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2. To facilitate linkages among maize stake holders to disseminate up-to-date and relevant technology/information needed for end through organizing conferences/symposia/ seminars/ meetings, *etc.*
3. To publish a multidisciplinary scientific journal of international standards exclusively devoted to the maize research named “Maize Journal”

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MINI REVIEW

REVIEW

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MINI REVIEW

Perspective of maize scenario in India: Way forward

Sujay Rakshit · Chikkappa G. Karjagi

Abstract: The requirement of maize is increasing day-by-day due to burgeoning population. In order to meet the growing demand, there is a need to increase maize production. The maize area, production and productivity of India have increased by 1.97, 15.62 and 4.6 times during 1950 to 2017. However, achieving such progress in future is the major challenge considering depleting land and water resources on one hand, and increased biotic and abiotic stresses on the other hand. In spite of above major challenges, there are opportunities to enhance the productivity, of maize provided the strategy must involve all stakeholders like researchers, planners, farmers, maize based food, feed and other processing industries and consumers, who are directly or indirectly responsible for enhancing the maize production. The most important among several strategies would be bringing maize area under single cross hybrids from present 60% to 100%, development of climate resilient hybrids through germplasm diversification, accelerated development of new and improved hybrids through application of advanced tools and techniques like doubled haploids, marker assisted election, genomic selection, genetic engineering techniques like CRISPR-Cas9 etc. Thus, it is possible to increase the maize production to meet the growing demand.

Keywords: Backward and forward linkages · Climate resilient cultivars · Genetic improvement · Mechanization · Single cross hybrids · Production and protection technologies · Utilization pattern · Value addition

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Introduction

The world population is increasing exponentially and food requirement is also increasing proportionately. Hence, per unit area production not only needs to be sustained but is to be increased substantially, and this is to be achieved under the scenario of changing climate and depleting availability of arable land and water (Rakshit *et al.*, 2014). Climate change is evident in every sphere of life including agriculture. Its impact on production of agricultural commodities is likely to be the most drastic in tropical and subtropical regions of the world. South Asia with low adaptive capacity is the most vulnerable region for multiple stresses (IPCC, 2007; Annonymous, 2009; Rodell *et al.*, 2009; Niyogi *et al.*, 2010). Ground water level at various parts of Asia more particularly in north western Indo-Gangetic plains is at very critical level. The challenge of increasing food production from depleting land and water resources on one hand, and increased biotic and abiotic stresses on the other can be achieved through higher crop yields per unit area (Foulkes *et al.*, 2011) and developing and growing climate resilient crops (Rakshit *et al.*, 2014). Among the principal cereals, water requirement of maize is the lowest (500 mm) compared to rice (2100 mm) and wheat (650 mm). Beside this maize has the versatility to be used as food, feed, fodder and raw material of over three thousand industrial products.

Maize scenario

India produced over 281 million MT food grains in 2018-19, out of which cereals share the major part. Among cereal grains rice represent 44% of the gross cultivated area followed by wheat (30%), maize (9%), pearl millet (8%) and other millets. Rice and wheat constitute 44% and 39% of cereal production, respectively while maize represents little over 9% of cereal production (Rakshit *et al.*, 2017).

Maize production between 1950-51 and 1958-59 almost doubled from around 1.73 million MT to 3.46 million MT. This happened due to nearly 35% increase in area and 48% in yield (Yadav *et al.*, 2015). During 1950 to 2017 the maize production has increased by 15.62 times. This has happened due to 1.97 times increase in area and 4.6 times increase in productivity. The dynamics of yield gain and productivity in India has always remained very intriguing (Figure 1). Annual increment in maize area during 1949-60 was 109 thousand ha per year, while the productivity enhanced by 24.7 kg/ha/year. The corresponding figures in the 1960s were 168 thousand ha/year and 7.4 kg/ha/year, respectively. During 1970s and 1980s the maize area was almost stagnant, while in 1980s India experienced significant yield increment at 29 kg/ha/year. During 1990s the figure was 37 kg/ha/year. From 2000-10 the yield gain was over 46 kg/ha/year, while current figure is nearly 52 kg/ha/year. Though during 1980-90 there was a slowdown in area increase, the maize area has increased substantially and maintaining a growth rate of around 200 thousand ha per since beginning of this millennium. The five yearly average areas under maize is 9.2 million ha and production is 23.3 million MT.

Maize was a rainy season (*kharif*) crop predominantly in India. It was largely grown in northern India the states of Uttar Pradesh, Bihar, Rajasthan and Madhya Pradesh. After 1980s a significant shift in area towards peninsular region was noticed. "Currently this region represents nearly 40% of the total area under maize and over 52% of production. The major maize growing states are Karnataka (14.8%), Maharashtra (10.9%), Madhya Pradesh (10.8%), undivided Andhra Pradesh (10.4%), Rajasthan (10.6%), Uttar Pradesh (8.3%), Bihar (7.9%), Gujarat (5.0%) and Tamil Nadu (3.6%), accounting for nearly 80% of the total maize area of the country. However, productivity of maize in many of these states like in Rajasthan (1.6 t/ha) and Gujarat (1.6 t/ha) are quite low, while that in Uttar Pradesh (1.7 t/ha), Madhya Pradesh (1.9 t/ha) and Maharashtra (2.3 t/ha) are below the national average of 2.6 t/ha" (Rakshit, 2018).

Maize with its wide adaptability is cultivated throughout the country during all the three seasons. However, in few states like Kerala and Goa has very little area under maize, where specialty corns have more presence. The *kharif* maize is cultivated almost across the country winter or *rabi* maize is cultivated more in Bihar, West Bengal and Peninsular India. Summer maize is gaining popularity in Punjab, Haryana and western Uttar Pradesh. *Kharif* maize represents around 80% of maize area while *rabi* maize represent 19% of area. Summer maize occupies 1-2% of total maize area in India. Out of three maize seasons nearly 80% of *kharif* maize is cultivated under rainfed condition, while *rabi* and summer maize is cultivated under assured ecosystem. Thus *rabi* maize has yield level of over 4.0 t/ha, while *kharif* maize has little over 2 t/ha productivity. To increase the yield level of maize productivity of *kharif* maize needs to be augmented.

Out of 24 million MT requirement of maize in India around 60% is used as feed, 14% for industrial purposes, 13% directly as food, 7% as processed food and around 6% for export and other purposes (Figure 2). The demand growth trend suggests an increase in demand of 7.18%, leading to targeted demand for maize of 50-60 million MT by 2025 (Rakshit, 2018). Not only domestic demand the

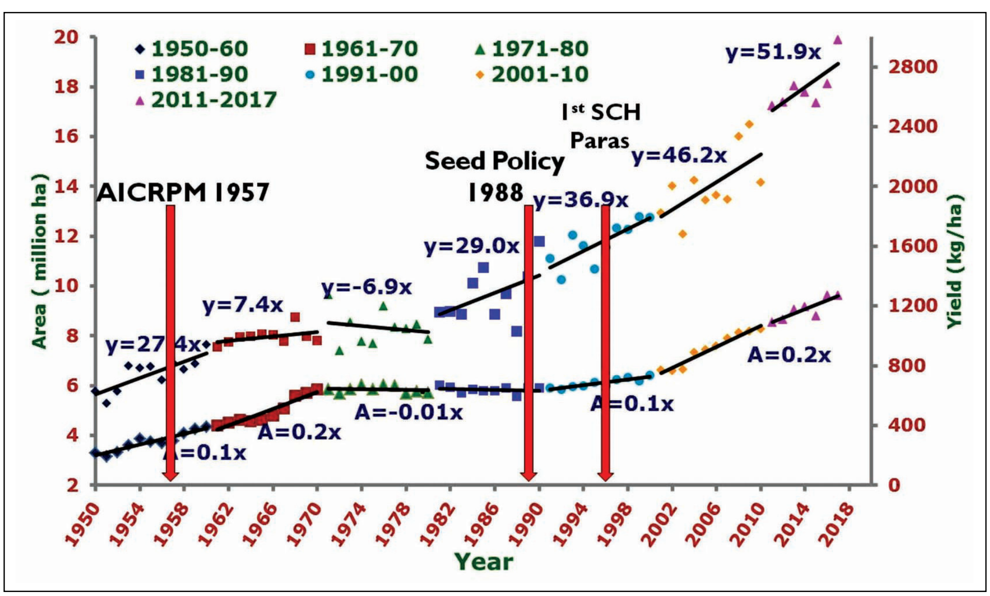

Figure 1. The scenario of maize area and productivity in India during 1950-2017

international demand for maize is also increasing and will continue to increase. Thus, maize opens up a unique opportunity not only to supplement the maize-based industry but the export as well. The demand for maize is increasing not only as grain but for specialty purposes as well. Among specialty corns, sweet corn, baby corn and pop corn have not only immense market potential but can contribute significantly towards crop diversification and doubling farmers income. Maize is extensively being used in dairy industry not only as feed stock but as fodder, which is used as both green fodder and silage.

Progress in maize research

Genetic improvement

The All India Coordinated Research Project (AICRP) on Maize was initiated in 1957 and showed its significant impact in increasing maize production in India. Rightly during the initial period the emphasis was on hybrid research. This led to release of first set of double cross hybrids, *viz*., Ganga 1, Ganga 101, Ranjit and Deccan in 1961. However, slowly the main focus diverted towards composite breeding, leaving hybrid research in the backburner. This may be considered as a major setback to the progress of maize research and development in India. Some centres under AICRP on Maize continued their focus of research on hybrids, this lead to release of first single cross hybrid, Paras by Punjab Agricultural University in 1996. This was followed by shifting of maize research on single cross hybrids alone. This may be evident from the significant increase in maize yield gains post 2000 (Figure 1). During late 1960s onwards focus of research was also diverted towards development of quality protein maize (QPM). The initial QPM varieties did not gain success due to chalky grain, susceptibility to storage pests etc. However,

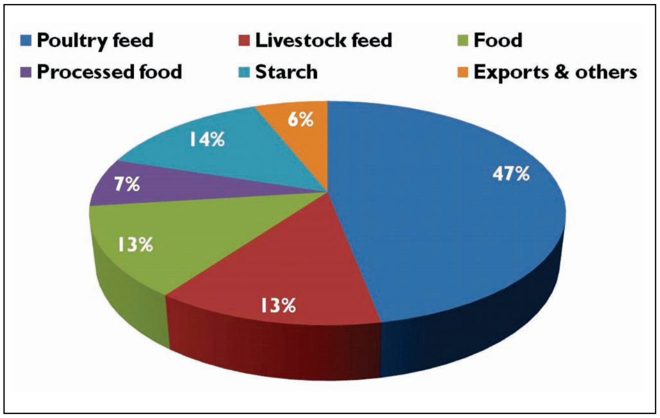

Figure 2. The usage pattern of maize in India

with availability of hard endosperm QPM sources first three-way cross QPM hybrid, Shaktiman 1 was released in India in 2001. Since then though several QPM hybrids (mainly single cross hybrids) have been released in the market by various AICRP centres, in roads of these hybrids remained restricted due to non-availability of any additional price to QPM produce, with little yield penalty to QPM hybrids and non-cultivation of QPM in large contiguous field leading to reduction in quality of the produce. Since 2000 a total of 237 cultivars have been released in India, out of which 82% (195) are hybrids. Public sector contributed 50% of released hybrids, while remaining have been released by private sector companies. In the public maize breeding except QPM none of the specialty corns received focused attention until recently.

