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INVITED ARTICLE

Development of climate resilient varieties of Sunflower, Castor, Safflower, Sesame & Niger

ABSTRACT

Climate change (CC) is the present challenge to mankind, which has direct effect on agriculture. There are various strategies developed to face climate change in agriculture. Crop diversification is one among the best strategies, in which oilseeds fits very well since they are climate resilient crops by their true nature. Oilseed crops such sunflower, castor, safflower, sesame and niger take the advantage of elevated CO_2 with increase in both quality and quantity. Nevertheless, climate change will restrict resource availability and alter conditions that are vital to oilseed crop growth and yield, thus instigating environmentally induced shifts in phenotypes. Understanding this phenotypic plasticity is essential to predict and manage climate change impact on current and future oilseed crops. Breeding for phenotypic plasticity in traits other than seed or oil yield will potentially provide resilience under increasingly unpredictable environmental conditions. Major changes in breeding and management programs may be required for achieving these interconnected goals.

Introduction

Vegetable oils are one of the most valuable commodities in world trade. They are subject to specific quality requirements, both for food and non-food uses, there being a continuous demand for new oil types. Thus, plant breeders have made great efforts over the past four decades to develop those quality features demanded by the industry, mainly related to the fatty acid composition of the seed oil. Initially, breeders had to focus on the natural variation occurring within each oilseed crop and closely related species. Oilseed crops, such as soybean (*Glycine max* L.), rapeseed/canola (*Brassica napus*L.), sunflower (*Helianthus annuus*L.), peanut (*Arachishypogaea*L.), safflower (*Carthamustinctorius*L.), flax (*Linumusitatissimum*L.), castor (*Ricinuscommunis*L.), sesame (*Sesamumindicum*L.) etc., are predominantly grown for the oil con-tained in their seeds. The major oilseed producing countries in the world are the United States, Brazil, China, Argentina, and India. Oil crops are primarily used as a source of edible oil and as protein-rich meal for livestock feed; however, they are also utilized to produce pharmaceuticals, surfactants, plasticizers, emulsifiers, detergents, lubricants, adhesives, cos-metics, oleo-chemicals, fuels, etc. (FAOSTAT, 2014).India's total oilseed production in 2016-17 is 32.10 mt covering an area of 26.21m hacters (DAC 2017). Oilseeds in India are primarily grown under rained situation. Climate change (CC) is characterized by higher temperatures, elevated atmospheric CO_2 concentrations, extreme climatic hazards, and less water available for agriculture. Over the last three years,

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an estimated two million hectares of traditional oilseed area was lost to dry weather conditions in India. Rainfed crops are more vulnerable to climate change because of the limited options for coping with variability of rainfall and temperature. This will result in shift in sowing time and shorter growing season, which may necessitate effective adjustment in sowing and harvesting dates. Frequent and more intense extreme events such as untimely rain, dry spells, low or high temperature and water logging have become the norm of the day for oilseed farming. Climate change will restrict resource availability and alter conditions that are vital to oilseed crop growth and yield, thus instigating environmentally induced shifts in phenotypes. Understanding this phenotypic plasticity is essential to predict and manage climate change impact on current and future oilseed crops. Breeding for phenotypic plasticity in traits other than seed or oil yield will potentially provide resilience under increasingly unpredictable environmental conditions. The present review paper attempts to give an insight into impact of climate change and strategies adopted to improve minor oilseeds for climate resilience. For the foreseeable future, CC will help prioritize the objectives of the research agenda of oilseed crops breeding.

Climate change components

The definition of global climate change is a change in the long-term weather patterns that characterize different regions of the world, while weather refers to the short-term (daily to weekly) changes in temperature, wind, and precipitation of a particular location. Drivers of CC through changes in atmospheric composition can influence growth and development of oilseed crops directly by their impacts on crop physiology (IPCC, 2013). In regions where crops are growing at or close to their physiological maxima, CC (especially high temperature, warming, and salinity) will have an immediate impact on their growth and yield. Moreover, CC impacts agro-ecosystems through changes over the long term in key variables affecting plant growth (e.g. rising temperatures and increased salinity) and through increasing the variability (frequency and intensity) of weather conditions (rainfall, drought, and elevated temperature). These changes also affect crop productivity and product (seed or oil) quality as well as how biotic stresses impact such crops (Ortiz et al. 2014).

