			24.2			26.1	35.22

Table 7 Seed yield of different order spikes, total seed yield (g/plant), TDM at harvest and HI (%) of two years

Genotypes	Primary seed yield (g/plant)	Secondary seed yield (g/plant)	Tertiary seed yield (g/plant)	Total seed yield (g/plant)	TDM at harvest (g/plant)	HI (%)		
						2014	2015	Mean
48-1	30.7	49.0	0	79.8	264.4	31.9	28.2	30.1
RG 111	18.3	38.5	15.3	72.0	236.1	32.3	29.3	30.8
RG 298	18.4	41.7	30.7	91.0	250.5	45.1	27.1	36.1
RG 1437	26.2	46.9	16.7	89.6	291.6	22.9	38.7	30.8
RG 1494	41.9	40.9	18.3	100.9	326.2	32.7	30.0	31.3
RG 1826	24.4	32.8	37.8	95.5	222.9	46.1	39.0	42.6
RG 2797	41.2	22.2	0	63.1	364.5	10.9	22.2	16.6
DCH-519	39.1	43.0	0	83.2	272.0	32.6	28.5	30.6
Mean	30.2	39.4	14.9	84.4	278.5	31.9	30.4	31.12
SEm(±)	1.89	2.6	2.13	3.37	8.97	1.39	1.42	0.9
CD(0.05)	5.48	7.55	6.18	9.76	25.97	4.23	4.2	2.62
CV(%)	15.32	16.21	35.22	9.78	7.89	7.58	8.7	7.12

Table 8 Total dry matter (TDM) at harvest (g/plant) during two years

Genotypes	Stem weight at harvest (g/plant)			Leaf weight at harvest (g/plant)			TDM at harvest (g/plant)		
	2014	2015	Mean	2014	2015	Mean	2014	2015	Mean
48-1	195.1	107.4	151.3	8.5	6.9	7.7	302.4	226.3	264.4
RG 111	118.7	99.7	109.2	8.5	12.1	10.3	195.3	276.9	236.1
RG 298	129.0	87.8	108.4	8.6	17.6	13.1	256.6	244.3	250.5
RG 1437	203.8	86.9	145.4	15.8	8.4	12.1	297.5	285.8	291.6
RG 1494	136.9	131.9	134.4	11.5	27.8	19.7	233.3	419.1	326.2
RG 1826	121.1	69.0	95.1	5.5	6.0	5.8	241.9	203.8	222.9
RG 2797	244.5	156.8	200.7	27.0	31.6	26.3	312.1	417.0	364.5
DCH-519	155.8	97.7	126.8	17.8	17.4	17.6	268.6	275.5	272.0
Mean	163.1	104.7	133.9	12.9	16.6	14.4	263.5	293.6	278.5
SEm(±)	10.79	8.35		1.45	1.28		12.23	12.67	8.97
CD(0.05)	32.72	24.6		4.39	3.8		37.1	37.3	25.97
CV(%)	11.5	13.2		19.45	13.4		8.04	7.8	7.89

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Foliar application of plant growth regulators on growth, yield and economics of linseed (*Linum usitatissimum* L.)

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ABSTRACT

Growth regulators are widely used in various crops to boost the growth and yield attributing characters and ultimately the yield. The present experiment was carried out during *rabi* season of 2018-2019 and 2019-2020 at IGKV, Raipur, Chhattisgarh in randomized block design with eight treatments and three replications with an objective of finding out the effect of plant growth regulators on growth, yield attributes and yield of linseed variety RLC-92. The treatments consisted of four plant growth regulators (PGRs) with varied concentrations. Results revealed that the application of plant growth regulators significantly improved the growth, yield attributes and yield of linseed as compared to spray with water. Among the eight treatments, application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded highest growth and yield attributes and seed yield of linseed. The auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded 26.9% higher seed yield than control (T8) and 15.5 and 11.4% higher seed yield than sole application of auxin @ 1.0 ppm (T1) and GA_3 @ 200 ppm (T3) treatments, respectively. However, application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) and GA_3 @ 400 ppm (T4) recorded the highest oil content during 2018-19 and 2019-2020, respectively. The maximum oil yield was recorded under the application of GA_3 @ 400 ppm (T4) treatment. The application of auxin @ 2.0 ppm (T2) resulted in the highest B:C ratio and was found to be most remunerative for getting good returns.

Keywords: Growth and yield attributes, Linseed, Oil content and Plant growth regulators

Linseed (*Linum usitatissimum* L.) is one of the ancient crops (dating back to more than 5000 BC) cultivated for its seed and fibre. It is an annual, herbaceous, dicotyledonous plant cultivated in *rabi* season. In India, linseed is the most important *rabi* oilseed crop. In modern world, people are attracted towards linseed cultivation due to its nutritive and multifarious quality. Seeds contain 35-45% oil (rich in unsaturated fatty acids), 20-25% protein and vitamins. Linseed oil is well known for its rich source of ω-3 fatty acid (α-linolenic acid) that are abundant in fish oil, lowers level of cholesterol in the blood thereby, reducing heart disease and also very effective against rheumatoid arthritis. Linseed has also an important position in Indian economy due to its wide industrial utility. But the cultivated area of linseed is declining yearly, due to competition of other economic winter crops, a gap between production and consumption has emerged. Therefore, linseed productivity per unit area should be increased which could be accomplished by using high yielding cultivars and improving nutrition (Saini *et al.,* 2017). Recently plant growth regulators are considered as new generation agro-chemicals which are known to modify plant architecture, enhance source-sink relationship and stimulate the translocation of photo-assimilates thereby helping in better retention of flowers, pod and seed development, enhance seed yield and quality of the crop. However, the studies on influence of growth regulators on yield and quality of linseed are limited.

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Auxin and gibberellic acids are the most commonly used plant growth regulators and recently salicylic acid is new emerging growth regulator. In oilseed crops, PGRs shows significant effects on growth and yield. Plant growth regulators can be successfully working to enhance the yield in the economically important oilseed crops (Rastogi *et al.*, 2013). The auxin NAA (1-Naphthaleneacetic acid) showed a positive result to increase the seed yield of sesame by changing the plant architecture and biomass production (Siddik *et al.*, 2015). Application of GA_3 had positive impact on growth and yield of mustard because the yield loss had been reduced to 17.7% (Akter *et al.*, 2007). Salicylic acid is a secondary metabolite which acts as analogues to the substance that regulates growth. Application of fungicide belonging to the triazole groups showed a significant increase in the growth and yield parameters of winter rapeseed (Ijaz *et al.*, 2019).

MATERIALS AND METHODS

The experiment was conducted at Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. Geographically, Raipur lies at 21°15' N latitude and 81°37' E longitude at an altitude of 296 meters above mean sea level (MSL) and located in the plain zone of Chhattisgarh under agro-climatic zone VII (eastern plateau and hills) which has a sub-tropical climate, characterized by sub humid type i.e., hot summer and cold winter. The normal annual rainfall of this region is 1326 mm. The soil of experimental field was clayey

(Vertisol) in nature with low, medium and high in available nitrogen, phosphorus and potassium, respectively. Experiment was laid out in randomized block design with eight treatments and three replications. The treatments involved four different plant growth regulators of varied concentration and combination applied at vegetative (30 DAS) and reproductive (70 DAS) stages of linseed. The treatments were auxin @1.0 ppm (T1), auxin @ 2.0 ppm (T2), GA_3 @ 200 ppm (T3), GA_3 @ 400 ppm (T4), salicylic acid @ 75 ppm (T5), tebuconazole @ 0.1% (T6), auxin @ 1 ppm + GA_3 @ 200 ppm (T7) and control (T8). The linseed variety RLC-92 was sown as a test crop on 18th and 22nd November of 2018 and 2019, respectively with a seed rate of 30 kg/ha and 30 cm row to row distance. The recommended dose of nutrients were 40:20:20 kg/ha N: P_2O_5: K_20 applied through urea, SSP and MOP. In order to assess the response of PGRs, periodic observations on crop growth parameters *viz.,* plant population, plant height, no of branches/plant, leaf area/plant, shoot dry weight/plant, root length/plant and root dry weight/plant and yield attributes *viz.,* number of capsules/plant, number of seeds/capsule, 1000-seed weight as well as oil content, seed and stover yield of linseed crop were taken.

RESULTS AND DISCUSSION

Growth attributing characters

Plant height: The pooled analysis of two year data indicated that plant height differed considerably due to foliar application of PGRs (Table 1). Significantly higher plant height (87.33 cm) was recorded in all the treatments involving GA_3 (auxin @ 1 ppm + GA_3@ 200 ppm, GA_3 @ 400 ppm and GA_3@ 200ppm treatment which were at par whereas control (T8) treatment recorded the minimum height. Increase in plant height might be due to GA_3 which stimulate cell elongation and cell division by inducing mitotic divisions. Application of PGRs alone at higher concentrations also increased the plant height but combination of auxin and gibberellic acid even when included at lower concentrations showed synergistic effect on the plant growth. Saied *et al.* (2018) also observed that mixture of more than one growth hormone increased plant height (8.3%).

Primary branches: Effect of plant growth regulators on primary branches/plant (Table 1) revealed that the foliar application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded highest number of primary branches/plant (4.66), which was at par with the GA_3 @ 400 ppm (T4) treatment. While less number of primary branches was recorded in control (T8) treatment. Similar finding was reported by Sarkar *et al.* (2002).

Crop dry matter: The highest crop dry matter (5.73 g/plant) was recorded under foliar application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7), which was at par with GA_3 @ 400 ppm (T4) while least dry matter was noted in control (T8) treatment (Table 1). Increase in dry matter accumulation under foliar application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) might be due to GA_3 which enhanced the source-sink relationship in the plant and induced photo-assimilate translocation in the plant. Auxin delays senescence primarily due to increased chlorophyll content in the leaf resulting in more photosynthesis, enhancing the accumulation of dry matter in the plant. The similar outcome was corroborated by Khan *et al.* (2003). Same study done by Saied *et al.* (2018) on mustard (cv. BINAsarisa-6) and revealed that application of GABA (gamma amino butyric acid) increased total dry mass (22.2%) over the control.

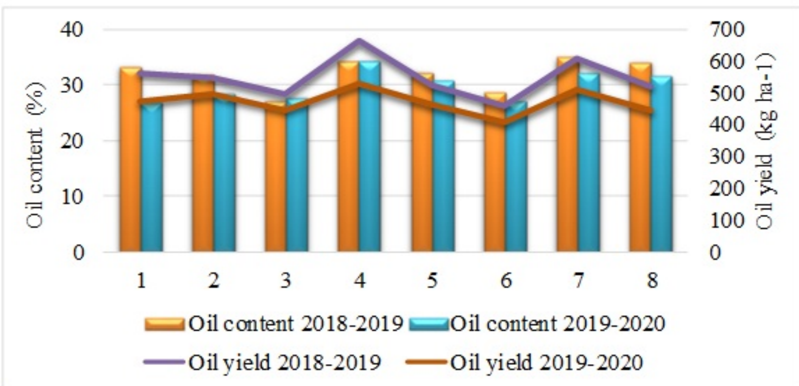

Fig. 1. Oil content (%) and oil yield (kg/ha) of linseed as influenced by different treatments

Table 1 Growth attributes, net monetary return and B:C ratio of linseed as influenced by different treatments (pooled data of two years)

Treatment	Plant height (cm)	Primary branches/plant	Secondary branches/plant	Crop dry matter/plant (g) at harvest	NMR ($\times 10^3$ ₹/ha)		B:C ratio	
					2018-2019	2019-2020	2018-2019	2019-2020
T1 Auxin @ 1.0 ppm	84.3	4.15	19	5.07	56.95	50.91	2.97	2.56
T2 Auxin @ 2.0 ppm	84.8	4.22	19	5.24	58.57	51.26	3.05	2.58
T3 GA_3 @ 200 ppm	85.3	4.34	19	5.32	52.92	48.33	2.1	1.87
T4 GA_3 @ 400 ppm	87.2	4.70	20	5.63	56.15	47.20	1.8	1.48
T5 Salicylic acid @75 ppm	82.6	4.13	18	4.97	54.05	50.70	2.81	2.54
T6 Tebuconazole @0.1%	81.5	4.09	18	4.89	52.86	49.07	2.7	2.42
T7 Auxin @1 ppm + GA_3 @ 200 ppm	87.3	4.66	20	5.73	56.94	56.40	2.26	2.18
T8 Control Water spray	80.7	4.05	17	4.28	49.84	44.93	2.6	2.26
SEm ±	1.09	0.08	0.4	0.11	-	-	-	-
CD (P=0.05)	3.15	0.22	1.09	0.32	-	-	-	-

NMR= Net monetary return

Table 2 Yield attributes of linseed as influenced by different treatments (pooled data of two years)

Treatment	Dosage	Capsule/ plant	Seeds/ capsule	Seed yield (kg/ha)	Stover yield (kg/ha)	Test weight (g)	HI (%)
T1 Auxin	1.0 ppm	55	8.23	1610	3478	7.01	31.6
T2 Auxin	2.0 ppm	56	8.26	1631	3531	7.03	31.6
T3 GA3	200 ppm	56	8.32	1669	3598	7.07	31.7
T4 GA3	400 ppm	60	8.76	1767	3839	7.14	31.5
T5 Salicylic acid	75 ppm	55	8.13	1576	3424	6.93	31.5
T6 Tebuconazole	0.1%	53	8.02	1553	3363	6.85	31.6
T7 Auxin + GA3	1 ppm + 200 ppm	61	8.85	1860	4010	7.15	31.7
T8 Control	Water spray	48	7.57	1465	3193	6.83	31.4
SEm±		1	0.15	44	102	NS	NS
CD (P=0.05)		3	0.43	128	296	NS	NS

Yield and yield attributing characters

Secondary branches/plant: The pooled data on secondary branches (Table 1) showed that foliar application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded the highest no. of secondary branches/plant, which was at par with the application of GA_3 @ 400 ppm (T4) and GA_3 @ 200 ppm (T3) treatments. Sarkar *et al.* (2002) and Ramesh and Ramprasad (2013) reported similar findings.

Number of capsules/plant: The data on capsules/plant as influenced by PGRs (Table 2) indicated that all the PGRs significantly enhanced this trait as compared to control. Among the PGR treatments, auxin @ 1 ppm + GA_3 @ 200 ppm (T7) produced significantly highest capsule/plant (60.83) and was at par with GA_3 @ 400 ppm (T4) treatment. While in control (T8), least number of capsules was noted. Higher capsules/plant may be caused by increased secondary branches/plant by PGRs.

Number of seeds/capsule: Pooled data showed that all PGRs produced considerably higher number of seeds/capsule over control (T8) treatment (Table 2). Among various PGRs, auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded the highest no. of seeds/capsule (8.85) which was statistically at par with the GA_3 @ 400 ppm (T4) treatment and least number of seeds/capsule was recorded in control (T8) treatment. The combined application of auxin and GA_3 increased seeds/capsule because both PGRs enhanced source sink relationship.