Crop production and management

No yield gain in any crop is achieved through genetic gains alone but effective crop production technology and management practices play a very important role in this regard. Right plant stand for different growing conditions, method of sowing, **s**ite-specific nutrient management, intercropping with various crops (particularly *rabi* maize), weed management etc. have been proved significant intervention to increase productivity of maize. Consistent research efforts on resource conservation technology (RCT), particularly Zero tillage (ZT) technology and crop residue incorporation in maize-based cropping system have been found to be highly remunerative. Maize system productivity of 11.3–12.9 t/ha with reduced water requirement by 40–65 ha-mm under ZT has been reported in maize (Parihar *et al.*, 2016). RCT practices are becoming popular in the Indo-gangetic region and in peninsular India. Effective plant protection is key to sustainable production. Over period of time the project as strive hard to contain the onslaught of various biotic and abiotic stresses. Sources of resistance against major diseases and insect pests have been developed and deployed to strengthen host plant resistance (HPR) to combat these stresses. Effective chemical and cultural control measures have been developed against these stresses in an integrated manner.

Mechanization

With reduced availability of labour farm mechanization from land preparation, sowing to post-harvest handling play a very important role. Unlike other cereals mechanization in maize cultivation is not much in practice except land preparation. In recent past combined harvesters are being introduced on hire and use basis in southern states. But this needs much popularization with governmental support. Dehusker cum sheller and grain driers need to be integrated with maize production and processing system. Unlike rice and wheat maize is more prone to damage during storage due to aflatoxin infection and damage by rice weevil. This problem is more severe if grains are not dried properly (<14%).

Value addition

Over a period of time maize being a food crop has gained its popularity as feed crop. However, considering the low glycemic index of maize it can be an important part of dietary component as well. Many maize-based ready-to-cook (RTC) and ready-to-eat (RTE) products can be developed. QPM grains may further add value to these products. Rajendra Agricultural University, Dholi and University of Agricultural Sciences, Mandya have made significant contribution in this direction. In recent past UAS, Mandya is marketing many of the value added products in the brand name of 'Maizy' in the state of Karnataka. Besides grain corn, specialty corns – sweet corn, baby corn and pop corn assumes immense potential in terms of value addition.

Strategies for enhancing maize production

The strategy must involve all stakeholders who are directly or indirectly responsible for enhancing the maize production. The main stakeholder is the farmer, the actual producers of maize. However, farmer needs technology and policy support; the extension personnel located at krishi vigyan kendras, department of agriculture of different states can take an active role in transfer of technology whereas the planners and government can devise policies to provide financial security to farmers involving in maize cultivation. The backward and forward linkages through Public-Private-Producer Partnership (PPPP) can go a long-way to sustain the interest of farmers in maize cultivation which is the back-bone for enhancing the maize production through increasing the maize productivity in a sustainable manner. The following strategies could be adopted to bring sustainable increase in maize productivity:

- Development of high-yielding climate resilient cultivars
- Expansion of area under hybrid cultivars
- Production and protection technologies
- Development of backward and forward linkages
- Policy interventions

Strategies for development of high-yielding climate resilient cultivars

Diversification of maize germplasm

Maize has tremendous genetic diversity; significant yield gain achieved in maize as compared to other cereal crops during the last six decades across the globe signifies the fact that maize is the crop with highest yield potential. However, the hidden potential existed in the form of genetic diversity available in different landraces and its wild relatives has not yet explored largely. The growing demand for maize by entirely different kinds of industries like bio-fuel, paper and bio-degradable plastic and changing climate especially the vagaries of monsoon has necessitated the need to explore the possibility to use genetic diversity existed in landraces and wild-relatives. In addition, the heterosis between temperate into tropical germplasm has not yet been exploited largely in developing countries and particularly in India. Development of novel germplasm through temperate into tropical crosses and also introgression of exotic germplasm into active breeding material would create genetic variability to further enhance the yield potential.

Development of climate resilient cultivars

The intra-seasonal fluctuations in rainfall and temperature in different agro-ecological zones demand for cultivars with climate resilience trait. Identification of cultivars with tolerance to various kinds of moisture stress like drought and waterlogging at critical crop growth stages would help to reduce the yield losses due to different kinds of moisture stresses. Development of phenotyping network in different agro-climatic zones by creating managed stress conditions would assist in selection of right kind of cultivars. Thus the focused research on development of climate resilient hybrids and deployment of such climate resilient hybrids in targeted areas would certainly increase the productivity of rainfed areas. The large-scale demonstration of climate resilient hybrids on farmers' field across multiple locations would increase the rate and percentage of adoption of such hybrids by farmers.

Applications of novel methods to accelerate the rate of cultivar development

The maize genome sequence information is out in public domain, several thousands of gene(s) and quantitative trait locus (QTL) determining key traits like resistance to different biotic stresses, tolerance to abiotic stresses; different yield contributing traits, quality traits etc. have been identified. The novel precise targeted gene editing technique like CRISPR-Cas9 is also available. In addition, other advanced technique like doubled haploid techniques (DH), marker assisted selection (MAS) and of late speed breeding technology would facilitate accelerated breeding. Application of such novel tools and techniques in maize improvement would help in breeding by design. The techniques have also increased the rate of cultivar development by substantially reducing the breeding cycles. The simultaneous development in high-throughput field-phenotyping facilities, statistical algorithms for analysis of complicated data etc. together can help in increasing the genetic gain thus help in developing new, high yielding, climate resilient cultivars.

Development of genetically modified (GM) maize

The area under genetically modified maize across the globe has been continuously increasing and the number of countries adopting GM maize is also increasing (ISAAA, 2018). In India also several transgenic events against insect resistance, herbicide tolerance have been tested under contained conditions under the supervision of the Genetic Engineering Appraisal Committee (GEAC). In fact transgenic events with tolerance to abiotic stress like drought have been developed; Drought Gard™, the first commercial genetically modified maize hybrid released for drought tolerance. Similarly, for other traits where the sources of resistance are not available or available in low frequency could be considered to improve through transgenic approach.

Expansion of area under hybrid cultivars

Presently around 60% of the total maize area of the country is under hybrid maize, whereas the national average productivity of maize is around 3 t/ha. There is scope to bring additional 40% of maize area under hybrid cultivars to further increase the productivity by at least by 50%. In order to expand the maize area under hybrids, the promotion of hybrid seed production in different parts of the country would bring awareness among farmers about hybrids. Several sites have already been identified in different states like Rajasthan, West Bengal, Bihar, Jharkhand etc. to enhance the hybrid seed production capacity involving National Seed Corporation (NSC) and other state seed corporations like Rajasthan Gujarat etc. The government policy push to bring more area under hybrid maize would certainly help to increase the maize productivity.

Production and Protection Technologies

Adoption of improved agronomic practices and also undertaking timely plant protection measures depending on the need would help in reducing the yield gaps substantially and reduces the losses due to various insect pests respectively. The plant production practices like crop diversification, crop rotation, intercropping, adoption of conservation agriculture practices help in enhancing the soil health in long-run. The application of conservation agriculture (CA) practices like residue retention would serve as moisture conservation technique. Retention of soil residue would modulate soil temperature, soil pH, organic carbon, soil micro-biome etc. The CA practices also reduce the cost of cultivation which in turn helps in enhancing the farmers' income. In order to augment and enhance farmers' income, the specialty corn cultivation like sweet corn and baby corn can be promoted in selected areas around urban areas. Contract farming approaches can provide market stability to farmers and also continuous supply to traders. The government's policies can also focus and shuld consider to promote specialty corn cultivation due to huge export market for specialty corn.

Development of backward and forward linkages

The maize production in India is increasing gradually. During the last one decade (2007-2017), the area, production and productivity of maize have increased by 15, 51 and 31 per cent respectively. In order to avoid post-production losses and also maintain the farmer's interest in maize cultivation, there is need to create adequate large-scale storage facilities and also provide the farmers the market stability respectively. The diversified uses of maize coupled with increased maize production have directly or indirectly helped several industries to expand their consumption capacity. The policy support in this direction to promote further industrial growth is needed. The policy should consider all the stakeholders like farmers, industrialist and consumers. One of the current developments in this direction is the initiative taken by Haryana Government with respect to crop diversification. The Haryana government has announced the comprehensive package to farmers cultivating maize. The government has giving assurance to farmers that the government will buy-back all their maize produce at MSP; such kind of policy support would not only increase the maize production but also help in conserving the precious natural resources like water. Further, promotion of maize as food crop is also required by highlighting the nutritional importance of quality protein maize (QPM). The advantages of QPM over other cereals like rice and wheat would increase maize consumption as food. The number of persons with diabetic is increasing in India; initiative like promotion of QPM would certainly reduce the burden on spending on health. However, the strategy should be developed to link, QPM producing farmers, food processing industries and the consumer. Considering the existing infrastructure and business models in India like omni-presence of super markets, the health awareness the task is easy to accomplish. Similarly linking maize producers, starch industry, poultry industry and consumers could create enabling environment to further enhance the maize production and productivity.

Policy intervention to further enhance the maize production in India

- Establishment of centralized state-of-the-art research facilities or centre of excellence to carryout advanced research on DH, MAS, gene editing techniques etc. to further enhance maize productivity.
- Mission mode approach to bring 100% maize area under hybrids through National Seed Corporation (NSC), State Seed Corporations (SSC) and private companies by linking with State Agriculture Departments to supply hybrid seeds at the door steps in subsidized rate.
- Large-scale campaign to promote mechanization in maize cultivation from land preparation to sowing to harvesting and facilitating either subsidy or through PPP to establish custom-hire centres to rent big and small machineries.
- Linking food, feed and starch industries with farmers to purchase the maize produce from the farmers door-steps along with establishing community based large scale dryers to produce, market and procure quality maize.

Challenges and future outlook of maize research and development in India

The challenges in maize production are dynamic. The major challenge is the low productivity in rainfed areas of *kharif* season. The major reason for low yield is the vagaries of monsoon as 70% of maize area is under rainfed condition which largely depends on the monsoon rains. The 70% of maize area often experience moisture stress either in the form of low moisture (drought) or high moisture (waterlogging) at different growth stages. About 80% of maize area is being cultivated during *kharif* season. The *kharif* season and dependencies on monsoon rains are the two major factors which is responsible for low productivity. Heavy incidence of weeds and losses due to weed infestation during *kharif* season is the other major challenge. However, in recent years one or two post-emergence herbicides are available to control weeds but use of herbicides increases the cost of production. On the contrary we are aiming to double the farmers' income which is possible either by increasing the yield or by reducing the cost of cultivation. The third most important challenges is scarcity of labor and lack of customized small to medium to big machineries for complete mechanized cultivation of maize by small to marginal to large farmers. The labor wages are increasing across all states and percentage of agriculture laborers is decreasing. On the contrary, in order to reduce the cost of cultivation and also to overcome the labor scarcity, mechanized maize cultivation is not happening mainly due to lack of desired machines in sufficient number. The fourth most important challenge is lack of availability of quality seed in sufficient quantity at affordable price at the farmer's door step. The hybrid maize seed production has concentrated largely in coastal Andhra Pradesh and some parts of Telangana and most of the hybrid seed produced is get sold-out in peninsula part of India. Recently an invasive pest fall armyworm has created an alarming situation in most parts of India. The losses may go up to 100% if proper measures not taken at right stage of infestation. Finally, the application of modern tools and techniques in India to develop new and improved maize cultivars is not comparable with other parts of World.