Impact of climate change on oilseeds production

Climate change (CC) is expected to alter the availability of resources and the conditions that are crucial to oilseeds crop performance. One way these crop plants will respond to CC is through environmentally induced shifts in phenotypes (i.e., phenotypic plasticity); therefore, understanding plastic responses is crucial for predicting and managing the effects of CC on current and future oilseed crops (Nicotraet al. 2010). Climate change is predicted to bring about increased temperatures across the world in the range of 1.6°C to as much as 5- 6°C by 2050. The rainfall pattern is predicted to change, and some areas will receive less annual rainfall, while others may receive much more. The timing of rains and crop-growing periods will also change. The frequency and duration of extreme weather events are also predicted to increase, although uncertainty exists about the expected degree of changes. These predicted changes in climate are expected to have fairly widespread impacts on oilseeds production in India. Changes in climate are likely to place new pressures on conservation of wild relatives and land races of oilseed crop species (IPCC, 2013). Climate change is likely to be an additional threat to agricultural biodiversity, increasing genetic erosion of land races and threatening wild species, including crop wild relatives (Pignoneand Hammer, 2013).

The response of oilseed crops to CC will be primarily dictated by a complex set of interactions to temperature, CO_2, solar radiation, and precipitation. Most oilseed crops are currently grown at temperatures that match their threshold values; however, temperatures are expected to rise over the twenty-first century as a result of global warming and CC and shifts may occur in production areas due to temperature changes beyond critical thresholds for growth, flowering, seed set, and oil production. Nevertheless, differences among oilseed crop cultivars to temperature extremes seem to be larger than for other abiotic stresses (Rodriguez et al. 2014), thus highlighting the importance of genetic manipulation and plant breeding as important tools for adapting these crops to future CC. Increasing carbon dioxide concentration [CO_2] may have a positive effect on oilseed production; however, this positive effect may be negated by higher temperatures, lower water use efficiency, and subsequent accelerated development resulting in lower seed and oil yields.

Altered precipitation patterns, coupled with rising temperatures and increased [CO_2], will affect oilseed crop growth, development, and production, especially where rainfall coincides with the growing season (e.g., Southern region, India). Biotic stresses, including weed, insect, and disease pressure and competition for natural and external inputs, will be exacerbated by CC.

Interaction between abiotic and biotic stress

The interaction between biotic and abiotic stresses takes place at different spatiotemporal levels, from genes to the field, and may involve changes at the transcriptome, cellular, and physiological levels (Jaradat, 2014). Several molecular mechanisms that act together in a complex regulatory network are involved in the specificity in multiple stress responses; they include transcription factors, kinase cascades, and reactive oxygen species as key components of this crosstalk, as are heat shock proteins and small RNAs. Abiotic stresses associated with CC (e.g., high temperature, high humidity, and [CO_2]), will influence the occurrence, prevalence, and severity of biotic stresses (e.g., diseases, insects, and weeds). Moreover, CC will affect how biotic stresses will be managed as to timing, preference, and efficacy of chemical, physical, and biological measures of control within integrated pest management (IPM) programs.High throughput screening for biotic stress under CC will accelerate the identification of suitable resistance sources for example seedling screening in pots for *Fusarium* wilt resistance in Castor (Shaw et al. 2016), which does not require development and maintenance of sick plot.

Reproductive Fitness in Oilseed Crops under Climate Change

Biological and agronomic characteristics of reproductive fitness in oilseed crops are critical for genetic manipulation and to increase seed and oil yields. Integrated high-throughput plant-phenotyping (HTPP) and genome-wide association analysis in oilseed crops have the potential of accelerating the rate of trait discovery and improving phenotypic predictions of yield sink size (e.g., seed or fruit) and reproductive resilience under CC stresses. Especially when high heritability is associated with moderate to high genetic advance for the duration of the reproductive phase, then there will be a reasonable possibility for improvement of traits related to reproductive fitness (Jain, 2014). Several reproductive fitness traits are usually strongly correlated and QTL colocalized across environments (e.g., flowering time, dry rosette weight, seed yield, harvest index, ratio of reproductive to vegetative organs, seed C% and N%, and 1000-seed weight). These positive correlations are consistent with life history theory in that genotypic variation in resource acquisition masks tradeoffs (Chardon et al. 2014).

