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MAIZE JOURNAL

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REVIEW

Emerging biotic constraints to maize production in the global climate change- An overview

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Abstract: Changing weather can induce severe plant disease epidemics which threaten food security if they affect staple crops and can damage landscapes, if they affect amenity species. Thus, knowing the pathogens, their ecology, distribution, virulence patterns, and variability is important in minimizing diseases and the gap between actual and attainable yields. Maize is one of a few important crops that civilizations have cultivated for centuries for food and a vast variety of industrial products and it is highly vulnerable to climate change. This review paper provides a complete vision of an agenda for current and future research on maize. Advances in technologies for the high-throughput analysis of gene expression have made it possible to discriminate host, pathogen, and vector responses to different biotic and abiotic stresses and their responses. Initiatives need to be undertaken to synthesize the effects of climate variables on infection rates, though pathosystem specific characteristics are quite challenging. Modelling of plant diseases to incorporate more sophisticated climate predictions are only few. At the population level, the adaptive potential of plant and pathogen populations can be the most important predictors of the magnitude of climate change effects on plant disease. Ecologists need to address the role of plant disease in ecosystem processes, with the potential for greater understanding of the large-scale impacts of maize diseases. Here, we highlight the concepts and strategies aimed at controlling major biotic constraints affecting maize and present emerging challenges, with a special attention to the developing world.

Keywords: Corn · *Zea mays* · Climate change · Emerging potential biotic threats

Introduction

Debates on consequences of increasing atmospheric carbon dioxide (CO_2) concentration and its role in influencing climate change date back as far as 1827, but, concerns over climate change reached global dimensions almost a century later (Chiotti and Johnston, 1995). Climate change is a long-term shift in the statistics of the weather which is a threat to agriculture and food security. There is a paradigm shift in temperature which is likely to affect the time and type of pests and pathogens associated with crops. The relationship between climate change, agriculture and food security, is quite complex and is shaped by economic policies and political decisions, but, there is increasing concern about the impact of predicted climate change on the production and productivity of our cereal crops. Changing climate can induce severe plant disease epidemics, posing a threat to food security (Chakraborty, 2005; Bosch *et al.,* 2007; Bergot *et al.,* 2004).

The average global temperatures at the earth's surface are rising. Based on the range of several climate models (IPCC, 1990, 1995), the mean annual global surface temperature is projected to increase by 1 to 3.5^{o}C by the year 2100. This will affect the spatial and temporal patterns of precipitation (IPCC, 1995). The consequences of changes in variability will significantly affect the crop scenario (Hulme *et al.,* 1999; Carnell and Senior, 1998; Semenov and Barrow, 1997).

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International efforts have been recently initiated to address this problem through Intergovernmental Panel on Climate Change (IPCC) 1990, 1995. It is a widely addressed threat which can induce severe plant disease epidemics (Chakraborty, 2005; Bosch *et al.,* 2007), which in turn can endanger food security if they affect staple crops and can also damage landscapes if they affect amenity species (Bergot *et al*., 2004).

Maize (*Zea mays*) is the largest crop in terms of global annual production (about 844 million tonnes in 2013-14) and the second biggest crop related to the area harvested (about 162 million hectares in the world (Fig. 1). It is hypothesized that climatic changes could directly affect maize yield and quality (Bender & Weigel, 2011). A trend towards higher temperatures, increased evapo-transpiration, and high frequency of extreme weather events such as heat spells and temporary droughts, is likely to affect some major maize producing regions (Campos *et al.,* 2004). The potential global maize production has already been reduced by 3.8% due to impact of climate change during 1980 and 2008 (Lobell *et al*., 2011) countervailing some of the yield gains from breeding and other technological advances. Global food security is a matter of serious concern, if this trend continues, in view of the expected global human population increase from currently seven billion to about nine billion by 2050 (United Nations, 2011), leading to a considerable increase in the demand for maize grain in the future, consequently the demand of maize for animal feed and bio-energy production is also increasing. Hence, pre and postharvest grain losses must be minimized.

In many African countries, maize production is at risk due to heat and water stress and a decline of 10-36% in yield is projected until mid century due to the projected shortened grain filling period caused by increased temperature and water stress in this country (Chipanshi *et al.*, 2003). However, climate change might also affect maize production positively, particularly in regions where low temperatures prevail (Ewert, 2012).

Apart from climatic and atmospheric factors, the future maize productivity will be dependent on climate change manifested biotic stress factors such as diseases (Chakraborty *et al*., 2000). However, yield affecting biotic stresses have been neglected in yield simulation studies (White *et al.,* 2011) therefore, there is a risk that future maize grain yield potential might suffer if future altered effects from biotic stress factors are ignored (Boonekamp, 2012).

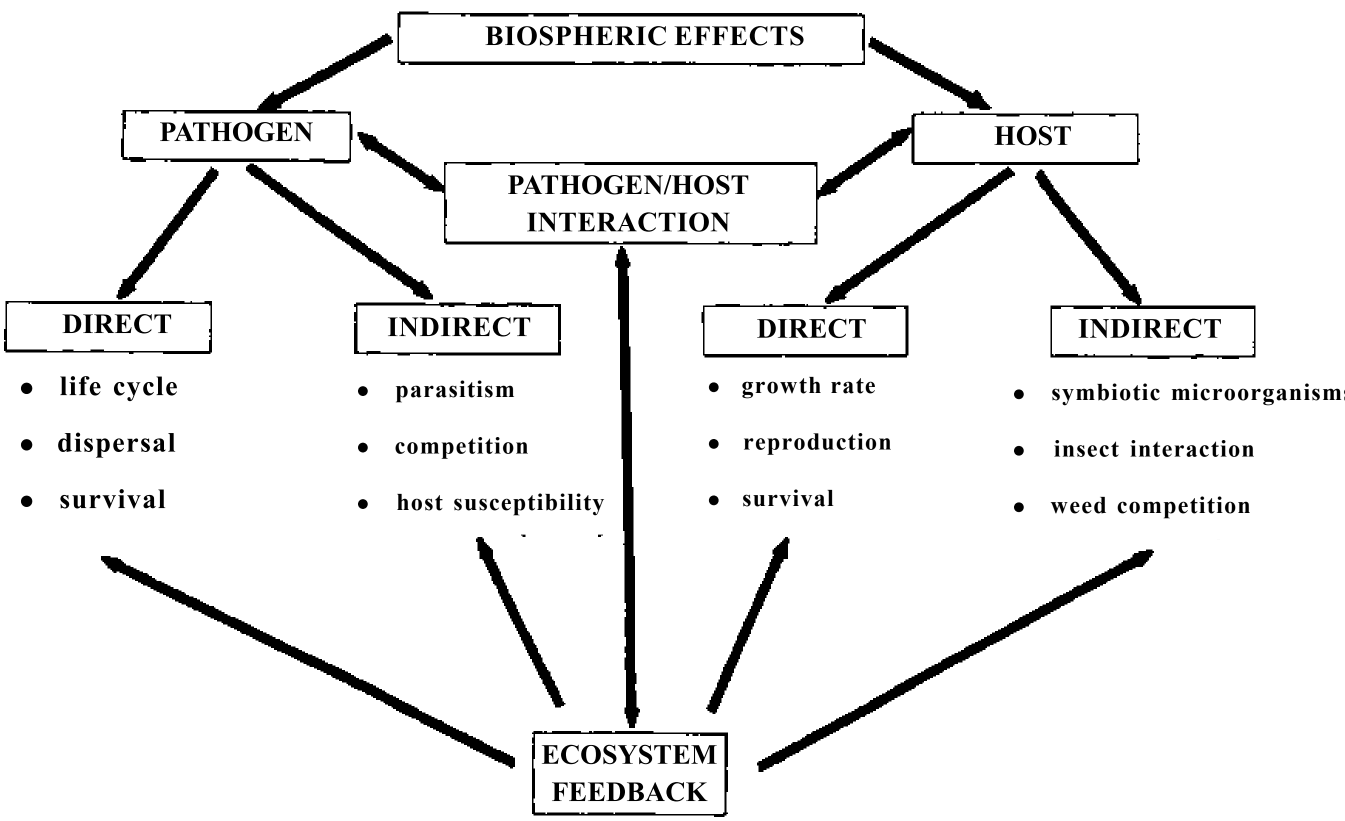

Fig. 1. An expanded disease triangle showing direct and indirect effects of biosphere factors on pathogen, host and host/pathogen interactions based on Wagner (1990) conceptual model for effects of climate change (Coakley, 1995)

Table 1. Anticipated effects of climate change on selected diseases of maize (*Zea mays*)

Name of disease	Pathogen (group)	Effect of climate change (anticipated increase/decrease)			Reasons for effects	Net effecton disease
		Primary inoculum or disease establishment	Rate of disease progress	Potential duration of epidemic		
Anthracnose	*Colletotrichum graminicola*	+	-	+	Increased survival in milder winters	-
Common smut	*Ustilago maydis*	+	+	+	Increased wound sites on hosts due to extreme weather (thunderstorms /hails/winds)	++
Eyespot	*Kabatiella zeae*	+	-	+	Warmer climate	—
Fusarium ear rot	*Fusarium* spp	+	+	+	Infected debris borne survival through wounds occurred in extreme weather	+
Grey leaf spot	*Cercospora zeae-maydis*	+	+	+	Infected debris and excessive rains	+
Northern leaf blight	*Exserohilum turcicum*	+	-	+	Infected debris survival	-
Stewart's disease	*Erwinia stewartii*	+	+	+	Insects due to warmer and dry conditions	+
Banded leaf and sheath blight	*Rhzoctonia solani*	++	+	+	Insects due to warmer and dry conditions	++
Downy mildew of maize	*Peronosclerospora sorghi, P. heteropogoni, Sclerophthora rayssiae var. zeae*	+	+	+	Infected crop residues, due to warmer and dry conditions	++
Polysora rust	*Puccinia polysora*	+	+	+	Infected crop residues, due to warmer and dry conditions	+
Maize streak disease	*Maize streak virus*	++	+	+	Crop residues, insects due to warmer/dry conditions	++
Maize chlorotic dwarf	*Maize chlorotic dwarf virus (MCDV)*	++	+	+	Crop residues, insects due to warmer/dry conditions	++
Maize Dwarf Mosaic	*Maize Dwarf Mosaic Virus (MDMV)*	++	+	+	Crop residues, insects due to warmer/dry conditions	++
Sugarcane Mosaic Disease	*Sugarcane Mosaic Virus (SCMV)*	++	+	+	Crop residues, insects due to warmer/dry conditions	++
Maize Yellow Stripe	*Maize Yellow Stripe Virus (MYStV)*	++	+	+	Crop residues, insects due to warmer/dry conditions	++
Maize Stripe Disease	*Maize Stripe Virus (MStV)*	++	+	+	Crop residues, insects due to warmer/dry conditions	++

In spite of current crop protection practices, 8.5% of the worldwide maize yield losses in 2001–2003 were estimated to be due to fungal and bacterial diseases (Oerke, 2006), where, the share of bacterial diseases was presumably very small. Losses varied greatly by region with estimated losses of about 4% in Western Europe and about 14% in West Africa and South Asia. Also, there are worldwide losses in maize due to viral diseases, estimated to about 2.7% in 2001–2003 estimated to be about 2% in Western Europe and about 6% in West Africa (Oerke, 2006). The potential losses (without plant protection) and the incurred actual losses (with plant protection) for maize diseases are almost similar (fungi and bacteria: 9.4 vs. 8.5%; viruses: 2.9 vs. 2.7%) (Oerke, 2006) suggesting there is a lack of efficient control practices in maize.

Economically important maize diseases in general include foliar diseases, smuts, stalk rots and ear rots (CIMMYT Maize Program, 2004). Predominant maize diseases vary across environments *viz.,* in Asia banded leaf and sheath blight (caused by *Corticium sasakii*, anamorph *Rhizoctonia solani* f. sp. *sasakii*) is an emerging disease problem. Diseases and pathogens with variable levels of importance in maize are enumerated in Table 1.

Climate change may also affect gene flow, which can increase population diversity of the pathogens, responsible for variations in host resistance, virulence and establish new host pathogen interactions. Thus, emergence of new diseases or pathogen and introduction of pathogens into new ecological niches will be facilitated. Changes in climate might interact with adaptations to enhance agricultural productivity. The *direct effects* may be through changes in temperature, precipitation, length of growing season, and timing of extreme or critical threshold events relative to crop development (Saarikko and Carter, 1996). The *indirect effects* might include potentially detrimental changes in diseases, pests, and weeds, the effects of which need to be quantified yet.

The aim of this review is to summarize the information available on 'climate change and maize diseases' to aware the maize researchers with the challenges for maize production in global climate change scenario. This is the comprehensive extended information on the potential future importance of maize pathogens and the diseases they cause. In this review, potential effects of variable temperature on pathogens their interactions with precipitation and humidity are being focussed. Effects of atmospheric factors such as CO_2 and O_3 on plant-pathogen interactions have also been reviewed previously for other crops (Manning & Tiedemann, 1995, Eastburn *et al.*, 2011, Pangga *et al.,* 2013).

Effect of biosphere factors on host pathogen interactions

The climate drives the incidence as well as temporal and spatial distribution of plant diseases through temperature, light and water. Climate change affects the survival, vigor, rate of multiplication, sporulation, direction, and dispersal of inocula, efficiency of spore germination and penetration of pathogens. In the modern age, the term 'biospheric changes' or 'global changes' are replacing the term 'climate change' as far as changes are concerned. There is complex interaction occuring between the physical and biological environments which affects each other and implicate additive or multiplicative effects on global environment. Interaction between host and pathogen directly or indirectly is regulated by biospheric factors (Fig. 1). Similarly, environmental factors which influence insect or weed competition have indirect effect on the host/pathogen interaction. Also, global change that increases or decreases the biocontrol of a pathogen, or the competition between pathogens directly affect the pathogen. Climate variations and changes are expected but, the intensity at which they will occur is critical to the efficiency of hosts and pathogens to adapt to new environments. Extremes of draughts/floods, cold/heat leave no hosts for pathogens as revealed from history. Succession of vegetation also follows climatic shifts and that pathogens associate with the hosts.

Maize-an economically important crop

Maize is one of a few important crops that civilizations have cultivated for centuries for food and a vast variety of industrial products. It is often described as "the grain that civilized the New World." *Zea mays* L. ranks third in production following wheat and rice with an average of 844 tons (approx.) produced annually by 10 countries (2013-14) (Fig. 2). It is world's most widely grown crop in almost all tropical areas of the world including tropical highlands over 3000 m in altitude, to temperate areas as far north as the 65^0 latitude. Maize is produced on nearly 100 million hectares in developing countries, with almost 70% of the total maize production in the developing world coming from low and lower middle income countries (FAO 2012). By 2050 demand for maize will be doubled in the developing world. It is predicted to become the crop with the highest production globally, and in the developing world by 2025 (Rosegrant *et al.,* 2008). Projections of climate change will further intensely affect food security and economic growth within many maize producing areas.

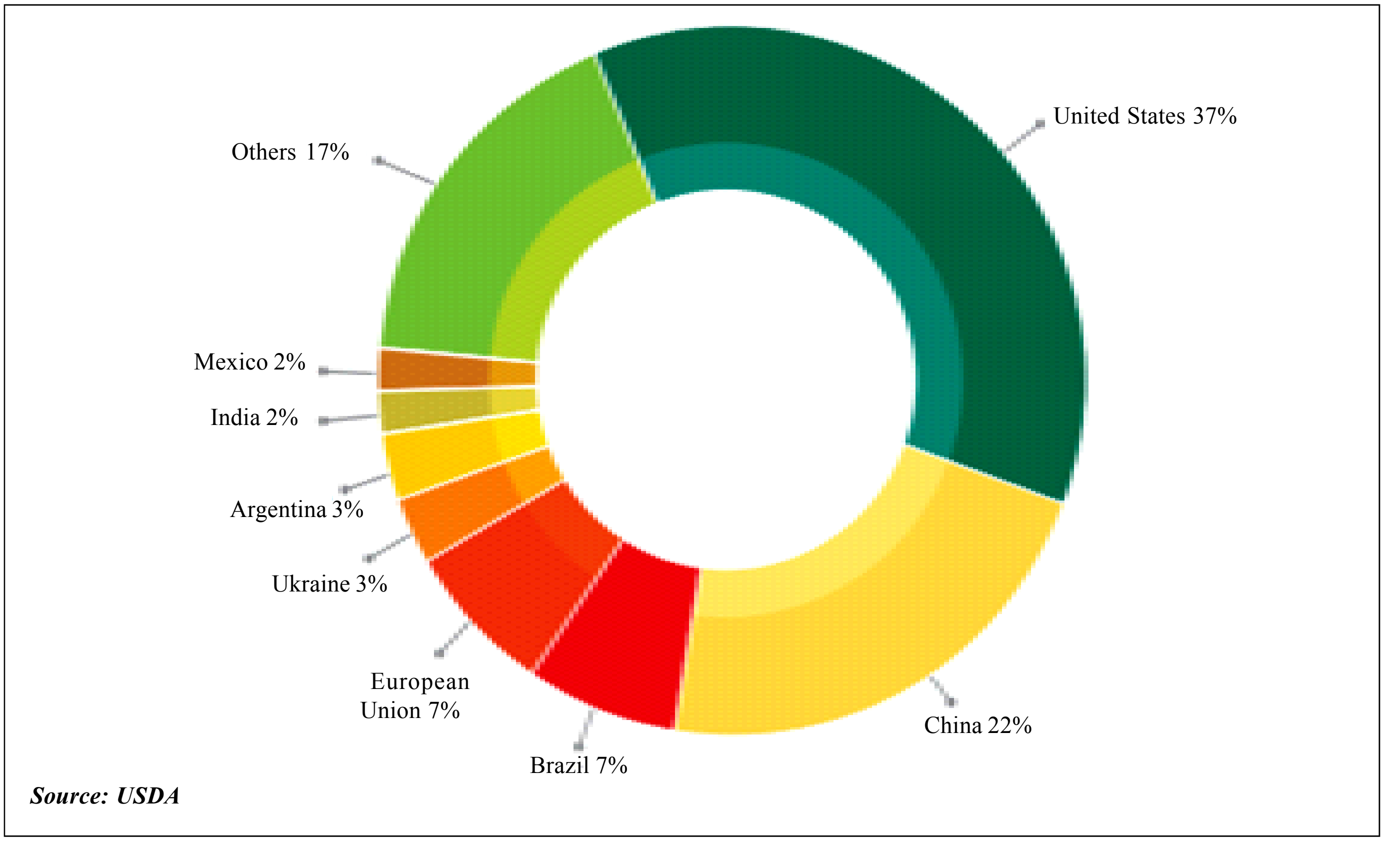

Fig. 2. Top maize producing countries worldwide in 2013-14

Anticipated effects of climate change on crops

Effects of rising temperatures

Due to rise in global climate it is projected that, temperature and precipitation regimes, climate change may alter the growth stage, development rate, pathogenicity of pathogen and the physiology and resistance of the host plant. This may lead to accumulation of phytoalexins or protective pigments in host tissue. Also, occurrence of bacterial diseases such as *Ralstonia solanacearum, Acidovorax avenae* and *Burkholderia glumea* is most likely. Bacteria can proliferate in areas where temperature dependent diseases have not been previously observed. Development and distribution of vectors is most likely to be affected hence, geographical distribution of pests and pathogens, increased over wintering, changes in population growth rates may occur. Rapid life cycles and enhanced reproductive potentials may lead to virulence outbreaks. Extension of the development season, changes in crop-pest synchrony of phenology, changes in interspecific interactions and increased risk of invasion by migrant pests are also some of the inevitable effects. More susceptibility to rusts and resistance to fungi are possible.

Effect of rising CO_2 levels

New races may evolve rapidly under elevated temperature and CO_2. Evolutionary forces might act on massive pathogen populations boosted by a combination of increased fecundity and infection cycles under favourable microclimate within an enlarged canopy. Leaves and stems show higher growth rates under high CO_2 concentrations which may result in denser canopies with high humidity that favour foliar pathogens. Lower plant decomposition rates in high CO_2 situations could increase the crop residue on which disease organisms can over-winter, resulting in higher inoculum levels at the beginning of the growing season, and earlier and faster disease epidemics. Pathogen growth can also be affected by high CO_2 concentrations resulting in greater fungal spore production. However, increased CO_2 can result in physiological changes to the host plant that can increase host resistance to pathogens. An increase in CO_2 levels may also encourage the production of plant biomass which can modify the microclimate and affect the risk of infection; however, productivity is regulated by water and nutrients availability, competition against weeds and damage by pests and diseases. Hence, a high concentration of carbohydrates in the host tissue is likely to promote the development of biotrophic fungi such as rusts. The increased plant density will tend to increase leaf surface wetness duration and regulate temperature, making conditions conducive for infection caused by foliar pathogens. Elevated ozone also has a similar effect; however this response is reduced by elevated CO_2.

Floods and heavy rains

Increased moisture due to floods may benefits epidemics and prevalence of leaf fungal pathogens. Fungal epidemics in maize are more likely. Mycotoxin problem (produced by *Fusariun* spp.) increased due to high humidity during harvest. Increased incidence of *Aspergillus flavus* (produces aflatoxin) is also projected. Water induced soil transport may increases dissemination of soil borne pathogens to non-infected areas. Continuous soil saturation may causes long-term problems related to rot development and increased damage, crazy top and common smut problem may arise in such conditions.

Drought

Water stress diminishes plant vigour and alters C/N lowering plant resistance to nematodes, and insects. Attack by fungal pathogens of stems and roots are favoured by weakened plant conditions. Dry and warm conditions may promote growth of insect vector populations, increasing viral epidemics.

Air currents

Air currents provide large-scale transportation for disease agents (e.g., spores of fungi) or insects from over wintering areas to attacking areas. The southern leaf blight of corn spread is predictable due to air currents of a tropical storm.

Warm winters

Warm winters may favour increased over wintering populations of all pests and insect vectors like corn borer. Increased population of aphids may carry the maize viruses.

Emerging challenges: new epidemics due to climatic changes and potential effects on maize pathogens/ diseases

Climatic changes can indirectly and directly affect pathogens and the respective diseases, which have been reviewed in detail by Pautasso *et al*. (2012); West *et al.* (2012) and Juroszek & Tiedemann (2013a). Indirect effects are mediated through the host plant and/or climate change driven crop management adaptations such as the introduction of irrigation, abolishment of deep soil tillage or shifted sowing dates e.g. irrigated maize in southeast Africa led to increased insect vector populations, culminating in increased *Maize streak virus* pressure in irrigated and also in rain-fed crops (Shaw & Osborne, 2011). In principle, all important life cycle stages of fungal, bacterial and viral pathogens (survival, reproduction, and dispersal) are more or less directly influenced by temperature, humidity, light quality/ quantity, and wind. Physiological processes of pathogens are particularly sensitive to temperature. Some ecological responses to recent climate change are already visible e.g. phonological changes in crop due to temperature changes. This can also affect crop pathogens (Siebold & Tiedemann, 2013) including maize pathogens, particularly those which infect maize during flowering stages *viz., Fusarium* species (Madgwick *et al.*, 2011; Magan *et al*., 2011; Wu *et al.,* 2011). Excess moisture favours some dreaded soil-borne diseases caused by *Phytophthora*, *Pythium*, *R. solani* and *Sclerotium rolfsii*.

At a given location, a shift in warm and other climatic conditions such as altered precipitation may result in various changes in maize pathogens which in general include (1) geographical distribution (e.g. range expansion or retreat, and increased risk of pathogen invasion), (2) seasonal phenology (e.g. coincidence of pathogen lifecycle events with host plant stages and/or natural antagonists/synergists), and (3) population dynamics (e.g. over-wintering and survival, changes in the number of generations of polycyclic pathogens). This may finally result in altered disease incidence and severity (e.g, Garrett *et al.*, 2006; Tiedemann & Ulber, 2008; Oldenburger *et al*., 2009; Sutherst *et al.*, 2011; Siebold & Tiedemann, 2012a; West *et al.,* 2012) thus modifying the regional distribution patterns of the diseases. The pathogens also have the capacity to adapt to warmer conditions (Zhan & McDonald, 2011), and hence temperature/humidity dependent disease resistance of crop cultivars may be altered in the future (Juroszek & Tiedemann, 2011). Most likely, plant pathogens will evolve and adapt to the new environmental conditions much faster than the crops including maize. Therefore, any speculations related to future disease risks in maize or other crops such as wheat (Juroszek & Tiedemann, 2013b) should be made with considerable uncertainty.

Climate change effects on viruses and bacteria of maize

The potentially altered future importance of maize pathogens and diseases due to projected climatic changes in different continents and countries is compiled in Table 1. There are only few economically important bacterial diseases which are affecting maize. Just one speculation of the future importance of a bacterial maize disease (bacterial stalk rot of maize) has been reported so far in the literature. In contrast, a large variety of viruses can cause maize diseases (CIMMYT Maize Program, 2004). Speculation of the future importance of a viral maize disease has been reported in Table 2 below; although plant viruses and their vectors may be particularly favoured by high temperatures until the upper temperature threshold of the vectors and viruses is reached. Vector numbers of the leafhopper *Cicadulina mbila* and incidence of maize streak disease were closely associated with temperature, both increasing quickly above a threshold temperature of 24°C, whereas relationship with rainfall and relative humidity were less consistent, although both warm temperature and high rainfall are considered to favour the vector and disease transmission.

Insects and vector borne diseases with special reference to maize viruses

The losses caused by plant viruses are greater in the tropics and subtropics, which provide ideal conditions for the perpetuation of both the viruses and their insect vectors. Viruses represent potential threat to maize productivity in global climate change. Maize chlorotic dwarf virus (MCDV), Maize Dwarf Mosaic Virus (MDMV), Sugarcane Mosaic Virus (SCMV), Maize Yellow Stripe Virus (MYStV), Maize Streak Virus (MSV) and Maize Stripe Virus (MStV) are common emerging viruses. Drought stress has been found to affect the incidence and severity of viruses such as *Maize dwarf mosaic virus.* Climate change may produce canopies that hold moisture in the form of leaf wetness or high-canopy relative humidity for longer periods, thus increasing the risk from pathogen infection and may simulate future scenarios of downy mildew. More rapid disease cycles, might lead to greater chance of pathogens evolving to overcome host-plant resistance.

In addition, other changes like concentration of CH_4, other greenhouse gases, UV light and sunshine hours will also have different impacts on pathogens and host/pathogen interactions, resulting in varied response in incidence and severity of diseases. Ultraviolet radiation plays an important role in natural regulation of diseases. Evolution of pathogen populations may accelerate from enhanced UV-B radiation and/or increased reproduction in elevated CO_2

Mycotoxigenic fungi and mycotoxins

Existing knowledge on potential threats to maize in the projected global climate change scenario is restricted to a few case studies only. In contrast to fungal pathogens, there is almost no information available on viral and bacterial diseases. Most studies related to fungi refer to *Aspergillus* and *Fusarium* species, which are causal agents of maize ear rot, and the related risk of mycotoxin contamination of maize grain, potentially harmful to animals and humans. Drought years may enhance the risk of aflatoxin contamination. It can be divided into that occurring (a) in the pre harvest and (b) post harvest contamination which are highly influenced weather conditions.

Pre-harvest mycotoxigenic fungi

Rain at or near harvest, generates unacceptable concentrations of aflatoxin in warm regions, with predictable risk. Semi-arid to arid and drought conditions in tropical countries are associated with contamination: changes in climate may lead to acute aflatoxicosis and deaths due to consumption of contaminated crops which occur even in modern times (Lewis *et al.,* 2005). Developing crops are frequently very resistant to infection by *Aspergillus flavus* and subsequent aflatoxin contamination, unless environmental conditions favour fungal growth and crop susceptibility.

The quantity of aflatoxigenic fungi associated with crops and soils varies with climate. Crops grown in warm climates have greater likelihood of infection by aflatoxin producers and in some regions, infection only occurs when temperatures rise in association with drought. Much of the organic matter in soils is colonized by *A. flavus* and related fungi in warm semi-arid regions, e.g. the Sonoran desert. The changes in the potential for particular mycotoxin production could be determined from direct analysis of environmental samples, with mycotoxin gene approach.