The domestic and international demand for maize is increasing continuously. Presently India is self sufficient to meet the domestic demand. However, it is estimated that the future demand for maize in India would increase at increasing rate. In order to meet the future demand India has to increase the rate of genetic gain in increasing rate in coming years which is not easy under decreasing natural resource base and changing climate. However, by application of advanced tools and techniques like DH, coupled with germplasm diversification, genomic selection, the future demand can be met, provided 100% adoption of hybrid technology. The application of advanced tools and techniques, would help in identification of gene(s) determining tolerance to different kinds of stress like biotic and abiotic stresses. Integration and use of genotypes carrying such gene(s) in active germpalsm would help in developing climate resilient cultivars. Further, integration of DH, MAS and genomic selection (GS) would further accelerate the rate of cultivar development.

The policy intervention towards ensuring 100% adoption of hybrid technology, availability of quality seeds at affordable price at the door step of farmers would not only increase the productivity but also enhance the farmers' income.

Conclusion

India has to achieve the maize production target of 50-60 million MT by 2025. Presently India is producing around 28.75 million MT of maize (2017-18). During last ten years (2007-2017), India has increased its maize production from 18.96 to 28.75 million MT. The challenge looks daunting; but, it is achievable through strong policy support. Because, presently large number of single cross hybrids are already available with yield potential of 6-7 tons/ha during kharif season and 9-10 t/ha during rabi season. However, the only major challenge is to adoption of already available technologies like single cross hybrids on 100% area and ensuring availability of quality seeds at the door steps of farmers. In addition, focused research on germplasm diversification, development of climate resilient hybrids, accelerated development of hybrid cultivar through application of advanced tools and techniques, promotion and popularization of new and improved hybrids, adoption of improved production and protection practices would ensure sustainable increase in maize production and productivity.

References

Annonymous (2009). The Asian Development Bank Annual Report Volume I. pp. 122.

Foulkes, M. J., Slafer, G. A., Davies, W. J., Berry, P. M., Sylvester-Bradley, R., Martre, P., Calderini, D. F., Griffiths, S., & Reynolds, M. P. (2011). Raising yield potential of wheat. III. Optimizing partitioning to grain while maintaining lodging resistance *J. Exp. Bot.*, **62**: 469-486.

IPCC Fourth Assessment Report (AR4) (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. pp 104.

ISAAA (2018). Global Status of Commercialized Biotech/GM Crops: 2016. ISAAA Brief No. 52. ISAAA: Ithaca, NY.

Niyogi, D., Kishtawal, C., Tripathi, S., & Govindaraju, R. S. (2010). Observational evidence that agricultural intensification and land use change may be reducing the Indian summer monsoon rainfall. *Water Resour. Res.*, **46**: W03533, 17, doi: 201010.1029/2008WR007082.

Parihar, C. M., Jat, S. L., Singh, A. K., Kumar, B., Singh, Y., Pradhan, S., Pooniya, V., Dhauja, A., Chaudhary, V., Jat, M. L., Jat, R. K., & Yadav, O. P. (2016). Conservation agriculture in irrigated intensive maize-based systems of north-western India: Effects on crop yields, water productivity and economic profitability. *Field Crops Research,* **193**:104-116.Doi: doi:10.1016/j.fcr.2016.03.013.

Rakshit, S. (2018). Maize improvement in India – status and prospects. In: 13th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition and Environmental Security – Extended Summary (eds. Prasanna, B. M., Das, A., & Kaimeney, K. K.), held at Ludhiana, Oct. 8-10, 2018, pp 77-83.

Rakshit, S., Chikkappa, K. G., Jat, S. L., Dhillon, B. S., & Singh, N. N. (2017). Scaling-up proven technology for maize improvement through participatory approach in India. In: Best Practices of Maize Production Technologies in South Asia (eds. Pandey, P. R., & Koirala, K. B.), SAARC Agriculture Centre, Dhaka, pp. 36-60.

Rakshit, S., Hariprasanna, K., Gomashe, S., Ganapathy, K. N., Das, I. K., Ramana, O. V., Dhandapani, A., & Patil, J. V. (2014). Changes in area, yield gains, and yield stability of sorghum in major sorghum-producing countries, 1970 to 2009. *Crop Science,* **54**(4): 1571-1584.

Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. *Nature,* **460**: 999–1003.doi: 10.1038/Nature08238.

Yadav, O. P., Hossain, F., Karjagi, C. G., Kumar, B., Zaidi, P. H., Jat, S. L., Chawla, J. S., Kaul, J., Hooda, K. S., Kumar, P., Yadava, P., & Dhillon, B. S. (2015). Genetic Improvement of Maize in India: Retrospect and Prospects. *Agricultural Research,* **4**(4): 325–338.

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REVIEW

An overview of crop loss assessment in maize

Pradyumn Kumar[1] · Ranvir Singh[2] · S.B. Suby[3] · Jaswinder Kaur[4] · J.C. Sekhar[5] · P. Lakshmi Soujanya[6]

Abstract: Maize is an important crop for food, feed, fodder and myriads of industrial products. The crop suffers biotic stress due to its vulnerability to weeds, insect pests and pathogens. The losses caused by these factors varies tremendously depending upon the cultivar used, season and the location. If the estimation of the crop loss can be done timely, control measures can be adopted and much of the loss can be averted. In plant protection, crop loss assessment methods are used to determine the pest status of an organism, its economic injury level and action thresholds. It is also used for screening germplasm for resistance against pests. Assessing the economic status of a pest helps in decision making for resource allocation in research activities to manage the pest and extension activities to deploy the management measures. Thus, crop loss assessment helps in policy making also. Crop loss assessment is often done by protecting a field from biotic stress using chemical pesticides and comparing its yield with the yield of an unprotected field. It is precisely done by attaining the desired levels of pest infestation by releasing laboratory reared insects and developing a relationship with yield reduction. For assessing the level of stemborer damage in maize, damage parameters such as plant height, length of stalk damaged, number of internodes damaged, number of dead heart formation or other damage parameters related with yield are used to assess the crop loss due to stemborers. Correlating the level of damage with yield parameters such as number of ears, weight of ears, weight of grains per ear, weight of 1000 grains, form the basis of crop loss assessment. The most important is to establish the relationship between extent of infestation and corresponding yield loss which form the basis of formulating economic injury level. Of late a method has been developed by relating the leaf injury with the yield reduction which help to assess loss at much early, which in turn help in timely adoption of control measures and preventing further losses.

Keywords: Assessment · Crop loss · Maize

Introduction

Maize (*Zea mays* L.) is an important cereal food crop of world with highest production and productivity. It is the most versatile crop which is being grown in more than 166 countries across the globe including tropical, subtropical and temperate regions from mean sea level to 3000 m AMSL. Maize is the third most important cereal after rice and wheat for human food, contributing almost nine per cent to India's food basket and five per cent to world's dietary energy supply. In India, its production has increased more than 13.8 times from a mere 1.73 million tons in 1950-51 to 29 million tons in 2018-19 Presently, it occupies 10.2 million hectare area with the mean yield of 3 tons per hectare (FAO, 2014). It engages 15 million farmers in India. Compared to most cereals, maize faces fewer biotic and abiotic constraints in production. So far over 65 per cent maize area is under hybrid cultivation. The development of new hybrids and improved crop management have contributed in the continuous increase in the productivity and production of maize. There are over 3,500 products where maize is used in one way or the other. The increasing demand from poultry feed sector, the largest consumer of maize and increasing demand of specialty corn, viz., sweet

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corn, baby corn and popcorn as well as Quality Protein Maize enhance the scope of its production and farmers' income. Thus, maize hold promises for doubling farmers' income.

The yield potential of a cultivar when grown in field, experiences various biotic (diseases insects and weeds) and abiotic (temperature, moisture, wind, *etc.*) constraints, which reduces quantity and/or quality of the produce, resulting in crop losses. Crop loss assessment is the quantification of impact of pest on crop yield. Insects are known to be the major factor for contributing towards crop losses the extent of which depends on the pest population density, its feeding behavior. Plant suffers various kinds of damage due to injury by insect activities, which may or may not reduce its yield, but economic yield loss is more a monitory concept based on the benefit of adopting plant protection over leaving the crop un attended. Economic yield loss is assessed by determination of economic threshold level (ETL) of pest. A pest management decision is taken on ETL. Crop loss assessment method is important to provide this vital input at farm level for IPM practitioners and on wider scale for policy makers.

Maize suffers from biotic stresses mainly from weeds, insects and diseases. The farmers fail to act on critical time for weed management. Among insects, though there is report of 250 insects in maize ecosystem (Mathur, 1992) but important ones are the key native pests, viz., stemborers, *Chilo partellus* Swinhoe and *Sesamia inferens* Walker, sorghum shoot fly, *Atherigona* spp. and the invasive pest, fall armyworm *Spodoptera frugiperda* (JE Smith). In high yielding varieties the losses were up to 35% of maize by *Chilo partellus* and *Sesamia inferens* (Pradhan, 1969). Termites, Corn ear worm, *Helicoverpa armigera* and chaffer beetles are potential pests which cause occasional yield losses.

C. partellus is a regular pest in *kharif* maize, occur throughout India. Losses caused by this pest ranges from 10-15 per cent, however, in epidemic form the loss reaches up to 80.4 per cent (Panwar, 2005). *S. inferens* is a regular pest in Rabi maize, distributed in almost all parts of India, but causes considerable yield losses in Peninsular India. Losses caused by this varied from 25.7 to 78.9% (Rao, 1983). In spring maize, the major pest is shootfly, *Atherigona* spp., Grain yield loss due to *A. soccata* is 21.28% and *A. orientalis* is 20% (Panwar, 2005, Pathak *et al.*, 1971). Fall armyworm (FAW) has reported to cause up to 73% yield losses, Turcicum leaf blight, *Exserohilum turcicum* and common rust *Puccinia sorghi* most devastating diseases in maize.

The pesticide consumption in India is generally low at 0.6 kg/ha against 7 kg/ha in USA and 13 kg/ha in China (Anonymous, 2013). In maize the scenario is no different. This being a marginal crop hitherto, receive even less insecticides. The most common among them are Carbofuran, Chlorpyriphos, Cypermethrin and Deltamethrin. Among fungicides, Carbendazim, Mancozeb, and Metalaxyl are the most commonly used. Atrazine, Glyphosate, Paraquat and 2,4-D are the common weedicide used in maize ecosystem. Crop loss assessment will further reduce the pesticide consumption.

Assessment of crop losses due to insect pests is done for the following purpose:

1. Assigning pest/economic status to an insect species
2. Screening of germplasm for resistance breeding
3. In policy making regarding the allocation of compensation in case of crop failure due to insect pest attack
4. In decision making for the resource allocation in the research and extension activities, based on the relative economic importance of the insect pest
5. Determination of Economic Threshold Level of a pest and evaluation of pest control measures

Methods of yield loss assessment in maize

Different workers have used different methods for the estimation of yield losses in maize.

Chemical protection

The chemical protection is most commonly used method of crop loss assessment, where yield of a naturally infested field is compared with fields protected with desired levels of insecticides treatments. This method has been used for crop loss assessment in maize due to *C. partellus* and *S. inferens* (Chatterji *et al.*, 1969). Singh *et al.* (1971) used this method for estimation of yield losses due to stem borer (*C. partellus* Swinhoe), gujia weevil (*Tanymecus indicus* Faust) and leaf roller (*Marasmia trapezalis* Guenee). In Kenya, yield losses due to borer complex have been estimated using chemical protection of the maize (Ouma *et al.*, 2003). Berg and Rensburg (1991) treated maize crop at whorl stage for crop loss assessment against *C. partellus*. Chemical protection is the widely used method as it can be implemented over large area. To reduce input costs assessment, chemical protection is done at the most susceptible stage of crop. However, measures to be taken to reduce the error in yield assessment due to change in the physiology of crop by certain insecticides.