Test weight and Harvest index (HI): No significant difference was observed with respect to test weight and harvest index of crop as influenced by application of different PGRs (Table 2). The highest and lowest test weight and harvest index was observed under the application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) and control (T8) treatment, respectively.

Oil content and oil yield :The data on oil content (%) and oil yield (kg/ha) showed that the application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) and GA_3 @ 400 ppm (T4) recorded the highest oil content (%) during 2018-19 and 2019-2020, respectively (Fig. 1). The application of GA_3 @ 400 ppm (T4) recorded the highest oil yield (kg/ha) followed by auxin @ 1 ppm + GA_3 @ 200 ppm (T7) treatment, during both the years. However the control (T8) treatment produced the lowest oil content and oil yield during both the years. Similar findings were reported by Solanke *et al.* (2018) and Ijaz *et al.* (2019).

Seed and stover yields: Seed and stover yields differed significantly when PGRs were applied . Pooled data indicated that among application of various PGRs, foliar application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded highest seed (1859.69 kg/ha) and stover (4009.84 kg/ha) yield, which was at par with GA_3 @ 400 ppm (T4) treatment. The control (T8) treatment recorded the lowest seed and stover yield. Application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) and GA_3 @ 400 ppm (T4) treatments recorded 25.6 and 20.2% higher seed yield than control (T8) treatment. The findings corroborated the reports by Sarker *et al.* (2002) and Kalyankar *et al.* (2007).

Economics: The highest net monetary returns (NMR) was recorded when foliar application of auxin @ 2.0 ppm (T2) and auxin @ 1 ppm + GA_3 @ 200 ppm (T7) were taken up during 2018-19 and 2019-2020, respectively. The application of auxin @ 2.0 ppm (T2) and auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded 17.5% (₹8723) and 25.5% (₹11473) higher net return, respectively than control (T8) treatment, which recorded the lowest NMR. The highest B:C ratio was recorded with the application of auxin @ 2.0 ppm (T2) followed by auxin @ 1.0 ppm (T1), during both the years.
From this study, it is concluded that the application of plant growth regulators had promising effect on growth and yield attributing characters and yield of linseed. The application of auxin @ 1 ppm + GA_3 @ 200 ppm (T7) recorded higher growth and yield attributes, but the application of auxin @ 2 ppm (T2) was most remunerative for getting good returns.

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Spatio-temporal performance of major edible oilseeds in Andhra Pradesh

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ABSTRACT

The current analysis examines the spatio-temporal performance of major edible oilseed crops *viz.,* groundnut, sesame and sunflower in Andhra Pradesh using time series data from 1970-71 to 2018-19. The total period was divided into three sub-periods *viz.,* Period I (1970-71 to 1985-86), Period II (1986-87 to 1999-2000) and Period III (2000-01 to 2018-19). Agro-climatic zones, in which these crops were consistently grown, were selected and their performance was evaluated using compound annual growth rates and decomposition analysis. Growth of area and production of groundnut and sunflower exhibited frequent declined growth rates, particularly in Period III, signifying the underperformance of these crops. The performance of sesame was better *vis-a-vis* groundnut and sunflower. There was no significant decline in growth rates of yields, which could be partly attributed to efforts from the research community and government to increase the yield through various oilseeds development programmes. Although efforts were made towards increasing area, production and yield, the positive growth momentum of area and production could not be sustained. Shift of major oilseeds' cultivation towards competing crops, low profitability, unremunerative market prices, low farm level technical efficiency, increased costs of inputs, higher biotic and abiotic stresses etc., could be some of the reasons for this scenario. Location specific research with focus on hybrids and HYVs with high oil content, addressing the constraints to technology adoption, favourable price policies, enhancing capacity utilization of processing units, creating more efficient supply and value chains may help in meeting the oil and oilseed requirements in the country.

Keywords: Andhra Pradesh, Compound annual growth rates, Decomposition analysis, Oilseeds

In the segment of field crops, oilseeds are the second most significant determinant of the agricultural economy, trailing next only to cereals. Self-sufficiency in oilseeds realized during the "Yellow Revolution" in the early 1990's could not be maintained for a long time, and as on date the country is one of the world's largest importers, with an exchequer of ₹ 82,098 crores during 2020-21.The annual oilseed crops being the country's primary source of vegetable oil, are mostly confined to rainfed conditions. At national level, they were cultivated across 27.14 million hectares producing 33.22 million tonnes with an average yield of 1224 kg/ha in 2019-20 (DES, 2020). Andhra Pradesh is one of the major states in the country in area and production of important edible oilseed crops in India. Groundnut, sesame and sunflower; and non-edible oilseeds crop *viz.,* castor are the major oilseeds cultivated in the state. The area, production and yield of oilseeds in Andhra Pradesh was 0.76 million ha, 0.90 million tonnes and 1194 kg/ha, respectively in 2019-20 (DES, 2020).

Among the nine annual oilseed crops grown in the state, groundnut and sesame occupy the principal share in terms of area and production. These crops are important at global, national and state level, due to their significant contribution to the edible oils. Sunflower, which was introduced in the later half of 1970's has performed very well in initial years after its introduction with high growth rates. However, due to several factors, the trends of area and production of the crop declined. Thus, this study aims to examine the spatio-temporal performance of major edible oilseeds *viz.,* groundnut, sesame and sunflower in Andhra Pradesh.

In the state, during the quinquennium from 2014-15 to 2018-19, the contribution of area under groundnut, sesame and sunflower to the total cultivated area under oilseeds was recorded as 86.11, 6.02 and 2.49 per cent, respectively, while with regard to production, the share of the aforesaid crops to the total oilseeds production of the state was 91.21, 2.21 and 2.79 per cent, respectively (DES, 2020).

Groundnut (*Arachis hypogaea* L.) was grown in an area of 4.83 million ha with the production of 9.95 million tonnes and a productivity of 2063 kg/ha at national level during 2019-20 (DES, 2020). Annually, the crop accounts for around 25 per cent of the total oilseed production in India. It is largely cultivated in Gujarat, Andhra Pradesh, Rajasthan, Tamil Nadu, Karnataka, Telangana, Maharashtra, Odisha, West Bengal, Madhya Pradesh, Uttar Pradesh and also cultivated in small tracts in states like Chhattisgarh, Haryana, Jharkhand, Manipur and Bihar. In Andhra Pradesh, during 2019-20, the area, production and yield of groundnut was recorded as 0.66 million ha, 0.85 million tonnes and 1284 kg/ha respectively.

Sesame (*Sesamum indicum* L.) was cultivated in an area of 1.62 million ha with the production of 0.66 million tonnes

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and yield of 405 kg/ha at national level during 2019-20 (DES, 2020). India is a net exporter of sesame seeds. It is grown mainly in Madhya Pradesh, Rajasthan, West Bengal, Uttar Pradesh, Maharashtra, Gujarat, Karnataka, Odisha, Andhra Pradesh and Tamil Nadu. In Andhra Pradesh, the area, production and yield of sesame during 2019-20 was documented as 0.04 million ha, 0.01 million tonnes and 343 kg/ha respectively.

Sunflower (*Helianthus annuus* L.) was cultivated in an area of 0.02 million ha with a production of 0.02 million tonnes and productivity of 931 kg/ha at national level during 2019-20 (DES, 2020). It was regarded as one of the most profitable crops in initial years of its introduction. Important states for sunflower cultivation in India are Karnataka, Maharashtra, Haryana, Odisha, Bihar, Gujarat, Punjab, West Bengal, Andhra Pradesh and Tamil Nadu. In Andhra Pradesh, the area, production and yield of sunflower during 2019-20 was documented as 0.01 million ha, 0.01 million tonnes and 942 kg/ha respectively.

The Indian Council of Agricultural Research (ICAR) has divided the country into 131 agro-climatic zones based on climate, soils, and existing cropping patterns of each state as a unit. The agriculture planning for each zone is supported with the research and recommendations of a Regional Agricultural Research Station (RARS) set up within the particular zone. Andhra Pradesh state has been divided into six agro-climatic zones viz., North coastal, Godavari, Krishna, Southern, Scarce rainfall, and High Altitude & Tribal area zones.

As the study is confined to assess the spatio-temporal performance of oilseeds in Andhra Pradesh, only three zones viz., North coastal zone, Southern zone and scarce rainfall zone were considered for the study, where the predominance of oilseeds cultivation is seen. For groundnut and sesame crops, the North coastal, Southern and Scarce rainfall zones were selected, while for sunflower crop, Southern zone and Scarce rainfall zone were selected, where the crops were grown consistently.

Several studies were conducted to assess the performance of oilseeds. Some relevant reviews of them were quoted. Review of literature highlighted that the studies regarding performance of oilseeds in Andhra Pradesh with reference to agro-climatic zones are scanty. Upendra and Venkateshwarlu (1996) investigated the growth in area, production and productivity of groundnut in Andhra Pradesh and all-India over the period from 1949-50 to 1990-91. The results of their linear growth rate analysis indicated that the annual growth rate of area, production and productivity were higher during the post-green revolution period for all-India, as well as for the state as compared to the pre-green revolution period. Paul (2013) measured the change and instability in area, production and yield of groundnut crop in Andhra Pradesh based on secondary data during 1995-96 to 2010-11. The result of the study reported that, the area, production and productivity declined during the study period. The compound growth rates of area, production and productivity of groundnut over the study period showed negative trend. The decomposition analysis revealed that, the change in total production of groundnut was completely due to change in the area under the crop while the yield and interaction effects were negligible. Rambabu *et al.* (2014) examined the performance of groundnut in Andhra Pradesh over a period of 1995-96 to 2010-2011 by fitting semi log trend equation. It was noticed that, the compound growth rates of area, production and productivity of groundnut over the study period was negative and non-significant. However, studies on trend analysis of oilseed cultivation in Andhra Pradesh with respect to agro-climatic regions are lacking. Therefore the present study was carried out with the specific objectives of analysing the growth rates of area, production and yield of major edible oilseeds and to examine the effect of area, yield and their interaction on change in production of these oilseeds in Andhra Pradesh with special reference to agro-climatic zones.

MATERIALS AND METHODS

The present study used the time series data on area, production and productivity of groundnut, sesame and sunflower crops, collected from Directorate of Economics and Statistics, Government of Andhra Pradesh. The total period from 1970-71 to 2018-19 was divided into three sub-periods *viz*., Period I (from 1970-71 to 1985-86), Period II (1986-87 to 1999-2000) and Period III (2000-01 to 2018-19). Significance of the time periods selected for the study are provided in Table 1 and the districts that fall under the selected agro-climatic zones in selected crops under the study are listed in Table 2.

Estimation of Compound Annual Growth Rates (CAGR)

In order to estimate the CAGR, the exponential time trend equation of the form $Y=a\,b^t$ was used
It becomes linear when converted to log form, i.e.,
$Ln\ Y = Ln\ a + t\ Ln\ b$ where,
Y: Variable whose growth rate is being computed
t: Time trend (1, 2…n)
a and b are regression coefficients to be estimated.

This form implies a constant growth rate over time. There will be a constant deceleration if $b < 0$. A value of $b=0$ indicates absence of any trend and a positive value for b indicates a constantly accelerating growth. In the context of CAGR estimation through the exponential time trend equation, Dandekar (1980) observed that when the exponential form is used, taking the parameter B (=Ln b) as the annual growth rate was not correct. Instead, the formula for finding growth rate (e^B-1) is derived using the compounding formula. Thus, the CAGR (per cent) is given by (e^B-1) x 100

In this study, Y represents the area or production or productivity of the crop. The 't' test was used to test the significance of 'b'.

Estimating the effect of area, yield and their interaction on the change in production of the crops under the study using decomposition model

A systematic scheme for decomposing the growth trend was first presented by Minhas and Vaidyanathan (1965). Many researchers (Vidya, 1977; Rehman and Salam, 2011; Sharma *et al,* 2017) have modified this model as the form given under and that was used in the present study.

Table 1 Time periods selected for the study

Time period	Significance	Selected years
Period I	Pre–Technology Mission on Oilseeds (TMO) period	1970-71 to 1985-86
Period II	TMO implementation to liberalization	1986-87 to 1999-2000
Period III	Post liberalization period	2000-01 to 2018-19

Table 2 Matrix showing various districts under selected agro-climatic zones and selected crops

Crops selected	Agro-climatic zones		
	North Coastal Zone	Southern Zone	Scarce Rainfall Zone
Groundnut	Srikakulam, Vizianagaram and Vishakhapatnam	YSR Kadapa, Chittoor and SPSR Nellore	Kurnool and Ananthapuramu
Sesame	Srikakulam, Vizianagaram and Vishakhapatnam	YSR Kadapa, Chittoor and SPSR Nellore	Kurnool and Ananthapuramu
Sunflower	-	YSR Kadapa, Chittoor and SPSR Nellore	Kurnool and Ananthapuramu

The change in production between two periods is decomposed into area effect, yield effect and their interaction effect as follows:

$$P=P_n-P_o = \underbrace{A_o*\Delta Y}_{\text{Yield effect}} + \underbrace{Y_o*\Delta A}_{\text{Area effect}} + \underbrace{\Delta A*\Delta Y}_{\text{Interaction effect}}$$

Where,
$P_o= A_o*Y_o$
$P_n= Y_o*Y_n$
$P= P_n - P_o$ (Change in production)
A_o=Area in the base year
A_n=Area in the current year
Y_o=Yield in the base year
Y_n=Yield in the current year
ΔA=Change in Area (A_n-A_o)
ΔY=Change in Yield (Y_n-Y_o)

The change in production when more pronounced through yield effect indicates that the technologies have contributed to the change in production.

In the present study, the estimation of the effect of area, yield and their interaction on the change in production of the crops under the study was worked for the three respective periods as indicated earlier. The triennium averages of area, production and yield of the respective base and current years under the respective crops were considered with a view to minimize and/or eliminate the biasness, since the cultivation of the crops under the study are chiefly confined to rainfed situations in the state.

RESULTS AND DISCUSSION

Growth rates of area, production and yield

Groundnut: Compound Annual Growth Rates (CAGR) of groundnut in North coastal, Southern and Scarce rainfall zones were calculated (Table 3).

The analysis indicated that in North coastal zone, during Period I, the growth rate of area was negative and statistically non-significant, while in Period II and Period III, the growth rates were negative and statistically significant (at p:0.01). The growth rates of production were negative and statistically non-significant in Period I and Period II, while in Period III, the growth rate was negative and statistically significant (at p:0.01). The growth rate of yield was statistically non-significant in Periods I and II but it was positive and statistically significant (at p:0.01) in Period III. The growth rate of area was slowest in Period III (-12.68%), rather than in Period II (-1.68%) and Period I (-0.29%). The growth rate of production was slowest in Period III (-9.45%), compared to Period II (-1.19%) and Period I (-1.12%).The growth rate of yield was highest in Period III (3.70%), followed by Period II (0.49%) and negative in Period I (-0.83%). Decline in area in Period II and Period III could be attributed to un-remunerative prices; diversion of crops to maize, blackgram and greengram in the zone, while decline in production in Period III could be attributed to low farm level technical efficiency, increased input costs, lower profitability in the zone. The unfavourable terms of trade in Period III due to liberalization seem to have significantly affected the crop (Rama Rao, 2008), while observed faster growth in yield in Period III could be due to positive impetus of technology emanated from oilseeds development programmes like Integrated Scheme of Oilseeds, Pulses, Oilpalm and Maize (ISOPOM) and National Mission on Oilseeds and Oil Palm (NMOOP).