Climate influences not only the quantity but also the "types" of aflatoxin producers present (Horn & Dorner, 1999). Although *A. flavus*, from which only B_1 and B_2 aflatoxins were detected, were present on crops in virtually all areas examined, *A. parasiticus, A. nomius*, etc. which have been reported to produce B and G aflatoxins, are absent or uncommon in certain regions. These differences might

Table 2. Emerging Maize viruses and their distribution (Sharma and Misra, 2011)

Diseases	Virus	Virus genus/group	Vectors	Seed transmission	Geographical distribution
Maize chlorotic dwarf	Maize chloroticdwarf virus (MCDV)	IV: (+)sense RNAViruses (Waikavirus)	Arthropods (*G. nigrifrons*, *Graminell asonora and Exitianus exitiosus*)	No	United States of America
Maize chlorotic mottle	Maize chloroticmottle virus (MCMV)	IV: (+)sense RNAViruses (Machlomovirus)	Arthropods (*Cicadulina mbila, C. zeae, C. storeyi* and *C. triangula*)	No	Nigeria, Rwanda, Sao Tome and Principe, Tanzania, Togo, Zambia, and Zimbabwe
Maize dwarf mosaic	Maize dwarf mosaicvirus (MDMV) strains A, D, E and F	IV: (+)sense RNA (Potyvirus)	Arthropods, insects	Yes	China, South Africa, and the United States of America
Maize mottle/chloroti-cstunt virus	-	-	Transmitted by a vector; an insect; *C. mbila, C. zeae, C. storeyi* and *C. triangula*; Cicadellidae	No	Nigeria, Rwanda, Sao Tomeand Principe, Tanzania, Togo,Zambia, and Zimbabwe
Maize streak dwarf	-	-	Transmitted by a vector; an insect; *Laodelphax striatellus* (both adults and nymphs); Delphacidae	No	China
Maize streak Mono geminivirus	-	-	Transmitted by a vector; an insect; *C. mbila, C. arachidis, C. bipunctella, C. triangula, C. bimaculata, C. similis, C.latens, C. ghaurii, C. parazeae*; Cicadellidae	No	African region; India,Madagascar, Reunion, and Yemen
Maize rough dwarf (nanismo ruvido)	Maize rough dwarfvirus (MRDV)	III: dsRNA Viruses	Virus is transmitted by a vector (*Delphacodes propinqua, Dicranotropis hamata, L. striatellus, Javasella pellucida, Sogatella vibix*). Virus is also transmitted bymechanical inoculation	No	Argentina, Czechoslovakia, France, Israel, Italy,Norway, Spain, Sweden, and Yugoslavia
Maize yellow stripe	-	-	Transmitted by a vector; an insect; *C. chinai*; Cicadellidae	No	Egypt
Maize streak	Maize streak virus (MSV)	Group II (ssDNA) (*Mastrevirus*)	African leafhopper, *C. mbila* Naudé	Unknown	Sub-Saharan Africa
Maize stripe (maize chlorotic stripe, maizehoja blanca)	Maize stripe virus	V: (-) sense RNA Viruses (Tenuivirus)	Virus is transmitted by arthropods, by insects *P. maidis*.	No	Australia, Botswana,Guadeloupe, India, Kenya,Mauritius, Nigeria, Peru, the Philippines, Reunion, SaoTome and Principe, the UnitedStates of America, and Venezuela
Maize white line mosaic	Maize white linemosaic virus (MWLMV)	Virus unclassified	Insect	No	France, Italy, and the United States of America

be reflected in the abundance of B and G aflatoxins in crops produced in various regions. Importantly, at warmer conditions and weather patterns, aflatoxin contamination may further restrict the area over which crops profitably may be grown. Maize has become a staple for many millions in warm regions throughout Africa, Asia, and the Americas. This crop is vulnerable particularly to influences of climate as exemplified by recent experiences with lethal aflatoxicoses in Kenya (Lewis *et al.,* 2005).

Recent developments in forecasting mycotoxin concentrations have provided to industry with management opportunities and the basis for decisions to reduce or re-direct high concentrations of mycotoxins into or from the food chain. The predictive tool 'DONcast' assists producers in decisions on whether to apply fungicide, and helps in grain marketing decisions. In addition, the tool will be useful in averting problems from climate change.

Climate change on disease scenario

Temperature rise projects will help in studying geographic expansion of pathogen and vector distributions, establishing pathogens contact with more potential hosts for pathogen hybridization. Pathogen evolution rates are determined by the number of generations of pathogen reproduction per time interval, along with other characteristics such as heritability of traits. Longer seasons due to higher temperatures will allow more scope for pathogen evolution which can be more rapid when large pathogen populations are present, so increased over wintering and over summering rates will contribute as well. Altered temperatures may favour over wintering of sexual propagules, thus increasing the evolutionary potential of a population. In case of biotrophic fungi, an increase in disease severity has been found. Under climate change, due to increased biomass of crops and alternative host plants, necrotrophic pathogen produces large quantity of inocula for secondary infection, as a result the advantage of using resistant varieties to reduce inocula. It is predicted that during autumn and winter more incidence of diseases is caused by soil borne pathogens due to increased thermal time. Availability of susceptible hosts, pathogens with short life cycles, high reproduction rates and effective dispersion mechanisms respond quickly to climate change, showing a faster adaptation to climatic conditions. As a result number of pathogens moving northward will increase as increasing temperature makes these areas more conducive. Climate change will also modify host physiology and resistance, and alter the stages and rates of development of pathogens. New disease complexes may arise, and some diseases may cease to be economically important. However, pathogens will follow migrating hosts and infect vegetation in natural plant communities not previously exposed to the often more aggressive strains from agricultural crops.

Changes in cropping systems *viz.*, changes in crop rotations or tillage practices, influence the survival and prevalence of residue borne pathogens, they can lead to shift in the disease pattern/spectrum. With the exception of an accidental introduction of a new race or parasite, the occurrence of a "new" disease in a determined geographic area or cropping system is rare. If a minor pathogen is present and remains marginal due to an unsuitable environment, it may become a significant potential threat when climatic conditions become favourable for its development. In early sixties banded leaf and sheath blight (BLSB) was considered as a disease of minor importance, now it is gaining importance in other geographical areas due to the lack of resistance, and becoming potential emerging threat. *Magnaporthe grisea* also needs urgent attention as its host range (maize and triticale are susceptible), hence, it may be a potential threat to these crops (Urashima *et al.*, 2005). In some regions *Rhizoctonia zeae* (teleomorph: *Waitea circinata*) can also be an emerging threat. Climate change may possibly induce a shift in the geographical area grown and associated biotic constraints to higher latitudes. Likewise, the present pathogen and pest spectrum may evolve. It can be assumed that by 2050, the Indo-Gangetic Plains which is high potential, irrigated, low rainfall mega-environment and production goes up to 51% of its area, might be reclassified as a heat stressed, irrigated, short season production mega-environment due to climatic shifts. It is expected that the water for irrigation might be more limited in many parts of the world due to increased urbanization and industrialization. Thus some regions will become suboptimal for production, and some diseases, notably soil borne pathogens, may increase in importance.

The biggest risk to mycotoxins contamination due to climate change is predicted in developed countries with temperate climates (e.g. parts of Europe and the United States of America, etc.). The climate of these regions will become warmer and temperatures may reach to 33^{o}C, close to the optimal for aflatoxin production. This may be the case with crops, prone to aflatoxin production e.g. peanuts and maize grown increasingly to exploit the new conditions, which may further increase the risk of aflatoxin build-up and will become a threat for future. Whereas it's not be a greater concern in currently cold climates (e.g. Norway, Canada, and Russia), *A. flavus* competes poorly under cool conditions and the prevalence of *A. flavus* is higher in warmer environments (>25°C) compared to cooler environments (20-25°C) documented by Shekhar *et al.* (2016). The tropical climates may face other more urgent concerns if the temperatures of these countries increase at the same rate. Fungi which favour high temperatures may not survive in such extreme conditions, and like other organisms may become extinct from alterations in climate.

Ochratoxin-A may become less important in the currently temperate climates as the temperature range becomes too high for these fungi. These toxins are associated with a wide range of lower optima temperatures. However, in already cold climates patulin and ochratoxin A may become more problematic as their temperatures become warmer. *Fusarium* toxins at approximately 25°C are marginal, but these may not be a problem where the temperature becomes high.

Potential adaptations to climatic change

The most obvious adaptations identified are (1) the development of a more heat tolerant hybrid of long-season maize and (2) switching from maize (C4 crop) to soybeans (C3 crop) to take advantage of increased atmospheric CO_2 concentrations promoting increased growth and greater tolerances for hot. Manipulating planting dates for increased heat tolerance in short and medium-season maize varieties to provide adaptation equal or superior to adaptation of long term varieties under same conditions, like increased climate variability and increased extreme events, soil moisture management will become more critical and will require improved soil infiltration and water holding capacity. Tillage and cropping systems that yield benefit will increase in economic value to farmers. Also, there will be increased concern about soil erosion with more extreme rain events, especially if agricultural program standards for conservation compliance that limits erosion are tightened. A lengthened growing season, dominated by a central period of high maximum daily temperatures, is a critical inhibitor to maize yields. Late spring and early fall frosts do not affect maize yields.

Emphasis must shift from impact assessment to developing adaptation and mitigation strategies and options by evaluation of efficacy of current physical, chemical and biological control tactics, including disease-resistant cultivars in changing climate, and, to include future climate scenarios in all research aimed at developing new tools and tactics. Disease risk analyses based on host–pathogen interactions on host response and adaptation can help to understand how an imminent change in the climate could affect plant diseases. A change in the efficacy of control strategies is likely due to geographical shift in crop patterns. While physiological changes in host plants may result in higher disease resistance under climate change scenarios, host resistance to disease may be overcome more quickly by more rapid disease cycles, resulting in a greater chance of pathogens evolving to overcome host plant resistance. Fungicide and bactericide efficacy may change with increased CO_2, moisture, and temperature. The more frequent rainfall events predicted by climate change models could result in farmers finding it difficult to keep residues of contact fungicides on plants, triggering more frequent applications. Systemic fungicides could be affected negatively by physiological changes that slow uptake rates, such as smaller stomatal opening or thicker epicuticular waxes in crop plants grown under higher temperatures. These same fungicides could be affected positively by increased plant metabolic rates that could increase fungicide uptake. It is not well understood how naturally-occurring biological control of pathogens by other microbial organisms could change as populations of microorganisms shift under changed temperature and moisture regimes–in some cases antagonistic organisms may outcompete pathogens while in others pathogens may be favoured. Exclusion of pathogens and quarantines through regulatory means may become more difficult as unexpected pathogens might appear more frequently on imported crops.

At the population level, the adaptive potential of plant and pathogen populations may prove to be one of the most important in predicting the magnitude of climate change effects. Climate variability is significant factor influencing maize yields because increased climate variability might results in the largest decreases in future maize yields.

Disease severity is positively correlated with increase in virulence and aggressiveness of pathogens. Thus, a positive effect of climate change on conduciveness to infection or pathogen aggressiveness or virulence could be offset by a concurrent increase in resistance, yielding no net change in disease impact. The effects of climate change will ultimately be modified by the evolutionary potential of host and pathogen. Social changes, such as shifts in the availability of agricultural labour, will also change options available for disease management. Widespread changes in land-use patterns will alter the potential for populations of plants and plant pathogens to migrate through fragmented landscapes. If agricultural land use decreases in temperate areas and expands in the tropics, policies in temperate areas may support restoration of natural areas or they may support expansion of suburban development while the development of land use policies in tropical areas will face related challenges to maintenance of agricultural productivity and plant biodiversity in a changing world.

Conclusions

Development of climate resilient germplasm through a combination of conventional, molecular and transgenic breeding approaches is the requirement of present day. Molecular breeding technology and phenotyping can be potential high-throughput approaches for developing germplasm for future climates. Donors with increased tolerance to drought stress incorporated into the breeding pipeline and novel alleles associated with drought, heat and water logging tolerance, and stress combinations can yield promising germplasm together with the development of climate adapted maize germplasm. Within the primary maize and wild relatives gene pool and unexploited genetic diversity for novel traits and alleles that can be used for breeding new high yielding and stress tolerant cultivars using conventional approaches. More research on heat stress needs to be conducted in maize. The on-going research at CIMMYT suggests that large genetic variation exists within tropical maize for adaptation to heat stress which can be an asset to breeding program. More research is needed on the interaction of heat and drought stress in cereals. Identification of traits associated with combined heat and drought tolerance, and the development of improved germplasm for high temperature, water-limited environments needs to be conducted. Decision support systems (crop modelling) may help project any likely effects of climate change on the outbreak and spread of disease and pest epidemics. Climate change may have positive, negative or neutral impact on diseases. Research in this area can help to identify new opportunities to minimize negative impacts with an improved understanding of the causes, impacts and consequences of climate change to devise mitigation strategies.

The shortage of critical epidemiological data on individual plant diseases needs to be addressed using experimental approaches. Studies in a controlled environment may be used to formulate hypothesis and to determine critical relationships to help indeveloping process-based approaches. Field-based for research examining the influence of which examines combination of interacting factors would be needed to provide a more realistic appraisal of impacts. More simulation studies, ideally those which also generate quantitative disease-yield loss data for different maize diseases and locations are needed in order to include the future potential disease risk in maize due to the climate change. Pathogen monitoring through scouting of commercial fields and observing trap nurseries at relevant hot spot or favourable locations along with limited sampling for race analysis might allow the early detection of new races and confirm the prevalence of major existing races

Changing disease scenario due to climate change highlights the need for better agricultural practices and use of ecofriendly methods in disease management for sustainable crop production. Choice of crop management practices, weather based disease monitoring, inocula monitoring, especially for soil-borne diseases and rapid diagnostics is critical. Adoption of novel approaches to counter the resurgence of diseases under changed climatic scenario and integrated disease management strategies need to be developed to reduce dependence on fungicides. Other approaches include healthy seeds with broad and durable disease resistance, and intercropping systems that promote harbouring of natural biocontrol organisms and monitoring and early warning systems for forecasting disease epidemics for economically important host/pathogens which have a direct bearing on the earnings of the farmers and food security at large. Use of botanical pesticides and plant-derived soil amendments such as neem oil, neem cake and karanja seed extract also help in mitigation of climate change by reduction of nitrous oxide emission by nitrification inhibitors such as nitrapyrin and dicyandiamide.

Breeding for durable resistance based on the accumulation of additive minor genes through use of race nonspecific (slow rusting) resistance is emphasized. DNA marker-assisted selection (MAS) should be utilized when feasible. Seed multiplication and distribution of diverse resistant improved genotypes are to be promoted through meaningful and efficient seed production programs also. Participatory variety selection schemes may prove useful in rapidly replacing old varieties in farmers' fields. Lastly, resources for research, training, and infrastructure are of primary importance. Use of resistant cultivars is the most economical and environmentally safe means of controlling obligate parasites like powdery mildew. Incorporation of durable, race nonspecific resistance into high yielding genotypes is effective approach with a shift in breeding strategies to avoid the 'boom and bust' cycles that are frequently observed particularly, for areas where a single genotype is sown and the risk of mutation to new virulent races increases under selection pressure. Integrated efforts to identify and incorporate resistance with international organizations, national programs, and advanced research institutions will enable all parties to harness resistant germplasm more rapidly and have it adopted more widely.

Importance of genotype and gene flow in spread of diseases can never be underestimated. As international travel continues to increase, the possibility of the accidental introduction and evolution of a new pest or disease to a region is more likely. One broad recommendation would be an increased focus on how a changing environment affects evolution and pathogen characteristics (frequency of generations and proportion of sexual reproduction), host characteristics (life span) affecting the rate of adaptation. Understanding trade-offs in plant gene expression in response to different stressors will allow more accurate predictions about responses to complex shifts in many climatic variables and perhaps also about the potential for adaptation. Invasive plant species might be better adaptive to climate change and move to new areas rapidly, leaving pathogens behind or at least limiting their evolutionary options through bottlenecks.

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RESEARCH PAPER

Identification of contrasting genotypes under heat stress in maize (*Zea mays* L.)

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Abstract: Heat stress causes an array of morpho-physiological, anatomical and biochemical changes in plants, which directly affect plant growth and development causing reduction in biological as well as economical yield. In this study twenty maize inbred lines were evaluated under heat stress during Spring 2014 and *Kharif* 2014 for morphological, physiological and yield attributes in Randomized Block Design (RBD) with three replications. Significant differences were observed for the interaction of genotypes and season on plant height, leaf area index, cob position, anthesis- silking interval, days to 50 % anthesis, tassel blasting and number of rows per cob. All the yield parameters were reduced significantly under heat stress. Overall less percent reduction of yield attributes under spring seasons compared to *kharif* season was observed for genotype DTPYC9F119 whereas maximum reduction was observed in K64R. The study concluded that few genotypes like HKI 1532, BJIM-10-36, HKI1015-WG8 and BLSB-RIL-8 showed a certain intermediate level of high temperature susceptibility, while some genotypes like HKI 335, DTPYC9F46, DTPYC9F73 and DTPYC9F102 showed a certain intermediate level of tolerance. The genotype DTPYC9F119 was highly tolerant to heat stress whereas K64R is highly susceptible. Hence, the tolerant genotype(s) could be used as a source of heat stress tolerance in future hybrid breeding programme.

Keywords: Contrasting genotypes · Heat stress · Maize

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Introduction

Over the next 50 years agriculture must provide support for an additional 3.5 billion people (Borlaug, 2007). Production of major cereal crops like maize, wheat and rice will need to increase by 70% by 2050 in order to feed the world's growing rural and urban populations (Cairns *et al.,* 2013). Maize (*Zea mays* L.) is the world's most extensively grown cereal and is the principal feed crop in many countries (Vasal, 2000). In India, maize is third most important cereal crop after rice and wheat. Globally, maize is known as queen of cereals because it has the highest genetic yield potential among the cereals. It is cultivated on nearly 150 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices. It contributes 36% (782 mt) in the global grain production. Most of the crop is grown in the warmer part of temperate regions and in humid subtropical climate. The greater production occurs in the area having the warmest month isotherms from 21 to 27p C and a frost free season of 120 to 180 days duration.

In India, maize contributes nearly 9% in the national food basket and more than Rs. 100 billion to the agricultural gross domestic product (GDP) at current prices, apart from generating employment of over 100 million man-days at the farm and downstream agricultural and industrial sectors. In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries and also extensively used for the preparation of corn starch, corn syrup, corn oil dextrose, corn flakes, gluten, grain cake, lactic acid and acetone which are used by various industries like fermentation, textile, foundry and food industries. Development of poultry and livestock industry also induces maize consumption. Human consume maize both in fresh and processed forms. Because of its immense economic importance and use, even little production loss is an important factor. At present area, production and productivity of maize in India are 9.42 million ha, 24.35 million tonnes and 2.58 tonnes/ha, respectively.

The World Meteorological Organization (WMO) has ranked 2014 as the hottest year on record, as part of a continuing trend. A report from the Asian Development Bank in 2009 warns that if the current trends persist until 2050, major crop yields and food production capacity of South Asia will significantly decrease by 17% for maize, 12% for wheat, and 10% for rice due to climate change induced heat and water stresses. In a situation of high global warming threats, maize is not an exception. Production and productivity of maize is also prone to rapid and constant changes due to global warming related environmental changes (Wahid *et al*., 2007). Among various abiotic stresses, heat stress is a serious threat to crop production worldwide. Maize can be cultivated in almost all type of climate condition, tropical to temperate, and more or less all types are affected by heat.

The degree and damage of the crop depends upon the intensity and duration of the heat spell. High temperature and heat waves especially coupled with low relative humidity can cause more damage to growing corn plant, pollination, seed set and yield. The situation may further be aggravated under drought condition. Warmer temperature during flowering and grain filling results less photosynthate conversion to plant carbohydrates (dry matter). During warm condition, plant burns excessive amounts of photosynthate due to respiration and evolve carbon dioxide back to the atmosphere. This loss of potential plant carbohydrate causes less availability of starch to fill the ear.

High temperature adversely affects seed germination, photosynthesis, respiration, transpiration, chlorophyll content, membrane stability, dry matter production, dry matter partitioning, quality of flowering, gene expression, crop quality, yield component (like grain number per cob, cob number per plant, 100 grain weight etc.). It also modulates level of hormones and primary and secondary metabolites and crop duration. Like other stress conditions, under high temperature also, some gene expression will reduce and at the same time some genes will express more than normal condition to avoid or reduce severity of stress. Plant responses to heat stress vary with the degree of temperature and duration and plant type. At extreme high temperature, cell death may occur within minutes, which may lead to a catastrophic collapse of cellular organization (Ahuja *et al.,* 2010).

Heat-stress generally affects all aspects of plant processes like germination, growth, development, reproduction and yield. But the effect of severity is generally different in different crops, like in case of rice, it is heading stage, and in wheat it is grain filling and maturation stage which is mostly affected by high temperature. In case of maize, overall reproductive stage is seriously hampered by high temperature (Hasanuzzaman *et al*., 2013). Even a few degrees increase in temperature during flowering time can result in significant losses in grain yield (Lobell *et al*., 2011).

Several studies on heat stress have indicated pollination, fertilization and kernel setting as the most heat-sensitive reproductive processes in cereals (Barnabás *et al*., 2008). In case of maize, it can desiccate exposed silk and pollen grains released from the anthers due to thin outer membranes (Sinsawat *et al*., 2004). However, the severity of damage depends upon the duration and intensity of temperature (Hussain, 2005). There is a strong source and sink relationship between vegetative and reproductive parts, which determines ultimate yield. Vegetative growth, mainly leaf growth increases in maize have been reported from 0-35ºC, with sharp decline at 35-40ºC. Beyond that, a sharp decline in photosynthesis and protein metabolism occurs which may be the result of protein denaturation, enzyme inactivation, inhibited protein synthesis and its degradation (Dubey, 2005; Wahid, 2007). The activation state of RUBISCO declines at 32.5ºC (Crafts-Brander and Salvucci, 2002) with more or less completely inactivated at 45ºC and plant dies at 54ºC (Steven *et al*., 2002).

Increase in temperature from 22ºC to 28ºC during grain filling stage, results in reduction of 10% yield (Thomson, 1966), and 42% yield reduction occurs when mean daily temperatures were increased by 6ºC (Badu-Apraku *et al*., 1983). Lobell *et al*. (2011) found that maize production decreased linearly with every accumulated degree day above 30ºC. Phenology is also significant under maize production in heat stress (Muchow *et al*., 1990). The response of vegetative and reproductive tissues to heat stress is different. Even male and female reproductive tissues under high temperature stress differs (Dupis and Dumas, 1990). According to a recent study, the period between silk pollination and ovary fertilization, is critical for grain yield under heat stress (Cicchino *et al.*, 2010).

Photosynthetic rate under heat stress is highly related to chlorophyll a and chlorophyll b ratio, total concentration of chlorophyll and rapid leaf senescence. Leaf temperature above 38ºC will inhibit photosynthesis in C_4 plants (Tashiro and Wardlaw, 1991). Cell membrane damage is an effect of heat stress and increased membrane damage will lead to reduction in water, ion and organic matters mobility, ultimately leading to decrease in dry matter production, transport and accumulation. Under heat stress conditions, cereals increase their grain growth ratios by shortening dry matter accumulation period (Zakaria *et al.,* 2002) and this will affect the ultimate size of grains.

The development of maize germplasm adapted to environments prone to high temperature stress has been a key strategy for reducing the associated loss in grain yield. Before development of maize hybrid tolerant to heat stress, the most important parameters that affect thermo-tolerance needs to be identified. So, identification of heat stress tolerant parental lines is of utmost importance to develop maize hybrids suitable for cultivation under high temperature conditions.

The present studies were aimed to identify contrasting maize genotypes in terms of heat-stress tolerance.

Materials and methods

The present investigations were carried out *kharif* and spring crop seasons at the experimental field of the ICAR-Indian Institute of Maize Research, Pusa Campus, New Delhi, India (28.61^o N, 77.20^o E, and 293 m *above sea level*). Twenty maize inbred lines (Table 1) were grown in 0.6 x 0.2 cm spacing in RBD with three replications. Recommended dose of fertilizers, irrigation and plant protection were followed.

Kharif 2014: Sowing was done on 15thJuly of 2014 (*kharif* season). The flowering occurred during the month of September, wherein the maximum and minimum temperature ranged between 25–37^{o}C and 15- 25^{o}C, respectively, while the mean relative humidity during the flowering period was 85% (Fig. 1, 2)

Spring 2014: Sowing was done on 11th March of 2014 (spring season). The flowering occurred during the month of May, wherein the maximum and minimum temperature ranged between 35–45ºC and 20-28ºC, respectively, while the mean relative humidity during the flowering period was 45% (Fig. 1, 2).

Observations

Morpho-physiological traits

a. Plant height: Plant height was measured by a meter scale from soil surface to a point where two developing leaves at the top of the plant forms a "V" shaped structure and represented in cm.

Table 1. Name and source of maize inbred lines used in the study

S.No.	Name	Source
1.	HKI 32517AN	CCSHAU, Karnal
2.	HKI 577	CCSHAU, Karnal
3.	HKI 1532	CCSHAU, Karnal
4.	LM 17	PAU, Ludhiana
5.	CA 14514	CIMMYT, Mexico
6.	HKI 209	CCSHAU, Karnal
7.	HKI 335	CCSHAU, Karnal
8.	CM 139	AICRP of Maize, New Delhi
9.	LM 16	PAU, Ludhiana
10.	BJIM 08-27	CSHPKVV, Bajaura
11.	BJIM 10-36	CSHPKVV, Bajaura
12.	BJIM 10-1	CSHPKVV, Bajaura
13.	DTPYC9F46-3-6	CIMMYT, Mexico
14.	DTPYC9F102-4-5	CIMMYT, Mexico
15.	DTPYC9F73-2-1	CIMMYT, Mexico
16.	DTPYC9F119	CIMMYT, Mexico
17.	LM 13	PAU, Ludhiana
18.	K64R	IARI, New Delhi
19.	HKI1015-WG8	CCSHAU, Karnal
20.	BLSB-RIL-8	IARI, New Delhi

b. Plant girth: Plant girth was measured by vernier calipers and represented in cm.

c. Leaf area index (LAI): Leaf area was measured with Planimeter. LAI = Leaf area/Soil ground area

d. Leaf firing: Leaf firing was observed by counting the number of plants that showed leaf firing symptoms (younger leaf near tassel burned or dried) in the total number of plants in a particular plot. It was calculated as percentage value.

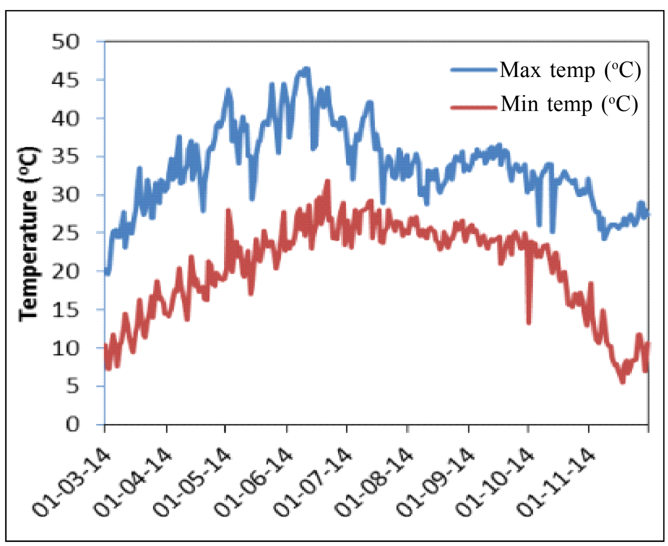

Fig. 1. Maximum and minimum temperatures during the year 2014

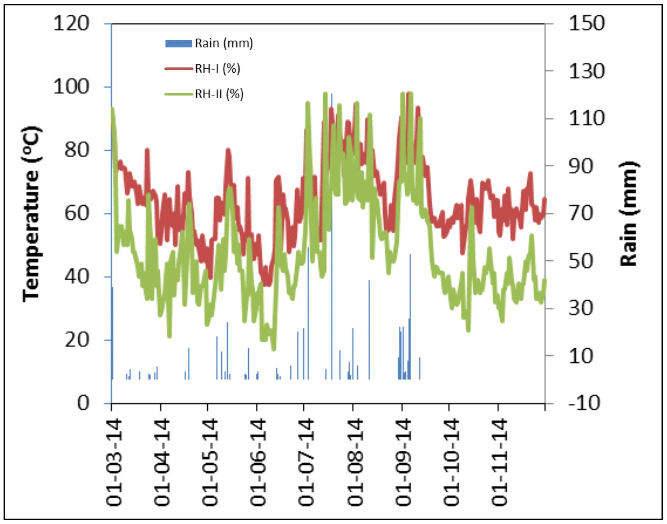

Fig. 2. Relative humidity and rainfall during 2014

e. Tassel blasting: Tassel blast was obtained by the counting the number of plants that showed tassel blast symptoms (tassel dried with no pollen shedding) in the total number of plants in a particular plot. It was calculated as percentage value.

f. Anthesis-silking-interval (ASI): Date of 50 percent anthesis (male flower) as well as the date of 50 percent silking (female flower) was recorded and difference between these two was calculated. This was expressed as ASI.

g. Cob position: Cob position was measured as a distance of cob from ground level with the help of a measurement tape and represented in cm.