Another source of variation in yield assessment in this method is the effect of natural enemies in yield advantage in non-protected field, effect of which is eliminated by pesticides in protected crop. To eliminate this variation, Cugala *et al.* (2006) studied yield losses in maize due to stem borers in the absence of their natural enemies, excluded by selective insecticides. The yield losses increased from 28.9 per cent to 43.3 per cent in the absence of natural enemies.

Simulation method

Many workers have studied the effect of simulated injury on the plant yield parameters for different insect pests. Brown and Mohamed (1972) manually removed the foliage of maize to simulate the damage of fall armyworm, *Spodoptera frugiperda*.

Artificial infestation

Crop loss assessment under natural infestation has many constraints as the pest may not infest the crop uniformly. The extent of natural infestation depends on various factors. Gebre-Amlake *et al.* (1989) reported that maize crop grown across different planting dates suffered different levels of plant damage due to *Busseola fusca*. The plant height was shown to have negative linear relationship with the level of egg density of *D. grandiosella* (Davis *et al.*, 1978). Also, the level of natural infestation may not be sufficient to the extent of causing reasonable crop damage which translates in loss. These limitations can be overcome by artificial infestation of the crop. However, the stage and plant part to be infested depends on the type of insect pest. To assess losses due to European corn borer *Ostrinia nubilalis*, the egg mass at black headed stage was placed deep into the whorl in whorl stage maize. In reproductive stage maize, at the time of pollen shedding, plants were infested by pinning the egg masses underside of the leaf through the midrib in the region of the ear (Lynch *et al.*, 1980) and at silking stage, the egg masses were dropped into folded two leaves above the primary ear (Umeozore *et al.*, 1985). For *Diatraea grandiosella*, eggs were placed into the whorl of the plant (Davis *et al.*, 1978). The crop was infested at first, fourth and seventh leaf stage with forth to sixth instar of stalk borer, *Papaipema nebris* (Davis and Pedigo, 1990). For *Eldana saccharina* the egg masses were placed between the leaf sheaths at the node just below the ear (Bosque-Perez and Mareck, 1991). Egg mass of *Chilo partellus* was placed in the whorl at different crop growth stages (Bate and Rensburg, 1992). Newly hatched neonates were placed in whorl at younger maize for the infestation of *Busseola fusca* (Usua, 1968) and *C. partellus* (Ajala and Saxena, 1994). Bate and Rensburg (1992) pointed out that assessment of whorl damage at 2 weeks after infestation could provide acceptable estimation of infestation levels as the percentage of plants with whorl damage, percentage of internodes damaged and yield losses decreased with the delay in the timing of infestation until after 3 weeks of crop development. For European corn borer, *O. nubilalis*, larvae were placed in whorl and leaf collar of maize plants (Bohn *et al.*, 1999). Newly hatched larvae were placed in whorl for the artificial infestation of *S. inferens* (Pavani *et al.*, 2013) and *S. frugiperda* (Williams and Davis 1990).

Damage indicators and their relationship with yield

Different damage parameters were used for the estimation of damage due to insect pests in maize. The number of infested plants was accounted for *C. partellus* (Mohyuddin and Attiue, 1978), *O. nubilalis* (Bohn *et al.*, 1999) and *B. fusca* (Ebenebe *et al.*, 1999) damage. The number of whorl damage and number of damaged internodes were counted for the estimation of *C. partellus* (Bate and Rensburg, 1992) and *B. fusca* damage (Ebenebe *et al.*, 1999). The plants were rated on scale based on the extent of foliage damage due to *D. grandiosella* (Davis *et al.*, 1978), *B. fusca* (Gebre-Amlak *et al.*, 1989), *P. nebris* (Davis and Pedigo, 1990), *O. nubilalis* (Bohn *et al.*, 1999) and *S. inferens* (Pavani *et al.*, 2013). For *S. frugiperda*, plant damage was rated on Davis scale (1 to 9 scale) (Davis and William, 1992). The number of dead hearts was accounted for *B. fusca* (Usua 1968, Gebre-Amlak *et al.*, 1989), *S. inferens* (Pavani *et al.*, 2013) and shoot fly, *Atherigona* spp. (Meti *et al.*, 2014; Kumar *et al.*, 2016; Kumar *et al.*, 2018). Maize stalks were split opened and observations were recorded on number of larvae per plant (Bohn *et al.*, 1999), number of entrance holes (Lynch *et al.*, 1980), cavities in the stalk (Lynch *et al.*, 1980, Umeozore *et al.*, 1985), ear and ear shank (Umeozore *et al.*, 1985) for *O. nubilalis*. Similarly, stalks were observed for per cent stalks bored by *B. fusca* (Gebre-Amlak *et al.*, 1989) number of exit holes, tunnel length, stem breakage and length of tunnel caused by *C. partellus* (Mohyuddin and Attiue, 1978, Sharma and Gautam, 2010) and *S. inferens* (Pavani *et al.*, 2013). The plants were split opened and number of larvae, pupae, pupal case were counted for *B. fusca* (Ebenebe *et al.*, 1999). Number of damaged ears were considered for *B. fusca* (Gebre-Amlak *et al.*, 1989, Ebenebe *et al.*, 1999). For *Atherigona* spp., number of eggs per plant was counted (Meti *et al.*, 2014; Kumar *et al.*, 2016; Kumar *et al.*, 2018). Apart from the parameters which directly indicate damage, plant traits viz., number of leaves per plant and plant height were also used as indirect indicators of damage. To estimate the yield, number of ears, weight of ear per plant, weight of grain per ear, weight of grains per plant and 1000 grain weight were considered.

Relationships of plant damage parameters with yield losses has been estimated by many workers. Correlation analysis revealed that, plant height, number of leaves per plant, weight of cob per plant, weight of grain per cob and weight of grains per plant decreased with infestation of *B. fusca* (Usua, 1968). Infestation of *B. fusca* (Gebre-Amlak *et al.*, 1989) and *C. partellus* (Ajala and Saxena, 1994) were found to reduce the plant height and number of ears in maize. Ear weight and shelled weight were negatively correlated with increase in level of infestation, total cavities and entrance holes caused by *O. nubilalis*. The yield reduction was higher when the pest was infested at pollen shedding than at whorl stage (Lynch *et al.*, 1980). Similarly, a significant negative relationship was observed between number of cavities and dry grain weight under the infestation of *O. nubilalis* (Umeozore *et al.*, 1985). Similarly, plant stand, number of ears harvested and 1000 grain weight were reduced, whereas the number of poor cobs increased in unprotected maize due to *C. partellus* infestation (Sharma and Gautam, 2010). Stem tunneling due to *Eldana saccharina* showed negative correlation with the 100-grain weight (Bosque-Perez and Mareck, 1991).

The reduction in yield showed positive correlation with foliage lesions, dead hearts and stem tunneling due to *Chilo partellus*. Among the damage parameters, stem tunneling contributed the most in yield reduction (Ajala and Saxena, 1994). Regression analysis was carried out to know the relationship between various damage parameters and yield reduction per plant. A single plant infestation with 1 or 2 larvae of *B. fusca* reduced the yield of the plant by 25 per cent (Usua, 1968). For every one percent damaged plant by O. *nubilalis* was estimated to reduce yield by 0.28 percent whereas, one larva per plant was estimated to reduce yield by 6.05 percent (Bohn *et al.*, 1999). However, one *O. nubilalis* larva per plant was also estimated to lose 2.81 to 4.03 per cent of the yield (Deay *et al.*, 1949) and one larva per cavity was shown to reduce 102.72 to 465.79 kg/ha (Umeozore *et al.*, 1985). Similarly, unit increase in percentage of stem tunneled due to *B. fusca* could decrease 100 grain weight by 0.125 g (Bosque-Perez and Mareck, 1991).

Estimation of yield losses in maize

Different workers have reported different extent of yield losses for a pest from same or different agro climatic region of the world.

International scenario

The *C. partellus* infestation reduced the yield by 43.21 to 44.46 per cent in Pakistan (Mohyuddin and Attiue, 1978), 0 to 95 per cent in South Africa (Berg and Rensburg, 1991), 27.1 to 29. 8 per cent in India (Sharma and Gautam, 2010). The Southwestern corn borer, *D. grandiosella* caused a yield loss of 5.73 to 28.03 per cent in Mississippi State (Davis *et al.*, 1978). The stalk borer, *P. nebris* reduced the maize yield by 18.9 to 24.8 per cent in Iowa (Davis and Pedigo, 1990). Bosque-Perez and Mareck, (1991) reported that infestation due to *E. saccharina* decreased the grain yield (g/plant) by 16 to 36 per cent. According to Cardwell *et al.* (1997), a borer complex infestation in maize caused a yield loss of 4.4 to 10.2 g per cob in Cameron. Ndemah and Schulthess (2002) reported a yield loss of 17 to 44 per cent due to prominent stem borers, *B. fusca*, *Sesamia calamistis* and *E. saccharina* in Cameroon. Groote (2002) presented the yield losses in maize resulting from stem borer attack, based on the farmers' estimate. The stem borers caused yield losses of 9.9 to 20.7 per cent (average 12.9%) across the agro-ecological zones of Kenya. Maize borer complex is known to cause a crop loss of about 14 per cent (0.44 million ton) of total maize production in Kenya, with at monetary value of US$ 25 to 60 million (Ouma *et al.*, 2003). A stem borer complex caused a yield loss of 0.32 to 0.39 ton per ha across the different climatic zones in Kenya (Ongamo *et al.*, 2006). A yield loss of 22 to 67 per cent (Day *et al.*, 2017) and 26 to 35 per cent (Rwomushana *et al.*, 2018) has been reported due to *S. frugiperda* in Ghana and Zambia.

Lynch *et al.* (1980) suggested that the extent of yield loss also depends on the stage of crop infested as infestation of European stem borer, *O. nubilalis* at whorl stage and pollen shedding stage caused a yield loss of 2.90 to 5.8

and 4.4 to 10.1 per cent, respectively. It has been reported that the extent of yield loss depends on the time of sowing. *B. fusca* caused a yield loss of 0 to 100 per cent (Gebre-Amlak *et al.*, 1989) and 0.4 to 36 per cent (Ebenebe *et al.*, 1999) across the planting dates.

Indian scenario

In India, the yield losses in maize reported by earlier workers (Rahman, 1940; Trehan and Butani, 1949; Reddy, 1968) were estimated empirically rather than by experimentation. Srivastava (1959) was of the opinion that at the very conservative estimate 10-15 per cent of the maize produce is lost annually in Rajasthan on account of the insects alone. Reddy (1968) also put forth estimated gross loss caused by insect pest and diseases in India to be at 10 percent. These guess work estimates are generally covered under the accepted loss of 10-12 percent. Singh *et al.* (1971) reported an avoidable yield loss of about 1.93 and 1.81 q/ha in early and late maize, respectively due to the attack of stem borer (*Chilo partellus* Swinhoe), gujia weevil (*Tanymecus indicus* Faust) and leaf roller (*Marasmia trapezalis* Guenee). The climbing cutworm, *Rhyacia herculea* known to cause a yield loss of 12 to 34 per cent in India (Verma *et al.*, 1979; Verma and Sinha, 1980). Pathak *et al.* (1971) reported that shoot flies caused a grain loss up to 20 per cent. Pradhan and Peshwani (1961) have estimated the crop loss caused by *Hieroglyphus nigrorepletus* to be about 18 per cent. Chatterji *et al.* (1969) showed that the percentage of avoidable loss primarily due to *C. partellus* varied from 24.30 to 36.30 per cent in different agro climatic regions of India. *S. inferens* cause loss in winter season in peninsular India which varies from 25-80 per cent (Rao, 1983).