In Southern zone, the growth rate of area, production and productivity did not differ significantly in Periods I and II whereas in Period III. The growth rate of area was negative and statistically significant (at p:0.01). The growth rate area was positive but statistically non-significant in Period I, followed by a negative but statistically non-significant growth rate in Period II. Growth rates of production were negative, but statistically non-significant in Period I, Period II and Period III. Growth rates of yield were negative and statistically non-significant in Period I and Period II. In Period III, growth rate of yield was positive and statistically significant at 5 per cent level. In this zone, the growth rate of area was highest with 0.24 per cent during Period I, followed by moderate negative growth rate in Period II (-0.76 %) and the slowest growth rate in Period III (-4.31%). The growth rate of production was slowest in Period II (-2.15%) rather than in Period III (-1.53%) and Period I (-0.86%). In the growth rates of yield, Period III witnessed the highest growth rate with 2.90 per cent, followed by a moderate negative growth rate in Period I (-1.10%) and slowest growth rate in Period II (-1.41%). In this zone, groundnut is grown both under rainfed and irrigated conditions. In irrigated regions, there was shift towards competing crops like maize, cotton and chillies (Rama Rao, 2008). Low productivity levels of groundnut coupled with high risk under rainfed conditions have compelled farmers to shift towards competing crops, which perhaps led to the decline of the growth rate of area in Period III. However, accelerated growth rate in yield was observed in the Period III, which could be attributed to many factors like increased use of inputs, particularly plant protection chemicals to cope up with biotic stresses, soil and moisture conservation technologies and use of micro-irrigation etc.

In Scarce rainfall zone, growth rates of area were positive and statistically significant at 1 % and 10 % level in Period I and Period II, respectively. In Period III, the growth rate of area was negative and statistically significant at 1 per cent level. In Period I, the growth rate of production was positive and statistically significant at p=0.05, while in Period II, the growth rate of production was negative but statistically non-significant. In Period III, the growth rate was negative and statistically significant at 10 per cent level. In Period I alone, the growth rate of yield was positive but statistically non-significant, while in the other two periods, the growth rates were negative but statistically non-significant. In this zone, highest growth rate of area was recorded in Period I (2.11%), followed by Period II (1.82%) and negative growth in Period III (-3.21%). The growth rate of production was highest in Period I (3.02 %), followed by a moderate negative growth rate in Period II (-0.52%) and slowest growth rate in Period III (-4.02%). In the growth rates of yield, highest growth rate was observed in Period I (0.89%), followed by moderate negative growth rate in Period III (-0.84%) and slowest growth rate in Period II (-2.30%). In the zone, the growth rates of area and production in Period I revealed acceleration, which could be attributed to encouragement of groundnut cultivation from the technologies emanated through AICRP on oilseeds in the zone, while the acceleration in growth rate of area in Period II could be credited to positive impact of TMO, which focused on transfer of technology, enhancement of production technologies, timely supply of inputs and services, favourable output price, processing and post-harvest support. However, the growth momentum did not sustain in Period III, which could be attributed to changing climate scenario, lower yields, drought spells, comparative advantage of competing crops like redgram, castor and cotton. Decline in growth rate of production during the Period III could be attributed to cheaper imports of vegetable oils due to liberalization, which discouraged the production of oilseeds domestically, through reduced input usage and lower management of farms.

Sesame: Compound Annual Growth Rates (CAGR) of sesame in North coastal, Southern and Scarce rainfall zones were calculated as described in the methodology (Table 4).

The analysis revealed that in North coastal zone, CAGR was statistically not significant for area, production and yield across Period I and Period II, while in Period III, it was significant for both area and productivity at 1 per cent and 5 per cent level of significance.

In this zone, the growth rate of area was highest in Period I (0.60%), followed by Period II (0.23%) and negative growth rate in Period III (-2.87%). The growth rate of production was highest in Period II (0.26%), followed by moderate negative growth rate in Period I (-0.39%) and slowest growth rate in Period III (-1.14%). The growth rate of yield was highest in Period III (1.78%), followed by Period II (0.03%) and negative growth rate in Period I (-0.98%). The decline in the growth rate of area observed during Period III could be ascribed to a host of factors viz., persistent biotic and abiotic stresses, lower profitability of the crop, comparative advantage of competing crops like maize and pulses (blackgram and greengram). An interesting acceleration in the growth rate of yield during Period III could be ascribed to better use of technology; better crop management including monetary and non-monetary inputs, providing life saving irrigation to the crop.

In Southern zone, growth rate of area was positive but statistically non-significant in Period I. In subsequent period i.e., Period II, the growth rate of area was positive and statistically significant at 5 per cent level. In Period III, the growth rate of area was negative but statistically non-significant. In Period I, with regard to production, the growth rate was found to be negative but statistically non-significant, while in Period II, the growth rate of production was positive but statistically non-significant. The growth rate of production was positive and statistically significant at 10 per cent level in Period III. The growth rate of yield in Period I was negative but statistically non-significant, while in Period II, growth rate of yield was positive but statistically non-significant. In Period III, growth rate of yield was positive and statistically significant at 1 per cent level. In this zone, the growth rate of area was highest in Period II (4.97%), followed by Period I (0.28%) and negative growth rate in Period III (-0.03%). The growth rate of production was highest in Period II (6.21%), followed by Period III (4.20%) and negative growth rate in Period I (-0.54%). The growth rate of yield was highest in Period III (4.23%), followed by Period II (1.18%) and negative growth rate in Period I (-0.81%).In the zone, during Period II, the observed faster growth rate in area can be attributed to positive impact of TMO, wherein emphasis was laid on extending awareness on crop management practices for increasing productivity of sesame to farmers; making available the good quality HYV seed; providing financial support to farmers; providing price support etc., (Sharma, 2014). In Period III, an acceleration in the growth rate of production could be attributed to factors such as shift of sesame cultivation towards coverage of larger area under irrigated ecosystem, relatively efficient management of the farms due to consistent yield of the crop, higher use of inputs and technology in the cultivation etc., Accelerated growth rate in yield during Period III could be attributed to factors like production of sesame in irrigated conditions, better use of technology, increased use of inputs to manage abiotic and biotic stresses etc.

In scarce rainfall zone, during Period I and Period II, the growth rates of area were negative and statistically significant at 1 per cent level, signifying decline of area during these periods, while in Period III, the growth rate of area was positive and statistically significant at 10 per cent level. The growth rates of production were negative and statistically significant at 1 per cent level in Period I and Period II, indicating declining growth rate of production. In Period III, growth rate of production was positive but statistically non-significant. The growth rate of yield was found to be negative but statistically non-significant in Period I, while in Period II and Period III, the growth rates of yield were positive but statistically non-significant. In this zone, the growth rate of area was highest in Period III (5.76%), followed by moderate negative growth rate in Period II (-8.64%) and slowest growth rate in Period I (-12.85%). The growth rate of production was highest in Period III (7.40%), followed by moderate negative growth rate in Period II (-7.28%) and slowest growth rate in Period I (-15.29%). The growth rate of yield was highest in Period III (1.54%), followed by Period II (1.49%) and negative growth rate in Period I (-2.80%).

In this zone, declined growth rates in area during Period I and Period II could be attributed majorly to poor management in the cultivation, unremunerative output price, dry spells, shift of sesame cultivation towards competing crops like cotton, redgram and bengalgram etc., declined growth rates of production in Period I and Period II could be ascribed to decline in the area under the sesame cultivation, coupled with farm level inefficiency, higher biotic and abiotic stresses and lower yields etc. However, in Period III, acceleration in the growth rate of area could be ascribed to availability of latest technologies in sesame, favourable market price and better farm level management practices.

Sunflower: Compound Annual Growth Rates (CAGR) of sunflower in Southern and Scarce rainfall zones were calculated and presented in Table 5. Period I was not considered for sunflower since the crop was introduced during the later half of the 1970's and analysing with a fewer number of observations would result to biasness in the results and the analysis indicated.

In Southern and Scarce rainfall zones, the growth rates of area were positive and statistically significant at 1 per cent level in Period II, while in Period III, the growth rates of area were negative and statistically significant at 1 per cent level. In both the zones, during Period II, the growth rates of production were observed to be positive and statistically significant at 1 per cent level, while in Period III, the growth rates were negative and statistically significant at 1 per cent level. For both the zones, growth rates of yield in Period II and Period III were positive and statistically non-significant. In Period II, the growth rates of area and production was noticed to be 57.51 per cent and 58.55 per cent respectively. In Southern zone, for the same period i.e., Period II, the growth rate of area and production were recorded to be 6.82 per cent and 9.20 per cent respectively. Higher growth rates in area and production were evidenced during Period II in Southern zone, when compared to Scarce rainfall zone.

In both the zones, during Period II, acceleration in the growth of area could be attributed to factors like positive impetus from implementation of TMO in sunflower cultivation, high profitability of crop, high productivity of crop in initial years of its introduction due to fertile soils, high price of the sunflower output etc., Accelerated growth rates in the production could be ascribed to factors like increased area, high input usage, higher yields due to fertile soils etc., However, the positive growth momentum in area and production during Period II was not sustained and even led to declined growth rates of area and production in Period III. This decline in growth rates of area could be attributed to plateauing of yields, incidence of sunflower necrosis disease, low profitability of the crop, low yield due to consistent mono-cropping of sunflower, comparative advantage of competing crops *viz.,* bengalgram, castor and cotton etc., Declined growth rates in the production of sunflower in both zones could be attributed to lower area under cultivation, lower yields due to reduced fertility of soils, as the crop is regarded as exhaustive crop, severe biotic and abiotic stresses like bird damage, sunflower necrosis disease etc.

Sources of production growth

Effect of the area, yield and their interaction on the change in production of groundnut, sesame and sunflower crops in selected agro-climatic zones were worked out using decomposition analysis and presented under the respective headings.

Groundnut: Effect of the area, yield and interaction on the change in production of groundnut in North coastal, Southern and Scarce rainfall zones were calculated and presented in Table 6.

In North coastal zone, decomposition analysis revealed that change in production was more influenced by area effect in Period I, while in Period II and Period III, the yield effect was the major contributor for the change in production. Yield effect was pronounced rather than area effect and interaction effect in all the periods, except in Period I, signifying that change in production is influenced by technology during Period II and Period III, while area effect had contributed to the change in production of the groundnut in the zone during the Period I. During Period I, yield effect (technology) had pulled down the production, while in case of Period II and Period III, area effect played a major role in pulling down the production. It can be observed that, though technology tried to make inroads, yet it could not catch up in realization of positive change in production in aforesaid periods primarily on account of pulldown by the area effect.

In Southern zone, in Period II alone, the change in production was influenced by area effect, while in the rest of the periods *viz*., Period I and Period III, the change in production was influenced by yield effect. This suggests that the change in production was influenced by technology in these periods, while in Period II, it was due to area expansion. During Period III, although the yield effect was quite substantial, the area effect had negatively contributed to change in production resulting to overall negative change in production.

In Scarce rainfall zone, the change in production in all the periods, except in Period II was influenced by yield effect, whereas only in Period II, the change in production was influenced by the area effect. This scenario suggests that technology was accountable for change in production in Period I and Period III. During Period III, change in production was primarily due to yield effect, followed by area effect, while change in production during Period II was due to area expansion. During Period II, technology has not percolated to the area, while in Period III, interaction between area and yield effects has pulled down the production, leading to negative change in production in the aforesaid periods.

Sesame: Effect of the area, yield and interaction on the change in production of sesame in North coastal, Southern and Scarce rainfall zones were calculated and presented in Table 7.

In North coastal zone, the change in production was influenced by yield effect in Period I and Period III, while in Period II, the change in production was influenced by area effect. During Period II, interaction between area and yield effects has pulled down the production, while in Period III, declined area has contributed to the negative change in production.

In Southern zone, the change in production was influenced by area effect in Period I and Period III, while in Period II, the change in production was influenced by yield effect, which indicated that change in production was majorly influenced by area expansion in Period I and Period III, while the change in production could be attributed to technology in Period II. During Period I, interaction effect between area and yield had pulled down the production, ultimately resulting to negative change in production.

In Scarce rainfall zone, the change in production during Period I and Period II was negative, suggesting that the production of sesame during the aforesaid periods declined over the base periods. It was only in Period III, that the change in production was positive, which could be ascribed to the yield effect (technology). During Period I, interaction between area and yield effects has pulled down the production, which led to negative change in production, while during Period II, the area effect has pull downed the production, due to declined area in this period.

Sunflower: Effect of the area, yield and interaction on the change in production of sunflower in Southern and Scarce rainfall zones were calculated and presented in Table 8.

Table 3 Compound annual growth rates (%) in area, production and yield of groundnut in Andhra Pradesh

Time Periods	North Coastal Zone			Southern Zone			Scarce Rainfall Zone		
	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield
Period - I	-0.29 NS	-1.12 NS	-0.83 NS	0.24 NS	-0.86 NS	-1.10 NS	2.11 ***	3.02 **	0.89 NS
Period - II	-1.68 ***	-1.19 NS	0.49 NS	-0.76 NS	-2.15 NS	-1.41 NS	1.82 *	-0.52 NS	-2.30 NS
Period - III	-12.68 ***	-9.45 ***	3.70 ***	-4.31 ***	-1.53 NS	2.90 **	-3.21 ***	-4.02 *	-0.84 NS

*** Statistically Significant at 1 per cent level, ** Statistically Significant at 5 per cent level, * Statistically Significant at 10 per cent level, NS- Statistically non-significant

Table 4 Compound annual growth rates (%) in area, production and yield of sesame in Andhra Pradesh

Time Periods	North Coastal Zone			Southern Zone			Scarce Rainfall Zone		
	Area	Production	Yield	Area	Production	Yield	Area	Production	Yield
Period - I	0.60NS	-0.39NS	-0.98NS	0.28NS	-0.54NS	-0.81NS	-12.85***	-15.29***	-2.80NS
Period - II	0.23NS	0.26NS	0.03NS	4.97**	6.21NS	1.18NS	-8.64***	-7.28***	1.49NS
Period - III	-2.87***	-1.14NS	1.78**	-0.03NS	4.20*	4.23***	5.76*	7.40NS	1.54NS

*** Statistically Significant at 1 per cent level, ** Statistically Significant at 5 per cent level, * Statistically Significant at 10 per cent level, NS- Statistically non-significant

Table 5 Compound annual growth rates (%) in area, production and yield of sunflower in Andhra Pradesh

Time Periods	Southern Zone			Scarce Rainfall Zone		
	Area	Production	Yield	Area	Production	Yield
Period - I	NA	NA	NA	NA	NA	NA
Period - II	57.51 ***	58.55 ***	0.66 NS	6.82 ***	9.20 ***	2.23 NS
Period - III	-12.47 ***	-10.88 ***	1.82 NS	-20.90 ***	-20.72 ***	0.23 NS

*** Statistically Significant at 1 per cent level, ** Statistically Significant at 5 per cent level, * Statistically Significant at 10 per cent level, NS- Statistically non-significant, NA- Not available.