Grain yield and its attributes

For measurement of grain yield and its attributes cob position, cob weight, cob girth, cob length, number of rows per cob, grain weight per plant and 100 grain weight was measured.

a. Cob weight: Cobs were first de-husked and then weighed by a weighing machine and the weight was represented in terms of g.

b. Cob girth: Cob girth was measured with the help of vernier calipers.

c. Cob length: Cob length was measured with the help of centimeter scale.

d. Number of rows per cob: Number of rows per cob was counted manually.

e. Number of grains per rows: Number of grains per rows was counted manually.

f. Grain weight per plant: Total weight of the grains per plant was measured by using a weight balance and expressed in g.

g. 100 grain weight: 100 grains were taken randomly and weighed. Weight was expressed in g.

Statistical analysis

Data was statistically analysed and means were compared between 20 lines among the treatments by RCBD (Randomised Complete Block Design) and then the tolerant and susceptible genotypes were identified.

Results

Effect of heat stress on morpho-physiological traits

Plant height: The plant height of the twenty genotypes under heat stress (i.e. spring planted maize) was compared with plant height of the same genotypes when grown in optimal conditions (i.e. *kharif* planted maize). For all the twenty maize genotypes, the plant height in case of spring planting decreased significantly as compared to that of *kharif* planting. The mean plant height of the twenty genotypes was reduced from 129.72 cm in *kharif* to 79.52 cm in spring. Minimum reduction was observed in DTPYC9F119 genotype (2.31 %), while the reduction was significantly high in LM13 (72.20%) and K64R (64.11%) (Table 2). Significant difference was found for the interaction of genotypes and season on plant height (S X G).

Stem girth: Significant differences among twenty genotypes were observed forstem girth under heat stress (spring season) as compared to optimal conditions (*kharif* season). The stem girth significantly reduced by 58.5%, 50.85%, and 47.14% in LM 16, K64R and HKI1015-WG8 genotypes respectively, while the minimum reduction was observed in DTPYC9F119 (3.78%) (Table 2). The mean stem girth of twenty genotypes was reduced from 6.87 cm in *kharif* season to 4.82 cm in spring season. However, the interaction of two factors viz. temperature and genotypes was found to be non-significant.

Leaf area index: In spring season, leaf area index was found to be significantly lower than that under *kharif* season in all

Table 2. Influence of different planting seasons on plant height (cm), stem girth (cm) and leaf area index in twenty maize genotypes

Genotypes	Plant height (cm)		Stem girth (cm)		Leaf area index	
	Kharif 2014	Spring 2014	*Kharif* 2014	Spring 2014	*Kharif* 2014	Spring 2014
HKI 325-17AN	106.83	93.37	7.60	5.32	2.30	1.88
HKI 577	167.78	108.66	6.73	4.39	4.37	2.83
HKI 1532	124.85	80.61	5.39	4.43	2.56	1.35
LM 17	179.37	131.45	7.96	6.98	3.18	2.25
CA 14514	104.59	88.56	7.62	5.06	2.43	1.96
HKI 209	96.01	51.96	4.81	2.41	1.65	1.16
HKI 335	135.49	100.76	7.85	6.72	4.08	3.80
CM 139	111.95	77.70	7.79	6.51	1.29	1.03
LM 16	136.47	54.22	6.60	3.33	2.30	1.14
BJIM 08-27	124.42	67.44	7.76	5.59	2.30	2.03
BJIM 10-36	120.84	58.84	8.37	5.25	3.39	1.78
BJIM 10-1	123.58	85.36	7.70	6.38	2.48	1.55
DTPYC9F46	126.15	92.81	5.48	4.57	2.46	1.49
DTPYC9F102	124.39	92.69	5.52	4.10	2.44	1.63
DTPYC9F73	136.92	91.45	6.71	5.29	1.72	1.44
DTPYC9F119	124.39	121.52	6.34	6.10	2.58	2.58
LM 13	150.08	41.72	7.77	3.22	2.67	1.02
K64R	139.08	49.91	7.57	3.72	3.07	1.02
HKI1015-WG8	132.36	51.97	6.58	3.48	2.67	1.11
BLSB-RIL-8	128.80	49.46	5.27	3.51	2.67	1.13
Mean	**129.72**	**79.52**	**6.87**	**4.82**	**2.63**	**1.71**
$LSD_{0.05}$ (Genotypes)	1.65		0.45		0.07	
$LSD_{0.05}$ (Season)	5.22		1.42		0.22	
$LSD_{0.05}$ (Genotypes X Season)	7.38		NS		0.31	

the twenty maize genotypes. The interaction between season and genotypes was significant. Under spring, maximum reduction in LAI was observed in K64R (66.71%), while in case of DTPYC9F119 no reduction was observed in spring season compared to *kharif* (Table 2).

Cob position: Reduction in cob position was significant from *kharif* to spring season. Cob position of twenty genotypes during *kharif* season ranged from 113.17 cm (LM17) to 59.59cm (CA 14514) while, in spring it ranged from 67.29 cm (LM17) to 32.21 cm (K64R). The interaction effect of season upon genotype was also found to be significant (Table 3).

Anthesis-silking-interval (ASI): ASI of all the twenty genotypes significantly increased under spring season as compared to *kharif* and a significant difference was observed in temperature and genotype interaction (S X G) on ASI. The increase was prominent in HKI1015-WG8 and HKI 209 with 1.3 days in *kharif* and 7.6 days in spring season for the former and 1.3 and 7.7 in case of later. It was also prominent in case of K64R (1.34 to 5.51 days). The increase in ASI was less in HKI 335, HKI 325- 17AN and DTPYC9F119 as compared to other genotypes (Table 3).

Days to 50% anthesis: Days to 50% anthesis varied significantly among twenty different genotypes in both under *kharif* and spring planting season (Table 3). Percent increase from *kharif* to spring season in days to 50% anthesis of DTPYC9F119 (9.35%) was significantly lower than all other genotypes but it was maximum incase of K64R (70.14%).

Leaf firing: Leaf firing is an important high temperature susceptibility indicator. There was no leaf firing observed in any of the genotype during *kharif* planted season, however, leaf firing was observed in most of the genotypes during spring planted season. Among them, highest leaf firing was found in K64R (89.34%) followed by CA14514

Table 3. Influence of different planting seasons on cob position (cm), anthesis-silking-interval (days) and days to 50% anthesis in twenty maize genotypes

Genotypes	Cob position (cm)		Anthesis-silking-interval (days)		Days to 50% anthesis	
	Kharif 2014	Spring 2014	*Kharif* 2014	Spring 2014	*Kharif* 2014	Spring 2014
HKI 325-17AN	78.13	52.11	2.07	3.12	42.55	51.73
HKI 577	93.24	65.99	1.69	3.32	40.68	51.12
HKI 1532	79.04	45.68	2.07	4.37	42.52	53.39
LM 17	113.17	67.29	1.28	3.33	41.34	50.74
CA 14514	59.59	34.75	1.34	3.03	41.03	54.21
HKI 209	76.95	39.46	1.32	7.70	37.33	55.93
HKI 335	65.65	51.89	2.13	3.16	43.35	50.68
CM 139	71.89	45.87	1.77	4.06	39.03	51.77
LM 16	87.70	41.59	1.65	4.41	43.01	59.28
BJIM 08-27	98.58	51.85	2.35	4.15	43.59	63.77
BJIM10-36	85.86	50.76	1.73	4.50	40.73	60.65
BJIM 10-1	93.99	56.28	1.68	4.39	38.55	53.65
DTPYC9F46	67.49	45.26	1.71	3.38	40.00	61.83
DTPYC9F102	72.02	41.47	2.28	4.29	41.03	56.36
DTPYC9F73	73.23	50.74	1.37	5.17	39.68	51.76
DTPYC9F119	72.56	59.49	1.42	2.31	40.20	43.96
LM 13	87.38	32.70	1.70	4.14	43.99	54.69
K64R	99.21	32.21	1.34	5.51	40.33	68.62
HKI1015-WG8	87.81	41.49	1.30	7.66	45.13	60.16
BLSB-RIL-8	83.95	42.30	1.37	5.14	44.49	58.75
Mean	**82.37**	**47.46**	**1.68**	**4.36**	**41.43**	**55.65**
$LSD_{0.05}$ (Genotypes)	1.01		0.07		0.84	
$LSD_{0.05}$ (Season)	3.20		0.23		2.65	
$LSD_{0.05}$ (Genotypes X Season)	4.53		0.33		3.75	

(65.85%) (Fig. 3), while minimum leaf firing was observed in HKI 335(13.69%) followed by DTPYC9F119 (15.75%).

Tassel blasting: Tassel blasting was not observed in *kharif* planted crop but in spring planted crop severe tassel blasting was observed in some genotypes like K64R (82.21%), CA14514 (73.13%), HKI209 (54.77%). Significant difference between temperature, genotypes and their interaction on tassel blasting was observed (CD of S = 1.156, G = 3.655, S X G = 5.169) (Fig. 4).

Effect of heat stress on grain yield and its attribute

Cob length: A marked difference in cob length was observed among different genotypes in the two seasons (*kharif* and spring). Cob length was significantly reduced under spring season in all the twenty genotypes. The result of cob length in twenty genotypes showed that minimum reduction of cob length occurred in DTPYC9F119 (7.09%). Significant higher reduction in cob length was observed in HKI1015-WG8 (5.1cm) and K64R (4.2cm) (Table 4).

Cob girth: The study indicated a significant reduction in cob girth of different genotypes in spring season as compared to *kharif* season. In spring season, the highest cob girth was registered in DTPYC9F119 (9.21 cm), while significantly lower cob girth was recorded 1.1 cm and 1.3 cm in HKI1015-WG8 and K64R genotypes (Table 4).

Cob weight: The cob weight was significantly reduced in spring season in all the twenty genotypes. Cob weight was significantly lower in HKI1015-WG8 and K64R genotypes in spring season. Significant Lower reduction was observed in DTPYC9F119 under spring season as compared to *kharif* (Table 4).

Number of rows per cob: The number of the rows per cob

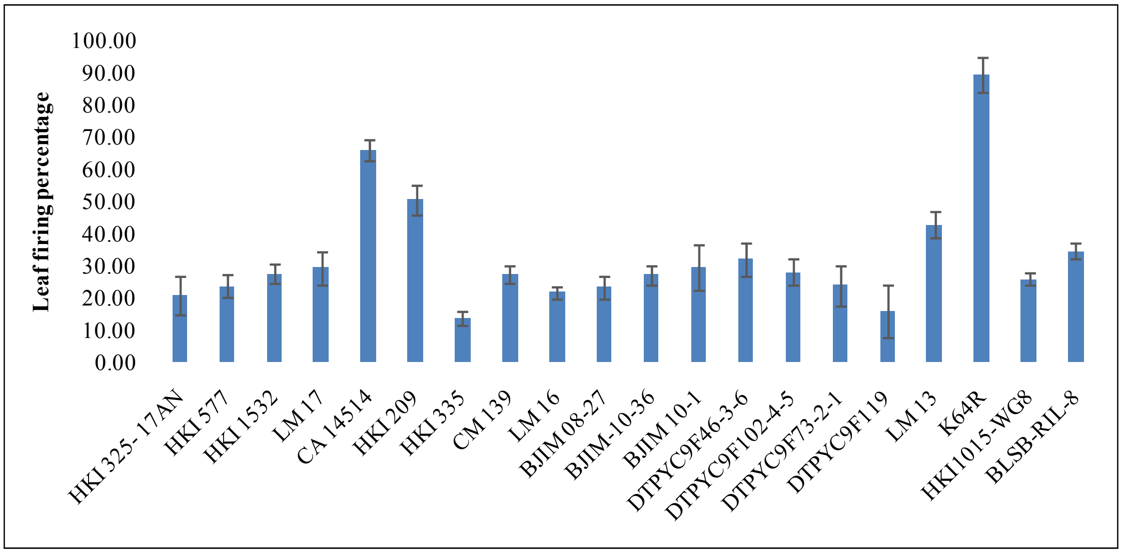

Fig. 3. Genotypic variations for leaf firing in spring planted twenty maize genotypes. Each vertical bar represents mean of three independent replicates ± SEm.

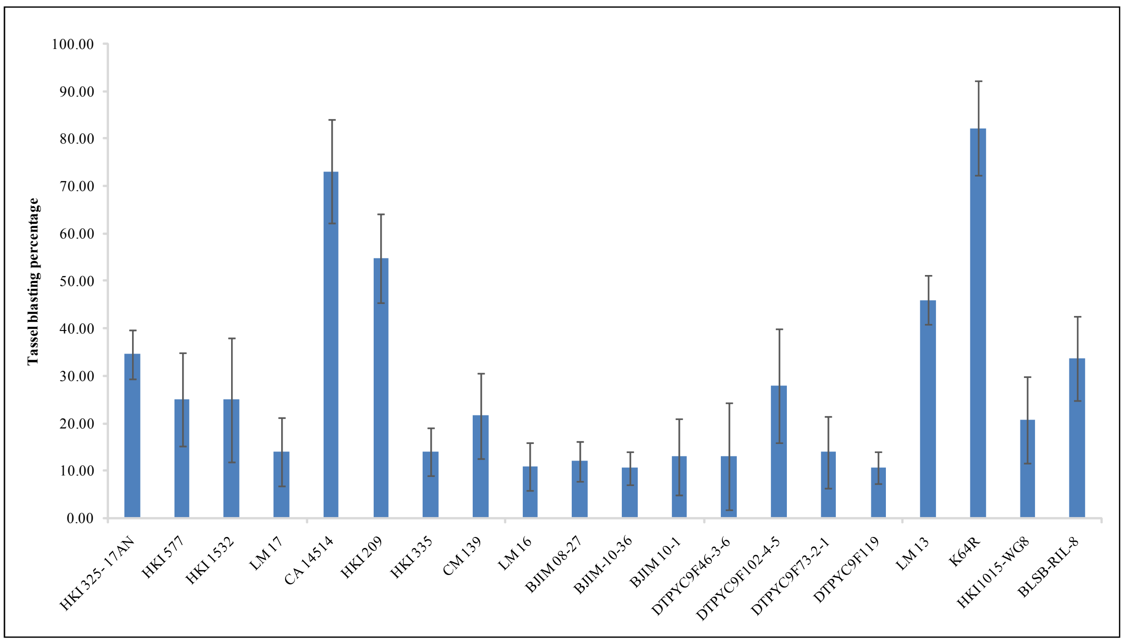

Fig. 4. Genotypic variations for tassel blasting in spring planted twenty maize genotypes. Each vertical bar represents mean of three independent replicates ± SEm.

reduce significantly during spring season in all the genotypes. There was no cob in HKI1015-WG8 and K64R genotypes in spring season, however, cob formation was observed in HKI 209 but there was no grain in the cob (Fig. 7,8) Significant less reduction found in number of rows per cobs under spring season compared to *kharif* in HKI 577, CA 14514 and DTPYC9F119 genotypes (Table 5). The interaction effect (S X G) was also found to be significant.

Grain weight per cob: The grain weight per plant was significantly reduced due to seasonal variation in all the genotypes. The influence of spring sowing on different genotype was significantly different. In the spring season, the highest grain weight per plant was recorded in DTPYC9F119 (45.62 g) (Table 5). The mean of grain weight per cob of twenty genotypes changed from 44.20g (*kharif* season) to 13.98g (spring season).

Number of grains per row: Significant reduction in number of grains per row was recorded in almost all genotypes except DTPYC9F119 and HKI 335 genotype under spring compared to *kharif* season. Mean number of grains per row of the twenty genotypes was reduced from 19.68 to

Table 4. Influence of different planting seasons on cob length (cm), cob girth (cm) and cob weight (g) in twenty maize genotypes

Genotypes	Cob length (cm)		Cob girth (cm)		Cob weight (g)	
	Kharif 2014	Spring 2014	*Kharif* 2014	Spring 2014	*Kharif* 2014	Spring 2014
HKI 325-17AN	14.48	11.58	7.31	7.47	71.42	35.06
HKI 577	13.32	7.30	6.78	5.49	53.05	7.35
HKI 1532	13.99	10.94	8.15	6.54	44.33	1.57
LM 17	14.65	12.03	9.10	7.31	66.48	35.25
CA 14514	11.63	6.63	4.70	3.56	51.02	25.22
HKI 209	12.71	6.94	4.73	3.18	41.67	1.20
HKI 335	14.24	9.92	10.68	7.93	68.18	49.58
CM 139	10.67	11.53	6.08	5.65	28.69	1.19
LM 16	14.49	10.88	7.32	5.42	44.40	0.73
BJIM 08-27	14.26	11.76	8.82	3.61	53.36	7.27
BJIM 10-36	14.56	10.44	7.66	4.24	71.43	6.38
BJIM 10-1	14.49	10.65	8.73	6.49	76.49	9.09
DTPYC9F46	8.43	7.11	6.28	4.33	73.49	27.88
DTPYC9F102	9.64	7.95	5.03	3.12	38.46	16.13
DTPYC9F73	14.84	12.71	11.68	4.17	74.45	39.87
DTPYC9F119	14.39	13.37	10.51	9.21	72.53	54.85
LM 13	11.46	10.56	8.29	3.98	37.56	12.36
K64R	10.67	4.20	7.78	1.30	36.61	1.00
HKI1015-WG8	9.69	5.10	6.68	1.10	16.55	1.00
BLSB-RIL-8	9.84	3.72	6.27	3.62	42.72	4.20
Mean	**12.62**	**9.32**	**7.63**	**5.04**	**53.15**	**16.70**
$LSD_{0.05}$ (Genotypes)	0.33		0.25		0.73	
$LSD_{0.05}$ (Season)	1.04		0.78		2.31	
$LSD_{0.05}$ (Genotypes X Season)	1.47		1.11		3.27	

Fig. 6. Tassel blasting in maize during spring 2014

11.05 under spring season as compared to the *kharif*. In the spring season, not a single grain per row was recorded in K64R, HKI 209 and HKI1015-WG8genotypes, whereas interestingly number of grains per row increased in HKI 335 (26.67) and DTPYC9F119 (26.33) (Fig. 7, 8) genotypes under spring as compared to *kharif* season (Table 5).

Fig. 5. Leaf firing in maize during spring 2014

Table 5. Influence of different planting seasons on number of rows per cob, number of grains per row, 100 grain weight (g) and grain weight per cob (g) in twenty maize genotypes

Genotypes	No. of rows/cob		No. of grains/row		100 grain wt. (g)		Grain wt./cob (g)	
	Kharif 2014	Spring 2014	*Kharif* 2014	Spring 2014	*Kharif* 2014	Spring 2014	*Kharif* 2014	Spring 2014
HKI 325-17AN	12.00	9.67	22.67	17.00	22.00	17.31	58.86	29.44
HKI 577	12.67	6.67	17.67	6.33	19.67	14.33	44.32	6.44
HKI 1532	12.00	2.00	13.33	3.67	23.00	18.58	36.61	1.48
LM 17	12.00	10.33	23.00	17.00	20.33	16.90	56.25	29.59
CA 14514	11.00	9.33	15.67	11.67	24.67	19.29	42.99	21.52
HKI 209	14.00	0.00	13.00	0.00	19.00	0.00	34.35	0.00
HKI 335	12.67	9.33	23.33	26.67	19.00	16.02	56.62	41.18
CM 139	9.00	1.00	18.00	7.00	15.00	12.32	24.42	0.99
LM 16	11.33	0.67	15.33	5.67	21.00	15.29	36.75	0.55
BJIM 08-27	13.33	6.67	22.67	7.33	15.00	12.29	44.36	6.27
BJIM10-36	13.33	5.33	22.00	8.33	20.33	11.36	58.84	5.26
BJIM 10-1	11.67	5.33	21.00	7.67	26.00	19.59	63.29	7.85
DTPYC9F46	10.67	7.67	23.33	16.00	24.33	19.20	60.99	22.33
DTPYC9F102	11.33	8.33	23.33	17.67	12.33	9.26	32.49	13.93
DTPYC9F73	11.33	8.00	28.67	22.67	18.67	15.42	62.23	33.22
DTPYC9F119	13.00	10.67	24.00	26.33	19.33	18.91	60.30	45.62
LM 13	11.33	7.67	18.00	12.00	15.67	11.54	31.14	10.60
K64R	12.00	0.00	18.67	0.00	13.67	0.00	30.35	0.00
HKI1015-WG8	12.67	0.00	13.33	0.00	7.67	0.00	13.39	0.00
BLSB-RIL-8	13.33	4.67	16.67	6.67	16.00	11.60	35.52	3.82
Mean	**12.03**	**5.67**	**19.68**	**11.05**	**18.63**	**12.96**	**44.20**	**13.98**
$LSD_{0.05}$ (Genotypes)	0.29		0.30		0.43		0.45	
$LSD_{0.05}$ (Season)	0.92		0.95		1.37		1.42	
$LSD_{0.05}$ (Genotypes X Season)	1.31		1.35		1.94		2.00	

100 grain weight: High temperature (in spring season) had significant influence on 100 grain weight among twenty different genotypes. The results under heat stress showed that the mean 100 grain weight of the three genotypes namely DTPYC9F119, BJIM 10-1 and DTPYC9F46 were statistically at par, but, the percent change in case of DTPYC9F119 was minimum (2.17%). Under *kharif* season, 100 grain weight of the twenty genotypes ranged from 7.67g (HKI1015-WG8) to 26 g (BJIM 10-1) with an overall mean of 18.63 g. While, under high temperature stress, it ranged from 0 g (K64R, HKI 209, HKI1015-WG8) to 19.59 g (BJIM 10-1) with an overall mean of 12.96 g.

Discussion

Maize is one of the most important cereal crops in the world as well as in India. Maize yield potential is always sensitive to biotic and abiotic stresses. Abiotic stresses are integral part of any agro ecosystem, which actually varies with space and time because of several factors that determine the impact and severity of the abiotic stress. Among the several stresses, high temperature stress is an important stress that leads to significant loss of productivity, especially in the spring planted maize crop, because the flowering time of the spring planted maize coincides with high temperature. High temperature stress induces many biochemical, molecular, and physiological changes and responses that influence various cellular and whole plant processes that affect crop yield and quality. High temperature stress at critical developmental stages, like, at the time of flowering in maize may cause significant yield reduction. In maize, yield component depends upon the physiological conditions of the crop around flowering (Cairns *et al.*, 2012). Transitory or constantly high

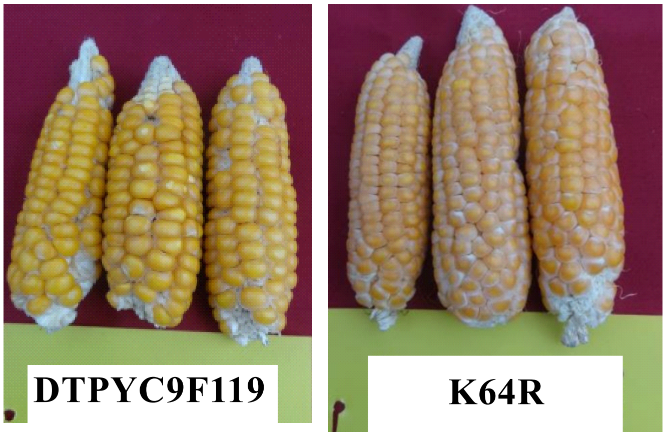

Fig. 7. Cobs harvested in *kharif* season in two contrasting maize genotypes

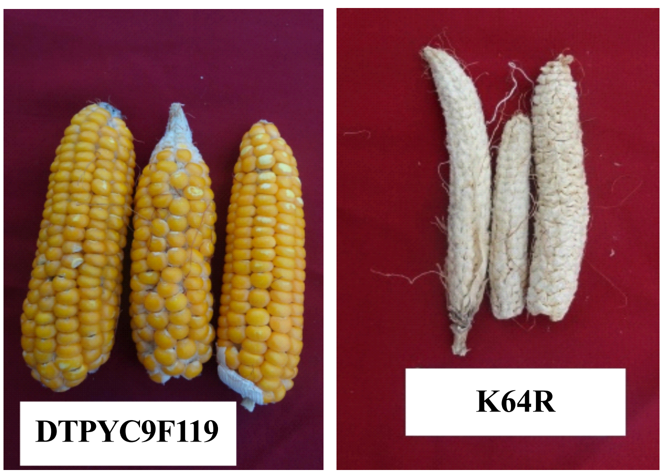

Fig. 8. Cobs harvested in spring season in two contrasting maize genotypes

temperatures causes an array of morpho-physiological, anatomical and biochemical changes in plants, which directly affect plant growth and development and lead to a drastic reduction in biological as well as economical yield.

In the present study, screening of twenty genotypes based on their performance at high temperature during flowering stage was carried out in two different crop seasons in the year 2014. The first sowing was done in the month of March to coincide maximum high temperature at the time of reproductive growth, while the second sowing was done in the month of July for normal condition screening. In this screen, based on a number of morphological and physiological parameters (plant height, plant girth, leaf area index, anthesis-silking-interval, days to 50% anthesis and different yield parameters)best line exhibiting tolerance trait and the worst line exhibiting highly susceptible trait for heat stress were identified. In the second part, selected contrasting two inbred lines were subjected to flowering stage heat stress in plant growth chambers and different biochemical, physiological and molecular parameters were characterized.

It was found that the natural heat stress could reduce plant height, and stem girth in all the twenty genotypes. Under heat stress, reduction of plant height and girth was also observed by Cairns *et al*. (2013). Plant height and stem girth are manifestations of the biological growth. Heat stress can severely impair multiple physiological processes, which could result in reduced height and stem girth. The genotypes grown under heat stress also showed significant decrease in leaf area index (LAI). LAI is a measure of canopy coverage of the ground and influences micro-climate as well as the primary productivity. In our experiment, leaf firing was more under spring season. Leaf firing is actually a strategy to cope under severe stress to reduce the light absorption and to reduce transpiration rate. Severe leaf firing and reduction of LAI has negative impact on net photosynthesis rate and overall production, so the tolerant genotype must have LAI reduction and leaf firing, but, the severity should be lesser than that of the susceptible one. DTPYC9F119 showed very little change in LAI under spring season as compared to *kharif*, while maximum reduction was found in K64R (78.83%).

Anthesis-silking-interval (ASI) is a reliable parameter to identify and screen heat stress tolerance level. Increase in ASI and the days to 50% anthesis were observed under high temperature conditions. But, among the genotype the degree of increase in ASI was highly variable. The genotypes having ability to cope certain level of heat-stress, always depicted almost same ASI as that in *kharif* season crops. This was found in a number of genotypes (HKI 335, HKI 325- 17AN and DTPYC9F119).

All the yield parameters like cob length, girth, weight, number of rows per cob, grain weight per plant, number of grain per row and 100 grain weight and harvest index were reduced significantly under heat stress. This may be due to the reduction of source capacity, as measured in terms of reduced leaf area. The most interesting things is that, under spring season grains per row increased in two genotypes (DTPYC9F119 and HKI 335) where rows per cob and 100 grain weight decreased (Table 5). Actually, cob girth also reduced during spring as compared to *kharif* season in these two genotypes which led to the reduction of number of rows per cob (Fig. 7, 8). Individual grains of these two genotypes were also found more bulky in *kharif* season as compared to spring season therefore 100 grain weight was much more in *kharif* season. Tassel blasting which reduces number of viable pollen and ultimately reduce cob filling can also be deemed responsible for yield reduction. Interestingly, genotypic variability in yield reduction was also evident, which points to the fact that different genotypes have different levels of resilience to stress.

The same finding was observed by Barnabas *et al*. (2008), where they observed that high atmospheric temperature at the repro-ductive developmental stage reduces pollen shedding, pollen viability, and pollination efficiency, and affected kernel development, resulting in a reduction in seed set, kernel size, and kernel weight. In our experiment, DTPYC9F119 genotype showed less percent reduction of yield attributes under spring seasons compared to *kharif* season, whereas maximum reduction was observed in K64R. On the basis of first experiment's results, DTPYC9F119 and K64R genotypes were identified as highly tolerant and highly susceptible respectively under natural heat stress.

Conclusion

It can be concluded from our study that DTPYC9F119 genotype was highly tolerant to heat stress whereas K64R is highly susceptible. Genotypes like HKI 1532, BJIM-10-36, HKI1015-WG8 and BLSB-RIL-8 also showed a certain intermediate level of high temperature susceptibility, while some genotypes like HKI 335, DTPYC9F46, DTPYC9F73 and DTPYC9F102 showed a certain intermediate level of tolerance. The tolerant genotype(s) could be used as a source of heat stress tolerance in hybrid breeding programme.