The application of crop loss assessment in decision making for pest management

Pest management decision is made based on Economic injury level (EIL). EIL is defined as the lowest population density that will cause economic damage and ETL is a population level, lower than the economic injury level, at which pest control measures are to be undertaken for preventing an increasing pest population from reaching the economic injury level (Stern *et al.*, 1959). One of the prerequisites for EIL determination is the estimation of yield losses under a range of pest density. The gradient pest density can be achieved by many techniques. The plants were grown with or without exclusion and artificially infested with varied levels of pest density. However, the crop stage to be infested depends on the pest type. For *C. partellus*, artificial infestation was done on the 20, 40 and 60 days old plants (Reddy and Sum, 1991) and 12, 17, 22 and 27 days after germination representing 3, 5, 7 and 8 leaf stages, respectively (Sharma and Sharma, 1987). For *O. nubilalis* the maize crop was artificially infested during 10 leaf, 16 leaf, blister and dough stage (Bode and Calvin, 1990), whorl and flowering stage (Sayers *et al.*, 1994). In another method, the crop was sprayed with different kind of insecticides for achieving different pest density (Hosny and El-Saadnay, 1973; Magdy *et al.*, 2016). Evans and Stansly (1990) compared naturally infested and chemically protected plants for *S. frugiperda*. Rejesus *et al.* (1990) carried out experiment in natural infestation for Asian corn borer, *Ostrinia furnacalis.*

EIL calculation

Extent of yield losses was estimated against the range of pest density. The regression analysis was worked out to establish the relationship between extent of infestation and corresponding yield losses. For most of the stem borers, the extent of infestation was determined by counting number of larvae from the sampling plants. (Bode and Calvin, 1990; Reddy and Sum, 1991; Magdy *et al.*, 2016). However, for *S. frugiperda*, the plants were marked as infested based on presence of larvae, newly emerged leaves with scraped area, presence of fresh frass in the whorl and perforations in the emerging leaves depending on the crop growth stage (Evans and Stansly 1990).

The EIL has been estimated by using formulas as suggested by Stone and Pedigo (1972) and Norton (1976).

$$EIL = \frac{C}{VIDK}$$

where,

C: the management cost per production unit,

V: market value per production unit

I: injury unit per pest equivalent

D: damage per unit injury

K: proportional reduction in injury due to management

Hosny and El-Saadnay (1973) used different approach for the determination of EIL. For each borer species, the Chi Square (χ^2) analysis was worked out for each pair of percentage plant infested and their corresponding yield in all the treatments. The level of percent infestation, at which the Chi Square (χ^2) was significant, considered to be the economic threshold levels for that borer species.

EIL of different insect pests of maize

For *Chilo partellus*, the EIL has been worked out as 1.24, 1.33, 2.56 and 3.36 larvae per plant for 12, 17, 22- and 27-days old plants for susceptible genotype, respectively, while it was 1.16, 1.71, 8.86 and 14.13 larvae per plant for resistant genotype (Sharma and Sharma, 1987). Reddy and Sum (1991) determined it as 3.2 and 3.9 larvae per plant for 20- and 40-day old plants, respectively.

For *O. nubilalis*, The EIL ranged from 9 to 70 per cent plant infestation across the sowing times (Hosny and El-Saadnay, 1973). EIL was considered as more than 2 to 3 per cent plants with larvae in whorl during whorl stage and more than 10 to 17 per cent plants with larvae in leaf axils during flowering stage (Sayers *et al.*, 1994). Rejesus *et al.* (1990) determined EIL as 1.37 larvae per plant for *O. nubilalis*. EIL values ranged from 0.34 to 1.35, 0.40 to 1.60, 0.64 to 2.56 and 0.83 to 3.32 larvae per plant for 10 leaf, 16 leaf, blister and dough stages of crop growth, respectively depending on the level of infestation (Bode and Calvin, 1990). Magdy *et al.* (2016) estimated EIL as 1.38 to 3.13 larva per 10 plants.

For *Sesamia certica* EIL was estimated as 5 to 10 per cent infested plants across the sowing times (Hosny and El-Saadnay, 1973). It ranged from 0.83 to 2.25 larvae per 10 plants (Magdy *et al.*, 2016). For *Chilo agamemnon*, EIL varied from 1 to 10 per cent plant infestation depending upon the sowing times (Magdy *et al.*, 2016). According to Hosny and El-Saadnay (1973) it ranged from 0.31 to 1.48 larvae per plant. For *S. frugiperda*, EIL was estimated as 14, 21, 23, 26 and 50 per cent infestation for 2, 3, 4, 5 and 6 weeks after germination of the crop (Evans and Stansly, 1990). The EIL ranged from 3 to 8 bug per 1000 plants for coreid bug, *Leptoglossus zonatus* (Foresti *et al.*, 2017). The studies showed that the EIL varies with stage of crop, sowing times, level of infestation, *etc.*

REFERENCES

Ajala, S. O. & Saxena, K. N. (1994). Interrelationship among *Chilo partellus* (Swinhoe) damage parameters and their contribution to grain yield reduction in maize (*Zea mays* L.). *Applied Entomology and Zoology*, **29**(4): 469-476.

Anonymous. (2013). Indian Agrochemical Industry, Imperatives of Growth. Knowledge and Strategy paper released at 3rd National Agrochemicals Conclave. 30-31 July 2013 FICCI, New Delhi.

Anonymous. (2014). FAO Statistical Year Book 2014.

Bate, R. & Rensburg, J. B. J. V. (1992). Predictive estimation of maize yield caused by *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in maize. *South African Journal of Plant and Soil*, **9**(3): 150-154.

Berg J. V. D. & Rensburg J. B. J. V. (1991). Unavoidable losses in insecticidal control of *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in maize and grain sorghum. *South African Journal of Plant Soil*, **8**(1): 12-16.

Bode, W. M. & Calvin, D. D. (1990). Yield loss relationship and economic injury levels for European corn borer (Lepidoptera: Pyralidae) populations infesting Pennsylvania field corn. *Journal of Economic Entomology*, **83**(4): 1595-1603.

Bohn, M., Kreps, R. C., Klein, D. & Melchinger, A. E. (1999). Damage and grain yield losses caused by European corn borer (Lepidoptera:Pyralidae) in early maturing European maize hybrids. *Journal of Economic Entomology*, **92**(3): 723-731.

Bosque-Perez, N. A. & Mareck, J. H. (1991). Effect of the stem borer *Eldana saccharina* (Lepidoptera:Pyralidae) on the yield of maize. *Bulletin of Entomological Research*, **81**: 2543-247.

Brown, E. S. & Mohamed, A. K. A. (1972). The relation between simulated armyworm damage and crop loss in maize and sorghum. *East African Agricultural and Forest Journal*, **37**(3): 237-257.

Cardwell, K. F., Schulthess, F., Ndemah, R. & Ngoko, Z. (1997). A systems approach to assess crop health and maize yield losses due to pests and diseases in Cameroon. *Agriculture, Ecosystems and Environment*, **65**: 33-47.

Chatterji, S. M., Young, W. R., Sharma, G. C., Sayi, I. V., Chahai, B. S., Khare, B. P., Rathore, Y. S., Panwar, V. P. S. & Siddiqui, K. H. (1969). Estimation of loss in yield of maize due to insect pests with special reference to borers. *Indian Journal of Entomology*, **31**(2): 109-115.

Chatterji, S. M., Young, W. R., Sharma, G. C., Sayi, I. V., Chahal, B.S., Khare, B. P., Rathore, Y. S., Panwar, V. P. S. & Siddiqui, K. H. (1969). Estimation of loss in yield of maize due to insect pests with special reference to borers. *Indian Journal of Entomology*, **31**(2): 109-115.

Cugala, D., Schulthess, F., Ogol, C. P. O. & Omwega, C. O. (2006). Assessment of the impact of natural enemies on stem borer infestation and yield loss in maize using selected insecticide in Mozambique. *Annals of Entomological Society of America*, **42**(3-4): 503-510.

Davis, F. M., Scott, G. E. & Williams, W. P. (1978). Southwestern corn borer: effect of levels of first brood on maize. *Journal of Economic Entomology*, **71**(2): 244-246.

Davis, P. M. & Pedigo, L. P. (1990). Yield response of corn stands to stalk borer (Lepidoptera: Noctuidae) injury imposed during early development. *Journal of Economic Entomology*, **83**(4): 1582-56.

Day, R., Abrahams, P., Bateman, M., Beak, T., Clotty, V., Cock, M., Colmenarey, Y., Corniani, N., Early, R., Godwin, J., Gomej, J., Moreno, P. G., Murphy, S. T., Oppong-Mensah, B., Phiri, N., Pratt, C., Richards, G., Silvestri, S. & Witt, A. (2017). Fall armyworm: impacts and implications for Africa: *Outlooks Pest Management*, **28**: 196-201.

Deay, H. O., Patch, L. H. & Snelling R. O. (1949). Loss in yield of dent corn infested with the August generation of the European corn borer. *Journal of Economic Entomology*, **42**: 81-87.

Ebenebe, A. A., Berg, J. V. D. & Linde, T. C. V. D. (1999). Effect of planting date of maize on damage and yield loss caused by the stalk borer, *Busseola fusca* (Lepidoptera:Noctuidae) in Lesotho. *South African Journal of Plant and Soil*, **16**(4): 180-185.

Evans, D. C. & Stansly, P. A. (1990). Weekly economic injury levels for fall armyworm (Lepidoptera: Noctuidae) infestation of corn in lowland Ecuador. *Journal of Economic Entomology*, **83**(6): 2452-2454.

Foresti, J., Bastos, C. S., Fernandes, F. L. & Silva, P. R. D. (2017). Economic injury level and economic thresholds for Leptoglossus zonatus (Dallas) (Hemiptera: Coreidae) infesting seed maize. *Pest Management Science*, **74**(1): 149-158.

Gebre-Amlak, A., Sigvald, R. & Pettersson, J. (1989). The relationship between sowing date, infestation and damage by the maize stalk borer, *Busseola fusca* (Lepidoptera:Noctuidae) on maize in Awassa, Ethiopia. *Tropical Pest Management*, **35**(2): 143-145.

Groote, H. D. (2002). Maize yield losses from stem borers in Kenya. *Insect Science and Application*, **22**(2): 89-96.

Hosny, M. M. & El-Saadany, G. B. (1973). The damage-assessment and the estimation of the injury level caused by stalk borers to maize plants in Egypt. *Zeitschrift fur Angewandte Entomologie*, **73**: 387-399.

Kumar, R., Malik, M. & Yadav, S. P. (2018). Effect of date of sowing on the infestation of shoot fly, *Atherigona soccata* (Rondanai) in spring maize and their varietal preference. *Universal Review*, **7**(9): 320-335.

Kumar, S., Singh, D. V., Sachan, S. K., Singh, G. & Singh, G. (2016). Studies of pest complex and seasonal incidence of shoot fly, *Atherigona scoccata* (Rondani) on maize in western UP. *Pro. Agric.*, **16**(1): 120-124.

Lynch, R. E., Robinson, J. F. & Berry, E. C. (1980). European corn borer: yield losses and damage resulting from a simulated natural infestation. *Journal of Economic Entomology*, **73**(1): 141-44.

Magdy, M. A., Osman, Z. A., Ahmed, B. S., Ahmed, E. M. & Gleel, A. A. (2016). Assessment of maize yield loss to determine economic injury levels due to the infestation by stem borers with insecticidal control under the Egyptian conditions. *Alexandria Science Exchange Journal*, **37**(4): 730-736.