The risk of high-temperature impact on oilseed crop production is increasing with increased global warming. Impaired fertility and yield loss due to heat stress are widely reported in oilseed crops (Yu et al. 2014). Adverse climatic conditions and environmental stresses particularly impact male reproductive development in oilseed crops. When exposed to stress, male gametophytic organs often show abnormalities at the morphological, structural, and metabolic levels; such changes usually lead to meiotic defects or premature spore abortion and male reproductive sterility. Pollen viability, flower number, bud number, seed and pod number, as components of the reproductive system, are used to identify genotypes with high-temperature tolerance. The number and length of buds emerged on main stem, and pod number produced under high temperatures, might provide a useful preliminary screening criterion for high-temperature tolerance in oilseed crops such as *B. napus* and identify genetic resources (e.g., *B. rapa*) to provide genes for heat stress tolerance (Annisaet al. 2013).

Depending on the type of stress involved (e.g., heat, cold, or drought) and the duration of exposure, the underlying cellular defects are highly variable and involve a wide range of aberrations (De Storme and Geelen, 2014). Interactions between leaf senescence and resource allocation to seeds, hence reproductive fitness, were revealed by QTL meta-analysis of traits related to senescence, resource allocation, and seed yield in *Arabidopsis thaliana*. Sequential and monocarpic senescence observed at vegetative and reproductive stages, respectively facilitate N remobilization and control the duration of C fixation. However, genetic and environmental factors control N and C resource allocation to seeds (Chardonet al. 2014). Heat-responsive genes, with organ-specific expression, have been identified through transcriptional profiling at the seed-filling stage in siliqua wall and seed of *B. napus*(Yuet al. 2014). The molecular bases of response to heat during late reproductive stages provided valuable information and identified gene resources for the genetic improvement of heat tolerance in *B. napus*. When reproductive tolerance to high temperature was increased by 2°C (Singhet al. 2012), reproductive efficiency was improved, especially after the plants were subjected to drought stress. Large genotypic variation for heat tolerance was found at the reproductive stage in several oilseed accessions (spring-type *B. rapa* accessions and one *B. juncea*accession). Heat tolerance was determined by the ability of accessions to set seed equally at normal (i.e., control) and high-temperature treatments (Annisaet al. 2013).

Oilseed Crop Ideotype(s) for a Changing Climate

Environmental and CC concerns, especially in the developed world, have already established a favorable context for developing environmentally friendly cropping systems and placed demands on plant breeders to design ideotype(s) (i.e., ideal combination of traits in a specific genotype) that can meet more complex objectives. Due to the complexity of such an endeavor, modeling has a major role in designing annual (Kang et al. 2014) and perennial (Kantar et al. 2014) oilseed crop ideotypes and in predicting the impact of changes to agricultural systems in view of CC. Simulation models are imbedded in the process of designing an ideotype because the impact of CC variability on plant growth is closely linked to the design of the ideotype. A functional–structural model for genotypic and phenotypic characterization of *Helianthusannuus*, for example (Kanget al. 2014), provides an opportunity to design and test an oilseed crop ideotype. In so doing, robust trait combinations are needed to fit specific agroecological conditions under future climate(s), while long-term experimental platforms and HTPP and genotyping systems are indispensable components (George et al. 2014). The ideotype concept has been used by breeders when screening plant populations for multiple morphometric and agronomic traits. In ideotype breeding, the relationship between crop yield and its determining factors is indirectly modeled, and the ideotype becomes a virtual, intermediary object, useful to formulate, challenge, and reconcile the different visions of classical breeders, geneticists, agronomists, plant pathologists, ecophysiologists, and others. Simulation models and structural equation models (SEMs) can be valuable tools in developing de novo oilseed crop ideotypes that do not appear in currently available germplasm, and in optimizing their phenotypes through tradeoffs between different plant traits in order to suit future climate(s).

Regardless of CC scenarios, an oilseed ideotype is expected to have positive effects on current and future agroecosystems; therefore, traits that may protect or improve the environment need to be integrated into its genetic makeup. Ideotyping for wide *vs*. specific adaptation to key environmental conditions and stresses can be based on simulation model(s) that calculate the probability distribution of expected yields on the basis of agroecological and environmental characteristics and best management practices of target production regions for a particular oilseed crop. Predicting the genotype × environment × management (G × E × M) interaction is a prerequisite to integrating environmental covariates and oilseed crop modeling into a genomic selection context (Heslotet al. 2014). One objective of this process is to improve the accuracy of predicting genotypic performance under environments for which weather data are available, then provide insights into the genetic architecture of G × E × M interactions to predict ideotype performance using past and future weather data and CC scenarios. Nevertheless, different responses to CC may occur both between populations throughout a species range, and between cooccurring individuals within a population. Therefore, plasticity could facilitate the expression of a relatively well-adapted oilseed crop ideotype under future environments, and phenotypic plasticity may play a bigger role than genetic diversity in its environmental adaptation.