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RESEARCH PAPER

Standardization of thermal induction response (TIR) protocol in maize

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Abstract: Temperature induction response (TIR) technique has been developed and standardized by using twenty nine maize germplasm lines for the rapid assessment of cellular level tolerance (CLT) in crop plants in order to predict genotype performance under thermal stress. Temperature of 50ºC for 3 hrs showed 100% seedling mortality while, the shorter duration of exposure of 1 hr and 2 hr as well as a lower temperature of 48ºC showed some percentage of seedling survvival. A significant genotypic variability in the parameters associated with cellular level tolerance CLT was observed. Per cent seedlings survival ranged from as low as 0 % to as high as 100 % with a mean survivability of 76.44 %, while recovery growth ranged from 0 cm to 26.52 cm with a mean recovery growth of 9.12 cm. The results therefore clearly indicated the existence of wide and significant genetic variability for CLT in maize germplasm lines. This available variability can be channelized in future breeding programme for isolating promising thermo stable genotypes.

Keywords: Temperature induction response · Cellular level tolerance · Maize

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Introduction

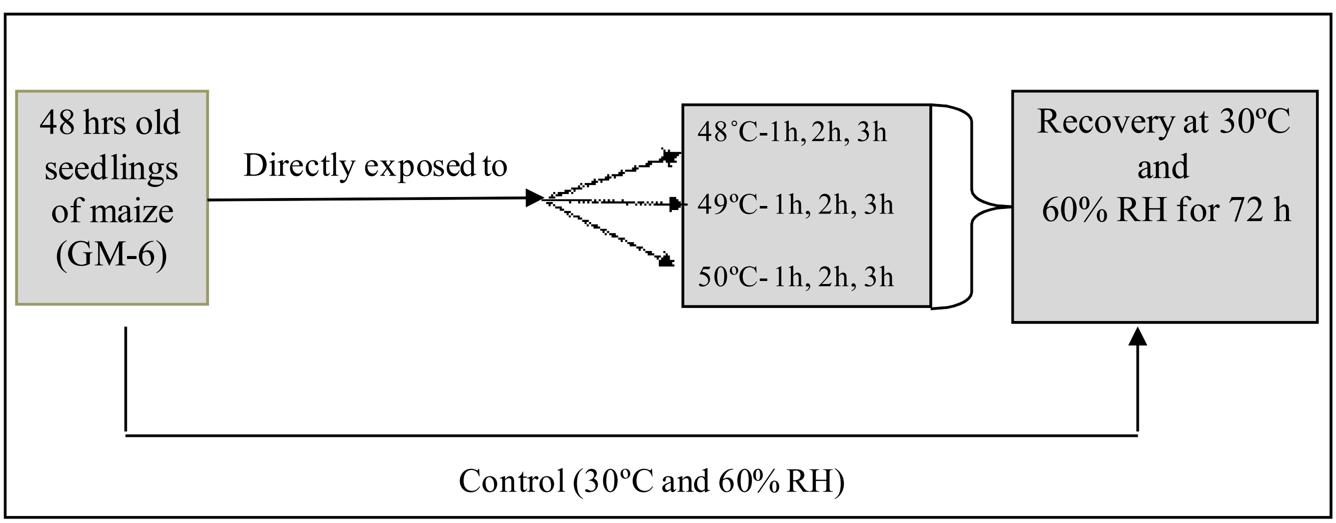
Maize (*Zea mays*) is one of the most important cereal food crops of globe. Maize was long been used as food and feed. However, in recent years, the demand of maize is increasing across the globe due to its utility in industrial utilization especially for bio-fuel production. The global maize production is predicted to grow continuously. About 67% of the total maize production in the developing world comes from low and lower middle income countries; hence, maize plays an important role in the livelihoods of millions of poor farmers. The United States, China, Brazil and Mexico account for 70% of global maize production. India has 5% of maize acreage and contributes 2% of world production. Maize occupies an important place in Indian Agriculture. It is the third most important cereal in India after wheat and rice. The major maize growing states are Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, Punjab, Andhra Pradesh, Himachal Pradesh, West Bengal, Karnataka and Jammu & Kashmir, jointly accounting for over 95% of the national maize production. In India, about 28% of maize produced is used for food purpose, about 11% as livestock feed, 48% as poultry feed, 12% in wet milling industry (starch and oil production) and 1% as seed. In the last one decade, it has registered the highest growth rate among all food grains including wheat and rice because of intervention of single cross heterotic hybrids. Maize contributes nearly 9% in the national food basket and more than 100 billion to the agricultural GDP at current prices apart from the generating employment to over 120 million man-days at the field and downstream agricultural and industrial sectors. In addition to staple food for human being and quality feed & fodder for animals, maize serves as a basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc. In Jammu and Kashmir, 0.5 million quintals were produced from an area of 0.31 million hectares with a productivity of 16.47 q ha^{-1} during 2014.

The relevance of cellular level tolerance (CLT) to various stresses is amply explained in several reviews (Senthil Kumar *et al.,* 2007). A novel Temperature Induction Response (TIR) technique has been developed and standardized for the rapid assessment of cellular level tolerance in crop plants. This approach is based on the fact that, drought stress develops gradually and the plants are normally exposed to sub-lethal stress before being exposed to more severe stress. An array of response events are activated when plants experience milder level of stress. These responses would lead to the protection against a severe stress (Abdullah *et al.,* 2001). Following this concept, genetic variability for cellular level tolerance has been reported in several crop species such as finger millet (Uma *et al*., 1995); sunflower (Senthil Kumar, 2001); cotton (Ehab Abou Kheir, 2006) and rice (Narayanaswamy, 2009). Further, the genotypes/ varieties identified or developed through temperature induction response (TIR) approach not only showed tolerance to high temperature, but also to other abiotic stresses like drought (Senthil-Kumar *et al*., 2003).

Materials and methods

A novel technique of TIR was developed at the Department of Crop Physiology, University of Agricultural Sciences, Bangalore to screen genotypes for cellular level tolerance. In this technique, the germinated seed were initially exposed to a mild temperature (sub lethal stress) following which, the seeds were exposed to relatively a high temperature for a specific period of time. The percent survival of seedlings and recovery growth of seedlings when transferred back to normal temperature was considered as a measure of tolerance. Selective maize germplasm lines were screened to differentiate cellular level tolerance. In an earlier attempt, Narayanaswamy (2009) had standardized the TIR protocol for screening rice germplasm lines. This protocol was slightly modified using GM-6 a drought tolerant cultivar to standardize the TIR protocol. Lethal temperature is the temperature at which seed mortality would be around 100%. To standardize the lethal temperature, uniform sized seedlings kept in aluminium trays with wet filter paper were exposed to different temperatures for varying durations without prior induction in controlled growth chamber. The seedlings were then allowed to recover at 30ºC with 60% RH for 72 hrs. At the end of the recovery period, the per cent survival of seedlings was taken to arrive at the challenging or lethal temperature. Here, the temperature at which nearly 100% seed mortality occurred was considered as challenging or lethal temperature. The protocol followed to standardize the lethal temperature is given in the form of a flow chart (Flow chart 1).

In order to standardize the induction protocol, two days old uniform sized seedlings of GM-6 and twenty eight other inbreds of maize were taken in aluminium trays with wet filter paper. These trays with seedlings were exposed to a gradual temperature of 30 to 42ºC for 5 hr in growth chamber and subsequently, they were exposed to the standardized lethal temperature as well as a few other temperature regimes for different durations. The objective here was to determine the combination of induction and lethal temperature at which the genetic variability for CLT is clearly evident. At the end of the lethal treatment, the seedlings were kept for recovery at room temperature (30ºC, 60% RH) for 72 hrs and end of which, the genotypic variability in terms of variation in percent seedlings survival and recovery growth were measured. For comparison, one



Flow chart 1: Standardization of lethal temperature protocol for maize more set of seedlings were kept at room temperature all through without exposing them to any kind of stress. Based on these two parameters, the induction protocol was standardized.

$$\% \text{ Survival} = \frac{\text{No. of seedlings survived after recovery period}}{\text{No. of seedlings taken}} \times 100$$

Recovery growth = Final growth of root & shoot – Initial growth of root & shoot

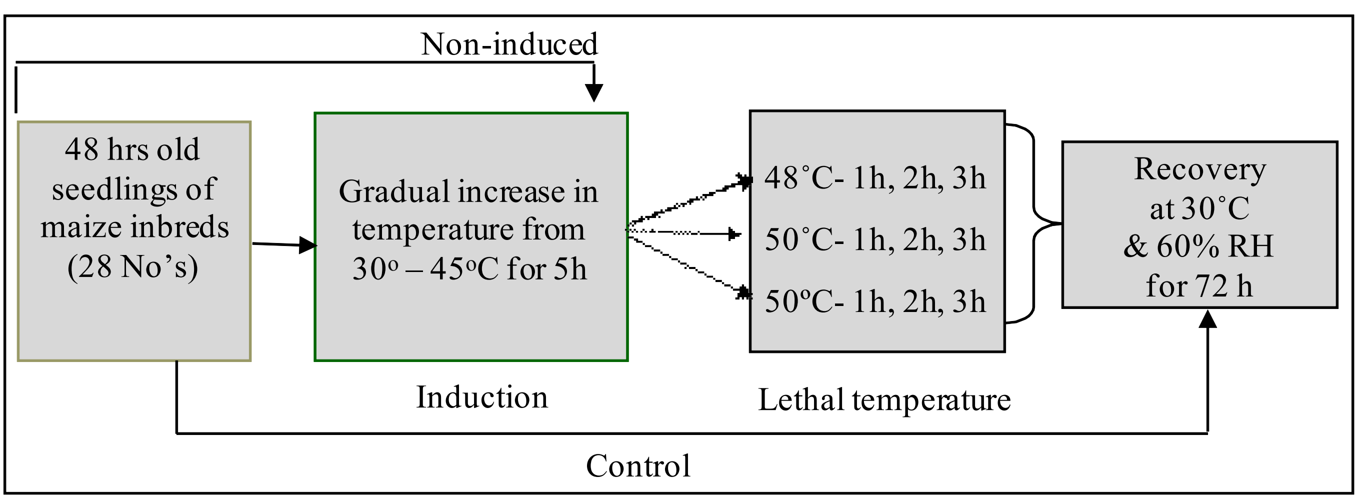
A flow chart depicting the standardization of induction protocol is given below (Flow chart 2).

Based on the standardized induction and lethal protocol, the TIR protocol was standardized and fixed for screening diverse germplasm lines of maize for cellular level tolerance. In summary, this protocol involved three sets of seeds with the first set kept continuously at 30ºC (absolute control) and the second set exposed to lethal temperature directly and goes though the induction cycle prior to exposure to lethal temperature (induced) and then kept for recovery at room temperature.

Results and discussion

In general under natural conditions, organisms are exposed to a sub-lethal stress (which is referred to as induction stress) before they are exposed to a severe stress. The induction stress induces several mechanisms; thereby the machinery gets prepared to face the higher level of stress as a result, the lethal stress effect is reduced considerably. Thus, while screening the germplasm lines for assessing the stress tolerance and in this case for cellular level tolerance, exposure to a sub-lethal stress before exposing them to high stringency stress is a pre-requisite. Through this, it is possible to exploit the genetic variability for stress tolerance (CLT). TIR technique has an option of creating induction as well as lethal stress under laboratory condition for exploiting genetic variability for CLT in crop plants. Since the major objective of the study is to look for the genotypic variability for CLT, a standardized TIR protocol which is crop specific is required. The study involved the standardization of lethal temperature as well as standardization of sub-lethal temperature (induction temperature) for the crop in question, and here in this case, TIR has been standardized for maize. As a pre-requisite, lethal temperature has to be standardized first, followed by standardization of induction temperature. Accordingly in this case, two days old seedlings of maize variety, GM-6 were exposed to high temperature for different durations and later, they were kept for recovery at room temperature for 72 hrs. The results of the study indicated that, a temperature of 50ºC for 3 hrs showed 100% seedling mortality while, the shorter duration of exposure of 1 hr and 2 hr as well as a lower temperature of 48ºC showed some percentage of seedling survvival. Therefore, 50ºC for 3 hrs where 100% seedling mortality observed was considered as standardized lethal temperature for screening maize germplasm lines (Fig. 1).

After having standardized the lethal temperature, the induction temperature was standardized by exposing the seedlings of 28 different varities of maize to a gradual induction temperature of 30-45ºC for 5 hrs and then exposed to standardized lethal temeprature and a few other temeprature regimes for 1, 2 and 3 hrs and later kept for recovery at room temperature for three days (Fig. 2). At the end of the recovery period, variation in seedlings survival and recovery growth was recorded in all the twenty eight inbreds of maize and based on the best results, the induction



Flow chart 2: Standardization of induction temperature protocol for maize

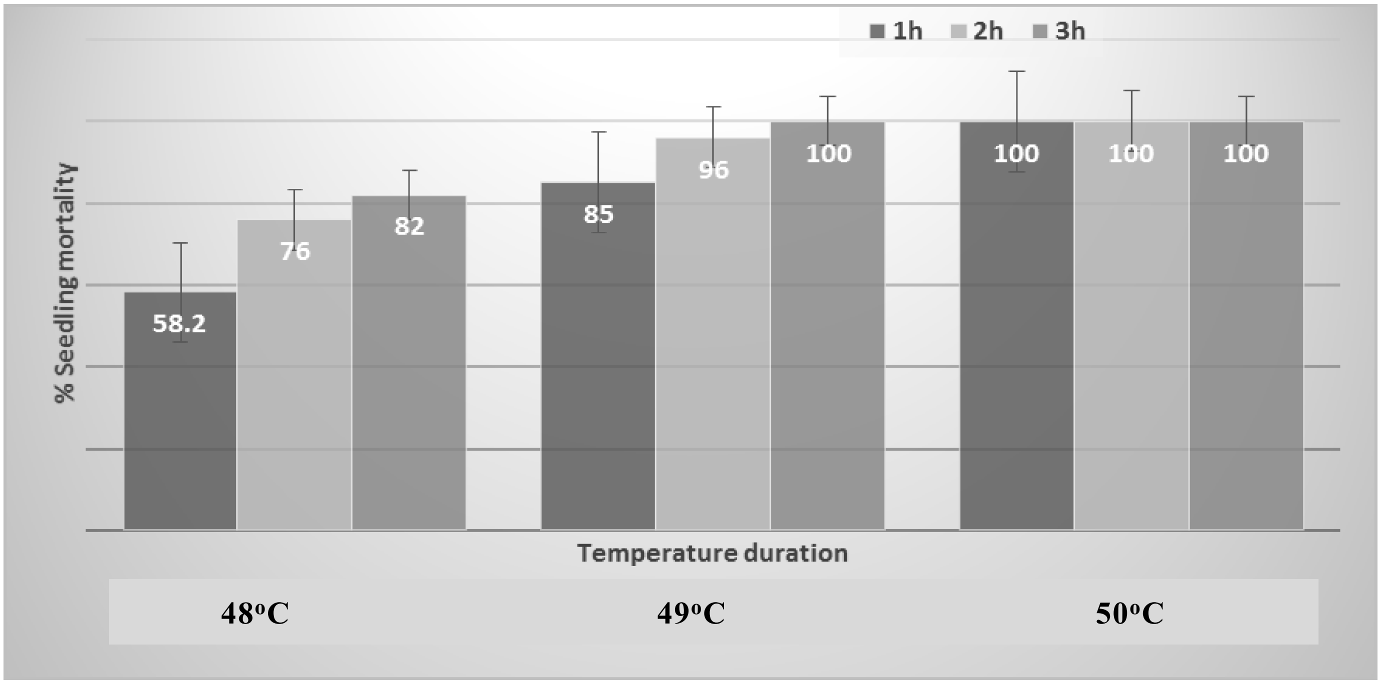


Fig. 1. Identification and standardization of lethal temperature based on seedling mortality in maize

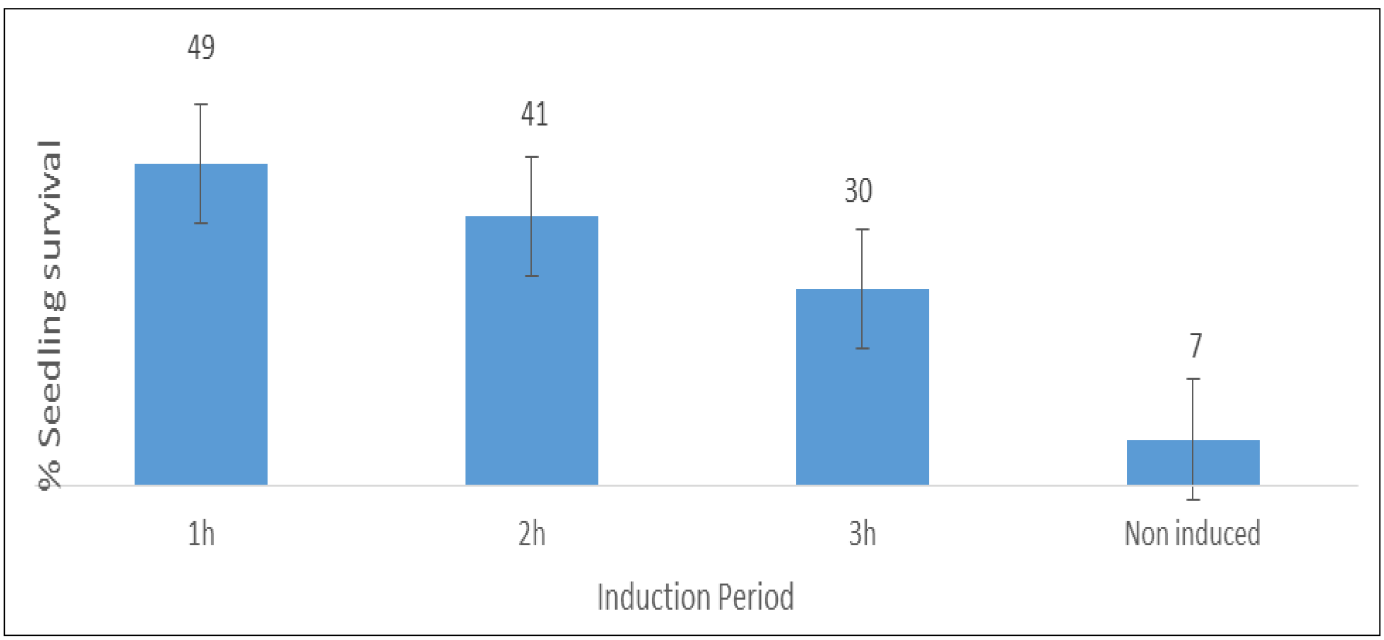
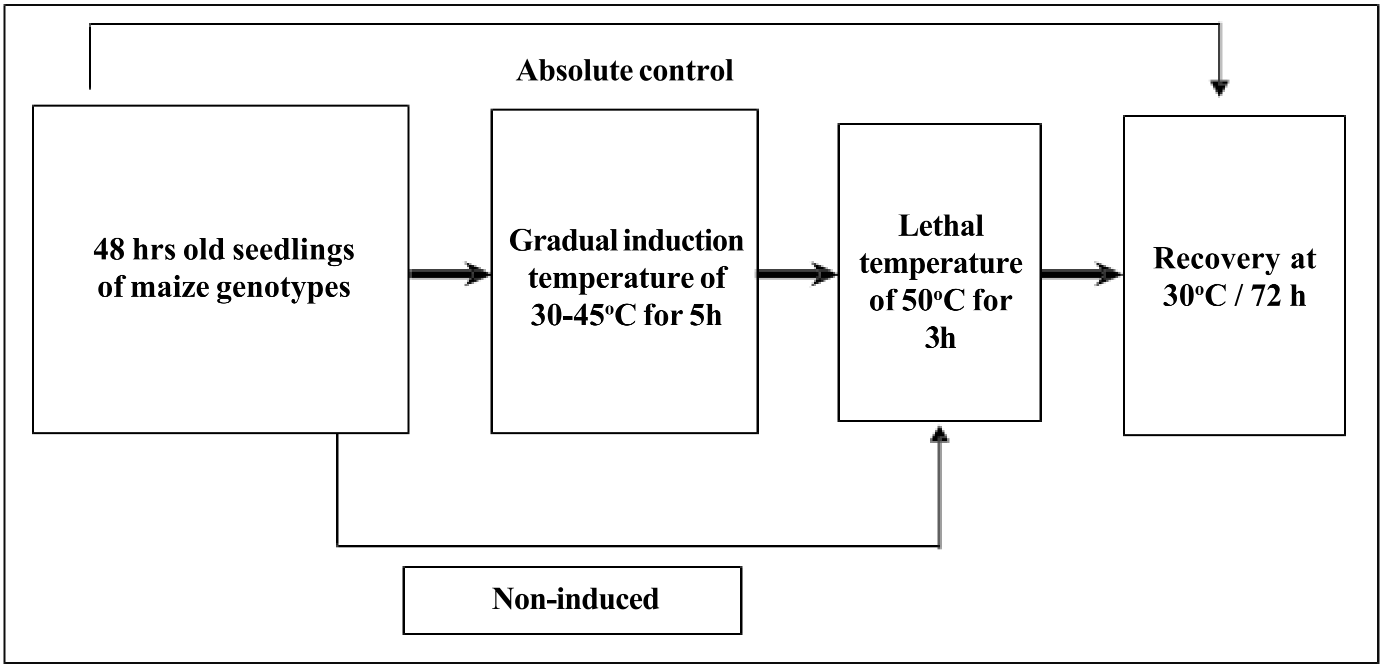


Fig. 2. Identification and standardization of induction temperature based on seedling mortality in maize

protocol was standardized. The results of the study indicated that, an induction temperature of 30-45ºC for 5 hrs followed by a lethal temperature of 50ºC for 3 hrs was found to be the ideal protocol as it showed considerable variability in percent seedlings survival as well as seedlings recovery growth and percent reduction in recovery growth over control. the protocol of 30-45ºC for 5 hrs as induction temperature followed by lethal temperature of 50ºC for 3 hrs was considered as standardized induction and lethal protocol to screen diverse maize germplasm lines (Flow chart 3).

Seedlings of maize were subjected to various induction temperature treatments and then they were exposed to a challenging temperature of 50°C for 3 hrs and recovery growth was measured after 72 hrs (Fig. 2). Optimum induction protocol was arrived based on least reduction in recovery growth compared to control seedlings. Maximum recovery growth of seedlings was seen when maize



Flow Chart 3: Standardized temperature induction response (TIR) protocol to screen maize germplasm lines

seedlings were induced with a gradual temperature induction protocol (30°C to 45°C gradually increased in 3h and maintained at 45°C for 2h).

Following the standardized TIR protocol, a set of 28 diverse inbred lines of maize were phenotyped for cellular level tolerance. Two days old seedlings of uniform size taken in an aluminium trays were exposed to a gradual induction temperature followed by standardized lethal temperature. Later, the seedlings were allowed for recovery at room temperature of 30ºC and 60% relative humidity. At the end of recovery period, percent seedlings survival and recovery growth were measured. For comparision, one more set of seedlings were directly exposed to lethal temperature while, the other set of seedlings were continuosly kept at room temperature throughout the experimental period which served as absolute control. A significant genotypic variability in the parameters associated with CLT was observed. Accordingly, the percent seedlings survival ranged from as low as 0% to as high as 100% with a mean survivability of 76.44 %. Similarly, the recovery growth ranged from 0 cm to 26.52 cm with a mean recovery growth of 9.12 cm. The reduction in the recovery growth (RRG) which was determined based on the recovery growth of control and the recovery growth of induced seedlings ranged from 16.52 % to 100% with a mean % RRG of 61.24 % (Table 1). The results therefore clearly indicated the existence of wide and significant genetic variability for CLT in maize germplasm lines.

Research in understanding the response of crop plants to drought stress conditions over the past couple of decades has enumerated several traits ranging from CLT to whole plant processes. Any trait would be relevant for crop improvement programme if and only if it is associated with increased crop growth rates. In this context, the ability of the plant to harness water from deeper soil profiles associated with root system and the efficiency of using transported water for biomass production; cellular level tolerance (Ehab Abou Kheir, 2006) and water conservation associated with wax (Mamrutha *et al.*, 2010) are considered as most relevant. Of the so many drought tolerance traits,

Table 1. Genetic variability in TIR parameters among 28 lines of maize

Parameters	Minimum	Maximum	Mean	SE
Seedlings survival (%)	0.00	100.00	76.44	16.20
Recovery growth in control (cm)	2.42	28.64	14.55	3.16
Recovery growth in induced (cm)	0.00	26.52	9.12	3.82
Reduction in recovery in growth over control (%)	16.52	100.00	61.24	16.80

intrinsic tolerance at cellular level which is referred to as cellular level tolerance appears to be most important. This is because, tolerance of plants to any kind of stress is possible only when there is intrinsic ability to tolerate the stress effects at cellular level. Therefore, it would be worthwhile to introgress many of the drought tolerance traits onto agronomically superior genotypes having higher cellular level tolerance. In this scenario, it is necessary to screen and identify germplasm lines having intrinsic tolerance at cellular level. Although a number of screening techniques have been developed based on the plant responses to high temperature, the screening protocols do not reflect the variability in adaptation observed in natural conditions. In nature, most abiotic stresses occur gradually and therefore, the plants are generally exposed to gradual stress rather than severe stress. In the process of gradual stress, plants develop the ability to withstand severe stress which is likely to occur at later times. This phenomenon of adaptation of plants is what is referred to as acquired tolerance (Vierling *et al.*, 1991). Therefore, in order to determine the genetic variability for stress tolerance, plants need to be exposed initially to a gradual stress level followed by high stress. During this process of gradual induction, the relevant stress genes get expressed differentially which ultimately impart stress tolerance upon exposure to severe stress. Therefore, it is quite evident that, genetic variability is seen only when the organisms are exposed to induction stress before they are subjected to severe stress (Senthil Kumar *et al*., 2003). Until recently, stress responses were often assessed by directly exposing the plants/seedlings to severe stress and probably that was the main reason why significant genetic variability was not noticed. In several earlier studies, no quantitative differences in heat shock proteins were observed between heat resistant and heat sensitive lines when the plants were directly exposed to severe stress. These reports therefore confirm that, the genetic variability for the trait of interest cannot be seen when the plants are directly exposed to severe stress. However, several other reports do indicate that, the genotypic variability can be seen upon induction prior to severe stress (Senthil Kumar *et al*., 2003).

In order to determine the genetic variability for stress tolerance and in this case, for intrinsic tolerance at cellular level (CLT), suitable technique/approach is required. Further, the technique so selected should have an option of creating induction stress followed by lethal stress. TIR technique has an option of exposing the seedlings/plants to gradual induction stress prior to lethal stress. This technique is an empirical screening technique and non-destructive and therefore, survived seedlings can be established into plants. The other unique feature of this technique is that, the stringency of severe temperature can be altered to obtain highly tolerant lines. Following this technique, genetic variability for CLT was identified by a number of workers. The genetic variability for intrinsic tolerance was shown in cotton (Ehab Abou Kheir, 2006) and rice (Narayanaswamy, 2009). Even the differential expression of genes upon induction stress between heat tolerant and heat susceptible genotypes were shown in sunflower (Senthil Kumar, 2003). The temperature stress response varies from species to species or from crop to crop. Therefore, it is necessary to develop induction as well as lethal temperature protocols before genetic variability in stress responses are assessed. In the first place, lethal temperature has to be standardized first and later, the induction temperature protocol. To standardize the lethal protocol, the seedlings are exposed directly to different high temperature regimes and look for the temperature at which nearly 100% seedlings mortality observed. Once the lethal temperature is standardized, the seedlings are exposed to different gradual induction temperature protocol prior to their exposure to lethal temperature. Since the seedlings are exposed to induction stress before exposure to lethal stress, the mortality rates come down significantly and thus seedlings put on recovery growth during recovery period. Based on this, the induction and lethal temperatures are standardized and used for screening the germplasm lines to assess the genetic variability. Accordingly in the present study, the induction and lethal temperatures were standardized. The induction temperature was 30-45^{o}C for 3hrs while the lethal temperature was 50^{o}C for 3 hrs with a recovery period of 72 hrs at 30^{o}C and 60% RH.

Narayanaswamy (2009) had standardized the TIR protocol for screening the rice germplasm lines for cellular level tolerance. With slight modification, the TIR protocol was again standardized and 28 germplasm lines of maize were screened in the present study for CLT. In the present study with 28 germplasm lines of maize, a significant genetic variability for CLT was observed. To determine the variability, a few parameters associated with CLT such as per cent seedlings survival and recovery growth was measured and percent reduction in recovery growth over control was determined. The per cent seedlings survival ranged from 0 to as high as 100% with a mean survivability of 76.44%. The percent reduction in recovery growth ranged from 16.52 to 100% with a mean of 61.24%. The results therefore clearly indicated the existence of wide and significant genetic variability for CLT in maize germplasm lines. Similar kind of genetic variability for CLT was also shown in a number of crops by several earlier workers (Ehab Abou Kheir, 2006; Narayanaswamy, 2009). During this process of induction, several cellular, metabolic and molecular alterations take place which lead to the development of acquired tolerance.