Mathur, L. M. L. (1992). Insect pest management and its future in Indian maize programme. *XIX International Congress of Entomology*, June 27-July 4, Bejing, China.

Meti, P., Sreenivas, A. G., Prakash, K., Venkateshalu, M. L. J., Prabhuraj, A., Manjunath, N. & Singh, Y. K. (2014). Population dynamics of shoot fly and stem borers of maize under conservation agriculture system. *Journal of Experimental Zoology*, India, **17**(2): 563-566.

Mohyuddin, A. I. & Attique, M. R. 1978. An assessment of loss caused by *Chilo partellus* of maize in Pakistan. *PANS*, **24**(2): 111-113.

Moyal, P. (1998). Crop losses caused by maize stem borers (Lepidoptera:Pyralidae) in cote d'Ivoir, Africa: statistical model based on damage assessment during the production cycle. *Journal of Economic Entomology*, **91**(1): 512-516.

Murúa, G., Molina-Ochoa, J. & Coviella C. (2006). Population dynamics of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and its parasitoids in northwestern Argentina. *Florida Entomologist*, **89**(2): 175-82.

Ndemah, R. & Schulthess, F. (2002). Yield of maize in relation to natural field infestations and damage by lepidopteran borers in the forest and forest/savanna transition zones of Cameroon. *Insect Science and Application*, **22**(2): 183-192.

Norton, G. A. (1976). Analysis of decision making in crop protection. *Agro-ecosystems*, **3**: 27-44.

Ongamo, G. O., Ru, B. P. L., Dupas, S., Moyal, P., Calatayud, P. A. & Silvain, J. F. (2006). Distribution, pest status and agro-climatic preferences of lepidopteran stem borers of maize in Kenya. *Annals of Society of Entomology Fr*., **42**(2): 171-77.

Ouma, M. O. J., Wachira, S. & Wanyama, J. (2003). Economic assessment of maize yield loss due to stem borer in major maize agro-ecological zones in Kenya. *African Crop Science Conference Proceeding*, **6**: 683-687.

Panwar, V. P. S. (2005). Management of maize stalk borer, *Chilo partellus* (Swinhoe) in maize. In: "*Stresses on Maize in the Tropics*" (P.H. Zaidi, N.N. Singh, eds.). Directorate of Maize Research, New Delhi. pp. 376-395.

Pathak, P. K., Sharma, V. K. & Singh, J. M. (1971). Effect of date of planting on the spring maize on the incidence of shootfly, *Atherigona* spp. and loss in yield due to its attack. In: *Annual Report* 1970-71 Experiment Station, UPAU, Pantnagar. pp. 279-281.

Pathak, P. K., Sharma, V. K. & Singh, J. N. (1971). Effect of date of planting of spring sown maize on the incidence of shootfly, *Atherigona spp*. Infesting maize. In 2nd International science congress, Nov 17-24, 1996, New Delhi, India.

Pavani, T., Uma Maheswari, T. & Sekhar, J. C. (2013). Evaluation of efficacy of different insecticides and bioagents against *Sesamia inferens* Walker in maize. *European Journal of Zoological Research*, **2**(4): 98-102.

Pradhan, S. & Peshwami, K. M. (1961). Studies on the ecology and control of *Hieroglyphus nigrorepletus* Bolivar (Phadka). *Indian Journal of Entomology*, **23**(2): 79-105.

Pradhan, S. (1969). Increase in India's pest problems. *Span*, **12**(2): 81-83.

Rahman, K. A. (1940). Insect pests of maize and Jowar. *Punjab Agric. College Magazine*, pp 7-25.

Rao, A. B. (1983). Technique of scoring for resistance in maize stalk borer (*S. inferens*) In: Techniques for scoring for resistance to the major insect pests of maize. AICMIP, IARI, New Delhi pp. 16-26.

Rao, A. B. (1983). Technique of scoring for resistance to maize stalk borer (*Sesamia inferens*) In: *Technique of scoring for resistance to the maize insect pests of maize*. AICMIP, IARI, New Delhi, pp. 16-26.

Reddy, D. B. (1968). *Plant Protection in India*. Allied Publishers, Calcutta.109-114 pp.

Reddy, K. V. S. & Sum, K. O. S. (1991). Determination of economic injury level of the stem borer, *Chilo partellus* (Swinhoe) in maize, *Zea mays* L. *Insect Science and Application*, **12**(1/2): 269-274.

Rejesus, B. M., Buctuanon, E. M. & Rejesus, R. S. (1990). Defining the economic threshold determinants for the Asian corn borer, *Ostrinia furnacalis* (Guenee) in the *Philippines. Tropical Pest Management*, **36**(2): 114-121.

Rwomushana, I., Bateman, M., Beak, T., Besech, P., Cameron, K., Chiluba, M., Clottey, V., Davis, T., Day, R., Early, R., Godwin, J., Gonzalez-Moreno, P., Kansiime, M., Kenis, M., Makale, F., Mugambi, I., Murphy, S. W. N., Phiri, N., Pratt, C. & Tambo, J. (2018). Fall armyworm: impacts and implications for Africa. Evidence Note Update, Oxfordshire, UK.

Sayers, A. C., Johanson, R. H., Arndt, D. J. & Bergman, M. K. (1994). Development of economic injury levels of European corn borer (Lepidoptera: Pyralidae) on corn grown for seed. *Journal of Economic Entomology*, **87**(2): 458-464.

Sharma, A. N. & Sharma, V. K. (1987). Studies on the economic injury level in maize, *Zea mays* L. to stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera:Pyralidae) in India. *Tropical Pest Management*, **33**(10): 44-51.

Sharma, P. N. & Gautam, P. (2010). Assessment of yield loss in maize due to attack by the maize borer, *Chilo partellus* Swinhoe. *Nepal Journal of Science and Technology*, **11**: 25-30.

Singh, D., Tyagi, B. N., Khosla, R. K. & Avasthy, K. P. (1971). Estimate of the incidence of pests and diseases and consequent field losses in the yield of maize (*Zea mays* L.). *Indian Journal of Agricultural Science*, **41**(12): 1094-1097.

Srivastava, B. K. (1959). Insect pests of maize in Rajasthan. *Journal of Bombay Natural History Society*, **56**: 665-668.

Stern, V. M., Smith, R. F., Van Den Bosch, R. & Hagen, K. S. (1959). The integrated control concept: *Hilgardia*, **29**: 80-101.

Stone, J. D. & Pedigo, L. P. (1972). Development and economic injury level of the green cloverworm on soybean in Iowa. *Journal of Economic Entomology*, **65**(1): 197-201.

Trehan, K. N. & Butani, D. K. (1949). Notes on life history bionomics and control of *Chilo partellus* Swinhoe in Bombay Province. *Indian Journal of Entomology*, **11**: 47-59.

Umeozor, O. C., Duyn, J. W. & Kennedy, G. G. (1985). European corn borer (Lepidoptera:Pyralidae) damage to maize in Eastern North Carolina. *Journal of Economic Entomology*, **78**(6): 1188-94.

Usua, E. J. (1968). Effect of varying populations of *Busseola fusca* larvae on the growth and yield of maize. *Journal of Economic Entomology*, **61**(2): 375-376.

Verma, G. D. & Sinha, C. P. M. (1980). Evaluation of some insecticides for the control of *Rhyacia herculean* Corti and Daudt. *Entomon*, **5**(1): 109-111.

Verma, G. D., Singh, J. & Singh, I. P. (1979). Field evaluation of some insecticide treatments for control of *Rhyacia herculean* Corti and Draudt, on rabi maize in Bihar. *Entomon*, **5**(1): 129-131.

Williams, W. P. & Davis, F. M. (1990). Response of corn to artificial infestation with fall armyworm and southwestern corn borer larvae. *Southwestern Entomologist*, **15**(2): 163-166.

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RESEARCH PAPER

Identification of resistant sources against turcicum leaf blight of maize (*Zea mays* L.)

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Abstract: Turcicum leaf blight (TLB) caused by *Exserohilum turcicum* (Pass.) Leonard and Suggs is one of the most important foliar diseases of Maize. Host-plant resistance provides sustainable disease management option. With an objective to identify new source of resistance to TLB, 237 newly developed maize inbred lines were evaluated for two consecutive years at four location in India (Dharwad, Mandya, Almora and Bajaura) under artificially created disease epiphytotics. The disease reaction of individual genotype was rated on 1-9 scale. On the basis of pooled mean over locations, 41 inbred lines were found resistant (disease incidence <3.0), 181 inbred lines were moderately resistant (disease incidence 3.1-5.0) and 15 inbred lines were moderately susceptible (disease incidence 5.1-7.0). Out of 41 inbred lines, 33 lines *viz.* IMLSB-57-2, IMLSB-119-1, IMLSB-143-1, IMLSB-205-1, IMLSB-244-1, IMLSB-246-2, IMLSB-266-2, IMLSB-306-1, IMLSB-317-1, IMLSB-334B-1, IMLSB-343-1, IMLSB-343-2, IMLSB-380-1, IMLSB-428-2, IMLSB-446-2, IMLSB-475-2, IMLSB-568-2, IMLSB-748-1, IMLSB-801-2, IMLSB-807-1, IMLSB-825-2, IMLSB-955-1, IMLSB-956-2, IMLSB-975-2, IMLSB-976-2, IMLSB-1018-1, IMLSB-1041-4-1, IMLSB-1043-1-1, IMLSB-1299-1, IMLSB-1299-7, IMLSB-1381, IMLSB-2034, IMLSB-2136 were resistant at three locations and across location (mean basis), whereas 8 inbred lines IMLSB-282-2, IMLSB-310-2, IMLSB-1046-3-1, IMLSB-1047-1-1, IMLSB-1376, IMLSB-2051, IMLSB-2119, IMLSB-2166 were resistant at two locations and across mean basis. These 41 maize inbred lines, possessing resistance to turcicum leaf blight can be used successfully in developing promising hybrids.

Keywords: Artificial disease screening · Inbreds · Maize · Multilocation evaluation · Turcicum leaf blight resistance

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Introduction

Maize (*Zea mays* L.) is the leading cereal crop of the world with total production of 1.13 billion tons. It is a versatile crop grown in 169 countries across the globe due to its vast adaptation ability in tropical, sub-tropical and temperate regions under irrigated to semi-arid conditions. China mainland (42.39 million ha), United States of America (33.47 million ha) together account 38.48 per cent of total area of maize of the World (197.19 million ha) and contribute 55.52% of the total global maize production. In India maize is the third most important cereal crop after rice and wheat which provides food, feed, fodder and serves as a source of basic raw material for several industrial products *viz*., starch, protein, oil, alcoholic beverages, food sweeteners, cosmetics, bio-fuel, *etc*. Globally India ranks 4th in maize area (9.2 milion ha) after China, USA and Brazil and 5th in production (28.72 million tons) after USA, China, Brazil and Argentina. However, the average maize productivity of India (3.1 t/ha) is quite low as compared to USA (11.1 t/ha), China (6.1 t/ha), Brazil (5.6 t/ha), and World average (5.8 t/ha) (FAOSTAT, 2017).