Phenology and Plasticity under Climate Change

The ability of an oilseed plant to adjust to seasonal variations during development is an indicator of its phenological plasticity (Bloomfield et al. 2014), which is a desirable trait in the context of breeding crops resilient to CC. Developmental plasticity (i.e., the capacity of a genotype to express phenotypic variation without DNA sequence mutation) and functional plasticity, a complex system of plasticity found in polyploid oilseed crops (i.e., the ability of a genotype to relocate vital biological functions among tissues as a result of paralogous genes; Bloomfield et al. 2014), may become more important adaptation strategies to seasonal environmental (and edaphic) variations under CC. Oilseed crop phenology will accelerate in response to higher temperatures and will be accompanied by reduced yield as a result of increased risk of reproductive failure (De Storme and Geelen, 2014). Coupling downscaled weather scenarios with phenology model(s) to study CC stress during critical phenological stages of oilseed crops emphasizes the importance of earliness for heat tolerance in these crops. However, higher temperatures will most likely be associated with elevated [CO_2]. Plastic changes in phenology due to e[CO2] will be manifested in fluctuations in flowering time, seed longevity, leaf duration, and a multitude of metabolic processes. Plasticity could facilitate the expression of relatively well-adapted phenotypes under new environmental conditions brought about by CC (Merilä and Hendry, 2014). Phenotypic plasticity, rather than genetic diversity, is likely to have a more significant role for oilseed crops in tolerating stress conditions caused by rapid CC in their current agroecosystems (Redden, 2013). Plasticity can be facilitated by epigenetic processes that modulate chromatin through dynamic changes in DNA methylation, histone variants, small RNAs, and transposable elements (Bloomfield et al. 2014). Genetic and epigenetic regulation play important roles in abiotic stress gene networks (Uranoet al. 2010). New knowledge about signaling cascades and epigenetics is promising for predicting how plasticity will influence the responses of oilseed crops to CC. Directional selection in contemporary oilseed crop breeding may have led to reduced adaptive plasticity in modern cultivars; breeders did not address increased plasticity per se, instead, they targeted plant traits to obtain higher yields in particular environments, or for homeostasis under a range of environmental conditions. Breeding for phenotypic plasticity in traits other than seed or oil yield will potentially provide resilience under increasingly unpredictable environmental conditions of CC.

A number of functional traits that can be used in investigating adaptive phenotypic plasticity in oilseed crops include (Nicotraet al. 2010): leaf traits (specific leaf area as indicator of relative growth rate, photosynthesis capacity, leaf duration, and leaf nitrogen content; leaf size, shape, thickness, and pigmentation), flowering (time, flower size, and phenology as indicators of species ability to respond to CC), seed (size and number per fruit as indicator of fitness), root (specific length as relates to precipitation pattern shift under CC).The larger the genetic variation in an oilseed crop for a particular trait or group of traits, the better its ability to withstand and adapt to abiotic (and biotic) stresses associated with CC. A portion of the genetic variation is expected to determine the ability of a crop plant to sense a particular environmental change (e.g., high temperature) and produce a relevant plastic response.

Genetic resources and genetic diversity of oilseed crops

Several oilseed crops experienced bottlenecks after domestication; the vast genetic potential of wild relatives of these crops remains underutilized unless molecular breeding can be employed for their improvement and for the production of adapted commercial hybrids, especially in developing countries. The wild relatives of oilseed crops and oil-bearing plants have the genetic memory of thousands of years of adaption to CC and are a key resource of alleles for CC adaptation, providing researchers with genes and traits for multiple biotic and abiotic resistance (Jaradat, 2015). Climate change calls for increased consolidation of germplasm collections of narrowly adapted and endemic wild species and crop wild relatives due to increased likelihood of their extinction. Increased demand for novel, diverse, and resilient germplasm in the face of CC presents a challenge for gene banks to ensure that important germplasm is adequately conserved, as well as an opportunity for stimulating its greater use by breeders and agronomists through adequate characterization and screening for useful traits. A well characterized core set in castor (Sarada and Anjani, 2013) and sesame (Mahajan et al. 2007) are available for screening the genotypes for phenotypic plasticity under climate change.