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RESEARCH PAPER

Evaluation of non-destructive and destructive oil estimation techniques in maize (*Zea mays* L.) kernels

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Abstract: Maize (*Zea mays* L.) is one of the most important cereals of the world occupying third position after wheat and rice. Maize plays an important role in the world economy and is used for food, feed and industrial purpose as well. In recent years, the corn-oil has been used for various commercial purposes. There are need to evaluate a rapid, easy and non-destructive technique for determination of oil content in maize kernel from existing methods of oil estimation. In this study, efficacy of four oil estimation methods, *viz*., Soxhlet method, Colorimetric method, Cold extraction and Near Infrared Reflectance Transmission spectophotometer (NIRTs) were compared. In the study, five cultivars, two composite varieties (Narmada Moti, Kiran) and three hybrids (HM 9, HQPM 5, Prakash) were used for oil estimation in their karnel. The NIRT was self calibrated with oil references. Pair-wise comparision was carried out between various methods and cultivars. We observed that minimum mean difference was found between NIRTs and colorimetric method (0.17±0.075) followed by soxhlet and NIRTs (0.19±0.075). Maximum mean difference was recorded between cold extraction and colorimetric method (0.97±0.075). NIRT and Soxhlet method did not show significant differences, and at the same time colorimetric method and NIRT also revealed non-significant differences. Cold extraction method shows significant difference with Soxhlet, Colorimetric and NIRT methods. A linear correlation (R^2 = 0.850, Adjusted R^2= 0.830) was observed between the methods compared. The NIRT technique thus offers a promising alternative rapid, easy and non-destructive method for determining the oil content in maize karnel.

Keywords: NIRT · Soxhlet · Colorimetric method · Corn oil

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Introduction

Maize (*Zea mays* L.) known as miracle crop, has tremendous potential to feed millions of the third world countries, which are facing acute problems of food scarcity and malnutrition. Besides these with its much industrial usages, maize plays an important role in the world economy. In India, the maize is used as human food (25%), poultry feed (49%), animal feed (12%), industrial (starch) products (12%), beverages and seed (1% each) (Rakshit *et al.*, 2003). Cereal grains are predominantly composed of carbohydrates, mostly in the form of starch, with considerable amounts of protein with essential amino acids, as well as some lipids, vitamins, and minerals. Both genetic and environmental factors create significant variation in the amount and quality of each of these constituents. Multiple methods have been developed to help breeders to screen genotypes for various seed composition traits (Baenziger *et al.*, 2001, Dunlap *et al.*, 1995).

Improving the nutritional quality is an important goal in national maize breeding programme. In maize grain, starch content is around 60.68%; of which; nearly 30% is amylase whereas 70% is amylopectin. It has 8-12% protein, 3-5% oil, and some of the important vitamins (0.38%-2.8%) and minerals (1.5%) (Rakshit *et al.,* 2003) also. Oil content in maize reported to be of variable range, which is genetically controlled, with values ranging from 3 to 6%. In maize kernel 95 % of the total oil is in the germ and 5% oil present in endosperm (Hallauer, 1988). Most of the normal maize lines have 3-4% oil content. In general, lines with more than 6 % oil are considered high-oil lines. The high-oil corn, out of the specialty corn, plays a vital role in improving the quality of feed ration lots. Chemical composition of corn-oil as reported by Lambert *et al.* (1994). Almost 99% corn-oil is composed of five fatty acids, *viz*., palmitic (16:0), stearic (18:0), oleic (18:1), linoleic (18:2) and linolenic (18:3) acids. Lenoleic fatty acid content is 40-60% and oleic fatty acid is 25-45% (Joyoung *et al.*, 2010). Maize oil is considered as high quality oil for human health due to the high proportion of polyunsaturated fatty acids (PUFA). The traditional methods of oil estimation are destructive in nature, slow and cumbersome. Hence, these are not suitable for rapid screening purpose. Therefore, there is need for a rapid, easy to perform and accurate method for determining oil content in maize. Among the several methods that are available soxhlet method, colorimatric method and cold extraction method have been used for the estimation of oil content in cereals (Egesel *et al*., 2012). The Near-infrared (NIR) spectroscopy has been widely used for estimation of different type of bio-molecule among various crops (Baye *et al.,* 2006). Numerous applications of NIR Technology (NIRT) have been developed covering almost all cereals. Mostly the key traits being handled using NIRT are moisture, oil, starch and protein (Fox and Manley, 2013). In recent past high-oil maize have assumed higher importance in terms of breeding objectives, calling for a need to establish a rapid and non-destructive method to screen maize germplasm in term of oil content, aiding breeding for high oil. Thus, the objective of this work was to establishing a rapid and non-destructive method for mass oil estimation in maize kernel.

Materials and methods

The study was conducted on five popular maize cultivars. Two of them were composite varieties (Narmada Moti and Kiran) and three were single cross hybrids (HM 9, HQPM 5 and Prakash). Different method of oil estimation, *viz*., soxlet method, colorimetric method, cold extraction and NIRT were followed to estimate oil content in the maize kernels. The experiments were conducted in completely randomized block design with three replications of each sample. Each method of estimation is discussed briefly below:

Soxhlet Method

It is the most commonly used destructive methods of extraction and estimation of lipids from foods as proposed by Soxhlet (1879). For extraction of oil and fat, accurately weighed 2g finely ground maize kernel samples were transferred into a piece of filter paper and it was folded in such a way to hold the sample. It was again wrapped around by a second piece of filter paper which was left open at the top. The wrapped sample was placed into Soxhlet extractor, after placing some cotton at the bottom. A piece of cotton was placed at the top to evenly distribute the solvent as it drops on the sample during extraction. Two and half times the capacity of the extractor of solvent (500 ml) was added, and oil was allowed to be extracted for a period of six hours or till the solvent in the extractor became colourless. After cooling of apparatus the extraction flasks were dismantled and the solvent was allowed to be evaporated on the water-bath until no odour of the solvent remained. The flasks were kept in oven at 70°C for 10 min and cooled at room temperature. Any dirt from outside the flask was removed carefully and the flasks were weighed. The process was repeated till constant weight was recorded. Oil percentage was calculated using the following formula:

$$\text{Percent oil in the sample} = \frac{\text{Weight of oil}}{\text{Weight of sample}} \times 100$$

$$\begin{array}{l}\text{Percent oil in the sample} \\ \text{on dry weight basis}\end{array} = \frac{\text{Percent oil in the sample}}{100\text{–moisture\%in sample}} \times 100$$

Colorimetric method

Fatty acids and acetyl acetone forms a complex, which gives yellow color and best visualized at 412 nm was recorded. Stock solution of Triolein extrapure (SRL) of 1000 ppm was prepared by dissolving 100mg of Triolein in 100ml of Hexane:Acetone (4:1) mixture. This stock solution was diluted Hexane:Acetone (4:1). in a series of 10 ppm, 50 ppm, 100 ppm, 150 ppm, 200 ppm, 250 ppm, 300 ppm, 400 ppm, 500 ppm and 1000 ppm. Colour producing agent, acetyl acetone was prepared through mixing of 10.8% l-ascorbic acid, 3% ammonium molybdate, 0.56% antimony potassium tartrate and 13.98% sulphuric acid. One ml of standard solution, blank (hexane: Acetone, 4:1) and sample were took in test tube in three replications. Test tubes were incubated in water bath for 1 h at 100°C or until the solvent evaporated. To this 0.5 ml of alcoholic 2% potassium hydroxide was added and incubated at 65°C for 15 minutes. This was followed by addition of 0.5 ml 0.2 N sulphuric acid and 0.5 ml 0.05 M sodium metaperiodine. These were incubated at room temperature for 10 minutes. To this 0.1ml of 0.05 M sodium arsenate was added and incubated at room temperature for 5-10 minutes. To each tube, 1 ml sterile distilled water was added. For colour development 2 ml of acetyl acetone reagent was added to the solution and incubated in water bath at 55°C for 10 minutes. The aliquot was allowed to cool at room temperature and optical density (OD) was recorded at 412 nm in Unicam helox β UV-vis spectrophotometer. Series dilution stock was used to draw standard graph. Subsequently standard curve was used to calculate oil concentration in samplse. Oil percentage was calculated using the following formula:

Percent oil in sample = X × Total volume sample (ml) × Concentration of sample (mg/ml).

Here, X = O D of sample/coefficient value

Coefficient value = 0.0036 (calculate by standard curve)

Cold extraction

This is the most popular and simple method for extraction of oil from seed. This procedure is also known as Folch method. For estimation of oil content in maize seed, 1 g seeds were fine grounded. Fine grounded seed were homogenized with 20 ml of 2:1 chloroform:methanol solution. After dispersion, the whole mixture was agitated for 15-20 min in an orbital shaker at room temperature. Homogenate was filtered to recover the liquid phase and collected in fresh tube. The solvent was washed with 0.2 volume of water and vortexed for few seconds. The mixture was centrifuged at 2000 rpm. Upper phase was removed and lower phase was used to estimate lipid content. The lower phase, containing chloroform was evaporated under vacuum in a rotary evaporator. Oil percentage was calculated using the following formula:

$$\text{Percent oil in the sample} = \frac{\text{Weight of oil}}{\text{Weight of sample}} \times 100$$

NIRT method

InfraLUMft 10 (lumax) NIR spectrometer, an auto analyzer was used to oil estimation in maize cultivars. Which was calibrated using Partial least squares regression (PLSR) model to absorbance spectra from 860 to 1250 for representing protein, starch, oil, sugar and moisture in maize kernel. Prior to estimation of oil content, the instrument was allow to warm to its operating condition for at least an hour before use. At the start for standardization of a blank reading was recorded, after that a dark spectrum reading was taken by shutting off power to the light source of sample holding compartment. 200 g (approximate 100) seeds were taken to estimation of oil content in a specially designed adapter (40 cm^3) for maize. Sample was positioned at the sampling holder. The instrument was allowed to re-warm for a minimum of three minutes before taking observations. After warm up, select measurement procedure using menu with attached personal computer. For each sample, the spectrum absorbance values were automatically computed in to contents percent value by spectra LUM/ pro software and stored in the PC memory. Further data were transfer to excel format for further use.

Statistical analysis

The experiment was laid in factorial randomized block design with three replications each. There were two factors, method (with four levels) and genotype (with five levels). Data were analyzed using SPSS software (Ver16.0). For analysis of variance oil percentage data were subjected to angular transformation. Pair wise comparison of various methods and genotypes for oil percent mean were determined by the Turkey's harmonics significant mean (HSD) test. Least square differences (LSD) at 5% level were also used for comparison of means.

Results and discussion

The aim of present study was to evaluate non-destructive method for oil detection in maize kernel visa-vis other destructive methods of oil estimation. ANOVA of the factorial analysis is presented in Table 1. ANOVA suggested significant effect of methods showed df (3), MS (2.70), F (63.89) and P value (1.88474E-17). Genotypes were also showed significant effects with df (4), MS (1.09), F (25.90) and P value (7.7094E-12). The mean values of estimated oil percent in different genotypes through various methods is given in Table 2. Among genotypes, Kiran recorded maximum kernel oil (4.77%) followed by Narmada moti (4.41%), Prakash (4.23%), HQPM 5 (4.16%) and HM 9(3.98%). All were significantly different from each other in terms of oil content (Fig. 1).

Table 1. ANOVA factorial analysis for kernel oil content in different maize cultivars as estimated following different methods of oil estimation

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	12.47	7	1.78	42.18	2.99287E-19
Intercept	1114.57	1	1114.57	26398.28	4.73326E-72
Method	8.09	3	2.70	63.89	1.88474E-17
Genotype	4.37	4	1.09	25.90	7.7094E-12
Error	2.20	52	0.04		
Total	1129.23	60			
Corrected Total	14.66	59			

a = R Squared = .850 (Adjusted R Squared = .830)

Table 2. Kernel oil content in different maize cultivars as estimated following different methods of oil estimation

	HM-9	HQPM-5	Kiran	N M	Prakash	Total
Sohlet	3.93±0.03	3.97±0.14	4.70±0.05	4.40±0.14	4.47±011	4.29±0.17
Colori.	3.57±0.02	3.58±0.03	4.48±0.00	4.28±0.00	3.76±0.051	3.93±0.18
Cold.	4.63±0.07	4.93±0.07	5.40±0.09	4.83±0.11	4.73±0.07	4.91±0.14
NIRT	3.77±0.03	4.17±0.05	4.52±0.06	4.12±0.10	3.97±0.10	4.11±0.13

The average oil content over all genotypes detected by soxhlet method was 4.29%. Corresponding values in colorimatric method, cold extraction method and NIRT were 3.93%, 4.90% and 4.10%, respectively. The result was obtained by the four methods were highly correlated $R^2 = 0.85$, (Adjusted to $R^2 = 0.83$) with sum of type III error square 2.19. The estimations in NIRT and soxhlet methods differed non significantly, at the same time colorimetric method estimates and that using NIRT also differed non significantly (Fig. 2). In general, cold method of estimation overestimated the oil content, while colorimetric method underestimated. The soxhlet is the standard method that provided reliable and robust oil estimation in sample. However, it is impractical for analysis of large number of samples (Leon e*t al.,* 2004). Our study clearly demonstrated that the non-destructive method of NIRT is as good as soxhlet method to estimate oil content in maize kernel. This method takes 2-3 minutes per sample to estimate the oil content as against 6 h for 1 sample/unit samples in soxhlet method. Hence, NIRT can safely and easily be adopted for rapid non-destructive oil estimation in maize.

In the current study using NIRT, the absorbance spectra ranged from 860 to 1250 nm. Spielbur *et al*. (2009) studied calibration and validation of NIRs using 120 maize ear following partial least square (PLS) model. They reported linear regression value (R^2=0.86) for prediction of oil by NIRs and analytical reference methods. This regression value is l comparable to present result.

Orman and Schuman (1992) studied accuracy of protein, oil and starch content prediction in maize grain by using near-infrared technology and found best constituents

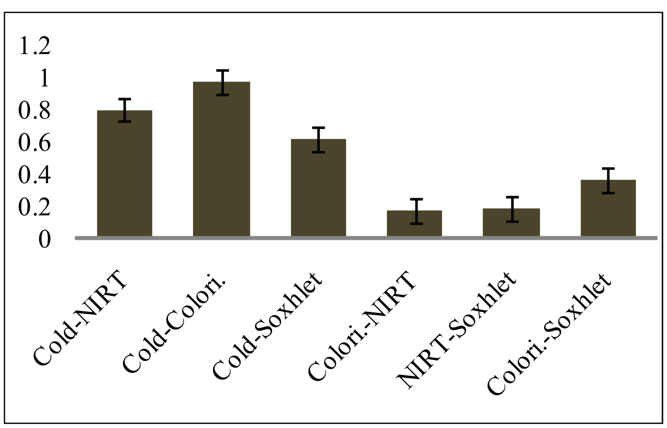

Fig. 1. Pair-wise comparison (LSD) of mean values of various methods used for maize kernel oil estimation.

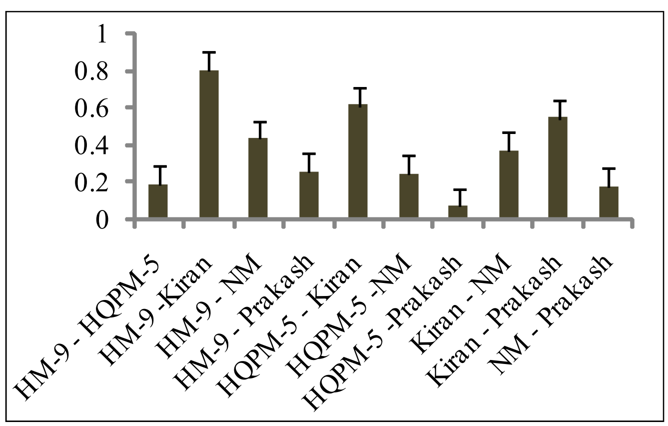

Fig. 2. Pair-wise comparison (LSD) of mean values of various cultivars used for maize kernel oil estimation.

predictions by reflectance spectra. In our study, we used PLSR model based, pre-calibrated NIRT instrument for prediction of oil content in maize kernel. Similarly, various studies were reported same model based calibrated NIRTs gave accuracy and reliability for estimation of oil in maize kernel (Egesel *et al.,* 2012; Tallada *et al.,* 2009; Baye *et al.*, 2005; Codgill *et al.*, 2004). Though soxhlet method took 6 hours time in estimation of oil per cycle, colorimetric method took 1h time in one set of reactions and cold extraction was also time consuming method and the grounded sample was used in these methods. While NIRT took 3-5 minutes in estimation of oil content per sample and intact seed was used for analysis. In our study, we found non-significant difference between soxhlet and NIRT method. Several studies were reported that NIRT is simple, rapid and safe technique for screening quality traits in maize (Melchinger *et al.,* 1990; Robutti e*t al.*, 1995; Valdes *et al.,* 1990; Cozzolino *et al.,* 2000; Williams and Norris, 2001).

Conclusion

In this study, we found non significant difference between NIRT and soxhlet method of oil estimation, as well as NIRTs and colorimetric method. Although soxhlet method is reliable standard method for oil estimation and colorimetric method did work on basis of chemical reaction, provide only fatty acid information only. Further, these are destructive method, which often breeders do not like to adopt. The study showed that non-destructive method of NIRT may be potentially useful to estimate oil content in maize kernel.

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RESEARCH PAPER

Gene effects and combining ability for yield and quality traits in maize (*Zea Mays* L.)

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Abstract: Combining ability analysis was done using 63 F_1 hybrids obtained from nine lines and seven testers generated by following Line × Tester mating design. Six quantitative traits including yield and quality traits were considered for the analysis. Both general and specific combining ability variances were highly significant for almost all the characters studied. The variance due to SCA was more pronounced than variance due to GCA for all the characters indicating the importance of non-additive genetic variance in the material studied which favours the production of hybrid cultivars. Based on GCA effects among the lines, HKI 288-2, HKI 1126, HKI 536YN, HKI 1040-4 and HKI 323 contributed maximum favorable genes for yield and quality traits (Protein, oil and starch content). Among the testers, HKI 163 and HKI 161 were desirable for both grain yield and QPM traits (lysine and tryptophan content). HKI 170 (1+2) a QPM inbred lines was found good pollinators mainly for lysine content. HKI 288-2 × HKI 5072-BT(1-2)-2 possessed significant SCA effects for starch content and lysine content and HKI 659-3 × HKI 193-2 had significant specific combining ability for both lysine and tryptophan content. Similarly, HKI 488 × HKI 170(1+2) was best for lysine content and HKI 323 × HKI 170(1+2) was promising for lysine, tryptophan, oil and starch content. These crosses were also exhibited more than 10 % superiority for yield and quality traits over the best hybrid check. Hence, lines with higher GCA effects can be used more effectively in the development of synthetic variety whereas SCA effects could help in the selection of parental material for hybridization, when high yielding specific combinations are desired. Best cross combinations could be advanced further for isolation of transgressive segregants and also to develop good inbred lines.

Keywords: Combining ability · Inbred · Grain yield · QPM · GCA · SCA

Introduction

Maize (*Zea mays* L.; 2n = 20) is a principal cereal crop in tropical and subtropical regions throughout the world and considered as important staple food crop among the most popular cereal crops after wheat and rice. It was evident that major breakthrough in yield of maize came with the release of hybrids with high yield potential. The single cross hybrids including quality protein maize (QPM) hybrids have become popular among Indian farmers due to their high yield potential and excellent uniformity. Information about combining ability of experimental breeding materials is very important to develop high yielding hybrids and composite varieties, especially when a large number of parental lines are available and most promising ones are to be identified. Information on GCA and SCA has been well documented in maize germplasm. Significant values for general combing ability (GCA) and specific combining ability (SCA) are the results of additive and non-additive gene action, respectively. The information on GCA and SCA shows the type of gene action involved in controlling quantitative characters, thereby assisting breeders in selecting suitable parents. The studies on gene effects for various morphological parameters would be helpful in formulating suitable breeding methodology for the development of high yielding quality protein maize hybrids. The present investigation was, therefore, planned to estimate the extent of combining ability of parents and crosses in QPM hybrid breeding programme.

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Materials and methods

The experimental material consisted of nine diverse and productive inbreds used as female lines *viz*., HKI 1128, HKI 288-2, HKI 659-3, HKI 323, HKI 1126, HKI 1105, HKI 536YN, HKI 488 and HKI 1040-4 and seven inbreds as testers namely HKI 163, HKI 161, HKI 170(1+2), HKI 194-6, HKI 193-1, HKI 193-2 and HKI 5072-BT(1-2)-2. The experiment was planted at CCSHAU, Regional Research Station, Uchani, Karna (India). The crosses were made in both the cropping seasons of *Kharif* and *Rabi* of 2013-14 in line × tester mating design by using manual pollination procedures for crossing and selfing as described by Russell and Hallauer (1980). The resultant sixty three single cross hybrids along with their parents (16) and two checks hybrids *viz*., HQPM 1 and HM 5 were evaluated in the randomized block design with three replications during *kharif* 2014-15. Each genotype was planted in a single row of 3 meter length and the distance between rows and plants was kept at 75 cm and 20 cm, respectively. Recommended cultural practices were adopted to maintain a healthy crop. From every row 5 competitive plants were randomly selected from each replication and data were recorded on following quantitative characters *viz.,* grain yield per plant (g) and contents of protein (%), lysine (%), tryptophan (%), oil (%) and starch (%). Maize kernels were sorted into different modification classes on a light box. Quality characters were determined at quality laboratory using Near Infrared Spectrophotometer (NIRS) (Rosales *et al*., 2011). The data were subjected to analysis of variance, and combining ability using standard procedures.

Results and discussion

The analysis of variance revealed highly significant difference for all the quality characters studied (Table 1). The variance due to parents' *vs* crosses differs significantly indicating the presence of high GCA and SCA effects in the material studied. Significant differences were also observed among the crosses for all the characters. Among the lines and testers, significant differences were observed for all the characters studied and line × tester crosses were also significant when tested against error mean squares for all the characters under study. This indicated significant amount of genetic variability among lines and testers for all the characters. This warranted further estimation of GCA and SCA effects for characters being studied. Combining ability analysis revealed the importance of both additive and non-additive gene action in governing most of the characters but non-additive gene action was found to be predominant. Hence, recurrent selection was suggested to improve these characters. The relative importance of additive and non-additive gene action was reported by Jebaraj *et al*. (2010).

The variance due to SCA was more pronounced than variance due to GCA for all the characters indicating the importance of non-additive genetic variance in the material studied which favour the production of hybrid cultivars. These results are in agreement with earlier reports of Singh *et al*. (2012). In the study of proportional contribution of lines (females), testers (males) and line × tester interaction to total hybrid variance, it was clear that contribution towards total hybrid variance was found to be higher in

Table 1. Mean sum of squares of parents, hybrids and combining ability for different traits in a line x tester crosses of maize

Sources of variation	d.f	Grain yield per plant	Protein content	Lysine content	Tryptophan content	Oil content	Starch content
Replication	2	75.541	0.070	0.022	0.002	0.018	0.995
Genotypes	78	1999.455**	1.716**	1.035**	0.044**	0.858**	18.575**
Females	8	209.538**	1.617**	0.100**	0.014**	2.189**	18.850**
Males	6	74.447	1.188**	0.253**	0.040**	1.996**	36.790**
Hybrids	62	939.183**	1.182**	0.770**	0.032**	0.516**	12.997**
Males Vs Females	1	8.281	20.018**	17.565**	1.053**	0.243**	11.745**
Parents Vs Hybrids	1	95596.874**	20.479**	13.111**	0.005	5.192**	259.763**
Error	**156**	**38.176**	**0.074**	**0.021**	**0.005**	**0.032**	**1.929**
Line	8	1324.496**	0.787**	0.823**	0.043**	0.890**	12.129**
Tester	6	1182.406**	0.390**	0.509**	0.022**	0.237**	16.819**
Line × Tester	48	844.562**	1.346**	0.793**	0.032**	0.489**	12.664**
Error	**124**	**45.180**	**0.091**	**0.023**	**0.006**	**0.040**	**2.276**

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

females than males for all characters under study (Table 2).

Among the lines HKI 1128 was found to be the best combiner for high starch content as it had significant positive GCA effects. HKI 288-2 and HKI 536YN had significant and desired GCA effects for both lysine and tryptophan content (Table 3). Similarly, HKI 659-3, HKI 323, HKI 288-2 and HKI 1105 were considered good combiner for oil content. In respect of grain yield per plant as well as oil content, HKI 323 alone was found best combiner. The inbred line HKI 1126 was the best combiner for lysine content only as it had significant GCA effects in desired direction. HKI 1040-4 was the best combiner for grain yield per plant, protein content and starch content.

Table 2. Proportional contribution of lines, testers and their GCA and SCA variances along with additive and dominance variances for different traits in maize crosses

Character	σ^2 gca	σ^2 sca	Ratio gca: sca	σ^2 (A) Additive	σ^2 (D) Dominance	σ^2 (A) / σ^2 (D)	Percentage Contribution of		
							Lines	Testers	Interaction
Grain yield per plant (g)	338.77	296.52	1.14	355.08	1186.09	0.30	12.18	18.20	69.62
Protein content (%)	299.23	79.17	3.78	916.92	313.67	2.92	3.20	8.60	88.21
Lysine content (%)	3.60	3.04	1.18	14.40	12.15	1.18	6.40	13.80	79.80
Tryptophan content (%)	0.10	0.13	0.83	0.42	0.50	0.83	6.49	17.16	76.35
Oil content (%)	1.07	0.27	4.01	4.29	1.07	4.01	4.44	22.23	73.34
Starch content (%)	347.46	130.04	2.67	1389.86	520.15	2.67	12.52	12.04	75.44

Table 3. Estimates of GCA effects for different traits in lines and testers of maize

S.No.	Lines	Parents	Grain yield per plant (g)	Protein content (%)	Lysine content (%)	Tryptophan content (%)	Oil content (%)	Starch content (%)
1	L1	HKI 1128	**-5.358****	-0.09	0.092	0.029	-0.108	**1.111***
2	L2	HKI 288-2	**-7.492****	-0.089	**0.332****	**0.067****	**0.148***	-0.113
3	L3	HKI 659-3	2.606	-0.135	**-0.118***	0.002	**0.129***	0.618
4	L4	HKI 323	**7.393****	-0.174	**-0.128****	-0.01	**0.147***	-0.371
5	L5	HKI 1126	2.478	0.084	**0.148****	0.025	-0.079	-0.075
6	L6	HKI 1105	**-13.82****	0.096	**-0.253****	**-0.044***	**0.284****	-0.852
7	L7	HKI 536YN	0.219	**-0.211***	**0.182****	**0.049****	0.057	-0.476
8	L8	HKI 488	1.353	0.118	**-0.22****	**-0.076****	**-0.356****	-0.891
9	L9	HKI 1040-4	**12.621****	**0.401****	-0.065	-0.033	**-0.223****	**1.050***
Standard Error (Lines)			**2.074**	**0.093**	**0.047**	**0.023**	**0.061**	**0.465**
C.D. (5 %)			**4.066**	**0.182**	**0.093**	**0.046**	**0.120**	**0.912**
C.D. (1 %)			**5.343**	**0.240**	**0.122**	**0.061**	**0.158**	**1.199**
S.No.	Testers	Parents	Grain yield per plant (g)	Protein content (%)	Lysine content (%)	Tryptophan content (%)	Oil content (%)	Starch content (%)
10	T1	HKI 163	**7.15****	-0.044	**0.168****	**0.045***	-0.039	-0.888
11	T2	HKI 161	**8.001****	0.023	**0.131****	0.030	**0.126***	0.162
12	T3	HKI 170(1+2)	-3.149	0.04	**0.088***	-0.012	**-0.136***	0.601
13	T4	HKI 194-6	0.342	-0.017	-0.035	-0.018	0.073	0.048
14	T5	HKI 193-1	**-11.175****	**0.162***	**-0.224****	-0.034	0.077	0.429
15	T6	HKI 193-2	-3.036	**-0.228****	-0.021	0.005	-0.057	-1.251
16	T7	HKI 5072-BT(1-2)-2	1.866	0.063	**-0.098***	-0.017	-0.046	0.899
Standard Error (Lines)			1.8294	0.082	0.0416	0.0208	0.0542	0.899
C.D. (5 %)			**3.586**	**0.161**	**0.082**	**0.041**	**0.106**	**1.762**
C.D. (1 %)			**4.713**	**0.211**	**0.107**	**0.054**	**0.140**	**2.316**

Among the 7 testers, HKI 163 was found best combiner for grain yield per plant, lysine content and tryptophan content. Taking grain yield as the most important character HKI 161 was identified as the best combiner possessing maximum positive and significant GCA effects and this was also best combiner for lysine content. HKI 170(1+2) and HKI 193-1 were found best testers for lysine and protein content respectively.