Table 6 Decomposition analysis of area, production and yield of groundnut in Andhra Pradesh

Time Periods	North Coastal Zone				Southern Zone				Scarce Rainfall Zone			
	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)
Period - I	-4041.67	162.01	-65.25	3.24	17695.33	-128.42	242.50	-14.08	204591.00	39.77	47.57	12.66
Period -II	-22320.00	-30.85	125.29	5.56	-128741.33	61.21	46.10	-7.30	-78218.00	243.54	-194.08	50.54
Period- III	-71193.33	-99.56	112.22	87.34	-55907.33	-260.56	247.03	113.53	-337642.00	32.63	79.56	-12.18

Table 7 Decomposition analysis of area, production and yield of sesame in Andhra Pradesh

Time Periods	North Coastal Zone				Southern Zone				Scarce Rainfall Zone			
	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)
Period - I	203.33	-177.35	294.43	-17.08	-256.00	69.49	32.60	-2.10	-1580.33	39.10	93.31	-32.41
Period - II	-954.44	82.55	19.33	-1.88	910.22	12.04	80.81	7.16	-203.89	-29.14	110.24	18.90
Period - III	-2829.33	-58.90	133.72	25.18	1631.33	77.98	14.18	7.85	91.00	11.84	77.17	10.99

Table 8 Decomposition analysis of area, production and yield of sunflower in Andhra Pradesh

Time Periods	Southern Zone				Scarce Rainfall Zone			
	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)	Change in Production (in tonnes)	Area Effect (%)	Yield Effect (%)	Interaction Effect (%)
Period - I	NA	NA	NA	NA	NA	NA	NA	NA
Period - II	38258.00	-0.05	108.59	-8.54	60517.67	18.15	62.59	19.26
Period - III	-37113.00	-87.10	110.28	76.82	-134574.33	12.11	99.64	-11.74

NA- Not available

The results suggest that in both Southern and Scarce rainfall zones, yield effect was the major contributor to the change in production in Period II. This scenario suggests that in both the zones, the change in production was primarily due to yield effect (technology) during Period II. With regard to Period III, the yield effect was responsible for change in production, which was negative. In both the zones, the negative change in production was evidenced during Period III due to sharp decline in area under sunflower cultivation.

In conclusion, an analysis of growth rates in area, production and yield of groundnut, sesame and sunflower in the selected zones under the study showed variable growth patterns with declining yields and production in the more recent period. In particular, the performance of sunflower was poor in terms of growth as evident from the declining production and yield. This scenario is alarming to farmers, researchers and policy makers and there is an immediate need to reorient the situation. The performance of sesame was better vis-a-vis groundnut and sunflower, as evident from the growth rates in area, production and yield. However, there was no significant decline in yields of the three crops which can be partly attributed to efforts from the research community and government to increase the yield in oilseeds through programmes like AICRP on Oilseeds, TMO, ISOPOM and NMOOP. Although efforts were made towards increasing area, production and yield, the positive growth momentum of area and production could not be sustained in the state for the crops under the study. Many generic and specific reasons could be ascribed to this pattern at agro-climatic zonal level viz., shift of major oilseeds cultivation towards competing crops (Rama Rao, 2008), low profitability, unremunerative market prices, low farm level technical efficiency (Mruthyunjaya *et al.,* 2005), lower capacity utilization of processing units (Reddy and Bantilan, 2012), increased costs of inputs, higher biotic and abiotic stresses etc., Further, decomposition analysis of groundnut, sesame and sunflower in the selected zones revealed that yield effect was the major driver of change in production. However, a declining area under the oilseed crops is a possible reflection of eroding profitability of the crops and thus warrant appropriate policy interventions considering the demand-supply gap. Location specific research with focus on hybrids and High Yielding Varieties (HYVs) with high oil content, addressing the constraints to technology adoption, favourable price policies, enhancing capacity utilization of processing units through Public Private Partnership (PPP), creating more efficient supply and value chains are some of the critical areas of interventions which are needed to be focused to meet the oil and oilseed requirements in the country.

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Sanchita (YSWB 2014/2) and Anushka (YSWB 2011-10-1) - two yellow sarson (*Brassica rapa* var. yellow sarson L.) varieties notified for West Bengal

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ABSTRACT

Sanchita (YSWB 2014/2) was developed through crossing between Rajendra Sarson and PYS 2005 and Anushka (YSWB 2011-10-1) was developed through crossing between Benoy (B-9) and Rajendra Sarson. Both the varieties were tested during *rabi* 2010-11 to 2015-16 at different locations with National Checks (NC) YSH-0401, NRCYS-05-02 and PT-303, the latest release (LR) Pitambari and the Zonal Check (ZC) B-9 and Panchali. Sanchita has the distinction of attaining 24.04% yield advantage over YSH-0401, 6.7% over Pitambari and 26.7% over B-9. It also registered 8% higher oil yield advantage over YSH-0401, 7% over Pitambari and 32.9% over B-9. Anushka registered 29% higher mean seed yield during 2010-11 and 18% higher mean seed yield during 2012-13 over B-9. During 2014-15, Anushka also recorded 8.7%, 9.0% higher seed yield and 13.9 and 14.2% higher oil yield over the two *toria* varieties Panchali and PT-303, respectively. It was 10-12 days earlier in maturity than Benoy. Superior performance of Sanchita and Anushka in the coordinated and multilocation trials over the years, led to their notification by Central Variety Release Committee (CVRC) for release in West Bengal. Molecular marker analysis depicted distinct SSR alleles for Sanchita and Anushka compared to Benoy.

Keywords: Anushka, Sanchita, Variety, Yellow Sarson

The oleiferous Brassica species, commonly known as rapeseed-mustard are one of the economically important agricultural commodities. These crops are grown in 67 countries in Asia, Europe, America, Africa and Australia. India ranked third and fourth in area and production of rapeseed-mustard, respectively. Rapeseed-mustard in India consists of eight different species. Of these, toria (*Brassica rapa* L. var. toria), brown sarson (*Brassica rapa* L. brown sarson), yellow sarson (*Brassica rapa* L. var. yellow sarson), gobhi sarson (*Brassica napus* L. ssp. oleifera DC var. *annua* L.) and taramira (*Eruca sativa*/vesicaria Mill.) are together termed as rapeseed; and Indian mustard (*Brassica juncea* (L.) Czern. & Coss.); black mustard (*Brassica nigra* [L.] Koch) and Ethiopian mustard or karan rai (*Brassica carinata A. Braun*) are collectively called mustard.

The diverse agro ecological condition of West Bengal is favourable for growing rapeseed-mustard crop. Rapeseed-mustard solely contributes 53% to the total oilseed production with a productivity of 909 kg/ha in the state (Dutta, 2014) which is far below the potential yield. Although there are several factors for poor yield (late sowing due to late harvesting of *kharif/aman* paddy, inadequate moisture at sowing time, particularly in rice fallow lands, flood affected areas leading to delayed land preparation and formation of heavier soils and major biotic stresses *viz.* mustard aphid, Alternaria blight, white rust and club root. Yellow sarson is mainly grown in Odisha, Assam, West Bengal, Bihar and eastern Uttar Pradesh. One of the main factors is the use of very old varieties such as B-9 in large areas of the state (Dutta *et al.*, 2019). Thus, development of high yielding varieties of rapeseed mustard is foremost to enhance productivity (Meena *et al.,* 2014). Objective of the study was to develop high yielding early maturing and high oil content varieties of yellow sarson for the state of West Bengal.

Sanchita and Anushka varieties were developed through pedigree method of breeding. Sanchita (YSWB 2014/2) was developed through crossing between Rajendra Sarson (female parent) and PYS 2005 (male parent) whereas, Anushka (YSWB 2011-10-1) was developed through crossing between B-9 (female parent) and Rajendra Sarson (male parent). Rajendra Sarson is characterized with 130-135 cm plant height with 107-110 days maturity; PYS-2005 with 110-120 cm plant height with 95-99 days maturity and B-9 with 110 cm plant height with 100 days maturity. Hybridization between respective parents was initiated at Pulses and Oilseed Research Station, Berhampore West Bengal in the year 2003. Selection in F_2 and subsequent generations resulted into the development of early maturing yellow seed coat high yielding genotypes which were evaluated at multiple different locations covering different agro-climatic zones of West Bengal during the period 2009-10 to 2015-16.

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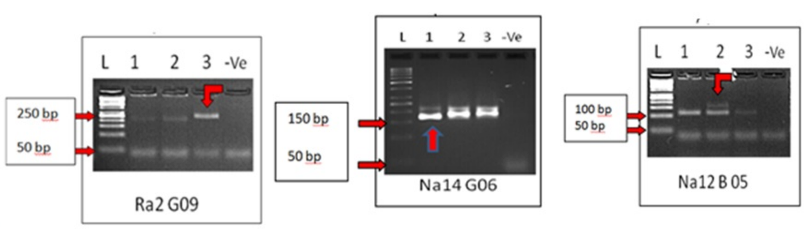
Sanchita was tested during *rabi* 2011-12, 2014-15 and 2015-16 at 10, 4 and 4 locations respectively with national check (NC) YSH-0401 and NRCYS-05-02, latest release (LR) Pitambari and zonal Check (ZC) B-9. Anushka was tested during 2010-11 and 2012-13 with Yellow sarson varieties and during 2014-15 with Toria trial at national level. The experimental design was Randomized Complete Block Design (RCBD) having three replications and plot size of 5.0×1.5 m^2 (5 rows at 30 cm row spacing). Seeds were sown in lines and after emergence one healthy seedling was maintained at a spacing of 10 cm. Uniform dose of fertilizer @ 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha was applied. 50% N, full dose of P_2O_5 and K_2O were applied as basal. Rest 50% N was applied at 30 days after sowing. Observations were recorded on ten randomly selected plants per plot to record the data on plant height, days to 50% flowering and maturity and 1000 seed weight. Seed yield, oil content and oil yield were also recorded. The mean values were subjected to statistical analysis. For genotyping the developed varieties, DNA from Sanchita and Anushka along with check variety Benoy (B-9) was isolated from leaf tissue using CTAB method (Doyle anf Doyle, 1990) at Bhabha Atomic Research Centre, Trombay, Mumbai. Five hundred and twenty (520) microsatellite markers (SSR) (http://www.brassica.info/resource/markers/ssr-exchange.php) were used to study DNA polymorphism. The PCR reaction was set for 25 µl reaction volume which comprised of 2.5 µl 10 × PCR reaction buffer (Invitrogen), 0.5 µl dNTPs, 1 µl each forward and reverse primers, 0.25 µl (5 U/µl) Taq DNA polymerase (Invitrogen), 2 µl template DNA (25 ng/µl) and 17.75 µl sterile Milli-Q water. The PCR reaction conditions were initial denaturation at 95°C for 5 minutes, followed by 35 cycles of denaturation at 94°C for 30 seconds, annealing at 50-55°C for 30 seconds and extension at 72°C for 30 seconds and final extension at 72°C for 10 minutes and reaction was hold at 4°C. All the PCR products were stored at 4°C until resolved on 2.5% agarose prepared in 1× TBE buffer containing 0.5 µg/ml ethidium bromide (EtBr). Of the 520 primers tried, three of the primer pairs gave polymorphic bands among the three varieties and the primer sequences, their annealing temperatures are given below.

Primer name	Forward primer sequence (5'-3')	Reverse primer sequence (5'-3')	Ta
Ra2G09	ACAGCAAGGATGTGTTGACG	GATGAGCCTCTGGTTCAAGC	55 °C
Na14 G06	AAACGGCTTGCATTGTTCTC	GGCTTGCTTGATCCAGTCTC	55 °C
Na12B05	CAAATATCCGTCATCGGAGC	CCTGCGGGATATTGAAGACC	55 °C

During 2014-15 and 2015-16, Sanchita (YSWB-2014/2) was significantly superior to YSH O401, NRCYS 05-02 and B 9 at 4 locations and in 4 States of India with highest mean productivity of 1316 kg/ha (Table 1). Sanchita exhibited moderately tolerant/resistant reaction to major insect-pests and diseases with duration of 95-97 days and oil content 44-45%. Mean performance over three years revealed that Sanchita was higher yielding by 24.04% over YSH-0401, 6.7% over Pitambari and 26.7% over B-9. Its oil yield exceeded by 8% over YSH-0401, 7% over Pitambari and 32.9% over B-9. Anushka (YSWB-2011-10-1) recorded 28.8, 7.1 and 6.8% more seed yield and 28.5, 10.1 and 14.84% more oil yield than B-9, NRCYS 05-02 and YSH-401, respectively during 2010-11 (Table 2). It produced seed yield of 21 kg/ha/day and attained maturity 15 days earlier than the B 9. Varieties B-9, NRCYS 05-02, and YSH-401 produced seed yield of 13, 16, and 16 kg/ha/day. Since the predominant cropping sequence of West Bengal is kharif rice-yellow sarson-Boro rice, farmers prefer short duration oilseed as catch crop in between two rice crops. Anushka may suit such condition. During 2012-13 Anushka produced 18%, 16%, 11% and 2% higher yield than B-9, NRCYS 05-02, YSH-401 and Pitambari respectively (Table 2).



Legend: lane 1-Benoy, 2 Anushkaand 3, Sanchita. Arrows indicate the polymorphic bands observed.