Historically, breeding of oilseed crops confronted the challenge of bridging a widening gap between demand and supply of oil and its byproducts for food, feed, and industry, by breeding and releasing genetically uniform cultivars (Keneniet al. 2012). As a result, the wide variation present in traditionally cultivated and maintained land races was replaced with a few genetically uniform cultivars of each oilseed crop. Consequently, depleted genetic diversity and large-scale uniformity created ideal conditions for vulnerability to biotic stress. Therefore, a new paradigm of plant breeding advocated a solution based on breeding for specific adaptation instead of wide adaptation, systematic spatiotemporal gene deployment, integrated horizontal and vertical disease resistance, and even the use of interspecific cultivar mixtures (Podevinet al. 2013). Efficient but moderate selection pressure can be used to replenish genetic diversity and enhance adaptation to CC in oilseed crops, provided that a high effective population size with migration and mutation can be maintained (Cowling, 2013). Selection strategies, such as best linear unbiased prediction and genomic selection, in addition to short generation intervals, may contribute to sustainable oilseed breeding under CC.

Prebreeding of oilseed crops for climate change

Historically, plant breeding was based on the introduction of new genetic variability based on the old saying "cross the best with the best and hope for the best" (Podevinet al. 2013), provided that the right traits were evaluated and measured under the right climatic conditions and management practices. The need for diverse germplasm will increase dramatically with the advent of CC to sustain and strengthen adaptation, tolerance, or resistance to increasing abiotic and biotic stresses, and to optimize the seed and oil yield of current and future oilseed crops and oil-bearing plants. Hence, the availability of a more diverse germplasm represents both a challenge for gene banks to ensure that important gene pools are properly conserved and an opportunity for stimulating greater use of ex situ as well as in situ conserved germplasm.

Linkage drag, usually but not exclusively associated with secondary and tertiary gene pools, is the most important factor responsible for low use of germplasm by breeders in oilseed crop improvement. Nevertheless, recent developments in genetics and genomics have made it possible to obtain genes much easier from novel sources of germplasm. For example, using cisgenesis (Houet al. 2014), breeders can avoid linkage drag, enhance the use of existing alleles, and combine traditional breeding techniques with modern biotechnology, while efficiently speeding up the breeding process. The presence of molecular markers will greatly assist in reducing linkage drag and increasing the efficiency of introgression (Sharma et al. 2013).Implementation of prebreeding by gene banks will encourage greater use of genetic diversity and reduce the cost and increase the efficiency of breeding programs. Germplasm characterization and preliminary evaluation are the basic activities in prebreeding to meet the germplasm needs of oilseed crop breeders.

Molecular Breeding

Molecular breeding, or MAS, refers to the technique of using DNA markers that are tightly linked to phenotypic traits to assist in a selection scheme for a particular breeding objective. Therefore, the identification and characterization of suitable genetic markers – such as, intersimple sequence repeats (ISSRs), amplified fragment length polymorphism (AFLP), simple sequence repeats (SSRs) and Single nucleotide polymorphic (SNP) markers – are the most important components of molecular breeding (Cooper et al. 2014). Notably, two oilseed crops, *G. max* and *B. napus*, are well advanced due to contributions from molecular breeding, while others such as *H. annuus* and *Carthamustinctorius* are still lagging behind (Pearl and Burke, 2014). However, in spite of the problems encountered in improving these two oilseed crops, the information generated from molecular markers, transcriptome profiling, and genome sequencing could facilitate genetic improvement and lead to full domestication of wild oilseed plants (e.g., *Ricinuscommunis*) or to improving underutilized oilseed crops (e.g., *Sesamumindicum, Guizotiaabyssinica and Linumusitatissimum*). Genomic selection, a fast emerging molecular breeding method for crop improvement, assists in the identification of superior genotypes with higher breeding value in segregating breeding populations. Due to its efficiency, MAS was suggested as a breeding method for drought and salt-tolerant Brassica oilseed crops (Zhang et al. 2014). In addition, MAS can provide valuable contributions to the design and development of oilseed crop ideotype (s). The statistical methods used in MAS, when linked to dynamic system modeling, provide a realistic procedure of defining an ideotype as a combination of genetic markers. Molecular breeding has made spectacular progress in a wide range of applications, such as genetic transformation, genetic diversity assessment, large-scale transcriptome and proteome studies, identification of candidate genes for trait improvement, and whole genome sequencing (Johnson et al. 2011).