The lines or testers having desirable genes for large number of important characters are considered best as seed parent, and testers as good pollinators. In addition to QPM lines (HKI 288-2, HKI 1126, HKI 536YN), other lines like HKI 1040-4 and HKI 323 were desirable for both yield and quality traits (HKI 1040-4 for protein and starch content and HKI 323 for oil content). Similarly testers like HKI 163 and HKI 161 were desirable for both grain yield and QPM traits (lysine and tryptophan content). HKI 170 (1+2), a productive QPM inbred line was found good pollinator for lysine content. The above lines and testers could be efficiently utilized in, (i) formation of gene pool and extraction of inbred lines (ii) testing newly developed inbred lines by using them as testers (iii) hybrid development either as seed or as pollen parent. The results were supported by the work of Hemlatha *et al.* (2014) for grain yield per plant and quality. Similar reports of good combiner for more than three characters were also reported by Hemavathy *et al.* (2008); Ojo *et al.* (2007); Ruth *et al.* (2010); Rezaei *et al*. (2005); Abrha *et al.* (2013); Ram *et al*. (2015); Elmyhum (2013); Chahar *et al.* (2014); Singh and Gupta (2009)

The five most promising combinations selected separately on the basis of SCA effects and their GCA effects are presented character-wise in Table 4. Among the 63 crosses (Table 5) desirable gene expression for grain yield per plant was observed in HKI 659-3 × HKI 194-6, HKI 1126 × HKI 161 and HKI 536YN × HKI 193-1, whereas HKI 1128 × HKI 163 was promising for grain yield per plant as well as for oil content. In addition, HKI 288-2 × HKI 5072-BT(1-2)-2 possessed significant SCA effects for starch content and lysine content, HKI 659-3 × HKI 193-2 had significant specific combining ability for both lysine and tryptophan content and HKI 488 × HKI 170(1+2) was best for lysine content. For quality traits, HKI 323 × HKI 170(1+2) was promising for lysine content, tryptophan content, oil content and starch content. The superiority of crosses involving high × low combiners as parents could be explained on the basis of interaction between positive alleles from good combiners and negative alleles for the poor combiners as parents. The superior cross combinations involving low × low general combiners could result from over dominance and epistasis. Thus the above results indicate that high SCA alone could not be sole criteria for getting a superior hybrid. However the high yield of such crosses would be non-fixable and thus could be exploited for heterosis breeding. The relationship between GCA and SCA indicates the importance of epistasis and crosses are expected to produce desirable transgressive segregants.

Hence, the crosses *viz*., HKI 1128 × HKI 163, HKI 288-2 × HKI 5072-BT(1-2)-2, HKI 659-3 × HKI 193-2, HKI 488 × HKI 170(1+2), HKI 323 × HKI 170(1+2) could be advanced further for the isolation of transgressive segregants and also to develop good inbred lines. These crosses exhibited 15-20 % yield superiority over the best

Table 4. Top 5 crosses with high SCA, per se performance and their GCA effects

Grain yield per plant (g)				Protein content (%)				Lysine content (%)			
Crosses	Mean	sca	gca	Crosses	Mean	sca	gca	Crosses	Mean	sca	gca
L1×T1	146.43	27.729	LxH	L1×T7	11.72	1.311	LxA	L3×T6	2.88	1.031	HxL
L3×T4	146.67	27.820	AxL	L2×T3	11.62	1.233	LxA	L8×T3	2.84	0.991	HxH
L7×T5	132.89	27.937	LxH	L3×T5	11.69	1.230	HxH	L5×T7	2.82	0.779	HxH
L5×T2	147.61	21.225	AxH	L4×T2	11.41	1.125	HxL	L4×T3	2.70	0.728	HxH
L8×T4	137.48	19.876	AxL	L5×T6	11.55	1.259	AxH	L5×T1	2.92	0.616	HxH

Tryptophan content (%)				Oil content (%)				Starch content (%)			
Crosses	Mean	sca	gca	Crosses	Mean	sca	gca	Crosses	Mean	sca	gca
L3×T6	0.82	0.242	AxL	L4×T3	4.77	0.899	HxH	L4×T1	72.64	5.217	AxL
L4×T3	0.63	0.174	LxL	L1×T1	4.47	0.764	AxA	L4×T3	72.37	3.457	AxA
L8×T2	0.58	0.151	HxA	L3×T7	4.65	0.710	HxA	L6×T3	71.45	3.015	AxA
L2×T5	0.64	0.125	HxA	L5×T4	4.51	0.660	LxA	L1×T2	64.75	2.982	HxA
				L6×T5	4.77	0.553	HxA	L2×T7	72.43	2.962	AxA

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Table 5. Estimates of SCA effects for different single crosses of maize

Sr. No.	Crosses	Grain yield per plant (g)	Protein content (%)	Lysine content (%)	Tryptophan content (%)	Oil content (%)	Starch content (%)
L1×T1	HKI 1128 × HKI 163	**27.729***	-0.228	**-0.811****	-0.119	**0.764****	**-4.155****
L1×T2	HKI 1128 × HKI 161	**-11.322***	**-0.715****	**-0.368****	-0.034	-0.214	**2.982***
L1×T3	HKI 1128 × HKI 170(1+2)	1.438	**-0.549***	**0.412****	0.065	0.004	0.869
L1×T4	HKI 1128 × HKI 194-6	-0.300	-0.469	**0.565****	0.044	-0.081	0.97
L1×T5	HKI 1128 × HKI 193-1	-0.469	0.056	**0.594****	0.100	0.041	0.151
L1×T6	HKI 1128 × HKI 193-2	8.988	**0.593***	**-0.508****	**-0.133***	-0.191	-0.668
L1×T7	HKI 1128 × HKI 5072-BT(1-2)-2	**-26.064****	**1.311****	0.115	0.076	**-0.323***	-0.149
L2×T1	HKI 288-2 × HKI 163	**-11.317***	-0.136	-0.064	-0.04	**0.535****	-2.407
L2×T2	HKI 288-2 × HKI 161	7.426	0.008	**0.259***	0.078	0.269	0.013
L2×T3	HKI 288-2 × HKI 170(1+2)	**-11.581***	**1.233****	**-0.938****	**-0.203****	-0.202	-0.813
L2×T4	HKI 288-2 × HKI 194-6	-1.402	**-0.796****	0.088	0.012	**-0.718****	-0.399
L2×T5	HKI 288-2 × HKI 193-1	0.888	0.278	**0.481****	**0.125***	**0.348***	0.619
L2×T6	HKI 288-2 × HKI 193-2	**13.379***	-0.065	**-0.335****	-0.077	-0.011	0.026
L2×T7	HKI 288-2 × HKI 5072-BT(1-2)-2	2.607	**-0.523****	**0.509****	0.105	-0.222	**2.962***
L3×T1	HKI 659-3 × HKI 163	**17.485****	-0.251	**0.469****	0.102	-0.103	-1.622
L3×T2	HKI 659-3 × HKI 161	-10.242	0.096	-0.241	-0.063	0.135	1.345
L3×T3	HKI 659-3 × HKI 170(1+2)	-2.973	-0.441	**-0.438****	-0.077	-0.123	**-2.535***
L3×T4	HKI 659-3 × HKI 194-6	**27.82****	0.062	0.008	0.021	0.128	-0.608
L3×T5	HKI 659-3 × HKI 193-1	**-18.406****	**1.23****	**-0.38****	-0.106	**-0.389***	1.931
L3×T6	HKI 659-3 × HKI 193-2	-0.139	0.244	**1.031****	**0.242****	**-0.359***	0.605
L3×T7	HKI 659-3 × HKI 5072-BT(1-2)-2	**-13.544***	**-0.941****	**-0.448****	-0.119	**0.710****	0.884
L4×T1	HKI 323 × HKI 163	10.381	**0.915****	**-0.321***	-0.059	-0.137	**5.217****
L4×T2	HKI 323 × HKI 161	**15.761****	**1.125****	-0.165	-0.008	-0.316	**-3.94****
L4×T3	HKI 323 × HKI 170(1+2)	**-12.109***	-0.262	**0.728****	**0.174****	**0.899****	**3.457****
L4×T4	HKI 323 × HKI 194-6	**-23.18****	-0.029	**-0.275***	-0.074	**-0.467****	1.538
L4×T5	HKI 323 × HKI 193-1	2.570	-0.467	-0.200	-0.074	**-0.341***	-1.358
L4×T6	HKI 323 × HKI 193-2	**-12.199***	**-0.640****	**0.301***	0.043	**0.327***	**-3.860****
L4×T7	HKI 323 × HKI 5072-BT(1-2)-2	**18.776****	**-0.642****	-0.068	-0.001	0.036	-1.054
L5×T1	HKI 1126 × HKI 163	-0.891	-0.186	**0.616****	0.096	-0.064	1.271
L5×T2	HKI 1126 × HKI 161	**21.225****	-0.106	**-0.511****	-0.096	-0.143	-0.645
L5×T3	HKI 1126 × HKI 170(1+2)	10.572	-0.223	**-0.755****	-0.114	-0.107	0.758
L5×T4	HKI 1126 × HKI 194-6	**-19.763****	0.117	**0.248***	0.088	**0.66****	0.039
L5×T5	HKI 1126 × HKI 193-1	-0.589	**-0.758****	**-0.446****	-0.099	-0.081	-1.880
L5×T6	HKI 1126 × HKI 193-2	**-19.128****	**1.259****	0.068	0.022	0.043	2.171
L5×T7	HKI 1126 × HKI 5072-BT(1-2)-2	8.573	-0.103	**0.779****	0.104	-0.308	-1.713
L6×T1	HKI 1105 × HKI 163	-8.719	**-1.011****	**0.247***	0.058	-0.780	0.455
L6×T2	HKI 1105 × HKI 161	**-11.55***	-0.148	**0.45****	0.099	0.177	0.425
L6×T3	HKI 1105 × HKI 170(1+2)	-6.160	**1.121****	**-0.284***	-0.049	**-0.374***	**3.015***
L6×T4	HKI 1105 × HKI 194-6	**-13.661***	**0.945****	**-0.264***	-0.070	0.180	**-3.311****
L6×T5	HKI 1105 × HKI 193-1	**13.936***	-0.274	0.242	0.060	**0.553****	-0.573
L6×T6	HKI 1105 × HKI 193-2	9.313	**-0.64****	-0.134	-0.023	**0.474****	-1.922
L6×T7	HKI 1105 × HKI 5072-BT(1-2)-2	**16.841***	0.008	**-0.257***	-0.074	-0.231	1.911

Table 5 cont............

Sr. No.	Crosses	Grain yield per plant (g)	Protein content (%)	Lysine content (%)	Tryptophan content (%)	Oil content (%)	Starch content (%)
L7×T1	HKI 536YN × HKI 163	**-14.035***	-0.444	0.232	0.011	-0.314	0.482
L7×T2	HKI 536YN × HKI 161	-6.792	0.209	-0.001	-0.031	**0.420****	-0.051
L7×T3	HKI 536YN × HKI 170(1+2)	-1.963	-0.415	-0.002	0.055	**-0.517****	-2.374
L7×T4	HKI 536YN × HKI 194-6	9.186	0.329	**0.395****	0.084	0.380	1.387
L7×T5	HKI 536YN × HKI 193-1	**27.937****	0.013	-0.123	-0.033	-0.264	-0.768
L7×T6	HKI 536YN × HKI 193-2	**19.614****	0.240	**-0.689****	**-0.143***	-0.310	**2.439***
L7×T7	HKI 536YN × HKI 5072-BT(1-2)-2	**-33.948****	0.069	0.188	0.056	**0.606****	-1.115
L8×T1	HKI 488 × HKI 163	**-31.269****	**0.940****	**-0.666****	-0.117	-0.097	-0.173
L8×T2	HKI 488 × HKI 161	-7.313	**-0.756****	0.664	**0.151***	-0.056	-0.513
L8×T3	HKI 488 × HKI 170(1+2)	**13.387***	-0.037	**0.991****	0.074	0.073	-0.772
L8×T4	HKI 488 × HKI 194-6	**19.876****	0.233	**-0.343****	-0.051	-0.170	-0.175
L8×T5	HKI 488 × HKI 193-1	-0.407	-0.326	-0.097	0.009	-0.027	1.610
L8×T6	HKI 488 × HKI 193-2	-6.666	-0.215	**-0.280***	-0.044	**0.324***	0.984
L8×T7	HKI 488 × HKI 5072-BT(1-2)-2	**12.392***	0.16	**-0.269***	-0.022	-0.047	-0.96
L9×T1	HKI 1040-4 × HKI 163	10.637	0.400	**0.299***	0.067	0.196	0.933
L9×T2	HKI 1040-4 × HKI 161	2.806	0.287	-0.088	-0.095	-0.273	0.383
L9×T3	HKI 1040-4 × HKI 170(1+2)	9.389	-0.427	**0.285***	0.074	**0.346***	-1.607
L9×T4	HKI 1040-4 × HKI 194-6	1.425	-0.393	**-0.422****	-0.054	0.087	0.561
L9×T5	HKI 1040-4 × HKI 193-1	**-25.461****	0.248	-0.072	0.019	0.160	0.269
L9×T6	HKI 1040-4 × HKI 193-2	**-13.164***	**-0.775****	**0.545****	0.113	-0.296	0.226
L9×T7	HKI 1040-4 × HKI 5072-BT(1-2)-2	**14.367****	**0.660****	**-0.548****	**-0.125***	-0.221	-0.765
Standard Error		5.4882	0.2461	0.1249	0.0623	0.1625	1.2317
C.D. (5 %)		**10.757**	**0.482**	**0.245**	**0.122**	**0.319**	**2.414**
C.D. (1 %)		**14.138**	**0.634**	**0.322**	**0.160**	**0.419**	**3.173**

hybrid check. Lines with higher GCA effects can be used more effectively in the development of synthetic variety whereas SCA effects could help in the selection of parental material for hybridization, when high yielding specific combinations are desired.

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RESEARCH PAPER

Effect of abiotic factors on the incidence of insect-pests of maize

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Abstract: A study was carried out to find out the effect of various weather parameters on the occurrence of major insect-pests of maize crop. Among the abiotic factors, morning, evening and mean relative humidity and total rainfall exhibited significant positive correlation with per cent dead hearts and leaf injury rating while, a non-significant negative correlation with mean temperature and a significant negative correlation with maximum temperature but a non-significant positive correlation with minimum temperature. The population of grey weevil and aphids did not exhibit any significant correlation with maximum, minimum and mean temperature, morning, evening and mean relative humidity and total rainfall. The abiotic factors of environment had a non-significant effect on armyworm larval population, although the larval population was found negatively correlated with maximum, minimum and mean temperature whereas, positive with morning, evening and mean relative humidity and total rainfall. The correlation between the mean population of cob worm and minimum temperature exhibited a significant negative correlation while, maximum and mean temperature; morning, evening and mean relative humidity and total rainfall did not exhibit any significant correlation.

Keywords: Dead heart · *Chilo partellus* · Leaf injuryrating · Grey weevil · Aphids · Cob worm

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Introduction

Maize (*Zea mays* L.) is an important cereal crop grown all over the world and as for human consumption, animal feed, fodder and industrial products. Its grain contains protein (10 %), oil (4 %), carbohydrates (70 %), fat (5 to 7 %), fiber (3 to 5 %) and minerals (2 %). In India, it covers an area of 9.09 M ha with the production and productivity of 23.29 MT and 2563 kg ha^{-1}, respectively (Anonymous, 2013-14). In Rajasthan, it is being grown in an area of 9.09 lakhs ha with the production and productivity of 15.67 lakh tones and 1724 kg ha^{-1}, respectively (Anonymous, 2014-15).

Among various biotic factors responsible for low production of maize, the damage caused by insect pests forms an important limiting factor for profitable cultivation. In India, Sarup *et al.* (1987) reported that as many as 130 insect species which causes damage to all the parts of plants from sowing till harvest. While, Bhagat *et al*. (2012) recorded seventeen species of insect pests, among which *Chilo partellus* (Swinhoe), *Agrotis ipsilon* (Hufnagel) and *Holotrichia sp*. were the major ones in maize crop. In general, insect pest complex of a particular crop vary from area to area depends on agro climatic condition of that particular region. Rajasthan is one of the biodiversity rich states of India in terms of flora and fauna. Furthermore, status of insect pest of a particular crop is shifting under changing climate scenario. Concerning these pests, the regular monitoring is needed which will be highly helpful to develop best forecast module for the farmers for the timely management of these pests in maize crop. Keeping in this view, the present study was undertaken to find out the relationship between abiotic factors and insect pests of maize.

Materials and methods

The present investigations was carried out at the Agronomy farm, Rajasthan College of Agriculture, Maharana Pratap

University of Agriculture and Technology, Udaipur during *kharif* (July to October 2014). Geographically, Udaipur is located at 23.4^{0}N longitude and 75^{0}E latitude at an elevation of 579.5 MSL (mean sea level) in state of Rajasthan. The variety, Pratap Maize-5 was sown in well prepared field on 11th July, 2014. The plot size was maintained 3.0 m x 3.0 m (9 sq m.) and row to row distance and plant to plant spacing maintained at 65 and 25 cm, respectively. All agronomic practices were followed as per recommendations given in package of practices for raising a good and healthy crop except the insecticidal spray. The meteorological data on temperature, relative humidity and rainfall was recorded at weekly intervals. The meteorological data recorded was correlated with the pest incidence.

The populations of different insect-pests were recorded on the five tagged plants at weekly intervals when most of the insect species are less active. The appropriate sampling techniques adopted for estimating the populations of different insect pests were as:

(I) Stem borer [*Chilo partellus* (Swinhoe)]: The incidence of stem borer infestation was studied in terms of number of plants showing leaf injury symptoms and number of plant showing dead hearts. The observation was recorded at 30 days after sowing from central rows (each row comprised 13 plant) of each plot at weekly interval.

(II) Grey weevil (*Myllocerus discolour* Bochemann): The population of grey weevil was counted visually on five randomly selected plants at weekly interval.

(III) Armyworm (*Mythimna separata* Walker): The population of armyworm was counted on five randomly selected plants in each plot.

(IV) Maize aphid (*Rhopalosiphum maidis* Fitch): The population of aphid was counted on five plants selected randomly at weekly interval with appearance of pest. The adults and nymphs were counted visually from top, middle and lower leaf of each selected plant.

(V) *Kharif* grasshopper (*Hieroglyphus nigrorepletus* Bolivar): The population of *kharif* grasshopper per plot was counted by net sweep method (Five to six sweeps per 3-m row length).

(VI) Cob worm [*Helicoverpa armigera* (Hubner)]: The population of cob worm was counted visually on five randomly selected plants at weekly interval.

Statistical Analysis

The abiotic factors *viz*. temperature, relative humidity and rainfall were recorded during the crop season and their simple correlation with the population of insect pests and natural enemies were calculated by the Karl Pearson formula of correlation coefficient:

$$r_{xy} = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{n}}{\sqrt{\left[\sum X^2 - \frac{(\sum X)^2}{n}\right]\left[\sum Y^2 - \frac{(\sum Y)^2}{n}\right]}}$$

Where,

r_{xy} = Simple correlation coefficient.

X = Variable i.e. abiotic component (Temperature, relative humidity and total rainfall).

Y = Variable i.e. mean number of insect pests per plant.

n = Number of observations.

The correlation coefficient (r) values were subjected to the test of significance using t-test:

$$t = \frac{r}{\sqrt{1-r^2}} \times \sqrt{n\text{-}2} \sim t_{n\text{-}2} \text{ d.f.}$$

The calculated t-value obtained was compared with tabulated t-value at 5% level of significance.

Results and discussion

Maize stem borer, Chilo partellus (Swinhoe): Correlation coefficients (r) worked out between dead heart and leaf injury rating and among the abiotic factors of environment, mean temperature had a non-significant negative correlation and maximum temperature had a significant negative correlation but minimum temperature had a non-significant positive correlation with per cent dead hearts and leaf injury rating (Table 1).While, the morning, evening and mean relative humidity and total rainfall had a significant positive correlation with dead hearts and leaf injury rating. The present findings are in conformity with Kandalkar *et al*. (2002) who observed that only minimum temperature showed significant and negative correlation with stem borer leaf injury and also reported that maximum temperature, morning and evening relative humidity, and rainfall did not influence stem borer incidence significantly. Meti *et al.* (2014) observed that the minimum temperature showed highly significant positive correlation whereas rainfall and relative humidity had significant positive correlation with per cent leaf damage caused due to stem borer complex which support the present findings.

Table 1. Correlation co-efficient between maize insect-pests, their natural enemies and abiotic factors (*Kharif* 2014)

Parameters	Maxi. Temp. (°C)	Mini. Temp. (°C)	Mean Temp. (°C)	Mor. RH (%)	Eve. RH (%)	Mean RH (%)	Rainfall (mm)
Stem borerDead heart	-0.71*	0.59	-0.16	0.88*	0.91*	0.93*	0.85*
Stem borerLeaf injury rating	-0.73*	0.49	-0.27	0.89*	0.87*	0.91*	0.87*
Grey weevil	-0.003	-0.13	-0.11	0.39	0.22	0.26	-0.05
Army worm	-0.32	-0.37	-0.62	0.60	0.30	0.38	0.48
Aphid	-0.18	-0.07	-0.24	0.82*	0.48	0.58	0.48
Grasshopper	-0.27	-0.43	-0.63	0.68	0.31	0.42	0.43

*Significant at 5%

Grey weevil, *Myllocerus discolour* Bochemann: The population of grey weevil exhibited non-significant negative correlation with maximum, minimum and mean temperature and total rainfall whereas, non-significant positive with morning, evening and mean relative humidity. The findings of present investigation are supported by the work of Kalaisekar and Ramamurthy (2004) who observed that the population of *Myllocerus* weevil showed a non-significant negative correlation with both temperature and rainfall.

Armyworm, *Mythimna separata* Walker: The pest showed negative correlation with maximum, minimum and mean temperature whereas, positive with morning, evening and mean relative humidity and total rainfall, however the correlation was non- significant (Table 1). The findings of present investigation are in close conformity with findings of Mallapur and Kulkarni (2002) reported that population fluctuation of *M. separata* egg density was negatively correlated with infertility and maximum temperature. The mean maximum temperature and total rainfall exhibited positive association with larval density. Jeengar (2005) who observed that the increase in population showed inverse correlation with the average temperature and positive with mean relative humidity and rainfall however, the correlation was non-significant.

Maize aphid, *Rhopalosiphum maidis* Fitch: The maximum, minimum and mean temperature exhibited a non-significant negative correlation with the mean population of aphid while, morning, evening and mean relative humidity and total rainfall exhibited non-significant positive with the mean population of aphid (Table 1). The present findings are in accordance with that of Singh and Singh (2013) who reported that the population of aphid in maize increases with decrease in temperature and relative humidity.

Kharif grasshopper, Hieroglyphus nigrorepletus Bolivar: The *kharif* grasshopper showed a non-significant negative correlation with maximum, minimum and mean temperature while, non-significant positive with morning, evening and mean relative humidity and total rainfall (Table 1). Reports of earlier workers confirm the present findings of Sisodiya *et al.* (2005) who studied various host plants of grasshopper *viz*., maize, bajra (pearl millet), sorghum, soybean, sugarcane and rice and observed that maize was significantly the most preferred host, followed by sorghum and bajra. Jeengar (2005) reported that the mean temperature is having a negative correlation with grasshopper's population while mean relative humidity and rainfall showed positive correlation with the insect population. However, the correlation was non-significant which support the present findings.

Cob worm, Helicoverpa armigera (Hubner): The cob worm populations showed a non-significant negative correlation with maximum and mean temperature and evening and mean relative humidity but a significant negative correlation with minimum temperature and a non-significant positive correlation with morning relative humidity and total rainfall (Table 1). Morey (2010) observed that developmental times of *Helicoverpa zea* are influenced by a number of environmental factors, but temperature is the primary driver. Ranjith and Prabhuraj (2013) observed the incidence of *H. armigera* on important field crops and revealed that maximum and minimum temperature exhibited positive but non-significant correlation with larval incidence. While, rainfall and morning relative humidity recorded negative but non-significant correlation with larval incidence which is in agreement with the findings of this study.

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RESEARCH PAPER

Differential response of maize genotypes to stem borers under artificial infestation

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Abstract: The most important pest of maize in South Asia during *kharif* and *rabi* seasons is *C. partellus* and *S. inferens* respectively which cause heavy damage to maize crop resulting in 25-80 % yield losses in different agro climatic regions. Host plant resistance was found most viable option to reduce yield losses caused, therefore the present study has taken up to identify maize genotypes with high levels of resistance to stem borers of maize. A set of 207 diverse maize inbred lines were screened under artificial infestation against maize stem borers *C. partellus* and *S. inferens* during *kharif* 2012 and *rabi* 2012-13 respectively under artificial infestation in field conditions. The data of leaf injury rating (LIR) for each inbred lines was recorded visually by scoring LIR on individual plant at 5-6 weeks after artificial infestation by following 1-9 scale. The mean LIR against *C. partellus* ranged across different inbred lines was 1.9 to 7.4, whereas the mean LIR against *S. inferens* across different inbred lines ranged was 3.0 to 8.9. Out of 207 inbred lines screened against *C. partellus* 21 inbred lines were resistant with <3.0 LIR whereas out of 207 inbred screened against *S. inferens* only one inbred line WNZPBTL9 was resistant. The inbred WNZPBTL9 has showed resistant against both stem borers of maize. The results also showed the low frequency of resistance source against *S. inferens* (1 in 152 i.e. 0.00657) as compared *C. partellus* (14 in 81, i.e. 0.173). The inbred lines which have identified in the present study can serve as base material in resistance breeding programme against *C. partellus* and *S. inferens*.

Keywords: Maize stem borers · *Chilo partellus* · *Sesamia inferens* · Artificial infestation

Introduction

Maize is one of the most important cereal food crops of India and World. Apart from food it is being used as feed, fodder and industrial crop. However, the present national average maize yield in India is quite low (~2.5 t ha^{-1}) as compared to World average maize yield (~5 t ha^{-1}). In fact the average of yield of USA and China were quite high i.e. 10 t ha^{-1} and >6 t ha^{-1}, respectively. The major factors responsible for low yields in India are biotic and biotic stresses. The major biotic factors are insect pests especially the maize stem borers i.e. *Chilo partellus* Swinhoe *Sesamia inferens* Walker. According to Hari *et al*. (2008) the most important pest in South Asia during *kharif* season is *C. partellus* which causes heavy damage to maize crop resulting in 26 to 80 % yield losses in different agro climatic regions (Panwar, 2005) whereas the losses due to *S. inferens* Walker during *rabi* season range from 25.7 % to 78.9 % (Chatterjee *et al*., 1969). Stem borer damage is the major constraint in maize production which causes damage in vascular tissue of a plant thus providing a portal of entry for stalk and ear rots. In the past the use of insecticides was found one of the most effective and quick methods of insect control but due to several adverse effects like mortality of natural enemies, environmental and water pollution and unsafe to human beings and animals, the host plant resistance is gaining significant importance in recent years. Host-plant resistance availablity in maize germplasm provides resistance to major insect pests which can be sustainable, low cost, economical, more productive and

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free from environmental pollution. In this context, identification of resistance sources to the stem borers by screening under artificial conditions is a pre-requisite for any resistance breeding. Further, identifying lines with resistance coupled with good adaptation to local environment and good agronomic performance is the cardinal component of IPM (Sekhar *et al*., 2008). Therefore, by keeping in view of all the above aspects the present study has taken up to identify maize genotypes with high levels of resistance to stem borers of maize.

Materials and methods

Maize genotypes

A set of 207 diverse maize inbred lines which includes 112 field maize, 81 quality protein maize, 4 sweet corn, 7 popcorn, 3 high oil maize were chosen for the present study along with CM 500 and CML 451 as resistant and susceptible check respectively against maize stem borers (*C. partellus* and *S. inferens*). Inbred lines were chosen by considering kernel colour, kernel texture, pedigree, geographical adaptation etc.

Mass rearing of maize stem borers

C. partellus

The *C. partellus* larvae were collected from infested maize plants in field and the culture was maintained on cut pieces of maize stems under laboratory conditions in rearing jars till pupation. The pupae were collected and kept in separate rearing glass jars till emergence into moths; subsequently moths were transferred to oviposition jars kept at 27±2˚C as explained by Siddiqui *et al*. (1977). The egg laying was examined on alternate days and portions of butter paper containing the egg mass were cut and incubated at 27±2˚C; the eggs thus obtained served as a nucleus culture for mass rearing of *C. partellus* in the laboratory.