Fig. 1. Genotyping of Sanchita and Anushka genotypes along with Benoy variety

Table 1 Zonal Performance of Sanchita (YSWB 2014/2) in respect of seed yield in national trial

Variety	Seed yield (kg/ha)	Oil yield (kg/ha)	Seed yield (kg/ha/day)
***Rabi* 2011-12**			
Sanchita	1437	619	15.1
YSH-401(NC)	883	380	8.4
Pitambari (LR)	1319	570	12.6
B-9 (LC)	1209	533	12.7
***Rabi* 2012-13**			
Sanchita	1255	554.7	13.2
YSH-401 (NC)	1254	559.3	11.9
NRCYS 05-02 (LR)	1149	510.2	11.3
Pitambari(LR)	1214	543.9	11.3
***Rabi* 2015-16**			
Sanchita	1316	582	13.9
YSH-401(NC)	1207	539	11.5
Pitambari (LR)	1223	544	12.0
B-9 (LC)	977	438	10.0

NC-National Check, LR-Latest Release, LC- Local Check

Table 2 Zonal Performance of Anushka (YSWB-2011-10-1) in respect of seed yield in national trial

Variety	Seed yield (kg/ha)	Oil yield (kg/ha)	Seed yield (kg/ha/day)
***Rabi* 2010-11**			
Anushka	1730	761	21
YSH-401(NC)	1620	648	16
NRCYS 05-02 (LR)	1615	691	16
B-9 (LC)	1343	592	13
***Rabi* 2012-13**			
Anushka	1478	657.7	17.4
YSH-401 (NC)	1335	582.1	12.7
NRCYS 05-02 (LR)	1272	559.7	11.9
Pitambari(LR)	1445	632.9	13.8
B-9 (LC)	1250	550	12.8
***Rabi* 2014-15**			
Anushka	1110	483	13.1
Panchali (ZC)	1021	424	11.7
PT-303(NC)	1018	423	10.7

NC-National Check, LR-Latest Release, LC- Local Check

Table 3 Ancillary characters of Sanchita (YSWB 2014/2) and Anushka (YSWB 2011-10-1) in comparison to B-9 (Benoy)

Variety	Plant height (cm)	Days to 50% flowering	Days to maturity	1000 seed wt. (g)	Oil content (%)
Sanchita	110	40	95	3.5	44
Anushka	100	35	85	3.5	44
B-9 (Benoy)	100	40	94	3.08	45.0

During *rabi* 2014-15 Anushka produced higher seed yield. It recorded higher seed yield to the extent of 8.72% and 9.04% over two toria varieties Panchali and PT-303 respectively. It also recorded oil yield of 13.9% and 14.2% over Panchali and PT-303 (Table 2).

To discriminate Sanchita, Anushka and Benoy genotypes, 520 microsatellite or simple sequence repeat (SSR) markers were screened, out of which only three primers (Ra2G09, Na14 G06, Na12 B05) showed allelic variation among the varieties.

The three primers Ra2G09, Na14 G06, and Na12B05 showed the size variation among the three genotypes Sanchita, Anushka and Benoy.

Salient morphological characters of Sanchita and Anushka in comparison to popular yellow sarson variety B-9 (Benoy) have been presented in Table 3. Recently developed varieties Sanchita and Anushka offer opportunity to replace the 40 years old variety Benoy (B-9) and to increase the production of yellow sarson in West Bengal. Both the varieties have been released through Gazette Notification of Government of India vide S.O.No. 3482(E) New Delhi, dated 7th October, 2020.

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Studies on genotype x environment interactions of sunflower hybrids (*Helianthus annuus* L.)

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ABSTRACT

Twenty eight hybrids derived from four CMS lines and seven restorer lines along with two checks were evaluated in randomized block design at three locations for G x E interactions and stability parameters. Stability analysis revealed that genotype x environment interactions were highly significant for all the eleven traits which indicated differential response of genotypes to varied environments. Cross combinations SVCMS-1 x SVSR-3, SVCMS-1 x SVSR-5, SVCMS-2 x SVSR-2, SVCMS-2 x SVSR-4, SVCMS-3 x SVSR-2, SVCMS-3 x SVSR-3, SVCMS-3 x SVSR-7, SVCMS-4 x SVSR-7 and check Phule Raviaj had significantly higher mean than population mean and regression coefficient less than unity which indicated their stable and wide adaptability to poor environment, while, hybrids, *viz.,* SVCMS-1 x SVSR-7, SVCMS-2 x SVSR-3, SVCMS-2 x SVSR-6, SVCMS-3 x SVSR-1, SVCMS-3 x SVSR-4, SVCMS-3 x SVSR-5, SVCMS-3 x SVSR-6, SVCMS-4 x SVSR-1, SVCMS-4 x SVSR-5 SVCMS-4 x SVSR-6 and check LSFH-171 were with high mean, regression coefficient more than unity (bi>1) with non-significant least deviation from regression line indicating their specific adaptation to favorable or rich environments.

Keywords: Genotype x environment interaction, Hybrids, Stability, Sunflower

Sunflower (*Helianthus annuus* L.) is an important oilseed crop in the world. The introduction of this crop to India helped a great deal in increasing total oilseed production. This crop has shown distinct superiority over other oilseed crops owing to its wider adaptability to different agro-climatic conditions, short duration, high potential yield and ability to withstand drought as compared to other rainfed crops. Sunflower is photoinsensitive and thus it can be grown round the year. Besides the genetic factors, complex physiological processes determine a specific character and the environment plays an important role in the final phenotypic expression of a character. Therefore, the estimates of combining ability effects based on single season may not reveal the real merits of the parents because of the G x E interaction. Per se performance and combining ability effects are considerably influenced by the environments and for more valid estimation, a study under different environments is likely to bring out the impact of the genotype x environment interaction on the estimates. Therefore, breeding efforts are directed towards stepping up the yield levels through the development of high yielding varieties and hybrids for different seasons. Hence, there is a need for the development of season specific hybrids in addition to the identification of stable hybrids over environments. The present investigation was carried out to assess the stability of 28 experimental hybrids of sunflower across three locations.

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In the present study 28 hybrids obtained by adopting line x tester mating design consisting of 4 CMS lines (SVCMS-1, SVCMS-2, SVCMS-3 and SVCMS-4) and 7 testers (SVSR-1, SVSR-2, SVSR-3, SVSR-4, SVSR-5, SVSR-6 and SVSR-7) along with two checks *viz.,* Phule Raviraj and LSFH-171 were evaluated in randomized block design with three replication and tested in three environments namely Navsari (E1), Bharuch (E2) and Vanarasi (E3) during *rabi* 2019-20. The performance of different hybrids, parents and checks in respect to eleven characters was studied for estimating the stability and significance of genotype environment interactions. Each hybrid was represented by single Rows of 3.0 m length with 60 x 30 cm spacing between and within rows, respectively. Observations were recorded in each of the entries on randomly selected five plants for eleven characters *viz.,* days to 50 per cent flowering, days to physiological maturity, plant height (cm), head diameter (cm), seed filling per cent, hull content (%), seed yield per plant (g), 100 grain weight, seed volume weight (g/100 ml), chlorophyll content (SPAD value) and leaf area (cm^2). The analysis of experimental data was carried out using software INDOSTAT as per standard method of Eberhart and Russell (1966) in order to estimate the three parameters of stability *viz.,* mean, regression coefficient (bi), and mean squared deviation (S2di) for each genotype.

The results revealed that genotypes and environments were highly significant for all the characters except for leaf area in environments when tested against pooled error as well as pooled deviation indicating significant difference among them. The genotype x environment interaction components were also found highly significant for all the characters. The environment (linear) component was also found significant and highly significant for all the traits except leaf area indicating the influence of environment on the expression of these characters.

Further the significance of genotypes x environment (linear) component for days to maturity, head diameter, hull content and seed volume weight when tested against pooled deviations indicated that all the regression coefficients were not statistically at par and variation in the performance of genotypes was due to regression of genotypes on environmental indices and hence performance of genotypes would be predictable reasonably for these traits. The mean squares due to pooled deviation were found to be highly significant for all the traits except days to maturity and leaf area which suggested that the prediction of the performance of genotypes over environment based on regression analysis for these traits might not be very reliable. Estimates of environmental indices (Ij), given in the Table 2 suggest that E3 was the most favourable environment for all the characters except days to maturity and seed filling percent. The significance of G x E interactions have also been reported in sunflower by Halaswamy *et al.* (2000), Nel *et al.* (2000), Pawankumar *et al.* (2003), Murali *et al.* (2004), Tabrizi (2012) and Bhoite *et al.* (2018b).

Table 1 Analysis of variance for stability for seed yield and yield attributes in sunflower

Characters	Genotype	E + (G x E)	Environment	G x E	E (L)	G x E (L)	Pooled deviation	Pooled Error
	40	82	2	80	1	40	41	240
Days to 50 per cent flowering	45.71**	8.12	31.11*	11.44**	62.22*	5.64	9.21**	3.56
Days to maturity	67.87**	9.61	17.27*	9.42**	34.54*	12.32*	6.35	4.81
Plant height (cm)	1262.93**	138.09	1572.69**	102.23**	3145.38**	88.29	113.33**	11.86
Head diameter (cm)	22.69**	2.67**	6.57*	2.57**	13.13**	3.81**	1.30**	0.30
Seed filling (%)	126.36**	34.79	184.30*	31.05**	368.59**	19.61	41.45**	4.64
Hull content (%)	71.75**	3.60*	18.88**	3.22**	37.76**	4.28*	2.10**	0.75
Seed yield per plant (g)	178.81**	11.23	25.21*	10.88**	50.43*	12.78	8.75*	5.68
100 grain weight (g)	2.35**	0.18	0.39**	0.17**	0.78*	0.20	0.14**	0.06
Seed volume weight (g)	87.35**	4.57*	18.08**	4.23**	36.16**	5.59*	2.80**	1.50
Chlorophyll content (SPAD value)	145.00**	8.28	26.18*	7.83**	52.36**	9.02	6.47**	2.23
Leaf area (cm^2)	50869**	1110	1049	1112**	2098	1463*	742	733

*, **Significant at 5 and 1 per cent, respectively

Table 2 Environmental indices of sunflower parents and hybrids for twelve characters

Characters	Environmental indices		
	E1	E2	E3
Days to 50 per cent flowering	0.970	-0.257	-0.713
Days to maturity	-0.504	-0.228	0.732
Plant height (cm)	-3.790	-3.357	7.147
Head diameter (cm)	-0.331	-0.114	0.445
Seed filling (%)	-2.448	1.267	1.180
Hull content (%)	-0.111	-0.616	0.728
Seed yield per plant (g)	-0.300	-0.590	0.890
100 grain weight (g)	0.019	-0.106	0.086
Seed volume weight (g)	-0.192	-0.547	0.738
Chlorophyll content (SPAD value)	-0.110	-0.738	0.848
Leaf area (cm^2)	-2.857	-2.984	5.841

Top most stable hybrids for earliness were SVCMS-1 x SVSR-6, SVCMS-2 x SVSR-1, SVCMS-2 x SVSR-6, SVCMS-3 x SVSR-7 and SVCMS-4 x SVSR-2. Among 28 crosses, six manifested low mean with non-significant deviation from regression out of which two crosses recorded above average stability and four showed below average stability as reported by Prusti *et al.* (1999), Panduranga *et al.* (2000), Murali *et al.* (2004), Rao *et al.* (2004), Taran *et al.* (2014) and Bhoite *et al.* (2018b). For days to maturity, three crosses *viz.,* SVCMS-1 x SVSR-1, SVCMS-2 x SVSR-2, SVCMS-3 x SVSR-4 and SVCMS-3 x SVSR-6 recognized as the most average stable crosses for favorable environment similar results reported by Prusti *et al.* (1999), Murali *et al.* (2004), Bhoite *et al.* (2018b), Chandra *et al.* (2018) and Ghaffari *et al.* (2020).

Among the hybrids, SVCMS-1 x SVSR-2, SVCMS-1 x SVSR-4 and SVCMS-4 x SVSR-6 showed below average stability with lower than hybrid mean (167.44) less deviation from regression line indicating stability of performance in rich environments. SVCMS-3 x SVSR-2 hybrid had shown above average stability with less deviation from regression line indicating the stability of performance in poor environments. Hybrid progeny SVCMS-4 x SVSR-1 recorded average stability suitable for all environments. Similar results have been reported by Pillai *et al.* (1995), Laishram and Singh (1997), Rao *et al.* (2004), Bhoite *et al.* (2018b), Chandra *et al.* (2018) and Ghaffari *et al.* (2020). Considering head diameter, hybrids SVCMS-1 x SVSR-3, SVCMS-2 x SVSR-4, SVCMS-3 x SVSR-3 and SVCMS-4 x SVSR-4 exhibited higher mean value coupled with regression coefficient significantly lower than unity and non-significant S^2di indicating above average stability, while hybrids SVCMS-1 x SVSR-4, SVCMS-1 x SVSR-7, SVCMS-2 x SVSR-1, SVCMS-2 x SVSR-6 and SVCMS-3 x SVSR-6 showed below average stability. These findings are in line with the results obtained by Bharathi (2000), Panduranga *et al.* (2000), Rao *et al.* (2004) and Balu *et al.* (2007) in their studies. For seed filling per cent, hybrids, SVCMS-2 x SVSR-4, SVCMS-3 x SVSR-3, SVCMS-3 x SVSR-5 and SVCMS-4 x SVSR-3 showed specific adaptation to poor environment. While, crosses SVCMS-2 x SVSR-1, SVCMS-2 x SVSR-5, SVCMS-2 x SVSR-7, SVCMS-4 x SVSR-4 and SVCMS-4 x SVSR-5 were stable and responded favorably for rich environments. Laishram and Singh (1997), Rukminidevi *et al.* (2006), Waghmare *et al.* (2011), Bhoite *et al.* (2015) and Neelima and Parmeshwarappa (2017) have also observed similar responses in their experimental material. Considering hull content per cent, the hybrids, SVCMS-3 x SVSR-1, SVCMS-3 x SVSR-5 and SVCMS-4 x SVSR-1 proved to be stable for better environmental conditions (higher mean, significant S2di, around unity bi>1). Whereas, hybrids, SVCMS-1 x SVSR-5, SVCMS-2 x SVSR-3, SVCMS-2 x SVSR-4, SVCMS-2 x SVSR-5, SVCMS-3 x SVSR-3, SVCMS-4 x SVSR-1 and SVCMS-4 x SVSR-4 were found suitable for poor management conditions depicting above average stability having regression coefficient values significantly less than one. Hybrid progeny SVCMS-4 x SVSR-5 exhibited high mean, non-significant deviation from regression and regression coefficient value was unity, indicating stability for this trait. These results are similar to the findings of Panduranga *et al.* (2000), Waghmare *et al.* (2011), Bhoite *et al.* (2015) and Bhoite *et al.* (2018b).

With regard to seed yield per plant, cross combinations, SVCMS-1 x SVSR-3, SVCMS-1 x SVSR-5, SVCMS-2 x SVSR-2, SVCMS-2 x SVSR-4, SVCMS-3 x SVSR-2, SVCMS-3 x SVSR-3, SVCMS-3 x SVSR-7, SVCMS-4 x SVSR-7 and check Phule Raviaj were with significantly higher mean than population mean and regression coefficient less than unity indicating stability and wider adaptability to poor environment, while, hybrids, SVCMS-1 x SVSR-7, SVCMS-2 x SVSR-3, SVCMS-2 x SVSR-6, SVCMS-3 x SVSR-1, SVCMS-3 x SVSR-4, SVCMS-3 x SVSR-5, SVCMS-3 x SVSR-6, SVCMS-4 x SVSR-1, SVCMS-4 x SVSR-5 SVCMS-4 x SVSR-6 and check LSFH-171 with high mean, regression coefficient more than unity (bi>1) with non-significant least deviation from regression line indicated their specific adaptation to favorable or rich environments. Similar results have been reported by Bharathi (2000), Halaswamy *et al.* (2000), Kumar *et al.* (2002), Rao *et al.* (2004), Balu *et al.* (2007), Mijic *et al.* (2007), Ahmed and Abdella (2009), Reddy *et al.* (2009), Tyagi (2012), Bhoite *et al.* (2018b) and Ghaffari *et al.* (2020). Twelve crosses performing better than respective means of F1s (37.07) and also possessed non-significant S^2di for seed volume weight. Among these, SVCMS-1 x SVSR-3, SVCMS-1 x SVSR-5, SVCMS-2 x SVSR-4, SVCMS-2 x SVSR-5, SVCMS-3 x SVSR-3, and SVCMS-4 x SVSR-4 were identified as above average stable hybrids which will be responsive to poor environments (bi>1). Hybrids, SVCMS-1 x SVSR-7, SVCMS-2 x SVSR-3, SVCMS-3 x SVSR-5, SVCMS-4 x SVSR-1, SVCMS-4 x SVSR-5 and SVCMS-4 x SVSR-6 were identified as the ones with average stability and responsive to rich environments (bi>1). The results were in correspondence to the findings of Bhoite *et al.* (2015) and Bhoite *et al.* (2018b).