Mutation-assisted Breeding

Valuable agronomic (Cheng et al. 2014), phenotypic (Gilchrist et al. 2013), quality (Rahman et al. 2013), and adaptation to abiotic stress (Gepts, 2002) traits have been improved in oilseed crops using forward screens of phenotypes or reverse screens of mutations in target genes of oilseed crops. As an alternative to selection breeding, mutation-assisted breeding contributed to oilseed improvement in which natural genetic variation was limited. Most changes brought about by G × E involve gain-of-function mutations (Gepts, 2002); however, during domestication, loss-of-function mutations were predominant (i.e., a functional enzyme or structural protein was converted into an inactive one), and were easily observed by humans. Hence, domestication syndrome traits resulted from selection of spontaneous mutations that occurred in wild populations and were selected at various stages of plant growth. Mutational hotspots (Nicotraet al. 2010), in addition to genome expansion, transposable elements, or somatic recombination, may result in genome plasticity which involves a change in genome structure or genome organization in response to environmental signals, and would lead to the development of new phenotypes adapted to climate change.

Participatory Breeding

Participatory plant breeding, as it applies to oilseed crops or oil-bearing plants, is a strategy for breeding crops which has a unique set of procedures that apply in situations where the demand for specific traits among farmers, industries, and consumers is not fully understood and challenging to identify with market research methods (Bhargav and Meena, 2014). This breeding method depends on the involvement of farmers and other stakeholder at all stages of the process. Because it is aimed at multiple breeding targets, it may accelerate the development of climate-resilient oilseed crop cultivars, as well as cropping systems where the crops will be produced (Banga and Kang, 2014). When combined with available germplasm, traditional plant-breeding expertise, and genomics tools, participatory breeding approaches succeed in developing high-yielding oilseed crop cultivars with wide acceptance by the farming community and adaptation to CC stresses (Geleta and Ortiz, 2013). Farmers participating in oilseed crop breeding (e.g., *A. hypogaea*) confirmed empirical findings – such as synchronous and early-flowering genotypes that may escape drought stress – and phenotypic traits of pods and kernels as indicators of quality Vindhiyavarmanet al. 2010). These findings indicate that farmer participation in the breeding process, including selection of parents, monitoring and evaluating crops on-farm and on-station, and seed production, has a much more formal character than often expected by scientists. Oilseed crop replacement rates, as a means of modifying crop genotypes when resource-poor farmers cannot afford to alter the production environment, may be determined, directly or indirectly, through farmers participating in crop breeding and selection. The rate of change may be based on performance, quality, or adaptation to changing climates.

Future of oilseed breeding for climate change

Future achievements in breeding oilseed crops, within a CC context, will benefit from further advances and innovations in low-cost sequencing, metabolic engineering, high throughput phenotyping techniques, genotyping, and spatiotemporal modeling of agroecosystems in order to account for environmental and edaphic variation. Genetic diversity, optimized for local adaptation and introduced at different levels in the form of intravarietal, intervarietal, interparental, or interspecific diversity, will support future advancement in oilseed crop breeding and industry (Dias, 2014). A modified form of systematic spatiotemporal gene deployment, interspecific varietal mixtures, and integrated horizontal and vertical resistance may be of value in combating abiotic stresses as was the case in combating biotic stresses (Keneniet al. 2012).

Agroclimatic-zoning models, aided by GPS–GIS technology, will help determine agroclimatic boundaries and future production regions for single or multiple oilseed crops, especially under marginal environmental and production conditions where current breeding approaches, cultivar release, registration and certification procedures are leading to more genetic uniformity (Keneniet al. 2012). The reflective plant-breeding paradigm, described as a robust system of germplasm development to support strategic diversification of agro-ecosystems (Runcket al. 2014), was proposed to enable close coordination of breeding and commercialization to coincide with germplasm development and lead to the emergence of a cost-effective production system and supply value chains for end user markets, whether for food, pharmaceuticals, or industry.

Due to the complexity of breeding for multiple abiotic stresses, and to the large diversity within and among taxa and species of oilseed crops, there will inevitably be an increase in the scale of breeding programs to accommodate wider germplasm diversity, including crop wild relatives.