S. inferens

The larvae of *S. inferens* were collected from infected maize plants in field at Winter Nursery Centre, Rajendra Nagar, Hyderabad and were kept in rearing jars under laboratory conditions. The top of each jar containing larvae and pupae was covered with muslin cloth and secured with rubber bands. In the initial instar, the larvae were allowed to feed on immature cobs and green husk, whereas in later instars, larvae were fed with stem portions of older maize plants. The larvae were transferred to another clean jar containing fresh food for every 2-3 days, until all the larvae enter into the pupal stage. The pupae were collected from each jar were kept separately for the emergence of moths; after emergence of moths an equal number of male and female moths were transferred into wooden ovipositional cages and allowed to lay eggs on potted ~10 day old maize plants. Three days after release of moths, the plants were removed and the leaf sheaths containing egg portion were cut and kept at 27±2 ºC for incubation, such collected eggs were used as nucleus culture for mass rearing of *S. inferens*.

Planting and artificial infestation

C. partellus

Sowing of 207 inbred lines was undertaken at Winter Nursery Centre, Rajendra Nagar, Hyderabad during *kharif* 2012 (as *C. partellus* is the major insect pest of maize during *kharif* season) under augmented design by repeating resistant and susceptible check randomly in each blocks. The size of each plot was 1 row of 2.5 m length with 75 cm × 20 cm spacing between row and plants within row respectively. The ideal plant population of 10-12 per plot was maintained by thinning out extra seedlings before artificially releasing black head stage eggs of *C. partellus* @ 15-20/plant. The eggs were pinned in the whorl of ten day old maize seedlings.

S. inferens

Sowing was undertaken at Winter Nursery Centre, Rajendra Nagar, Hyderabad during *rabi* 2012-13 by following the same methodology as explained above under '*C. partellus'* to screen the same set of 207 maize inbred lines against *S. inferens*, the major insect pest of maize during *rabi* season. The neonate larvae of *S. inferens* were released artificially @ 10/plant into the whorl of 10 days old seedling by using a camel hair brush.

Data collection and statistical analysis

The data of leaf injury rating (LIR) for each inbred lines was recorded visually by scoring LIR on individual plant at 5-6 weeks after artificial infestation by following 1-9 scale given by Sarup *et al*. (1978) for *C. partellus* and Reddy *et al*. (2002) for *S. inferens*. The LIR of over all plants was averaged and variance (V), standard deviation (SD) and standard error (SE) were calculated. The mean LIR scores further transformed into score (Fisher and Yates, 1963, page 94, Table XX) before carrying out multiple comparison tests of Tukey's honest significant differences (HSD) at online portal http://stat.iasri.res.in/sscnarsportal/main.do.

Results and discussion

Mean and variance of LIR within inbred lines

Since the numbers of plants were manageable, the LIR was recorded on all plants which varied from 7-10. As explained above, LIR was recorded on individual plants on all the inbred lines however, the LIR data of 80 against *C. partellus* and 153 inbred lines against *S. inferens* infestation was used to calculate mean LIR, variance (V), standard deviation (SD), standard error (SE). Out of all inbred lines whose LIR was considered for analysis 19 and 92 inbred lines were differed between *C. partellus* and *S. inferens* respectively whereas the remaining 61 inbred lines were common against both stem borers. The LIR data of other inbred lines were not used in an analysis due to poor plant stand/germination (i.e. <70% than the optimum plant density) before artificial infestation. The reason being, the additional space for individual plants due to absence of neighbouring plants might have effect on vigour of plant thus might influence LIR data. Therefore, mean LIR of only those inbred lines where optimum plant stand was available were used for further analysis. The LIR rating from 1-3 are considered resistant, >3-5 moderately resistant, >5-7 susceptible, >7-9 highly susceptible.

C. partellus

The mean LIR against *C. partellus* ranged across different inbred lines was 1.9 to 7.4, whereas the variance was ranged from 0.1 to 8.3 (Fig. 1). The mean LIR range of resistant and susceptible check was 2.7 to 2.9 and 7.8 to 8.0 respectively. Out of 81 inbred lines screened, 14 inbred lines *viz.,* WNZPBTL8 (2.6), WP21 (2.6), LM16 (2.6), HKI488 EARLY (2.5), HKI484-5 (2.4), WINPOP3 (2.4), CML305 (2.4), CML424 (2.4), WNZPBTL9 (2.4), AEBCYC534-3-1 (2.4), CML338 (2.1), AEBY2Ä (2.1), WINPOP8 (2.1), WNZPBTL5 (1.9) under optimum plant population have recorded lower LIR against *C. partellus* than the resistant check CM 500 (2.7-2.9). Based on LIR the inbred lines were grouped into resistant, moderately resistant, susceptible and highly susceptible. Out of 81 inbred lines 21 were resistant, 31 were moderately resistant, 27 were susceptible and 2 were highly susceptible (Table 1). Similar kinds of studies by Afzal *et al*. (2009) who screened 20 maize genotypes for resistance to *C. partellus* in field by artificial infestation and reported DK- 6525 was found to be resistant. Further, Chavan *et al*. (2007) evaluated 77 maize germplasm lines belonging to full season maturity (16 entries), medium maturity (31 entries) and extra early maturity group (30 entries) for resistance to stem borer, *C. partellus* under artificial infestation. The least susceptible germplasms (< 3.0 rating) included PARBHAT, BIO 9681 and KMH-22202 (Full season maturity); HKH-1191, L-166, CM-500 and KMH-22205 (medium maturity) and JH-31053, CHH-215 and CM-500 (medium maturity), NECH-129, SEEDTEC-2324 (Full season maturity).

S. inferens

The mean LIR against *S. inferens* across different inbred lines ranged was 3.0 to 8.9, whereas the variance was ranged from 0.1 to 8.3 (Fig. 1). The mean LIR range of resistant and susceptible check against *S. inferens* was 2.6 to 3.1 and 7.6 to 8.3 respectively. None of the 152 inbred lines screened against *S. inferens* have recorded lower than the

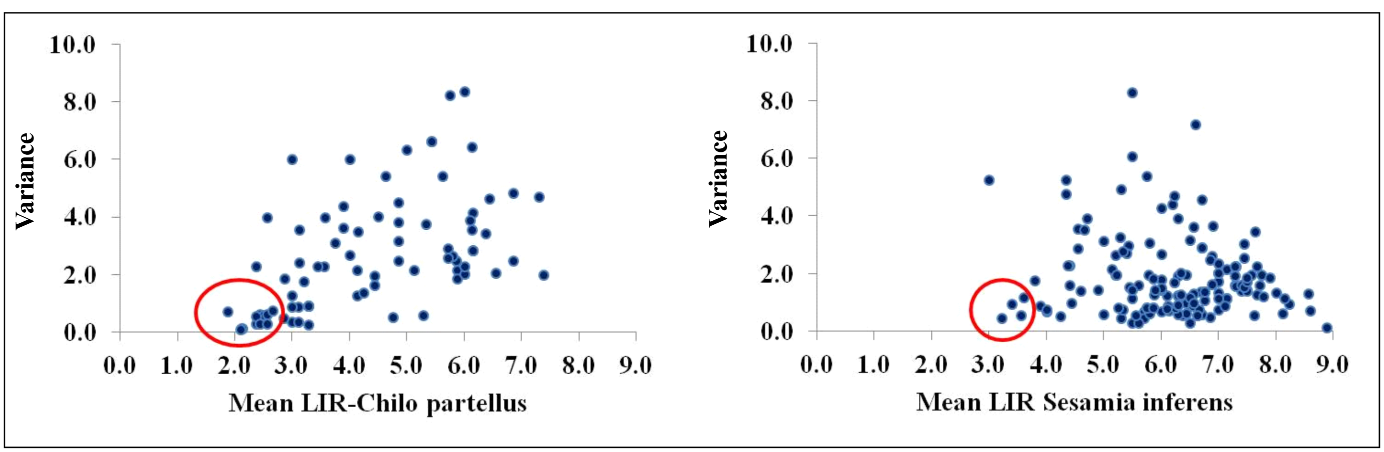

Fig. 1. The scatter plot of mean LIR vis-à-vis variance across all maize inbred lines

Table 1. The details of inbred lines grouped based on reaction to maize stem borers

Group	*C. partellus*	*S. inferens*
Resistant (<3.0)	P390AM/CMLC4F230-B-2, P63C2-BBB-17B, EC672591, CML227, WINPOPIIXWINPOPIII, CM501, WP21, LM16, WNZPBTL8, HKI488EARLY, CML305, HKI484-5, AEBCYC534-3-1, WINPOP3, CML424, WNZPBTL9, AEBY2Ä, WINPOP8, CML338, WNZPBTL5	WNZPBTL9
Moderately resistant (>3.0 to 5.0)	T2SR1101, CML49, S0S1YQBBB-13, P69(5869Q)BBB-24, P3C4S5-33-11-BBBB-2, SU2SU2COMP-7-B, CML304, HKI586, V351, CML485BBB, SWEETCORNSYNTHETIC, CM211, WNZEXOTICPOOLDC2, CM131, CM117, EC610584, WS2, BASILOCALSELECTION, CLQRCWQ31-B-6, V335, HKI326-3, ITNA004, HKI536-7, DMRN7CH7, POBLAC70C0, HKI1105, CM123, CML44-B-B-B, CML212, AEBYC538-1-1, CM142, CM502	97P65-BBB-26-B, AEBYC538-1-1, CML494, T2SR1101, LM13, BASILOCALSELECTION, WP21, LTP1, CML23, CML491, CML424, HKI2-6-2-4, AEBY2Ä, EC598464, WNZEXOTICPOOLDC2, E60FC, CML111BBB, WNZEXOTICPOOL1Ä, WNZPBTL8, P390AM/CMLC4F230-B-2
Susceptible (>5.0 to 7.0)	CM208, S991S1WQETBBB-32, EC440414, JCS796CH8, CML491, CM140, BML5, CML55BB, LTP1, BML7, CML376, CM121, CML479, EC614829, CML336, CM111, CML290, JAHNGRAPOP, CM201, CM117-3-4-1, COMPMODBCOBBB-48, CML73, LM13, DMRSC1, HKI287, CML111BBB, JCY3-7	CML256, CML162, CML306, CML116, POBLAC70C0, HKI287, HKI1040C2, HKI577, BML10, CLQ6310, HKI1831, BCK/BC2, HKI586-1WG33, BCK/BC8, CML479, HKI209, V351, CML435, CML485BBB, P3C4S5-33-11-BBBB-2, HKI536-7, JCS796CH8, CML212, CM117, P70C0BBB-5, EC655779, CML73, CML120, S0S1YQBBB-13, CM111, WSC1XMASMADHU, CML376, CM135, BML14, CM117-3-4-1, HIGHOILQPMC13-BBB-61, EC440414, HKI170(1+2), CML402, CM130, EC610584, HKI1532, G31QC2BB23, CLQRCY47B6, CLQRCWQ16-B6, HKI326-3, CML338, ITNA004, HKISCSTPINK, WS2, HKI164-3-(2-1)1, BML11, CML227, CM125, CML336, CML344BB, DMRN7CH7, P61C1BBB-8, WINPOP21, CML151, CML282, CML312, CML289, G18QC8-36, EC672591, JCS80106H, PFSRS2, PFSRS3, WINPOP3, CML292, HKI586, WINPOPIIXWINPOPIII, CML41, S87P66Q-BBB-30, V335, BML5, CML335, HKI193-1, CM502, CML114, CML317, CUBA378, TZAR106, CML290, G33QC20-BBB-37, TZAR101, CML90, AEBYC534-1-1, JCY3-7,
Highly susceptible (>7.0 to 9.0)	EC598464, (CML161/CML165)BBB7	CML165BBB, HKIPCBT3, CML448, CML77, CM142, HKI488EARLY, CML287, JAHNGRAPOP, CM208, CML238, Sow1wq-2-BBB-B, CM400, CML384X176F3-100-9, CM201, CML481, P69(5869Q)BBB-24, CM211, HKIPC5, CM119, CML423, CML482, CML12, HKI484-5, JCS789CH1, O2POOL33C23, CML49, CM131, HKI163EARLY, G24QC19BBB-4, HYBRID9415-BBB-4, CLQRCWQ02B-6, CM118, S00TLWQHGBBB35-B, BML7, CML420, AEB(Y), CM123, BML15, CML18, CML298, CML55BB

resistant check CM 500 (2.6-3.1). However, one inbred line WNZPBTL9 (3.0) has shown comparable resistance as that of resistant inbred line. Out of 152 inbred lines one was resistant, 23 were moderately resistant, 92 were susceptible and 36 were highly susceptible (Table 1). Santosh *et al*. (2012) screened 48 inbred lines against *S. inferens* under artificial infestation, eight were found to be resistant to pink borer with leaf injury rating (LIR) score less than 3.0, while 16 were moderately resistant and 24 were highly susceptible. Generation mean analysis of a cross between E 62 and CML 451 revealed presence of negative additive and dominance effects, and positive additive × dominance (*j*) and dominance × dominance (*l*) epistatic interaction effects. Sekhar *et al*. (2008) studied the differential response of CML'S and their hybrid combinations to pink borer and reported that inbred lines CML 421, CAD 3141, CA0 106, CA0 3120, and single crosses CLL429 X CML 474, CML 421 X CML 470 were resistant.

Multiple comparisons of inbred lines

The results of analysis of variance (ANOVA) of transformed data has shown significant differences among treatments, inbred lines, checks and also between checks and checks for both *C. partellus* (Table 2) and *S. inferens* (Table 3). The Tukey's test of HSD grouped whole inbred lines into different groups by indicating with different letters if they are significantly different and same letter if they are not significantly different at 5% level of significance.

The details of LIR rating of all inbred lines was not given in the paper as it run through several pages but the calculated SEd and CD at 5% and 1% for both actual and

Table 2. The ANOVA of screening under artificial infestation against *C. partellus*

Source	df	Type III SS	Mean Square	F Value	Pr > F	Significant
Blocks	4	0.0057024	0.0014256	1	0.5	NS
Treatments	82	20.8833705	0.2546752	178.64	<.0001	*
Inbred lines	80	20.0556123	0.2506952	175.85	<.0001	*
Checks	1	0.645888	0.645888	453.06	<.0001	*
Tests vs Checks	1	0.0273801	0.0273801	19.21	0.0119	*
Error	4	0.0057024	0.0014256	.	.	
Corrected Total	90	22.2041927	.	.	.	

Table 3. The ANOVA of screening under artificial infestation against *S. inferens*

Source	df	Type III SS	Mean Square	F Value	Pr > F	Significant
Blocks	4	0.0248944	0.0062236	0.59	0.6869	NS
Treatments	153	24.1378321	0.1577636	15.06	0.0082	*
Inbred lines	151	23.943863	0.1585686	15.14	0.0081	*
Checks	1	0.1928205	0.1928205	18.41	0.0127	*
Tests vs Checks	1	0.0028541	0.0028541	0.27	0.6293	NS
Error	4	0.0419056	0.0104764	.	.	
Corrected Total	161	26.8872123	.	.	.	

Table 4. The SEd and CD between and within plots to compare treatments

Insect Pest		*C. partellus*		*S. inferans*	
Details	Parameters	Actual LIR	Transformed LIR	Actual LIR	Transformed LIR
Two Control Treatments	SEd	0.01	(0.04)	0.15	0.065
	C.D. (1%)	0.06	(0.17)	0.69	0.298
	C.D. (5%)	0.04	(0.10)	0.42	0.180
Two Test Treatments (Same Block)	SEd	0.03	(0.08)	0.34	0.145
	C.D. (1%)	0.14	(0.39)	1.55	0.666
	C.D. (5%)	0.08	(0.23)	0.93	0.402
Two Test Treatments (Different Blocks)	SEd	0.04	(0.10)	0.41	0.177
	C.D. (1%)	0.17	(0.47)	1.90	0.816
	C.D. (5%)	0.10	(0.28)	1.14	0.492
A Test Treatment and A Control Treatment	SEd	0.03	(0.07)	0.30	0.129
	C.D. (1%)	0.12	(0.34)	1.38	0.596
	C.D. (5%)	0.07	(0.21)	0.83	0.359

transformed data was given in Table 4 to compare different inbred lines within and between blocks with respect to host plant reaction to *C. partellus* and *S. inferens* infestation. The significant difference between resistant and susceptible checks indicates proper imposition of sufficient insect pressure under artificial infestation. The inbred line WNZPBTL9 is the only inbred line which showed resistance against both stem borers of maize. The results also showed the low frequency of resistance source against *S. inferens* (1 in 152 i.e. 0.00657) as compared *C. partellus* (14 in 81, i.e. 0.173). However, there are quite a high number of inbred lines whose LIR was not considered for the analysis because of low plant population. Therefore, there is possibility of obtaining more resistant sources by maintaining the optimum plant population. The numbers of inbred lines with poor plant stand were quite high during *kharif* while screening against *C. partellus* as compared to *rabi* season while screening against *S. inferens*; it is quite expected that during *kharif* there were many stresses apart from insects which might have been responsible for poor plant stand. The studies on identification of resistant sources among the available germplasm and also understanding the resistance response of germplasm was undertaken in other crops as well. Marulasideesha *et al*. (2007) tested twenty sweet sorghum and three grain sorghum genotypes for resistance to the damage caused by *C. partellus* and reported that genotype SSV-7073 was found to be the most resistant with respect to all the damage types studied. Based on the present study it can be concluded that inbred lines which have shown resistant may serve as base material of interest and could be effectively utilised in resistance breeding programme against *C. partellus* and *S. inferens*.

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RESEARCH PAPER

Effect of tassel removal on crop growth, yield and economics of *rabi* maize

K.H. Patel · P.K. Parmar · S.M. Khanorkar · S.K. Singh

Abstract: The field experiment to find out the effect of detasseling on yield and crop growth by using maize composite and hybrid variety for middle Gujarat condition was conducted at experimental field of Main Maize Research Station, Anand Agricultural University, Godhra during *rabi* 2012-13 to *rabi* 2014-15. The five treatments comprising removal of tassels at different stages of crop growth *viz*., control, 50% removal of tassel after anthesis and pollen dispersal (15 days) and fertilization of alternate rows, 50% removal of tassel after anthesis (15 days) and fertilization to alternate plants within rows, 50% removal of tassel after anthesis (15 days) and fertilization to alternate plants within rows, removal of main stem after fertilization of alternate rows and 100% removal of main stem after fertilization of all rows. Among these, the treatment of 50 % removing of tassel after 15 days of anthesis in alternate rows is produced significantly higher yield with maximum net realization.

Keywords: Composite · Detasseling · Fertilization · Hybrids

Introduction

Maize (*Zea mays* L.) is an important cereal crop of middle Gujarat and grown in *kharif* and *rabi* seasons. In Gujarat, it is cultivated in the area of 4.23 lakh hectares with production of 6.72 lakh tones and productivity is 1589 kg/ha (2014-15). Apart from food, feed and fodder utilization of maize, it is also used as vegetable like baby corn in sub–urban and urban areas of the state and covers the country. After the tassel formation, the overall nutrients go towards the development of inflorescence. After anthesis and fertilization, if tassel removes, the whole nutrients would go for the cob and grain development that ultimately enhance yield of crop. The economy of these technologies may be high than other production technologies. Moreover, the green tassel can also be fed to the animals. This practice may have positive effect in reducing fungal infection because of dried tassel and pollen and glumes shading on the leaves. However, there is significant interaction exists between environment and technologies for achieving higher yield in crop plants (Dia *et al*., 2016). Yield and yield components are complex traits, which exhibit polygenic or quantitative inheritance pattern. The expression of quantitative traits is largely governed by environment in which they are exposed; and, thus, it results into scale or rank shift of their performance (Dia *et al*., 2016a; Dia *et al*., 2016b; Dia *et al*., 2016c; Dia *et al*., 2016d; Dia *et al*., 2012a; Dia *et al*., 2012b). Year to year environment variation is more unpredictable than location per se (Dia *et al*., 2016a; Dia *et al*., 2016b; Dia *et al*., 2012b). Therefore, future studies on multi-location x year in replicated trials may provide high performing management practices for specific or widely adapted location. Thus, a multi-year study was undertaken to optimize the tassel removal practices for higher grain yield and profitability of maize.

Materials and methods

The present investigations were carried out at Main Maize Research Station, Anand Agricultural University, Godhra in GM-3 and HQPM-1 variety during three consecutive *rabi* seasons (2012-13 to 2014-15). The trials planted in randomized complete block design using in four replications and five different treatments by keeping net plot size 2.40 m x 4.60 m. The different treatment followed were, T_1 : Control (no tassel removal), T_2 : 50% removal of tassel after anthesis and pollen dispersal (15 days) and fertilization

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of alternate rows, T_3: 50% removal of tassel after anthesis (15 days) and fertilization to alternate plants within rows, T_4: removal of main stem after fertilization of alternate rows and T_5 : 100% removal of main stem after fertilization of all rows. The crop was planted at 60 x 20cm using seed rate of 20 kg/ha. The fertilizer doses were 100:50:0 NPK kg/ha. The data on the yield, yield attribute and economics recorded and analyzed statistically as per the standard procedure.

Results and discussion

Growth and yield attributes

The results of ear length found significant in GM-3 in all the three years and on pooled bais treatment T_2 showed significantly higher ear length and it is at par with T_3 (Table 1). These results corroborate the findings of Komatuda *et al*. (2006). In HQPM-1 in pooled analysis, T_2 gave higher ear length (19.4 cm) and observed at par with T_3. Similar results were found by Komatuda *et al*. (2006). The test weight for GM-3 found significant in 2013-14 and 2014-15 and in pooled analysis where T_2 gave higher test weight which was at par with T_3. For HQPM-1 T_2 gave higher test weight (345 g) and it also at par with T_3. The results of pooled analysis indicated that interaction effects (YxT) for GM-3 and HQPM-1 was significant for grain yield, fodder yield, ear length and ear girth (Table 1 to 4).

Grain yield

In all the year, the effect of different treatments found significant on grain yield. The results revealed in GM-3, T_2 gave significantly higher yield (9847 kg/ha) in 2012-13 and in 2014-15 (8181 kg/ha) but it is at par with T3 (Table 2). While treatment, T_3 gave significantly higher yield (8250 kg/ha) in 2013-14 and it is at par with T_2. Pooled Results revealed that T_2 (50% Removal of tassel after anthesis and pollen dispersal and fertilization of alternate rows) exhibited significantly higher yield (8713 kg/ha) and it is at par with T_3 (50% Removal of tassel after anthesis and pollen dispersal and fertilization of alternate rows) which yielded (8523 kg/ha). The results revealed that the yield of maize hybrid, HQPM-1 was significantly higher in T_2 during 2012-13, (9988 kg/ha) and 2013-14 (7833 kg/ha) and it is at par with T_3. However, in 2014-15, T_3 gave significantly higher grain yield (7322 kg/ha) which was at par with T_2. The pooled analysis showed Treatment T_2 gave significantly higher yield (8341 kg/ha) and it is at par with T_2 (Table 2). Hunter *et al.* (1999) obtained the similar results.

Stover yield

The results showed non-significant for stover yield in GM-3 in 2012, whereas, significant effect observed in 2013-14 and 2014-15 (Table 3). Treatment T_2 exhibited significantly higher stover yield (8777 kg/ha) and it is at par with T_1 and T_3 during 2013-14 while during 2014-15, T_2 gave significantly higher yield (8930 kg/ha) and it is at par with T_3. The pooled analysis also observed significant differences between treatments for stover yield of GM-3 where T_2 yielded higher (9101 kg/ha) and it is at par with T_3 and T_1. These results are in conformity with finding of Hunter *et al.* (1999). It was found significant for the Stover yield in HQPM-1. Over three years, the treatments T2 gave significantly higher stover yield (12000 kg/ha) in *rabi* 2012-

Table 1. Effect of detasseling on various growth and yield characters of maize cultivars (pooled values of three years)

Treatment	GM-3			HQPM-1		
	Ear length (cm)	Ear girth (cm)	Test weight (g)	Ear length (cm)	Ear girth (cm)	Test weight (g)
T_1	16.5	14.5	310	17.5	15.0	319
T_2	19.0	16.5	360	19.4	15.7	348
T_3	18.9	16.4	349	19.2	15.7	365
T_4	15.9	14.2	312	17.2	14.4	312
T_5	15.0	13.8	298	16.7	14.3	304
SEm$\pm$	0.54	0.71	11.3	0.92	0.16	9.4
C.D. (0.05)	1.7	NS	32.2	NS	0.52	26.8
YxT						
SEm$\pm$	0.32	0.24	18.2	0.39	0.19	15.7
C.D. (0.05)	0.92	0.68	NS	1.13	0.55	NS

Table 2. Effect of tassel removal practices on grain yield of maize cultivars

Treatment	GM-3 (kg/ha)				HQPM-1 (kg/ha)			
	2012-13	2013-14	2014-15	Pooled	2012-13	2013-14	2014-15	Pooled
T_1	8666	6208	5680	6852	8244	7488	6456	7396
T_2	9847	8111	8180	8713	9988	7833	7200	8341
T_3	9527	8263	7778	8523	9700	7578	7322	8200
T_4	8958	6152	5653	6921	8000	6244	6522	6922
T_5	8375	5917	5375	6555	7644	5478	6433	6519
SEm±	186	160	209	242	282	114	168	278
C.D. (0.05)	573	495	637	756	869	352	520	867
Y x T								
SEm±	-	-	-	187	-	-	-	200
C.D. (0.05)	-	-	-	537	-	-	-	576

Table 3. Effect of tassel removal practices on stover yield of maize cultivars

Treatment	GM-3 (kg/ha)				HQPM-1 (kg/ha)			
	2012-13	2013-14	2014-15	Pooled	2012-13	2013-14	2014-15	Pooled
T_1	9875	8486	6916	8426	9155	9366	7400	8640
T_2	9597	8777	8930	9102	12000	10088	8577	10222
T_3	9666	8402	8833	8968	12000	9644	8522	10055
T_4	9222	7333	6916	7824	9588	7955	7888	8477
T_5	8680	6263	6916	7287	8422	7055	7477	7651
SEm±	325	269	155	342	354	125	168	424
C.D. (0.05)	NS	831	480	1068	1092	385	520	1322
Y x T								
SEm±	-	-	-	260	-	-	-	237
C.D. (0.05)	-	-	-	746	-	-	-	682

Table 4. Economics of different maize cultivars as influenced by tassel removal practices

Treatment	GM-3			HQPM-1		
	Gross returns (Rs./ha)	Net returns (Rs./ha)	BCR	Gross returns (Rs./ha)	Net returns (Rs./ha)	BCR
T_1	119632	102632	7.03	128220	109020	6.67
T_2	148899	131149	8.38	145559	125609	7.30
T_3	145781	128031	8.21	143110	123160	7.17
T_4	119463	101563	6.67	120784	100684	6.00
T_5	112899	94849	6.25	113087	92837	5.58

**Price of maize grain Rs. 15 /kg and price of maize fodder Rs. 2 /kg*

13. Whereas the stover yield showed significantly higher (10088 kg/ha) in 2013-14 and T_2 gave significantly higher Stover yield (8577 kg/ha) and it is at par with T_3 in 2014-15. The pooled analysis showed T_2 gave significantly higher stover yield (10222 kg/ha) and it is at par with T_3. The results were confirmed with the results obtained by the Hunter R B *et al.* (1999)

Economics

Economics results of different detasseling treatments indicated that maximum net realization for detasseling was recorded in Treatment T_2 with BCR of Rs. 8.38 (Table 4) in GM-3 and maximum net realization by using HQPM-1 recorded in T_2 with BCR of Rs.7.30 (Table 4). The higher yield in these treatments could have resulted in more net profit compared to the rest of the treatments.

Thus, the practice of removing tassel after 15 days of anthesis in alternate rows is to be followed for securing higher grain yield and net return in maize in *rabi* season in Gujarat and other similar agroecologies.

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RESEARCH PAPER

Effect of tillage management on direct seeded rice (*Oryza sativa*)-maize (*Zea mays*) cropping system

Hargilas[1] · Shankar Lal Jat[2]

Abstract: A field experiment was conducted for two consecutive years at Agricultural Research Station (MPUAT), Banswara to study the effect of tillage management on direct seeded rice (*Oryza sativa*) -maize (*Zea mays*) cropping system. The experiment comprised of four treatments, Zero till in both crops (ZT-ZT), conventional till in both crops (CT-CT), conventional till in rice and fresh ridge bed planting in maize (CT-FRB) and conventional till in rice and zero till with rice residue retention in maize (CT-ZT+R) were allocated randomly in a randomized block design with four replications. Results indicated that CT-FRB and CT-ZT+R were recorded comparable with respect to yield attributes and yield of both rice and maize. Maximum yield of direct seeded rice recorded in CT-ZT+R , whereas, maximum yield of maize was found in CT-FRB. Maximum water use efficiency recored for rice in CT-ZT+R (3.79 kg/ha-mm) and maize in CT-FRB (23.57 kg/ha-mm).The maximum maize equivalent yield of cropping system was recorded in CT-FRB (92.21 q/ha) which found at par with CT-ZT+R. The maximum net returns (Rs. 77651/ha) and B:C ratio (2.35) was fetched under CT-ZT+R followedby CT-FRB that found significantly superior over rest treatments. The short term two year study showed that convetional till, direct seeded rice and zero till with residue retention in maize found effective for enhancing productivity and profitability in heavy soils of Southern Rajasthan.