The hybrids namely SVCMS-1 x SVSR-5, SVCMS-2 x SVSR-5, SVCMS-3 x SVSR-3 and SVCMS-4 x SVSR-4 recorded significantly higher for test weight than hybrid mean (5.81 g) with regression coefficient less than unity and non-significant least deviation from regression, thus found stable and specific adaptable to a poor environment. While below average stability (bi>1) were exhibited in SVCMS-2 x SVSR-3, SVCMS-3 x SVSR-1, SVCMS-4 x SVSR-1 and SVCMS-4 x SVSR-5 hence non-significant deviation from regression and specific adaptation to the favorable or rich environment. SVCMS-3 x SVSR-5 recorded non-significant deviation from regression with unit regression coefficient was suitable for all the environments. These results are similar to the findings of Panduranga *et al.* (2000), Rao *et al.* (2004), Waghmare *et al.* (2011) and Bhoite *et al.* (2018b). For chlorophyll content total four crosses SVCMS-1 x SVSR-7, SVCMS-2 x SVSR-3, SVCMS-3 x SVSR-1 and SVCMS-4 x SVSR-5 showed high mean value than the hybrid mean (38.50) accompanied with bi greater than unity and non-significant S^2di values suggesting below average stability. Non-significant deviation from regression with regression coefficient less than unity exhibited by three crosses, SVCMS-1 x SVSR-5, SVCMS-2 x SVSR-4 and SVCMS-3 x SVSR-3 showed above average stability. However, one hybrid, SVCMS-3 x SVSR-5 was most suitable for all the environments.

Table 3 Stability parameters of sunflower parents and hybrids for days to 50 per cent flowering and days to maturity

Genotype	Day to 50 per cent flowering			Days to maturity		
	Mean (µ)	$S^{-2}di$	bi	Mean (µ)	$S^{-2}di$	bi
SVCMS-1 X SVSR-1	77.56	8.14	0.74	112.78	4.54	3.22
SVCMS-1 X SVSR-2	77.56	6.72	0.10	113.11	-4.80	6.71**
SVCMS-1 X SVSR-3	79.33	-0.86	2.73*	114.67	33.79**	-5.12
SVCMS-1 X SVSR-4	78.22	26.49**	-0.40	113.89	0.42	7.81**
SVCMS-1 X SVSR-5	79.44	21.06**	2.70	118.11	-4.05	-6.78
SVCMS-1 X SVSR-6	76.44	-0.43	0.18	111.78	-4.12	1.87*
SVCMS-1 X SVSR-7	77.67	23.96**	-1.84	117.33	-4.72	6.31**
SVCMS-2 X SVSR-1	76.11	-1.58	1.29	115.89	12.15	0.08
SVCMS-2 X SVSR-2	73.89	-1.66	-2.67	112.33	0.88	3.76
SVCMS-2 X SVSR-3	81.11	-3.18	1.12*	121.00	-3.84	2.50*
SVCMS-2 X SVSR-4	80.33	-3.55	1.01**	120.00	-3.96	0.22
SVCMS-2 X SVSR-5	81.22	-2.97	0.63	120.33	-4.71	0.38
SVCMS-2 X SVSR-6	75.78	6.10	1.26	113.78	-4.62	3.39**
SVCMS-2 X SVSR-7	77.78	4.01	-0.20	114.89	39.81**	0.37
SVCMS-3 X SVSR-1	79.22	8.33	-0.64	116.22	-4.30	4.88**
SVCMS-3 X SVSR-2	78.00	1.74	1.88	113.00	18.04**	0.23
SVCMS-3 X SVSR-3	81.22	-2.74	1.98*	120.33	-4.48	-1.96
SVCMS-3 X SVSR-4	77.00	-3.19	-3.30	111.89	3.27	6.29*
SVCMS-3 X SVSR-5	81.89	9.64	1.38	120.44	-4.33	1.38
SVCMS-3 X SVSR-6	77.33	5.10	-0.04	112.44	5.54	5.62
SVCMS-3 X SVSR-7	74.56	-2.28	1.74	112.78	-3.06	0.62
SVCMS-4 X SVSR-1	76.89	1.71	0.30	115.89	-4.80	4.28**
SVCMS-4 X SVSR-2	76.44	-3.00	1.42*	113.33	-4.30	2.45**
SVCMS-4 X SVSR-3	82.33	-2.08	1.45	119.22	1.91	0.90
SVCMS-4 X SVSR-4	81.44	-3.56	1.59**	119.78	0.89	1.33
SVCMS-4 X SVSR-5	80.56	-2.45	0.23	120.22	-4.01	0.85
SVCMS-4 X SVSR-6	77.33	-3.23	-0.47	113.89	-1.86	8.30**
SVCMS-4 X SVSR-7	76.89	-3.11	1.64**	113.78	-4.74	-0.09
SVCMS-1	69.33	2.63	0.14	105.67	4.18	2.93
SVCMS-2	76.00	21.77**	2.48	110.00	2.49	-3.38
SVCMS-3	65.22	45.94**	8.19	102.22	-4.70	-10.40
SVCMS-4	69.00	0.57	0.24	106.11	2.53	1.48
SVSR-1	72.33	-0.04	3.16*	108.00	-4.37	-2.12
SVSR-2	71.56	41.47**	3.31	107.00	9.22	-1.84
SVSR-3	75.44	10.96**	1.75	110.11	-4.77	-4.66
SVSR-4	72.22	3.98	-2.37	107.33	0.64	-0.81
SVSR-5	71.33	-3.45	-0.27	107.67	-4.41	-0.76
SVSR-6	74.00	17.14**	1.00	109.33	-2.90	0.33
SVSR-7	71.44	-2.87	1.76*	107.56	-0.85	1.50
PhuleRaviraj ©	80.00	1.78	3.27	116.56	12.15	0.08
LSFH-171 ©	79.78	8.93	2.54	116.00	3.64	-1.15
Mean	76.62			113.6		
SEm± mean	2.15			1.80		
SE (bi)	2.47			2.70		

*, ** Significant at 5 and 1 per cent, respectively

Table 4 Stability parameters of sunflower parents and hybrids for plant height (cm) and head diameter (cm)

Genotype	Plant height (cm)			Head diameter (cm)		
	Mean (μ)	$S^{-2}di$	bi	Mean (μ)	$S^{-2}di$	bi
SVCMS-1 X SVSR-1	159.49	65.50**	1.61	15.64	-0.24	3.69**
SVCMS-1 X SVSR-2	160.20	26.26	2.61**	16.64	1.23**	3.26
SVCMS-1 X SVSR-3	171.40	107.61**	-1.27	16.60	-0.25	-5.62
SVCMS-1 X SVSR-4	166.69	-11.58	2.20**	16.57	0.48	5.49**
SVCMS-1 X SVSR-5	172.24	45.80**	-1.08	17.97	5.20**	-7.37
SVCMS-1 X SVSR-6	159.11	65.53**	1.00	15.75	0.46	1.74
SVCMS-1 X SVSR-7	164.69	388.09**	2.32	17.58	-0.27	4.41**
SVCMS-2 X SVSR-1	168.44	119.64**	0.79	16.25	0.34	5.15**
SVCMS-2 X SVSR-2	163.87	47.15**	0.02	15.51	2.36**	-2.01
SVCMS-2 X SVSR-3	181.56	-6.22	0.05	20.24	0.90**	3.20
SVCMS-2 X SVSR-4	177.89	10.58	0.22	19.85	0.10	-2.40
SVCMS-2 X SVSR-5	168.11	487.65**	1.67	19.99	1.39**	-0.98
SVCMS-2 X SVSR-6	164.00	149.88**	2.25	16.60	0.33	6.11**
SVCMS-2 X SVSR-7	166.49	527.27**	1.66	17.80	10.56**	1.63
SVCMS-3 X SVSR-1	170.13	228.85**	1.37	18.00	2.54**	4.15
SVCMS-3 X SVSR-2	163.04	13.55	0.48	15.69	3.73**	-2.49
SVCMS-3 X SVSR-3	180.33	-11.42	-0.14	19.85	-0.14	-1.75
SVCMS-3 X SVSR-4	156.56	474.17**	2.72	16.71	1.16**	3.32
SVCMS-3 X SVSR-5	177.47	-0.45	0.37	19.65	0.43	0.92
SVCMS-3 X SVSR-6	165.07	14.44	1.74**	16.77	-0.17	4.03**
SVCMS-3 X SVSR-7	150.02	894.96**	2.40	15.93	0.11	-3.62
SVCMS-4 X SVSR-1	169.20	21.13	1.11	18.32	2.62**	6.17*
SVCMS-4 X SVSR-2	160.73	251.55**	1.40	15.67	0.48	1.26
SVCMS-4 X SVSR-3	179.38	17.72	-0.26	20.02	4.39**	-0.36
SVCMS-4 X SVSR-4	181.44	-11.56	-0.25	21.13	-0.19	0.74
SVCMS-4 X SVSR-5	180.27	-9.93	0.38*	20.57	0.95**	4.98*
SVCMS-4 X SVSR-6	160.38	3.11	2.94**	16.02	-0.30	8.34**
SVCMS-4 X SVSR-7	150.00	52.02**	2.55**	15.55	0.10	-2.97
SVCMS-1	104.29	-10.97	-0.01	10.82	-0.25	1.57**
SVCMS-2	125.76	68.72**	0.72	13.31	-0.29	-2.25
SVCMS-3	132.00	228.12**	-0.71	12.50	-0.17	-4.55
SVCMS-4	128.11	-10.07	1.02**	12.61	-0.13	-0.55
SVSR-1	133.13	-10.94	1.34**	12.73	0.69	0.06
SVSR-2	127.04	-10.34	0.28	12.97	-0.06	-1.89
SVSR-3	140.51	-10.72	0.72**	14.20	-0.30	-0.63
SVSR-4	134.36	-8.61	0.89**	13.32	0.67	1.15
SVSR-5	133.31	-11.52	1.31**	12.62	1.90**	0.52
SVSR-6	122.91	5.43	1.72**	12.11	-0.28	2.58**
SVSR-7	110.82	-11.76	2.26**	10.94	0.27	1.44
PhuleRaviraj ©	165.69	-6.79	0.58*	16.38	0.78	1.30
LSFH-171 ©	171.44	-10.99	0.03	17.08	-0.06	3.21**
Mean	156.50	P. Mean	126.56	16.21	P. Mean	12.56
SEm± mean	7.50	H. Mean	167.44	0.81	H. Mean	17.60
SE (bi)	1.20			0.02		

*, ** Significant at 5 and 1 per cent, respectively

Table 5 Stability parameters of sunflower parents and hybrids for seed filling (%) and hull content (%)

Genotype	Seed filling (%)			Hull content (%)		
	Mean (μ)	$S^{-2}di$	bi	Mean (μ)	$S^{-2}di$	bi
SVCMS-1 X SVSR-1	78.38	39.89**	1.17	32.72	-0.73	3.55**
SVCMS-1 X SVSR-2	80.11	34.98**	0.38	33.27	-0.40	3.19**
SVCMS-1 X SVSR-3	83.18	44.52**	-2.85	35.08	1.48	-1.64
SVCMS-1 X SVSR-4	82.08	111.99**	0.42	34.13	1.21	4.50**
SVCMS-1 X SVSR-5	85.60	113.99**	-1.53	37.50	-0.22	-4.00
SVCMS-1 X SVSR-6	77.96	30.98**	1.22	33.93	2.49**	1.39
SVCMS-1 X SVSR-7	78.72	95.67**	3.00	35.87	3.46**	3.68
SVCMS-2 X SVSR-1	80.57	-3.44	2.13**	35.05	1.27	1.45
SVCMS-2 X SVSR-2	79.71	39.48**	0.09	34.62	-0.55	-1.36
SVCMS-2 X SVSR-3	89.64	24.59**	2.05	39.28	-0.67	0.79**
SVCMS-2 X SVSR-4	90.91	-4.60	-0.39	38.21	-0.37	-1.13
SVCMS-2 X SVSR-5	89.09	-4.39	3.23**	38.71	-0.27	-0.12
SVCMS-2 X SVSR-6	81.62	128.54**	1.35	34.12	0.63	4.57**
SVCMS-2 X SVSR-7	82.28	-2.56	4.51**	35.83	11.40**	0.15
SVCMS-3 X SVSR-1	84.31	40.68**	1.36	36.17	-0.38	3.51**
SVCMS-3 X SVSR-2	77.53	69.76**	2.35	35.04	0.63	-3.62
SVCMS-3 X SVSR-3	89.67	1.24	-0.34	38.86	-0.36	0.50
SVCMS-3 X SVSR-4	80.40	47.34**	2.24	34.83	4.55**	2.15
SVCMS-3 X SVSR-5	90.24	9.21	-0.03	38.60	-0.11	1.41
SVCMS-3 X SVSR-6	80.67	24.60**	2.82	35.20	3.53**	2.29
SVCMS-3 X SVSR-7	77.42	21.50**	0.43	35.14	6.02**	-1.08
SVCMS-4 X SVSR-1	84.27	50.28**	1.67	37.13	-0.70	2.75**
SVCMS-4 X SVSR-2	76.76	24.25**	0.00	33.91	2.39**	2.79
SVCMS-4 X SVSR-3	88.96	11.00	-1.62	38.24	2.71**	0.12
SVCMS-4 X SVSR-4	89.60	2.32	2.33*	38.70	-0.66	-0.67
SVCMS-4 X SVSR-5	91.21	12.98	1.17	38.63	0.83	1.03
SVCMS-4 X SVSR-6	80.27	94.61**	1.76	34.43	3.49**	4.82*
SVCMS-4 X SVSR-7	76.47	-4.62	-0.33	35.29	2.40**	1.40
SVCMS-1	69.04	-2.31	1.86**	24.66	2.83**	2.34
SVCMS-2	71.44	23.55**	0.30	29.13	-0.66	-1.48
SVCMS-3	69.19	66.64**	-0.44	23.07	8.61**	-1.15
SVCMS-4	72.47	6.43	0.32	27.56	-0.19	1.43
SVSR-1	72.23	8.91	0.31	26.48	0.92	1.99
SVSR-2	72.24	156.19**	0.02	27.00	3.70**	-2.97
SVSR-3	75.51	44.69**	1.56	28.80	-0.21	1.13
SVSR-4	72.69	22.75**	-0.01	26.94	-0.70	-0.29
SVSR-5	74.96	44.83**	0.63	26.53	-0.68	0.21
SVSR-6	72.87	14.95**	0.08	24.06	0.16	3.19**
SVSR-7	69.53	71.92**	1.86	21.87	0.15	1.21
PhuleRaviraj ©	83.07	-0.01	2.55**	35.26	-0.72	0.87**
LSFH-171 ©	81.51	-4.55	3.37**	34.84	-0.68	2.12**
Mean	80.11	P. Mean	72.02	33.29	P. Mean	26.01
SEm± mean	4.55	H. Mean	83.13	1.03	H. Mean	33.29
SE (bi)	2.15			1.51		