The breeding process will have to be enabled by more complex models and genetic prediction methodologies, starting with prebreeding and germplasm enhancement until new cultivars are released. Genetic prediction methods, in turn, will have to be supported by, and integrated with, high-throughput plant phenotyping, the cost of which is expected to become affordable by most oilseed-breeding programs. This strategy will furnish breeders with large relational databases on multiple traits, including physiological determinants of adaptation to climate change. Simulation models can be more effective in predicting genotypic responses to abiotic stresses if allelic effects are simulated in current and future climate change scenarios and if individual or multiple phenotypic traits are assessed to guide breeding of oilseed crops, especially those with a narrow genetic base due to their monophyletic origin and self- pollination. Moreover, model algorithms that are closer to actual plant mechanisms are required in order to adequately and realistically estimate the effects of major and minor QTL, provided that relevant traits are measurable in phenotyping facilities.

Attempts to develop climate resilient snflower, castor, safflower, sesame and niger

Sunflower

Sunflower, could be more vulnerable to the direct effect of heat stress at anthesis and drought during its growing cycle, both factors resulting in severe yield loss, oil content decrease, and fatty acid alterations. Adaptations through breeding (earliness, stress tolerance), crop management (planting dates), and shifting of growing areas could be developed, assessed and combined to partly cope with these negative impacts. New cultivation opportunities could be expected in Eastern and North Eastern parts of India where sunflower is not grown presently and where it could usefully contribute to diversify cereal-based cropping systems. In addition, sunflower crop could participate to the mitigation solution as a low greenhouse gas emitter compared to cereals and oilseed rape. Sunflower crop models should be revised to account for these emerging environmental factors in order to reduce the uncertainties in yield and oil predictions. Elevated [CO_2] exposure significantly influenced seed yield but protein concentration decreased in the seeds (13%). However, oil content increased significantly in cultivar DRSF 113 (15%). Carbohydrate seed reserves increased with similar magnitudes (13%) in both the genotypes under high [CO_2] treatment. Fatty acid composition in seed oil contained higher proportion of unsaturated fatty acids (oleic and linoleic acid) under elevated [CO_2] treatment (Pal et al. 2014). These findings confirm that rising atmospheric CO_2 in changing future climate can enhance biomass production and seed yield in sunflower but also alter protein and oil contents, and finally fatty acid composition. However, the beneficial effects of high CO_2 can be counter-balanced by other climate factors such as the increase in atmospheric temperature and unfavorable patterns of rainfall. Optimum temperatures for high oleic acid accumulation were 33.4°C maximum temperature and 22.9 °C minimum temperature with a mean of 28.2°C based on response surface model. High oleic type genotypes were more sensitive to temperature with respect to oleic acid than low oleic types (IIOR Annual Report, 2016-17).

There are huge sources of wild *Helianthus* species and breeders have mainly used *H. argophyllus* as a source of donor genes for novel tolerant germplasm. Among the available hybrids in India, KBSH-44, KBSH-53 and LSPH-35 are suitable for cultivation under drought stress.

Safflower

Safflower is a drought-resistant oilseed crop grown under rainfed conditions all over the world. A rise in temperatures and the early or late withdrawal of the monsoon giving deficient or excess rain which adversely affects the sowing time and thus the production of safflower. Safflower has demonstrated drought resistance with a slight decrease in crop yield and significant stability in water use efficiency (Lovelli et al. 2007). The identification of adapted cultivars able to grow well in drought and saline environments may provide the germplasm for future breeding. Safflower is a climate resilient crop which can take the advantage of climate change to increase the area under this crop.

Castor bean

Elevated CO2 is a positive factor of climate change for castor crop under irrigated conditions where water is not a limitation, it is possible to realize higher yields due to elevation of CO2 in castor bean. However, drought and rise in temperature are big challenges for the crop's sustainability. Development inbreds with early vigour, bloom and samll leaf area are necessary for the crop to adapt to drought and temperature stress. Growth and yield responses of a variety DCS-9 was subjected to two elevated CO2 levels (550 and 700 ppm) and were evaluated up to the maturity of first order spikes in open top chambers (OTCs). The growth characteristics – root and shoot lengths, root volume, root:shoot ratios, leaf area, dry weights of different plant parts, leaf area duration and crop growth rate increased with 550 and 700 ppm of CO2 levels compared with ambient control. The spike length, pod and seed yield of first order spikes increased under enhanced CO2 levels over ambient control. Elevated CO2 levels significantly increased the total biomass and yield of castor bean, however enhanced CO2 levels per se did not changed the content and quality of the castor oil (Vanaja et al. 2008). These results indicated that elevated CO2 is a positive factor of climate change for castor bean. Molecular characterization data of inbred collection indicates reasonable level of genetic diversity with no marked population structure. Furthermore, the genetic diversity information generated by Senthilvel et al (2016) assist in selection of suitable genotypes for breeding as well as physiological and molecular studies in castor.