The major reason for low productivity of maize in India is losses caused by various biotic and abiotic stresses. Among the various biotic stresses, foliar diseases namely, turcicum leaf blight (TLB) also called northern corn leaf blight caused by *Exserohilum turcicum* (Pass.) Leonard and Suggs. (syn. *Heliminthosporium turcicum* Pass.) is of worldwide importance. The fungus *E. turcicum* is known to be highly variable in nature (Reddy *et al*. 2013; De-Rossi *et al*., 2015). The symptoms first appear as greyish green small elliptical spots on the leaves with water soaked lesions parallel to leaf margins, finally attaining a spindle shape with long elliptical greyish or tan lesions. TLB can affect the maize crop from seedling stage to maturity. Development of disease at an early stage reduces seed germination capacity, vigour, and total sugar content, thus, causes premature death of blighted leaves (Ferguson and Carson, 2004). If the disease establishes before silking, it causes enormous damage to crop in terms of grain yield (Nwanosike *et al.*, 2015). TLB affects the photosynthesis resulting in more than 50 per cent reduction in grain yield (Raymundo and Hooker, 1981; Perkins and Pederson, 1987: Tefferi *et al.*, 1996). Thus, there is need to enhance the yield levels of maize sustainability to meet the future demand by reducing the losses due to different stresses.

Disease management strategies like deep ploughing followed by exposure to sun during summer, crop rotation, fungicide application and planting of resistant hybrids have been recommended to reduce the losses. Among these practices, planting of resistant cultivars can effectively reduce the rate of disease development and is widely recommended. Host plant resistance is considered as most practical and economically viable method of plant disease management. Hence, it is most important to carry out screening under artificial epiphytotic conditions to identify resistant sources and utilize in breeding of disease resistant hybrids. The resistant varieties are not only environmentally friendly but also suitable to adopt at farmers level (Yousuf *et al.*, 2018 and Gulzar *et al.*, 2018). Identification of stable sources of TLB resistance requires continuous screening of germplasm across the locations and over the years. Thus keeping in view the above points, the present study was carried out to identify resistant sources against TLB. In the present study, 237 maize inbred lines were phenotyped for reaction to TLB under artificially inoculated field conditions at multiple location and over years. The sources of resistance identified based on multi-location and over years data would be useful in further improvement of maize by development of TLB resistant hybrids and populations.

Materials and methods

Genetic material

Disease phenotyping trial comprising 237 newly developed maize inbred lines along with resistant (LM 13, CL 4) and local susceptible (CM 202, CM 600) inbred line as check were evaluated against TLB under artificial epiphytotic conditions. The trial was conducted during kharif season of 2017 and 2018 at TLB hot-spot locations, *viz*., Dharwad, Mandya, Almora and Bajaura. In 2017, the trial was conducted in randomized complete block design whereas in 2018 it was conducted in alpha design. The trial in Dharwad and Mandya was conducted in two replications, whereas in Almora and Bajaura, it was conducted in one replication. The row length of each entry was of three metre and the distance between rows and plant to plant was maintained at 75 × 20 cm and the recommended agronomic practices were followed to establish good crop stand at each location. Two seeds per hill were sown and then thinned after 15 days after germination with one seedling per hill to maintain the optimum plant population of 13-15 plants in each row.

Pathogen isolation

The fungus, *Exserohilum turcicum* (Pass.) Leonard and Suggs was isolated at each locations separately and independently from the infected maize plant leaf tissue by following standard tissue isolation technique (Wathaneeyawech *et al.*, 2015). The necrotized leaf bits along with some healthy portions from infected maize plant leaves were surface sterilized in 1:1000 mercuric chloride solutions for 30 seconds and washed thoroughly thrice in sterile distilled water to remove the traces of mercuric chloride. The surface sterilized leaf bits were aseptically transferred to petri dish, containing Potato Dextrose Agar (PDA). Petri dishes were incubated at room temperature (25±1°C) for a week and observed periodically for fungal growth. The growth of the fungus was conspicuous after 24 hours of incubation. The pure colonies which developed from the bits were transferred to PDA slants and incubated at room temperature.

Maintenance of the culture

The cultures of the fungus were sub-cultured on PDA slants and kept in laboratory at 28±1°C for 15 days. Such mother culture slants were preserved at 5°C in refrigerator.

Mass multiplication of inoculum

The mass multiplication of the pathogen, *E. turcicum* was prepared on sterilized sorghum grain culture as suggested by Joshi *et al*. (1969).

Inoculation

Spore suspension of the isolate of *E. turcicum* from 20 days old pure culture was prepared by washing the conidia with distilled water at each location separately and independently. The spore concentration was measured by haemocytometer and maintained at 3×10^5 spore ml^{-1}. Equal volume of spore suspension of each isolate was mixed and sprayed by using atomizer at three to four leaf stage maize plants and humidity was maintained by spraying water at regular interval (Ahangar, *et al.,* 2016). Each and every plant of the entry in a trial were inoculated with spore suspension. The inoculation was repeated after two days, thus the inoculation was done twice in an interval of two days to ensure proper inoculation.

Disease assessment

The disease reaction was recorded by using 1 to 9 scales as suggested by Hooda *et al.* (2018) (Table 1). Recording of disease score was commenced from six-eight leaves stage (approximately 45 days after planting) and it was continued on weekly basis for 6 weeks. The genotypes showing disease score between 0.0–3.0 were considered as resistant (R), 3.1-5.0 as moderately resistant (MR), 5.1-7.0 as moderately susceptible (MS), >7.0 as susceptible (S). The disease reaction was recorded on five plants in the middle of the row and it was averaged to calculate TLB overall mean disease score of each line.

Data analysis

The disease phenotyping data generated across multiple locations and over the years was analysed separately for each locations. The data generated at Dharwad and Mandya were subjected to combined analysis across locations and over years. The analysis was performed using R programming language RG×E (Dia *et al*., 2017) in R studio (Version 1.1.463 – © 2009-2018 RStudio, Inc.). However, for the data generated at Almora and Bajaura was taken as such based on the mean of the lines as the experiments were conducted without replication.

Table 1. Disease scale for rating Turcicum leaf blight (TLB) incidence in maize

Rating scale	Degree of infection (per cent DLA*)	PDI**	Disease reaction
1.0	Nil to very slight infection (≤10%).	≤11.11	Resistant (R)
2.0	Slight infection, a few lesions scattered on two lower leaves (10.1-20%).	22.22	(Score: ≤3.0)
3.0	Light infection, moderate number of lesions scattered on four lower leaves (20.1-30%).	33.33	(PDI: ≤33.33)
4.0	Light infection, moderate number of lesions scattered on lower leaves, a few lesions scattered on middle leaves below the cob (30.1-40%).	44.44	Moderately resistant (MR) (Score: 3.1–5.0)
5.0	Moderate infection, abundant number of lesions scattered on lower leaves, moderate number of lesions scattered on middle leaves below the cob (40.1-50%).	55.55	(PDI: 33.34-55.55)
6.0	Heavy infection, abundant number of lesions scattered on lower leaves, moderate infection on middle leaves and a few lesions on two leaves above the cob (50.1-60%).	66.66	Mod. susceptible (MS) (Score: 5.1-7.0)
7.0	Heavy infection, abundant number of lesions scattered on lower and middle leaves and moderate number of lesions on two to four leaves above the cob (60.1-70%).	77.77	(PDI: 55.56-77.77)
8.0	Very heavy infection, lesions abundant scattered on lower and middle leaves and spreading up to the flag leaf (70.1-80%).	88.88	Susceptible (S) (Score: >7.0)
9.0	Very heavy infection, lesions abundant scattered on almost all the leaves, plant prematurely dried and killed (>80%).	99.99	(PDI: >77.77)

*DLA- Diseased leaf area; **Percent disease index (PDI)

Results and discussion

Symptomatology

Exserohilum turcicum (Pass.) Leonard and Suggs is capable to infect maize plants during all the stages of crop growth, right from seedling stage to maturity. The initial symptoms appeared as slightly oval, water soaked, small elliptical greyish green colour spots on the leaves. As the disease progressed, the greyish green spots enlarged and extended along the length of leaf. The elongated spindle shaped necrotic lesions later turned straw colour in the centre with dark margins. The lesions first appeared on lower leaves and later spread to upper leaves with increase in size, as the plants develop. The straw coloured centre of the lesion becomes darker during sporulation. Spores of the *E. turcicum* developed abundantly on both sides of the spots. The individual lesions measured around 2.5' to 15' cm in length and 1' to 4' cm in width. Severely infected leaves turned to sickle shape and broke at the point of mid-rib. The diseased plants showed stunted growth as compared to healthy plants. The disease progressed upwards till maturity and affected photosynthetically active leaf area, giving the plant a scorched or burnt appearance and lead to premature killing of leaves. The diseased plants yield small sized, curved, partially filled malformed ears with irregular kernel rows and shrivelled grains.

The analysis of variance across locations and over years showed the significant difference for genotypes, year x locations interaction but no significant difference for locations and year x genotypes interaction, which indicates that differential reaction of genotypes to TLB over years within location.

The mean TLB disease score data of the susceptible checks ranged from 6.0 to 9.0 on 1-9 rating scale with the mean score of 7.9, indicating the adequate disease pressure in artificially inoculated plots across the locations and years (Table 3). Among the four locations, Dharwad recorded the highest average TLB incidence (5.2) over two years, it was followed by Mandya (3.4) (Table 3). The mean disease incidence at Dharwad during 2017 and 2018 was 5.27 and 5.14 respectively, whereas it was 2.69 and 4.13 at Mandya in the respective years. This indicates that the TLB pressure was relatively higher at Dharwad as compared to Mandya. Further the TLB incidence at Dharwad was relatively the same in both the years whereas at Mandya it was relatively higher during 2018 as compared to 2017. This indicates the role of environment for development of disease severity. The mean disease incidence across locations (Mandya and Dharwad) in 2017 and 2018 was 3.98 and 4.63, respectively.

The overall mean TLB score calculated across locations over two years was considered to classify inbred lines into resistant, moderately resistant, moderately susceptible and susceptible inbred lines. Out of 237 inbred lines, 41 inbred lines were resistant with TLB score <3.0, 181 lines were moderately resistance with TLB score 3.1 -5.0 and 15 inbred lines were moderately susceptible with TLB score 5.1 to 7.0 (Table 2).

The genotypes showed differential reaction against TLB across locations and over the years; 53 and 44 inbred lines were found resistant based on the mean TLB score across locations in 2017 and 2018, respectively. Mean TLB score over years at different locations was considered for location-wise classification of inbred lines with differential response to TLB. Based on the mean disease score over two years, 100 inbred lines were found to be moderately resistant, 128 lines moderately susceptible and 9 lines susceptible at Dharwad. Similarly, at Mandya, 91 lines were resistant, 128 lines were moderately resistant, 18 lines were moderately susceptible. In North Hill Zone (NHZ) at Almora, 148 inbred lines were resistant, 68 lines were moderately resistant, 20 lines moderately susceptible and one line was susceptible, whereas at Bajaura location of the same Zone, 173 inbred lines were resistant, 61 lines were moderately resistant, 3 lines were moderately susceptible and no susceptible line was reported (Figure 1).