*, ** Significant at 5 and 1 per cent, respectively

Table 6 Stability parameters of sunflower parents and hybrids for seed yield per plant (g)

Genotype	Seed yield per plant (g)		
	Mean (μ)	$S^{-2}di$	bi
SVCMS-1 X SVSR-1	34.49	-2.60	2.50
SVCMS-1 X SVSR-2	34.88	-5.01	4.03**
SVCMS-1 X SVSR-3	37.60	11.57	-3.26
SVCMS-1 X SVSR-4	35.80	-5.51	5.34**
SVCMS-1 X SVSR-5	40.42	-4.01	-7.95
SVCMS-1 X SVSR-6	34.31	-5.65	1.55**
SVCMS-1 X SVSR-7	38.84	-0.26	4.01
SVCMS-2 X SVSR-1	34.96	-2.76	3.07
SVCMS-2 X SVSR-2	34.10	-5.40	-0.30
SVCMS-2 X SVSR-3	46.59	2.57	5.63*
SVCMS-2 X SVSR-4	45.62	14.67	-3.78
SVCMS-2 X SVSR-5	45.72	16.57**	-0.80
SVCMS-2 X SVSR-6	36.62	-5.36	6.09**
SVCMS-2 X SVSR-7	39.01	34.09**	-3.13
SVCMS-3 X SVSR-1	39.40	-1.61	5.84**
SVCMS-3 X SVSR-2	34.81	4.29	-2.34
SVCMS-3 X SVSR-3	44.34	-1.86	-3.37
SVCMS-3 X SVSR-4	35.17	13.26	1.77
SVCMS-3 X SVSR-5	44.73	-3.67	3.73**
SVCMS-3 X SVSR-6	35.89	-3.64	3.40*
SVCMS-3 X SVSR-7	36.88	-1.78	-0.43
SVCMS-4 X SVSR-1	37.49	-5.34	4.09**
SVCMS-4 X SVSR-2	34.66	-4.90	1.55
SVCMS-4 X SVSR-3	44.95	97.22**	0.47
SVCMS-4 X SVSR-4	46.51	43.10**	-1.49
SVCMS-4 X SVSR-5	47.54	-4.87	4.79**
SVCMS-4 X SVSR-6	36.49	-4.40	6.13**
SVCMS-4 X SVSR-7	36.52	-5.52	-1.16
SVCMS-1	19.28	-2.92	2.55
SVCMS-2	24.95	-5.40	0.34
SVCMS-3	20.77	1.68	-3.78
SVCMS-4	24.20	-5.66	1.35**
SVSR-1	25.77	-3.81	0.28
SVSR-2	25.62	9.67	-2.27
SVSR-3	29.32	-3.58	0.43
SVSR-4	27.21	-5.54	-1.37
SVSR-5	26.67	-5.34	0.11
SVSR-6	23.56	-2.09	3.10
SVSR-7	20.57	-3.08	2.21
PhuleRaviraj ©	36.25	-5.59	0.60*
LSFH-171 ©	36.27	-5.51	1.46**
Mean	34.99	P. Mean	25.90
SEm± mean	2.09	H. Mean	37.07
SE (bi)	2.67		

*, ** Significant at 5 and 1 per cent, respectively

Table 7 Stability parameters of sunflower parents and hybrids for seed volume weight (g) and 100 seed weight (g)

Genotype	Seed volume weight (g)			100 seed weight (g)		
	Mean (μ)	$S^{-2}di$	bi	Mean (μ)	$S^{-2}di$	bi
SVCMS-1 X SVSR-1	34.97	-0.97	2.40**	5.10	-0.06	4.27**
SVCMS-1 X SVSR-2	34.86	-1.47	3.62**	5.60	-0.06	2.36**
SVCMS-1 X SVSR-3	37.26	3.38	-3.12	5.63	0.28**	-0.30
SVCMS-1 X SVSR-4	35.17	2.06	4.05	5.20	-0.02	7.20**
SVCMS-1 X SVSR-5	37.99	-0.88	-5.53	5.96	0.08	-4.91
SVCMS-1 X SVSR-6	35.19	-1.19	0.98	5.30	-0.04	2.11
SVCMS-1 X SVSR-7	37.64	0.34	1.25	5.80	0.25**	0.86
SVCMS-2 X SVSR-1	35.17	0.34	3.98**	5.34	0.03	1.87
SVCMS-2 X SVSR-2	34.37	-1.30	0.27	5.24	-0.05	-0.62
SVCMS-2 X SVSR-3	41.30	-1.14	1.57*	6.69	-0.06	5.35**
SVCMS-2 X SVSR-4	39.80	3.00	-1.00	6.78	0.50**	-2.53
SVCMS-2 X SVSR-5	40.02	-0.20	-1.63	6.48	-0.01	0.40
SVCMS-2 X SVSR-6	35.53	-1.42	4.61**	5.33	0.15	6.90*
SVCMS-2 X SVSR-7	36.70	21.54**	0.20	5.64	0.15	-4.05
SVCMS-3 X SVSR-1	38.09	6.87**	4.57	5.86	0.07	4.62
SVCMS-3 X SVSR-2	35.06	2.41	-1.43	5.56	-0.06	-4.86
SVCMS-3 X SVSR-3	40.16	-1.28	-1.11	6.37	-0.02	0.09
SVCMS-3 X SVSR-4	35.56	4.16	2.83	5.18	0.50**	1.14
SVCMS-3 X SVSR-5	38.48	-1.49	1.94**	6.44	-0.05	1.06
SVCMS-3 X SVSR-6	35.93	1.80	4.52*	5.50	0.06	2.17
SVCMS-3 X SVSR-7	35.96	2.69	-1.19	5.50	0.05	-1.50
SVCMS-4 X SVSR-1	37.80	-1.48	4.01**	5.91	-0.04	2.07
SVCMS-4 X SVSR-2	34.39	1.06	1.84	5.12	0.05	7.20**
SVCMS-4 X SVSR-3	39.60	6.32**	-0.12	6.43	1.17**	2.10
SVCMS-4 X SVSR-4	40.09	0.70	-0.78	6.58	0.04	-3.17
SVCMS-4 X SVSR-5	40.50	-1.03	2.42**	6.96	-0.03	2.23
SVCMS-4 X SVSR-6	34.97	-1.43	4.86**	5.64	0.02	2.76
SVCMS-4 X SVSR-7	35.46	5.57**	1.34	5.52	0.02	-1.20
SVCMS-1	24.21	8.84**	2.10	3.31	0.04	2.21
SVCMS-2	26.94	-0.68	-0.37	4.24	0.01	1.75
SVCMS-3	24.30	3.92	-4.14	3.91	0.44**	-5.88
SVCMS-4	26.74	-1.23	1.67**	4.26	-0.06	0.54**
SVSR-1	25.43	-1.20	2.60**	4.43	-0.02	-0.25
SVSR-2	26.83	4.78**	-4.45	4.56	0.10	-2.44
SVSR-3	29.57	-0.69	0.58	4.83	-0.06	0.34**
SVSR-4	27.44	-1.17	-0.03	4.40	-0.06	-1.79
SVSR-5	27.00	-0.85	1.21	4.37	-0.06	-1.11
SVSR-6	24.28	-1.44	2.40**	4.04	-0.05	4.28**
SVSR-7	22.10	-1.31	1.36**	3.62	0.10	5.06
PhuleRaviraj ©	35.61	-1.49	1.28**	5.32	-0.06	1.65**
LSFH-171 ©	36.14	-1.09	1.42*	5.39	-0.01	3.02
Mean	34.01	P. Mean	25.90	5.35	P. Mean	4.18
SEm± mean	37.07	H. Mean	37.07	0.26	H. Mean	5.81
SE (bi)	25.90			2.72		

*, ** Significant at 5 and 1 per cent, respectively

Table 8 Stability parameters of sunflower parents and hybrids for chlorophyll content (Spad value) and leaf area (cm^2)

Genotype	Chlorophyll content (Spad value)			Leaf area (cm^2)		
	Mean (μ)	$S^{-2}di$	bi	Mean (μ)	$S^{-2}di$	bi
SVCMS-1 X SVSR-1	34.10	2.22	3.58	475.5	-728.2	11.6**
SVCMS-1 X SVSR-2	34.28	2.70	4.03*	515.8	-61.8	10.0**
SVCMS-1 X SVSR-3	37.75	28.48**	-2.69	529.5	158.2	-11.2
SVCMS-1 X SVSR-4	35.64	0.35	5.13**	496.4	-684.6	8.7**
SVCMS-1 X SVSR-5	40.64	-1.38	-6.83	564.5	-633.8	-13.1
SVCMS-1 X SVSR-6	34.39	-2.23	2.12**	486.3	-719.7	2.9**
SVCMS-1 X SVSR-7	39.00	2.53	4.36*	513.4	-549.0	-0.5
SVCMS-2 X SVSR-1	35.35	6.04	2.67	492.9	-710.2	5.9**
SVCMS-2 X SVSR-2	34.26	-2.21	-0.45	493.4	-732.4	0.1
SVCMS-2 X SVSR-3	44.70	-0.71	3.66**	602.3	4.6	1.8
SVCMS-2 X SVSR-4	44.66	-1.17	-1.80	595.6	919.0	-4.7
SVCMS-2 X SVSR-5	44.60	8.14**	-1.15	579.7	600.6	1.8
SVCMS-2 X SVSR-6	36.24	1.90	5.77**	501.9	-171.8	10.6**
SVCMS-2 X SVSR-7	37.37	45.81**	-2.52	535.2	4130.0**	-1.6
SVCMS-3 X SVSR-1	38.65	-1.10	4.68**	555.4	-43.2	8.4*
SVCMS-3 X SVSR-2	34.58	3.49	-2.42	479.7	649.9	-3.0
SVCMS-3 X SVSR-3	43.59	0.83	-1.79	565.8	-360.7	-7.5
SVCMS-3 X SVSR-4	34.50	10.63**	1.23	482.3	2940.1**	5.4
SVCMS-3 X SVSR-5	44.38	-1.83	0.97	584.5	-683.8	1.9
SVCMS-3 X SVSR-6	36.43	7.55**	2.95	503.3	782.9	6.5
SVCMS-3 X SVSR-7	35.47	6.09	-0.62	505.9	-731.5	-3.7
SVCMS-4 X SVSR-1	38.45	-2.20	3.58**	535.9	40.4	1.6
SVCMS-4 X SVSR-2	34.74	1.84	3.08	491.2	-25.6	2.4
SVCMS-4 X SVSR-3	43.43	30.44**	2.97	588.1	2299.3**	-2.8
SVCMS-4 X SVSR-4	44.70	6.73**	-1.60	578.8	-143.2	1.7
SVCMS-4 X SVSR-5	45.53	-2.22	1.88**	581.2	-709.4	2.1**
SVCMS-4 X SVSR-6	36.03	-0.97	5.64**	505.4	86.4	7.6
SVCMS-4 X SVSR-7	34.62	3.96	1.11	490.5	-2.4	-1.5
SVCMS-1	22.38	-1.90	0.49	198.0	-723.0	5.6**
SVCMS-2	25.34	-2.22	0.13	270.3	-350.9	2.4
SVCMS-3	22.95	-0.85	-1.36	228.7	-702.3	-5.9
SVCMS-4	24.67	-2.23	0.96**	259.2	-667.0	-0.9
SVSR-1	26.31	1.17	0.06	260.4	-678.5	-0.2
SVSR-2	25.91	5.96	-1.09	238.7	1261.8	-0.8
SVSR-3	29.23	-2.10	-0.16	284.2	-727.3	-0.4
SVSR-4	26.61	-0.08	-0.44	278.3	-725.3	-0.5
SVSR-5	26.31	-2.20	1.12**	273.1	107.7	1.2
SVSR-6	24.77	-2.14	2.34**	239.7	-692.4	0.1
SVSR-7	22.65	-2.08	1.41**	228.4	682.4	1.8
PhuleRaviraj ©	38.44	16.01**	-0.22	523.4	-687.7	-1.0
LSFH-171 ©	38.31	12.86**	0.23	530.4	-669.2	-1.5
Mean	34.93	P. Mean	25.19	454.7	P. Mean	250.8
SEm± mean	1.80	H. Mean	38.50	19.3	H. Mean	529.7
SE (bi)	2.25			3.8		

*, ** Significant at 5 and 1 per cent, respectively

Cross combinations, SVCMS-1 x SVSR-5, SVCMS-2 x SVSR-4, SVCMS-3 x SVSR-3 and LSFH-171 for leaf area with significantly higher mean than hybrid mean (529.66 cm2) and non-significant deviation from regression with regression coefficient less than unity indicated stable and wide adaptability to poor environment, while, hybrids, SVCMS-2 x SVSR-3, SVCMS-2 x SVSR-5, SVCMS-3 x SVSR-1, SVCMS-3 x SVSR-5, SVCMS-4 x SVSR-1, SVCMS-4 x SVSR-4 and SVCMS-4 x SVSR-5 were with high mean, regression coefficient more than unity (bi>1) with least deviation from regression line which indicated their specific adaptation to favorable environments (Table 3 to 8). Similar kind of observations have been made by Tyagi *et al.* (2018).

From the findings, it could be concluded that three hybrids; SVCMS-4 x SVSR-5, SVCMS-2 x SVSR-3 and SVCMS-2 x SVSR-4 exhibited stability for seed yield and these hybrids should be tested in multi-location trials in the future breeding program.

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Effect of nitrogen, phosphorus and sulphur on growth, yield and quality of Indian mustard [*Brassica juncea* (L.) Czern & Coss.]

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ABSTRACT

A field experiment was carried out at Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat during the winter 2018-19 to study the effect of different nutrient levels on growth, yield and quality of Indian mustard. Twelve treatment combinations viz., three levels of nitrogen (50, 75 and 100 kg N/ha), two levels of phosphorus (50 and 75 kg P_2O_5/ha) and two levels of sulphur (40 and 60 kg S/ha) were evaluated as per randomized block design in three replications. Soil of the experimental field was loamy sand in texture, low in organic carbon (0.18 %) and available nitrogen (171 kg/ha), medium in available P_2O_5 (37.2 kg/ha) and low in available sulphur (6.8 kg/ha) with soil pH of 7.3. Application of 75 kg N/ha along with 50 kg P_2O_5/ha and 40 kg S/ha resulted in higher seed yield, oil and protein content, as well as net returns.