Sesame

Sesame encounters a number of stress factors including salinity, drought, waterlogging, and chilling. Sesame is usually grown under rain-fed conditions where precipitation is irregular. It is regularly subjected to mild to severe water deficit stress. The crop is sensitive to drought, especially at the vegetative stage. The sensitivity of sesame to drought is reflected in the changes that occur subsequently in plant metabolism, growth development, and yield. Variable behavior in response to drought stress has also been noticed among various sesame cultivars, with some cultivars being highly resistant and others more susceptible (Boureima et al. 2011). Sesame has the ability to over-come drought by developing an extensive rooting system, although it experiences substantial yield losses if drought occurs when it is cultivated on marginal and low rain–fed areas. The effect of drought is more pronounced on sesame seed yield than other morphological characters. A variety GT-4 is a drought tolerant and can be cultivated under low soil moisture stress areas and for delayed monsoon varieties like Tilottama, Savitri, Rama and Kanke white (Maheshwari*et al.* 2015).

Sesame breeding was based on the use of naturally occurring variation or by inducing variation through inter and intraspecific hybridization or mutations. Sesame has a number of natural phenotypic variants in primary gene pool, secondary gene pool and tertiary gene pool. A comprehensive evaluation of germplasm for various traits such as water logging tolerance salinity tolerance, drought and disease resistance is to be given. A breeding program should be adopted such that sesame can be grown under a wider range of agro ecological conditions, based on combining the resistance and tolerance traits for major constraints in each area.

Niger

Niger is a climate resilient crop which is primarily grown on denuded soils in hilly and tribal pockets under input-starved conditions. Niger is less vulnerable to biotic and abiotic stresses than other oilseeds. The crop is capable of giving good seed yield under low soil fertility, moisture stress, and sensible crop management. It has good potential for soil conservation, land rehabilitation, and as a bio fertilizer. These attributes favor its cultivation on hilly areas, and marginal and sub marginal land in and around forests. However, drought stress is an important factor limiting productivity in the major niger-growing states. Early types are common in the Western Ghats and drought-tolerant types occur in the central peninsular region of India. Moderate salt-tolerant types of genetic resources have been reported in India. African germplasm, particularly from Ethiopia, is a good source of high-yield, bold-seeded and resistance to waterlogging and drought, grows in lowland areas, and exhibits vigorous growth and late maturity. Germplasm augmentation from Ethiopian lines and initiating breeding programme is necessary for sustainability of niger crop in the present climate scenario.

CONCLUSION

Climate change is the present challenge to mankind, which has direct effect on agriculture. There are various strategies developed to face climate change in agriculture. Crop diversification is one among the best strategies, in which oilseeds fits very well since they are climate resilient crops by their true nature. Many of the oilseeds listed above take the advantage of elevated CO2 with increase in both quality and quantity. A sincere effort in improvement of yield under stress situation will result tailor made resilient genotypes in oilseeds.

Genetic enhancement using wild sources and mutations are fruitful effort for developing climate resilient genotypes in oilseeds. In addition, more sustainable agronomic practices are required to help adapt new cultivars to climate change. However, Minor oilseeds crops such as castor, safflower, sesame, niger and linseed are neglected for genetic improvement in the light of climate change. Attention needs to be given to develop simulation models for crops such as sunflower, castor, linseed, sesame and safflower for improved analysis of climate change impacts and adaptation strategies for oilseed sector in India. Climate change will bring about greater demand for genetic resources, whether from related cultivated, semi-domesticated, or wild species. Past and recent genetic bottlenecks reduced the genetic diversity of many oilseed crops; therefore, crop wild relatives, as largely untapped genetic resources with genetic affinity to cultivated oilseed crops, remain a relatively low priority due to genetic barriers; however, their "genetic memory" of adaptation to abiotic stresses can now be more easily transferred and employed in breeding more resilient oilseed crops. The adaptive value conferred by largely undocumented locally rare or widespread alleles of underutilized oilseed crops and their relatives will increase in importance. Advances in molecular genetics will facilitate moving genes from more distant species to improve abiotic stresses in future oilseed crops.

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