Keywords: Direct seeded rice · Maize · Zero tillage · Crop residue · Fresh ridge bed planting

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Introduction

Direct seeded rice-maize cropping system is emerging dominant option for diversification of existing transplanted rice-wheat cropping system due to better stability and higher yield of maize compared to wheat and increasing demand in poultry and food industries. Minimum mechanical soil disturbance, organic mulch cover, and crop diversification constitute the major practices under conservation agriculture (CA). Transplanting of rice seedling is the major established practice in most parts of rice-growing areas, although this practice is labour, water, and energy intensive, as well as deteriorates the soil properties due to formation of compact hard soil surface. Whereas direct seeded rice aids in quick establishment and earlier harvest than transplanted rice and consequently facilitates timely maize sowing and thus enhances sustainability of the rice-maize cropping system. Direct seeded rice (DSR) needs only 34% of the total labour requirement and saves 27% of the total cost of transplanted rice (Mishra and Singh, 2011). Winter maize is rapidly emerging as a favourable option for farmers in southern Rajasthan as compared to wheat because maize has high yielding potential compared to wheat and it is considered a better alternative to counter abiotic stresses such as terminal heat stress in wheat and has fewer insect-pest and weed problems. The agronomic practices like zero tillage and ridge bed planting are found to be the potential resources conservation technologies (RCTs) which play a big role to save the scarce natural resource like water. Zero tillage is an ecological approach to soil surface management and seedbed preparation resulting in economical cultivation, better crop residue management, and moisture conservation and higher yield (Jat *et al.*, 2013; Parihar *et al.*, 2016a; 2016b). The bed planting provides better crop establishment, better water management, better weed management through inter bed cultivation and less soil compaction (Dhillon *et* *al.*, 2004). Several studies conducted across the production systems under varied agro-ecologies in India revealed potential benefits of raised beds and zero tillage on yield enhancement and adaptation (Gupta *et al*., 2010). Under these conditions resource conservation technologies and alternative cropping systems can play a vital role in improving farm productivity and profitability and soil quality thereby ensuring food security. In southern Rajasthan, winter maize is a more assured crop with higher productivity potential compared to wheat and other crops. Thus, the study was conducted to find out the effect of tillage and residue management on productivity and profitability of direct seeded rice-maize cropping system.

Materials and methods

A fixed plot experiment was conducted in two consecutive years of 2008-09 and 2009-10 at Agricultural Research Station (MPUAT), Banswara to study the effect of tillage management on direct seeded rice (*Oryza sativa*)-maize (*Zea mays*) cropping system. The experimental site is geographically situated at 23^0 33'N latitude, 74^0 27'E longitude and altitude of 220 M above Mean Sea Level. It is covered under humid southern plain agro-climatic zone of Rajasthan, which falls under sub-humid climate with dry, hot summer and mild winters. The average rainfall of the season was 862 mm. The soil of experimental field is clay loam in texture, slightly alkaline in reaction with contain low in organic carbon (0.36%), low in available N (156.75 kg ha^{-1}), low in available phosphorous (17.76 kg ha^{-1}) and high available potassium (480 kg ha^{-1}). The experiment was laid out in randomized block design with four treatments *viz*., T_1: Zero till in both crops (ZT-ZT), T_2: Conventional till in both crops (CT-CT), T_3: conventional till in rice and fresh ridge bed planting in maize (CT-FRB) and T_4: Conventional till in rice and zero till with rice residue retention in maize (CT-ZT+R) and were replicated four times. Under conventional tillage, the plots were ploughed at five times (2 disc harrowing + 2 cultivator +1 planking) followed by sowing, while in zero tillage furrows were opened at a spacing of 20 cm for rice and 60 cm for maize by seed cum fertilizer seed drill with based fertilizer application and crop seed sown by manual in opened rows. Ridge bed formed by bed former (FRB).Rice residue kept in zero tillage plots of maize. The variety of rice and maize were Ashoka 200F and HQPM-1. The crop was fertilized with recommended dose of 90kg N+40kg P_2O_5+ 30kg K_2O ha^{-1} in rice and 150kg N+60kg P_2O_5+ 40kg K_2O ha^{-1} in maize. Half dose of N and full dose of P and K were applied at the time of seeding and remaining N was applied in two equal splits at tillering and panicle initiation in rice. Whereas, dose of N applied in 5 splits as 10% at sowing, 20% at four leaf stage, 30% at eight leaf stage, 20% at tasseling and 10% at dough stage in maize. The mean data recorded were analyzed statistically to decipher the treatment effects.

Results and discussion

Rice yield and yield attributes

Different tillage practices had a significant effect on yield and yield attributing of direct seeded rice (DSR) and maize (Table 1). Conventional till in rice-Zero till with rice residue retention in maize recorded maximum number of panicles/ m^2 (192.71), grains/panicle (56.78), grain yield (17.13 q ha^{-1}) and biological yield (37.72 q ha^{-1}) as compared to other tillage practices. The grain yield (17.13 q ha^{-1}) of DSR in CT-ZT+R was found significantly 15.2, 9.4 and 16.1% higher over ZT-ZT, CT –CT and CT-FRB, respectively. The highest grain yield of DSR in CT-ZT+R plot was obtained due to highest number of yield attributes. Sarkar *et al*. (2003) reported similar results, substantially higher grain yield of DSR in CT-ZT than other practices, which was attributed to the increased number of panicles and grains/panicle. The maize yield attributes *viz*. cob weight (221.65 g), number of grains/cob (627) and grain yield (74.25 q ha^{-1}) and biological yield (130.18 q ha^{-1}) were maximum recorded in CT-FRB which was significantly higher over zero till and conventional till in both crops, respectively, and it was found at par with CT-FRB+R. Similar results recorded in system productivity in term of maize equivalent yield (MEY). The MEY (92.21q ha^{-1}) in CT-ZT+R was significantly higher by 9.9 and 6.4% over ZT-ZT and CT-CT. The MEY was found statistically at par with each other in CT-FRB and CT-ZT+ R because no significant difference obtained in maize yield. Maize yield enhanced in CT-FRB and CT-ZT+R may be linked to improve soil moisture retention, deep root penetration, improve soil micro-aggregates and enhance nutrient availability (Parihar *et al.*, 2016b) and reduce weed-crop competition. The similar finding, reported by Jha *et al.* (2012) for restoration of tillage under site of holding the labile C for longer periods and Girma *et al.* (2012) reported to higher labile C formation in soil, which improves acquisition of nutrients to the plant and finally reflected in higher yield.

Water productivity

Tillage management practices significantly influenced the water use efficiency (WUE) in term of water productivity (kg/ha-mm) in rice-maize cropping system (Table 2). The maximum water productivity (3.79) of rice was recorded in CT-ZT+R treatment that significantly 16.11, 9.40 and 15.24 % higher over CT-FRB, CT-CT and ZT-ZT in cropping sequence, respectively. However, it was found at par with ZT-ZT in crop sequence. The water productivity in CT-ZT+R treatment due to higher grain yield of rice that may be increased with improving water retention by residue retention in treatment. The similar finding, reported by Ram *et al.* (2010) to reduce cumulative use in mulched treatment due to less evaporation of water from the soil surface and higher WUE in No tillage was also reported by Chauhan *et al*. (2000). In case of maize, the maximum water productivity (23.57) recorded in CT-FRB treatment that was found at par with CT-ZT+R treatment and significantly 36.24 and 33.81 % higher over ZT-ZT and CT-CT in cropping sequence, respectively. The higher water productivity in CT-FRB treatment might be due to less amount of irrigation water than CT and ZT treatments. Aggarwal *et al* (2002) recorded similar results of higher water use efficiency in bed planted wheat. The highest water productivity (11.69 kg ha^{-1} mm^{-1}) of cropping system was recorded in CT-FRB treatment in the cropping sequence that was statistically at par with CT-ZT+R treatment, but significantly 21.14 and 18.08% higher over ZT-ZT and CT-CT treatments in cropping sequence, respectively. The water productively of cropping system is directly reflected by MEY of system and water productivity might be improved due to higher yield, less water application and moisture retention in bed planting and zero tillage with residue in maize. The similar findings reported (Jat *et al.*, 2013 and Parihar *et al*., 2016) that no-tillage bed required 24.7% less irrigation water than conventional tillage with 11.5% higher system productivity and demonstrated higher water productivity.

Economics

Cost of cultivation, gross and net return and benefit: cost ratio (B:C) of direct seeded rice -maize cropping system was significantly influenced by tillage management practices (Table 2). Conventional till in rice-zero till with residue in maize gave highest gross returns (Rs. 110656 ha^{-1}) followed by CT-FRB in cropping sequence. Similar, maximum net returns (Rs. 77651 ha^{-1}) and benefit: cost ratio (2.35) recorded in CT-ZR+R that was significantly higher over CT-CT,ZT-ZT and ZT-FRB in cropping sequence. The highest return and B:C ratio was recorded in CT-ZT+R might be due to the low cost of cultivation in zero tillage and higher productivity. Gangwar *et al*. (2006) reported

Table 1. Effect of tillage management on yield attributes and yields of cropping system (mean of two years)

Treatment	Rice				Maize				Maize
	Panicles/ m^2	Grains/ panicle	Grain yield (q/ha)	Biological yield (q/ha)	Cob's weight (g)	Grains/ cob	Grain yield (q/ha)	Biological yield (q/ha)	equivalent yield (q/ha)
ZT-ZT	173.20	48.65	14.52	32.45	203.19	568	67.59	118.74	83.13
CT-CT	182.78	53.41	15.52	35.17	209.67	590	70.21	123.25	86.36
CT-FRB	165.92	48.00	14.37	33.63	221.65	627	74.25	130.18	89.64
CT-ZT+R	192.71	56.78	17.13	37.72	218.74	624	73.87	129.84	92.21
C.D. (*P*=0.05)	8.51	2.76	1.52	2.48	12.25	53.8	3.37	6.18	4.67

ZT=Zero tillage, CT=Conventional tillage, FRB=Fresh ridge bed planting, ZT+R=Zero tillage with rice residue retention

Table 2. Effect of tillage management on water productivity and economics of rice-maize cropping system (mean of two years)

Treatment	Water productivity (kg/ha-mm)			Cost of cultivation	Gross returns	Net returns	B:C ratio
	Rice	Maize	Rice-maize	(Rs./ha)	(Rs./ha)	(Rs./ha)	
ZT-ZT	3.21	15.02	9.22	32625	99756	67104	2.06
CT-CT	3.43	15.60	9.57	35305	103632	68327	1.94
CT-FRB	3.18	23.57	11.91	34058	109584	75526	2.22
CT-ZT+R	3.79	16.42	10.07	34005	109044	75039	2.21
C.D. (*P*=0.05)	0.31	7.62	2.04		3853	3853	0.13

ZT=Zero tillage, CT=Conventional tillage, FRB=Fresh ridge bed planting, ZT+R=Zero tillage with rice residue retention that higher benefit: cost ratio observed in rotational tillage in cropping system.

The results of the study concluded that zero tillage without residue retention and conventional tillage in both crops produced lower yield. Conventional tillage in rice – zero tillage with residue retention in maize found to be most promising technology in direct seeded rice-maize cropping system for imroving productivity and profitability in heavy soil of Southern Rajasthan.

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RESEARCH PAPER

Technical efficiency and technological gaps in maize cultivation

Brij Bala

Abstract: In India, the productivity of maize is very low than the potential owing to many reasons; poor technology adoption being one of them. This study was conducted in Kullu district of Himachal Pradesh to assess the extent of technology adoption in maize cultivation and gaps there in and also the constraints/problems in adoption. A sample of 180 farmers (60 each from the three developmental blocks namely Kullu, Naggar and Banjar) was randomly selected. Average total land holding was observed to be 1.15 hectares, of which only 31.7 % was irrigated. Maize was the main cereal crop of *kharif* season occupying about 25.5 % of the total cropped area. The average yield of maize was 17.07 q per hectare. There was a wide gap between the frontier yield and average yield and 51 % of the farmers attained very low technical efficiency. A noticeable gap existed in the use of major inputs. A negative and significantly high gap (170%) was observed in seed rate. A gap of more than 90 % was observed for the practices viz., seed rate, spacing, plant population, soil treatment and weed control. The gaps in yields seemed to be exhibited more by the gaps in management practices because a technological gap ranging from 80-90 % was observed in almost all the practices. Poor knowledge about the recommended seed and management practices, non-availability of recommended seed, inadequate irrigation facilities, nil agro-processing were some of the major constraints responsible for poor adoption of recommended technology. Hence, the need to overcome these gaps by strengthening extension services and educating farmers cannot be over-emphasized. The availability of recommended seed and other critical inputs has to be ensured. Irrigation facilities are also required to be improved. Small scale agro-processing units need to be installed in the maize growing areas so that the growers get remunerative prices for their produce.

Keywords: Recommended practices · Technology adoption in maize · Technical efficiency · Technological gaps

Introduction

Maize is the leading food crop of the world grown over more than 177 million hectares with a total production of 960 million tonnes (USDA 2013-14). Maize is an important source of food for man and animals. It has wide range of geographical adaptation, immense genetical yield potential and multiple industrial uses such as production of liquor, lard, paper, wallboard, insecticides, paints, dextrin, plywood, corn syrup, corn sugar, corn oil, baby corn soup, pop corn, corn flakes and sweet corn etc. Maize is the third most important cereal crop in India after rice and wheat. It is grown in almost all the states. Major maize producing states are-UP, Bihar, Rajasthan, MP and Punjab. In 2012-13, India produced 22.23 million tonnes of maize from 8.71 million hectares of land. Globally, India ranked fifth in terms of area after USA, China, Brazil and Maxico; but due to its low productivity, its rank in production is seventh.

Countries like Kuwait, Israel, Jordan and Italy harvest 10-12 t ha^{-1} maize, whereas in India it hardly ever exceeded 3 t ha^{-1}. The degree to which a new technology is used in long-run equilibrium when farmers have complete information about the technology and its potential is called adoption. Therefore, adoption at the farm level indicates farmers' decisions to use a new technology in the production process. Adoption of technology is influenced by physical, socio-economic, and mental factors including, agro ecological conditions, age, family size, education, knowledge, source of information, and farmer's attitudes towards the technology (Feder *et al*., 1985; Neupane *et al*., 2002; Rogers, 2003). In order to assess the adoption

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of technology in maize cultivation by the farmers, the present investigation was conducted. The objectives of the study were:

- To study the cropping pattern and estimate the proportion of area under maize.
- To examine the technical efficiency and assess the technological gaps in maize cultivation
- To examine the reasons and constraints for non-adoption of recommended technology.

Materials and methods

The study was conducted in three developmental blocks namely Kullu, Naggar and Banjar of District Kullu, Himachal Pradesh. A list of villages along with their area under maize was prepared for all the three selected development blocks. Then, in each block, six villages with highest maize area were selected. Ten farmers were selected randomly in each village. Thus, a sample of 180 farmers, 60 each fromthe three developmental blocks, was randomly selected. A questionnaire was developed to collect the required information to meet the objectives and data were collected through personal interview method. The data were analysed using appropriate statistical tools.

Technical efficiency in maize cultivation

It refers to the proper choice of production techniques. A farmer is said to be more progressive and technically efficient if he consistently produces larger quantities of output from the same quantities of measurable inputs. Technical efficiency can be worked out by following formula:

$$Ti = \frac{Y_i}{Y_f} \times 100$$

Where,

Ti = technical efficiency of ith farmer

Yi = actual yield obtained by ith farm

Y_f = yield obtained by frontier (progressive) grower in the study area

Based on the technical efficiency, the farmers were categorized as;

High efficiency farmers	:	> 70%
Medium efficiency farmers	:	between 40% and 70%
Low efficiency farmers	:	< 40%

Technological gaps

Technological gaps were computed on the basis of difference between the management practices and input usage on progressive/frontier farm and the actual management practices and input usage on an average farm. These were computed by using following algorithm:

$$Tg = \frac{Y_f - Y_a}{Y_f} \times 100$$

Where,

Tg = technological gap (%) in input usage

Y_f = input usage of frontier farmer

Y_a = actual input usage of average farmer

In case of management practices, the technological gaps were computed as:

$$Tg = \frac{Ft - Fp}{Ft} \times 100$$

Where,

Tg = technological gap (%) in management practices

Ft = total number of farmers

Fp = actual no. of farmers practicing the frontier or recommended management practices

Results and discussion

Age-wise distribution and Educational status

In most adoption studies, the age of the farmer is commonly used to reflect experience. Farmers' age can generate or erode confidence; hence they become more/less risk averse to new technology. It is therefore hypothesized that a farmer's age can increase or decrease the probability of adopting the improved maize technologies. Young farmers are more likely to adopt a new technology because they have had more schooling and are more susceptible to attitudinal change than old farmers. The family members in the age group of 16-60 years are assumed to be active workers for agriculture and other sectors, while the rest are considered as dependents. About 26 % of the total population was below 15 years (Table 1). The average working population in the age group of 16-60 years constituted about 56 % of the total population. About 18 % of the total population was above 60 years of age. The proportion of dependents (i.e. population below 5 years

Table 1. Family-size and age wise distribution of sampled households (%)

Age group (years)	Male	Female	Total
0 to 5	6.75	10.58	8.39
6 to 15	15.87	19.58	17.46
16 to 60	60.52	49.21	55.67
Above 60	16.87	20.63	18.48
Total	100	100	100
Total (No.)	504	378	882
Family size (persons/farm)	2.80	2.10	4.90
Sex-ratio	750		

and above 60 years) was 26 % of the total population.Average family size was 4.9 on the sampled households with 2.8 males and 2.1 females. The sex ratio was 750 females per thousand of male population.

It was observed that the proportion of literate population was 92.26 % in males and 80.69 % in case of females (Table 2).This indicates that the literacy rate of male population was quite high as compared to their female counterparts. Theoverall literacy rate obtained was 87 %. Table also revealedmaximum proportion of the female population was having primary education while among males majority were matriculate. Only about 8 % of the total females were educated up to higher secondary level whereas about 20 % of males were educated up to higher secondary and 7 % were graduates. A perusal of the table states that the educational level of the sampled households was good enough to understand and adopt the improved technology.

Land utilization pattern

The average owned land on sampled farms was 1.094 ha (Table 3). Farmers also practiced leasing-in of land. Irrigated land was leased-in by the farmers for the cultivation of vegetable crops. Thus, the average total land holding was

Table 2. Educational status of the sampled households (%)

Educational status	Male	Female	Total
Illiterate	7.74	19.31	12.70
Primary	12.90	37.83	23.58
Middle	23.02	22.22	22.68
Matriculate	28.17	11.64	21.09
Higher Secondary	20.44	8.20	15.19
Graduate & above	7.74	0.79	4.76
Total	100.00	100.00	100.00
Total (No.)	504	378	882
Literacy rate	92.26	80.69	87.30

Table 3. Land Utilization Pattern (ha)

Particular	IR	UR	Total
Owned	0.310	0.784	1.094
Leased-in	0.054	-	0.054
Leased-out	-	-	-
Total holding	0.364	0.784	1.148
Land under buildings	-	0.021	0.021
Horticultural purpose	0.081	0.248	0.329
Ghasnis	-	0.065	0.065
Uncultivable land	-	0.034	0.034
Cultivated land	0.283	0.416	0.699

observed to be 1.148 hectares. Out of the total holding only 31.7 % area was irrigated and rest was un-irrigated. The main sources of irrigation were tube-wells, bore-wells and natural sources of water. On an average, 0.329 ha.of land was put under horticultural crops. About, 0.01 ha area was under ghasnis or uncultivated land. Thus, the net cultivated land was 0.699 ha of which 0.283 ha was irrigated.

Cropping pattern on sampled farms

A quick perusal of Table 4 reveals that crops were grown throughout the year. Crops like cereals, pulses and oilseeds constituted the major proportion (63 %) of the total cropped area and vegetables occupied remaining 37 % of the area. The cereal crops viz., (maize, wheat, and barley), pulses and oilseed were grown mainly on un-irrigated land however; almost 90 % of paddy and vegetable crops were grown under irrigated conditions.Maize was the main cereal crop of *Kharif* season occupying about 25.5 % of the total cropped area while in *Rabi* season wheat was the main crop with 20.5 % area. Among vegetables tomato, pea, garlic, onion, cabbage and cauliflower were the major vegetable crops being grown. Tomato occupied the first position with about 12 % of the total cropped area followed by pea (10.7%), cabbage (4.14%) and cauliflower (about 3%). Tomato was the main vegetable grown in Kharif season whereas, pea, cabbage and cauliflower were the main vegetables of *rabi* season. The overall cropping intensity turned out to be 127.3 %.

Production and utilization of maize

Total production of maize was observed to be 3.88 q, thus giving an average yield of 17.07 q ha^{-1} (Table 5). Maize used for food/home consumption was 0.88 q while 0.069

Table 4. Cropping pattern on sampled farms (%)

Crops	IR	UIR	Total
Kharif			
Maize	10.64	38.49	25.54
Paddy	2.90	0.17	1.44
Mash	0.39	3.87	2.25
Mash + Rajmash	1.35	0.17	0.72
Chari+Bajara	0.00	1.51	0.81
Soyabean	1.35	0.00	0.63
Tomato	15.09	1.01	7.55
Rajmash	1.26	5.46	3.60
Garlic	2.13	0.84	1.44
Kulthi	0.39	0.50	0.45
Iceberg	5.80	1.01	3.24
Brinjal	0.27	0.03	0.09
Zaidrabi			
Cauliflower	4.64	0.34	2.34
Cabbage	6.38	2.18	4.14
Cauliflower + Rajmash	0.00	1.06	0.57
Onion seed	1.16	0.67	0.90
Pea	1.93	0.17	0.99
Garlic	3.29	0.67	1.89
Rabi			
Wheat	11.61	28.24	20.50
Barley	2.71	0.91	1.74
Paddy	0.58	0.00	0.27
Oat	2.90	6.15	4.64
Pea	13.55	6.55	9.80
Zaid/kharif			
Tomato	9.68	0.00	4.50
Total	100.00	100.00	100.03
Total cropped area (ha)	0.414	0.476	0.890
Net sown area (ha)	0.283	0.416	0.699
Cropping intensity (%)	146.12	114.42	127.30

q was given as gifts and kind payments. Maize used for animal consumption was 0.98 q. Thus, the marketable surplus was about 1.6 q. A very low price was received for maize by the farmers in the study area, which was reported to be one of the reasons for not paying much attention towards enhancing maize production.

Technical efficiency in maize production

Technical efficiency worked out based on the maize yield obtained by selected farmers in the study area. The yield of the farmers was compared with the yield obtained by frontier farmer or the potential yield in the study area. The farmers were then categorized under three categories (Table 6). The table reveals that majority (51%) of the farmers obtained medium level of technical efficiency and about 38.5 % of the farmers were in the range of low technical efficiency. Only 10 % farmers could qualify for high technical efficiency. This infers that the yields obtained by the farmers were not satisfactory. The high yield variability shows the gap between the frontier yield and average yield and, thus, the potential for enhancing the yield of different crops.

Table 6. Technical efficiency rating of the maize growers

Technical efficiency rating	Growers (%)
Low (< 40%)	38.46
Medium (40-70 %)	51.15
High (>70%)	10.39
Total	100.00

Technological gaps in input use pattern in maize

It was observed that there was noticeable gap in the use of almost all the inputs by farmers (Table 7). A negative and significantly high gap (170%) was observed in seed rate. This shows that the farmers used the seed in excess of recommendation. The farmers resorted to this practice because they were suspecting poor seed germination percentage. Although they practiced thinning at later stages yet maintained a higher plant population than desired. Maize was mostly grown under unirrigated conditions, hence, the fertilizer use was less than recommended. Highest gap was observed in the usage of SSP. Also the farmers attached less importance to this crop and tried to make minimum expenses in terms of fertilizers and plant protection. Use of soil treatment chemicals and weedicides was negligible because the farmers were not aware about the importance of soil treatment and timely control of weeds in improving crop yields.

Table 5. Total production and utilization of maize

Area under maize (ha)	Total production (q/farm)	Ave. Yd. (q/ha)	Consumption (q)	Gifts/Kind payment (q)	Animal consumption (q)	Post harvest loses (q)	Marketable surplus (q)	Ave. Price (Rs./q)
0.2273	3.88	17.07	0.8796	0.0692	0.9806	0.3871	1.5636	7606

Table 7. Input use pattern and technological gaps in input use in maize (per ha)

S.No.	Input usage	Recommended	Existing use	Gap (%)
1.	Seed (kg)	20	54	-170.00
2.	FYM (q)	150	152.50	-1.67
3.	Fertlizers (kg)			
i	Urea	260	220	15.38
ii	SSP	375	100	73.33
iii	MOP	65	50	23.80
4.	Plant protection chemicals (kg)			
i	Bavistin	40	15	62.50
ii.	Endofil M-45	15	0.25	83.33
iii.	Atratraf	2.25	0.5	77.78
iv.	Folidol	25	5	80.00

Technological gaps in management practices in maize

The high yield variability among farmers across different locations clearly shows inter-farm differences in the awareness level and management practices (Table 8). It was observed that the extent of technological gaps varied from 55% to 94% for different management practices. More than 90 % gap was observed for the practices viz., seed rate, spacing, plant population, soil treatment and weed control. Excessive seed rate was responsible for more plant population and dense spacing which later affected the quality and yield of the crop. Line sowing with a spacing of 60x20 cm was recommended so that the plants get sufficient sunlight, aeration and nutrients and intercultural operations are also made easier but about 82 % of the farmers did not practice line sowing in maize. It is a well-established fact that pure crop gives better yield than grown with some other crop, still 80.5 % of the farmers were opting for mixed cropping of maize with pulses. There was a practice of using weeds in the crop as fodder for animals and farmers did not control weeds at critical stages of the crop which hampered crop growth. A gap of about 89 % was observed in case of balanced fertilizer use. It was also observed that about 45 % of the farmers used local variety seed as against the recommended hybrids or composites.

Table 8. Management practices followed by the sampled farmers and technological gaps

Recommended practice	Total farmers	Practicing farmers	Gap (%)
Seed (Hybrid/composite variety)	180	80	55.56
Seed treatment (with bavistin)	180	25	86.11
Soil treatment (with	180	18	90.00
Seed rate (20 kg/ha)	180	10	94.44
Spacing (60*20cm)	180	12	93.33
Line sowing	180	32	82.22
Pure crop	180	35	80.56
Plant population (60,000-75,000/ha)	180	12	93.33
Depth of seed (3-5cm)	180	54	70.00
Irrigations (at least two)	180	36	80.00
Weed control (using weedicide)	180	10	94.44
Balanced fertilizer application	180	20	88.89

Problems/constraints

Problems/constraints faced by the farmers in technology adoption and marketing which act as hindering factors for attaining efficient resource use and potential yield are summarized (Table 9). It was found that 68 % of farmers agree with the fact that they are not aware about the different varieties of seed. Generally, they used the varieties which were easily available in market. While 28 % were of the view that availability of different varieties recommended by government and non-government agencies was almost nil. Sixty per cent of the farmers opined that the seed was costly and 45 % complained that seed and other inputs were not available at nearby centers. About 58 % of the farmers had poor knowledge about the recommended package of practices because of inadequate extension services. Lack of proper procurement system and non-

Table 9. Problems /constraints faced by the farmers in technology adoption and marketing

Problems	Multiple (%)
Poor knowledge about recommended seed	68
Non availability of recommended Seed	28
Seed is very costly	60
Non availability of seed & other critical inputs at nearby sale centers/shops	45
Poor knowledge about recommended package of practice	58
Inadequate extension services	45
Lack of irrigation facilities	55
Consumption of maize is very less	50
Lack of proper procurement system	44
Non remunerative prices	64
Lack of proper storage/grading /handling facilities	50
Agro- processing is almost nil	42
Market related problems	15

remunerative prices were the other important factors reported to discourage the farmers for adopting improved technology in maize cultivation. Agro-processing in the maize producing areas was almost nil and there were no proper storage facilities available with the farmers because of which the farmers had to sell their produce immediately after harvesting at the throw away prices thus rendering maize crop as a non-remunerative crop.

Conclusions

Currently, there is no short cut for substantial and dramatic increases in production of maize without improved seeds and management practices. There were considerably high gaps in the yields obtained by average farmers and highest attainable yield as 90 % of the farmers could qualify only for low and medium range of technical efficiency. The gaps in yields seemed to be exhibited more by the gaps in management practices because a technological gap ranging from 80 to 90 % was observed in almost all the recommended practices. Significantly high gaps were observed for input use particularly seed and chemical fertilizers. Hence, the need to strengthen extension services and educate the farmers about improved cultivation practices in the area can not be over-emphasized.

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