Keywords: Economics, Growth, Indian mustard, Nitrogen, Phosphorus, Quality, Sulphur, Seed yield

Rapeseed-mustard is the third most important chief edible oilseed crop after soybean and groundnut in India (Chand *et al.,* 2021). India is the 4th largest oil seed producing economy in the world after USA, China and Brazil, which contributes about 10% of the world oilseeds production, 6-7% of the global production of vegetable oil, and nearly 7% of protein meal (ICFA, 2019). Of rapeseed-mustard group of crops, Indian mustard [*Brassica juncea* (L.) Czern & Coss.] accounts for more than 80% of the total cropped area in India. It is cultivated under semi-arid to arid tropical zones with nearly 26% area under rainfed cultivation (Singh and Chauhan, 2013). It is the most important winter season oilseed crop which performs best in light to heavy loam soil in areas receiving 25 to 40 cm rainfall.

The mustard yield can be increased to 2.0-2.5 t/ha by improved agronomic practices. Fertilizer management plays an important role in increasing the productivity of mustard, which can be realized by providing plant nutrients in the required amount at optimum stage of crop growth.

The chemical fertilizers being used as a source of major nutrients are either deficient or low in sulphur content. The significance of sulphur fertilization for increasing yield and quality of Indian mustard is being increasingly recognized (Kumar, 2015). Such information is lacking for the agroclimatic conditions of north Gujarat. Present study was conducted to find out the response of Indian mustard to application of sulphur in conjunction with nitrogen and phosphorus.

The experiment was conducted at the Agronomy Instructional Farm, C.P. College of Agriculture, S.D.A.U., Sardarkrushinagar, Gujarat during Winter season of the year 2018-19. Geographically, Sardarkrushinagar (24°-19' N latitude and 72°-19' E longitude with an 65 altitude of 154.5 meters above the mean sea level), Gujarat during winter season of 2018-19. The soil of the experimental field was loamy sand in texture, low in organic carbon (0.18 %) and available nitrogen (171 kg/ha), medium in available P_2O_5 (37.2 kg/ha) and low in available sulphur (6.8 kg/ha) with a pH of 7.3. Twelve treatment combinations comprising three levels of nitrogen (50, 75 and 100 kg N/ha), two levels of phosphorus (50 and 75 kg P_2O_5/ha) and two levels of sulphur (40 and 60 kg S/ha) were evaluated in factorial randomized block design in three replications. Mustard variety GDM-4 was sown manually on 30 October 2018 by maintaining - 45 cm row spacing at a depth of 3 cm at a seed rate of 3.75 kg/ha. Plant to plant spacing of 15 cm within rows was maintained by thinning at about 15 days after sowing. Nitrogen, phosphorus, and sulphur were applied as per the treatments through urea, di-ammonium phosphate and gypsum, respectively. The total quantity of phosphorus, gypsum and half dose of nitrogen was applied in opened furrow at the time of sowing as per treatments. The remaining half dose of nitrogen was top-dressed at 30 days after sowing. All other recommended cultivation practices of the region were followed for raising the crop. The observations recorded for growth and yield attributes, yield and quality parameters were subjected to the statistical analysis following analysis of variation techniques as suggested by Fisher (1950) for randomized block design (RBD).

Application of 100 kg N/ha resulted in highest plant height (166.7 cm), number of primary branches (5.85) and secondary branches (17.27) per plant which were on par with

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that of 75 kg N/ha (Table 1). Both these doses were significantly better (except number of primary branches with 75 kg N/ha) than 50 kg N/ha. The increase in plant height with nitrogen nutrition might have been due to enhanced meristematic activity- which might have increased division, enlargement and elongation of cells. Higher accumulation and translocation of assimilates in the plant might have improved vegetative growth and ultimately increased number of primary branches/plant. These results are in conformity with the findings of Dongarkar *et al.* (2005), Singh and Singh (2012), Saud *et al.* (2016) and Dhruw *et al.* (2017).

Application of 100 kg N/ha significantly increased the number of siliquae/plant (302), length of siliqua (5.29 cm), and test weight (5.12 g) over 50 kg N/ha (Table 1). Increase in test weight with 100 kg N/ha over 75 kg N/ha was also significant. However, number of seeds/siliqua was not influenced by application of nitrogen. Highest level of nitrogen might have resulted in better filling of grains resulting in bold sized seeds and other yield attributes. The beneficial effects of nitrogen on yield attributes were also reported by Keivanrad and Zandi (2014) and Kishore *et al.* (2014). Application of 100 kg N/ha resulted in highest seed (2485 kg/ha) and stover (5208 kg/ha) yield which were at par with that of 75 kg N/ha and significantly higher over application of nitrogen @ 50 kg/ha (Table 1). Thus application of 100 kg N/ha and 75 kg N/ha increased seed yield to the tune of 15.6 and 10.8 %, respectively over the 50 kg N/ha. Higher yield with higher dose of N might be due to the cumulative effect of improvement in plant height, number of primary and secondary branches/plant and yield attributes. This result is in line with that of Sah *et al.* (2006) and Dawson *et al.* (2009).

An application of 100 kg N/ha significantly increased the protein (20.47 %) and oil content (38.02 %) as compared to 50 kg N/ha (Table 1). Synthesis of fatty acids in plants occurs through the conversion of acetyl Co-A to malonyl Co-A in the presence of ATP and phosphate. Nitrogen is a component of amino acids which constitute the building blocks of protein. The results are in accordance with those reported by Dhruw *et al.* (2017) and Keerthi *et al.* (2017).

Application of 100 kg N/ha resulted in highest gross (₹ 89553/ha) and net return (₹ 60030/ha) as well as a benefit: cost ratio (BCR) (3.03).

Application of 75 kg P_2O_5/ha failed to cause any significant improvement in growth and yield attributes, yield, protein content and oil over 50 kg P_2O_5/ha (Tables 1 and 2). Higher dose resulted in higher gross return (₹ 86100/ha) and net return (₹ 56309/ha) and a benefit: cost ratio 2.89 over lower dose. Similar findings have also been reported by Singh and Singh (2012), Kansotia *et al.* (2015) and Mallick and Raj (2015).

Table 1 Effect of fertility levels on growth and yield attributes and yield of mustard under north Gujarat condition

Treatments	Plant height at harvest (cm)	Number of primary branches/ plant	Number of secondary branches/ plant	Seeds/ siliqua	Number of siliquae/ plant	Length of siliqua (cm)	Test weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)
Nitrogen levels (kg/ha)									
50 kg/ha	148.3	5.1	15.6	13.4	264.2	4.3	4.7	2150	4634
75 kg/ha	161.1	5.5	17.2	13.4	294.2	5.1	4.7	2382	5143
100 kg/ha	166.7	5.9	17.3	13.6	302.0	5.3	5.1	2485	5208
SEm ±	3.4	0.2	0.5	0.2	7.5	0.1	0.1	72	128
CD at 5%	9.9	0.5	1.4	NS	20.7	0.2	0.2	210	375
Phosphorus levels (kg P_2O_5/ha)									
50 kg/ha	155.3	5.4	16.5	13.4	279.6	4.9	4.8	2290	4880
75 kg/ha	162.1	5.6	16.9	13.5	293.9	5.0	4.9	2387	5110
SEm ±	2.8	0.1	0.4	0.7	5.8	0.1	0.1	59	104
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sulphur levels (kg/ha)									
40 kg/ha	154.0	5.3	16.3	13.3	282.3	4.8	4.8	2315	4902
60 kg/ha	163.5	5.6	17.1	13.6	291.2	5.0	4.9	2362	5088
SEm ±	2.8	0.2	0.4	0.2	5.8	0.1	0.1	59	104
CD at 5%	8.1	NS	NS	NS	NS	NS	NS	NS	NS
Interactions	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2 Effect of fertility levels on quality and economics of mustard under north Gujarat condition

Treatments	Protein content (%)	Oil content (%)	Gross return (Rs/ha)	Cost of cultivation (Rs/ha)	Net Return (Rs/ha)	BCR
Nitrogen levels (kg/ha)						
50 kg/ha	19.2	36.1	77558	28850	48708	2.69
75 kg/ha	20.2	37.3	85942	29189	56753	2.95
100 kg/ha	20.5	38.0	89553	29523	60030	3.03
SEm ±	0.3	0.5	---	---	---	---
CD at 5%	0.9	1.5	---	---	---	---
Phosphorus levels (kg P_2O_5/ha)						
50 kg/ha	19.8	36.9	82602	28584	54018	2.89
75 kg/ha	20.1	37.4	86100	29791	56309	2.89
SEm ±	0.3	0.4	---	---	---	---
CD at 5%	NS	NS	---	---	---	---
Sulphur levels (kg/ha)						
40 kg/ha	19.7	36.5	83482	28937	54545	2.88
60 kg/ha	20.2	37.9	85220	29438	55782	2.89
SEm ±	0.3	0.4	---	---	---	---
CD at 5%	NS	1.2	---	---	---	---
Interactions	NS	NS				
CV (%)	5.2	4.8				

Application of 75 kg S/ha failed to exert significant effect on any growth (except plant height), yield attributes, yield and quality (except oil content) over 50 kg S/ha (Table 1 and 2). Sulphur application is known to enhance the cell division and cell elongation or expansion, which ultimately increases the height of the plant (Singh *et al.,* 2017). This result is supported by Singh and Pandey (2017) and Yadav *et al.* (2017). Application of 60 kg S/ha significantly increased the oil content in seed by 3.9% over 40 kg S/ha. Sulphur is involved in the biosynthesis of oil. It is involved in the formation of glucosides and glucosinolates and sulphydril-linkage and activation of enzymes, which aid in biochemical reaction within the plant and on hydrolysis produces a higher amount of oil reported by Ray *et al.* (2015), and Yadav *et al.* (2017). Application of 60 kg S/ha recorded higher gross realization (₹ 85220/ha) and net realization (₹ 55782/ha) with the benefit:cost ratio (BCR) 2.89 than lower dose of S. Higher seed and stover yields with higher dose of S increased the income realization. The results are in agreement with the findings of Kumar *et al.* (2015) and Singh *et al.* (2017).

The interaction effect of nitrogen, phosphorus and sulphur levels on growth attributes, yield, yield attributes, quality parameter and chemical analysis was non-significant. It is concluded that in loamy sand soil of North Gujarat, mustard crop should be fertilized with 75 kg N/ha along with 50 kg P_2O_5/ha and 40 kg S/ha for obtaining higher seed yield, protein content, oil content and income.

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Singh R K and Singh P C 2012. Effect on nitrogen and phosphorus levels on Indian mustard [*Brassica juncea* (L.) Czern and Coss]. *New Agriculturist*, **23**(1): 35-40.

Yadav R, Singh P K, Tiwari P and Singh S N 2017. Impact of sulphur nutrition on promising mustard cultivars in eastern Uttar Pradesh. *International Journal of Pure and Applied Bioscience*, **5**(1): 389-394.

INDIAN SOCIETY OF OILSEEDS RESEARCH

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

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

General

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

Manuscript

Language of the Journal is English. Generally, the length of an article should not exceed 3,000 words in the case of full-length article and 750 words in the case of short communication. However completeness of information is more important. Each half-page table or illustration should be taken as equivalent to 200 words. It is desirable to submit manuscript in the form of soft copy either as an e-mail attachment to editorisor@gmail.com (preferred because of ease in handling during review process) or in a **compact disk (CD) (in MS Word document; double line space; Times New Roman; font size 12).** In exceptional cases, where the typed manuscript is being submitted as hard copy, typing must be done only on one side of the paper, leaving sufficient margin, at least 4 cm on the left hand side and 3 cm on the other three sides. Faded typewriter ribbon should not be used. Double space typing is essential throughout the manuscript, right from the **Title** through **References** (except tables), foot note etc. Typed manuscript complete in all respects, is to be submitted to the Editor, Journal of Oilseeds Research, Directorate of Oilseeds Research, Rajendranagar, Hyderabad-500 030. Every page of the manuscript, including the title page, references, tables, etc. should be numbered. Punctuation marks help to show the meanings of words by grouping them into sentences, clauses, and phrases and in other ways. These marks should be used in proper manner if the reader of a paper is to understand exactly the intended meaning. Receipt of the manuscript (in the form of either soft or hard copy) will be acknowledged by the editorial office of the Society, giving a manuscript number which should be quoted in all subsequent correspondence regarding that particular article.

Full-length Articles

Organization of the Manuscript

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

Full-length article comprises the following sections.

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

Guidelines for each section are as follows:

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

Short Title

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

Title

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

Author/Authors

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

Institution and Address

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

Abstract

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Short Communication

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

Tables

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

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

Figures

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

Title of the article and name(s) of the author(s) should be written sufficiently below the caption. The photographs (black and white) should have a glossy finish with sharp contrast between the light and the dark areas. Colour photographs/ figures are not normally accepted. One set of the original figures must be submitted along with the manuscript, while the second set can be photocopy. The illustrations should be numbered consecutively in the order in which they are mentioned in the text. The position of each figure should be indicated in the margin of the text. The photographs should be securely enclosed with the manuscript after placing them in hard board pouches so that there may not be any crack or fold. Photographs should preferably be 8.5 cm or 17 cm wide or double the size. The captions for all the illustrations (including photographs) should be typed on a separate sheet of paper and placed after the tables.

Expression of Plant Nutrients on Elemental Basis

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

SI Units and Symbols

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

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

Names and Symbols of SI Units

Physical Symbol for SI Unit Symbol Remarks quantity physical quantity for SI Unit

Primary Units					
length	l		time	t	
metre	m		second	s	
mass	m		electric current	I	
kilogram	kg		ampere	A	
Secondary Units					
plane angle	radian	rad	Solid angle	steradian	sr
Unit Symbols					
centimetre	cm		microgram	µg	
cubic centimetre	cm^3		micron	µm	
cubic metre	m^3		micronmol	µmol	
day	d		milligram	mg	
decisiemens	dS		millilitre	mL	
degree-Celsium	°C [=(F-32)x0.556]		minute	min	

gram	g	nanometre	nm
hectare	ha	newton	N
hour	h	pascal	Pa
joule J	(= 10^7 erg or 4.19 cal.)	second	s
kelvin	K (= °C + 273)	square centimetre	cm^2
kilogram	kg	square kilometre	km^2
kilometre	km	tonne	t
litre	L	watt	W
megagram	Mg		

Some applications along with symbols

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

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

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

Special Instructions

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

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

III. A sentence should not begin with an abbreviation.

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

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

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

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

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

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

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

Details of the peer review process

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

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

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

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

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

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

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

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

Important Instructions

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

SPECIAL ANNOUNCEMENT

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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