The results showed that inbred lines expressed differential response to TLB across locations, suggesting variability either in environments or in the pathogen. The higher incidence of TLB at Dharwad and Mandya indicates that the strains from that vicinity might be more virulent. In the present study, 237 maize germplasm were evaluated in different hot-spot locations for TLB to identify elite lines that have stable and broad based resistance against TLB across geographical locations in India. The disease phenotyping trial was conducted for two year (2017-2018), at four locations, has identified 41 inbred lines (Table 2) with resistance to TLB. Out of these 41 lines, 33 inbred lines (IMLSB-57-2, IMLSB-119-1, IMLSB-143-1, IMLSB-205-1, IMLSB-244-1, IMLSB-246-2, IMLSB-266-2, IMLSB-306-1, IMLSB-317-1, IMLSB-334B-1, IMLSB-343-1, IMLSB-343-2, IMLSB-380-1, IMLSB-428-2, IMLSB-446-2, IMLSB-475-2, IMLSB-568-2, IMLSB-748-1, IMLSB-801-2, IMLSB-807-1, IMLSB-825-2, IMLSB-955-1, IMLSB-956-2, IMLSB-975-2, IMLSB-976-2, IMLSB-1018-1, IMLSB-1041-4-1, IMLSB-1043-1-1, IMLSB-1299-1, IMLSB-1299-7, IMLSB-1381, IMLSB-2034, IMLSB-2136) showed resistant reaction on pooled

Table 2. Classification of maize inbred lines based on pooled location/year data of disease reaction against *E. turcicum* under artificially inoculated field conditions

Disease score	Reaction	Inbred line	No. of inbreds
<3.0	Resistant (R)	IMLSB-57-2, IMLSB-119-1, IMLSB-143-1, IMLSB-205-1, IMLSB-244-1, IMLSB-246-2, IMLSB-266-2, IMLSB-282-2, IMLSB-306-1, IMLSB-310-2, IMLSB-317-1, IMLSB-334B-1, IMLSB-343-1, IMLSB-343-2, IMLSB-380-1, IMLSB-428-2, IMLSB-446-2, IMLSB-475-2, IMLSB-568-2, IMLSB-748-1, IMLSB-801-2, IMLSB-807-1, IMLSB-825-2, IMLSB-955-1, IMLSB-956-2, IMLSB-975-2, IMLSB-976-2, IMLSB-1018-1, IMLSB-1041-4-1, IMLSB-1043-1-1, IMLSB-1046-3-1, IMLSB-1047-1-1, IMLSB-1299-1, IMLSB-1299-7, IMLSB-1376, IMLSB-1381, IMLSB-2034, IMLSB-2051, IMLSB-2119, IMLSB-2136, IMLSB-2166.	41
3.1 - 5.0	Moderately	IMLSB-2-1, IMLSB-5-2, IMLSB-6-1, IMLSB-13-2, IMLSB-15-2, IMLSB-49-2, IMLSB-52-2, IMLSB-56-1, IMLSB-58-2, IMLSB-61-2, IMLSB-81-1, IMLSB-92-1, IMLSB-95-A-1, IMLSB-100, IMLSB-102-1, IMLSB-106-2, IMLSB-114-1, IMLSB-121-2, IMLSB-123-1, IMLSB-126-2, IMLSB-137-2, IMLSB-139-1, IMLSB-141-2, IMLSB-142-1, IMLSB-145-2, IMLSB-147-1, IMLSB-154-1, IMLSB-160-1, IMLSB-162-2, IMLSB-164-1, IMLSB-170-1, IMLSB-171-2, IMLSB-173-2, IMLSB-178-1, IMLSB-181-1, IMLSB-183-1, IMLSB-184-1, IMLSB-196-2, IMLSB-201-1, IMLSB-207-2, IMLSB-208-2, IMLSB-210-A-2, IMLSB-215-1, IMLSB-218-1, IMLSB-219-1, IMLSB-219-2, IMLSB-224-1, IMLSB-228-1, IMLSB-231-2, IMLSB-238-1, IMLSB-246-1, IMLSB-253-1, IMLSB-269-1, IMLSB-274-1, IMLSB-280-2, IMLSB-288-1, IMLSB-291-1, IMLSB-301-2, IMLSB-310-1, IMLSB-313-1, IMLSB-324-2, IMLSB-325-1, IMLSB-328-2, IMLSB-332-B-1, IMLSB-339-2, IMLSB-342-1, IMLSB-343-3, IMLSB-375-1, IMLSB-375-2, IMLSB-376-2, IMLSB-389-1, IMLSB-393-1, IMLSB-394-2, IMLSB-401-1, IMLSB-406-1, IMLSB-420-1, IMLSB-427-1, IMLSB-431-2, IMLSB-435-3, IMLSB-446-1, IMLSB-448-2, IMLSB-449-2, IMLSB-454-2, IMLSB-455-1, IMLSB-457-2, IMLSB-466-1, IMLSB-466-2, IMLSB-472-2, IMLSB-489-1, IMLSB-507-1, IMLSB-507-2, IMLSB-511-1, IMLSB-519-2, IMLSB-539-2, IMLSB-544-2, IMLSB-554-2, IMLSB-563-1, IMLSB-570-1, IMLSB-571-2, IMLSB-582-2, IMLSB-592-1, IMLSB-596-1, IMLSB-617-1, IMLSB-618-1, IMLSB-625-1, IMLSB-665-1, IMLSB-678-1, IMLSB-707-1, IMLSB-719-1, IMLSB-756-2, IMLSB-758-2, IMLSB-763-3, IMLSB-764-2, IMLSB-777-2, IMLSB-791-2, IMLSB-794-1, IMLSB-794-2, IMLSB-800-2, IMLSB-810-2, IMLSB-812-2, IMLSB-814-2, IMLSB-882-1, IMLSB-883-1, IMLSB-885-2, IMLSB-921-3, IMLSB-941-2, IMLSB-956-1, IMLSB-960-2, IMLSB-1000-2, IMLSB-1022-2, IMLSB-1025-1, IMLSB-1041-1-1, IMLSB-1052-1-2, IMLSB-1053-1-2, IMLSB-1058-7-2, IMLSB-1060-3, IMLSB-1060-8-1, IMLSB-1064-1-2, IMLSB-1070-2, IMLSB-1084-A-1, IMLBG-1178, IMLBG-1179, IMLSB-1299-4, IMLSB-1299-5, IMLSB-1299-10, IMLSB-1300, IMLSB-1333, IMLSB-1382, IMLSB-2001, IMLSB-2003, IMLSB-2010, IMLSB-2012, IMLSB-2013, MLSB-2016, IMLSB-2025, IMLSB-2028, IMLSB-2037, IMLSB-2049, IMLSB-2052, IMLSB-2062, IMLSB-2067, IMLSB-2068, IMLSB-2077, IMLSB-2078, IMLSB-2083, IMLSB-2092, IMLSB-2100, IMLSB-2101, IMLSB-2106-1, IMLSB-2106-2, IMLSB-2146, IMLSB-2159, IMLSB-2162.	181
5.1- 7.0	Moderately Susceptible (MS)	IMLSB-43-2, IMLSB-46-1, IMLSB-68-2, IMLSB-105-1, IMLSB-118-2, IMLSB-501-1, IMLSB-572-2, IMLSB-574-2, IMLSB-588-1, IMLSB-591-2IMLSB-682-2, IMLSB-758-1, IMLSB-1059-2-2, IMLSB-1063-1-2, IMLSB-1067-1-1.	15
>7.0	Susceptible (S)	Nil	0

mean (across years and locations) and at three locations (Mandya, Almora and Bajaura), another 8 inbred lines (IMLSB-282-2, IMLSB-310-2, IMLSB-1046-3-1, IMLSB-1047-1-1, IMLSB-1376, IMLSB-2051, IMLSB-2119, IMLSB-2166) showed resistant reaction on pooled mean (across years and locations) and at two locations (Almora and Bajaura) (Table 3).

The graphical representation of location wise disease reaction of different 237 inbred lines is given in Figure 1. Similar kind of study using different set of inbred lines was reported by Hooda *et al*. (2012). The findings of the present study are in agreement with Hooda *et al*. (2012) in which 200 maize lines were screened against 10 major diseases, out of which 16 inbred lines were found resistant

Table 3. Turcicum leaf blight incidence in resistant/ moderately resistant inbreds of maize at different locations in India (2017-2018)

Name of genotype	Location and TLB incidence score on 1-9 rating scale					
	Dharwad	Mandya	Almora	Bajaura	Pooled disease mean score	Reaction
A. Resistant genotypes at three locations and across locations (mean basis)						
IMLSB-57-2	4.0	1.6	3.0	2.5	2.8	R
IMLSB-119-1	4.4	2.6	1.0	2.5	2.6	R
IMLSB-143-1	4.2	2.5	2.5	2.5	2.9	R
IMLSB-205-1	4.3	1.7	2.0	3.0	2.8	R
IMLSB-244-1	4.4	2.6	2.5	2.5	3.0	R
IMLSB-246-2	4.6	2.4	2.0	2.5	2.9	R
IMLSB-266-2	4.9	2.9	1.0	2.5	2.8	R
IMLSB-306-1	4.2	2.0	1.5	3.0	2.7	R
IMLSB-317-1	4.2	1.8	2.5	3.0	2.9	R
IMLSB-334B-1	3.4	2.5	1.5	3.0	2.6	R
IMLSB-343-1	5.1	2.1	1.5	2.0	2.7	R
IMLSB-343-2	4.4	2.6	1.0	2.5	2.6	R
IMLSB-380-1	5.0	2.8	1.0	2.0	2.7	R
IMLSB-428-2	4.9	2.5	1.5	2.5	2.8	R
IMLSB-435-3	4.3	2.6	2.5	2.5	3.0	R
IMLSB-446-2	4.4	2.6	1.0	2.0	2.5	R
IMLSB-475-2	5.4	1.8	2.0	3.0	3.0	R
IMLSB-748-1	5.0	2.2	1.5	2.5	2.8	R
IMLSB-801-2	3.2	2.7	1.0	3.0	2.5	R
IMLSB-807-1	4.9	2.3	2.0	2.5	2.9	R
IMLSB-825-2	3.8	2.2	1.5	3.0	2.6	R
IMLSB-955-1	4.3	2.9	1.5	3.0	2.9	R
IMLSB-956-2	3.9	2.4	2.0	3.0	2.8	R
IMLSB-975-2	4.2	2.3	1.0	2.5	2.5	R
IMLSB-976-2	5.5	2.1	1.0	2.5	2.8	R
IMLSB-1018-1	5.1	2.9	1.5	2.5	3.0	R
IMLSB-1041-4-1	3.4	2.7	1.5	2.0	2.4	R
IMLSB-1043-1-1	4.4	2.4	2.0	3.0	2.9	R
IMLSB-1299-1	6.5	2.5	0.5	2.5	3.0	R
IMLSB-1299-7	4.0	1.8	3.0	2.5	2.8	R
IMLSB-1381	5.2	1.8	2.0	2.5	2.9	R
IMLSB-2034	5.2	2.1	1.5	2.5	2.8	R
IMLSB-2136	4.0	3.0	1.5	2.5	2.7	R
Resistant Check	4.2	2.2	1.0	2.0	2.4	R
Susceptible check	8.2	7.4	7.5	8.3	7.9	S
Mean	*4.5*	*2.4*	*1.7*	*2.6*	*2.8*	
B. Resistant genotypes at two locations and across locations (mean basis)						
IMLSB-282-2	3.9	3.1	0.5	2.5	2.5	R
IMLSB-310-2	3.8	3.2	1.5	3.0	2.9	R
IMLSB-1046-3-1	3.9	3.6	0.5	2.5	2.6	R
IMLSB-1047-1-1	4.1	3.0	2.0	2.0	2.8	R
IMLSB-1376	4.0	3.3	1.5	3.0	2.9	R
IMLSB-2051	3.7	3.3	1.5	3.0	2.9	R
IMLSB-2119	4.1	3.1	1.5	2.0	2.7	R
IMLSB-2166	4.9	3.1	1.0	3.0	3.0	R
Resistant Check	4.2	2.2	1.0	2.0	2.4	R
Susceptible check	8.2	7.4	7.5	8.3	7.9	S
Mean	*4.1*	*3.2*	*1.3*	*2.6*	*2.8*	
Location mean	*5.2*	*3.4*	*3.1*	*3.1*	*3.7*	

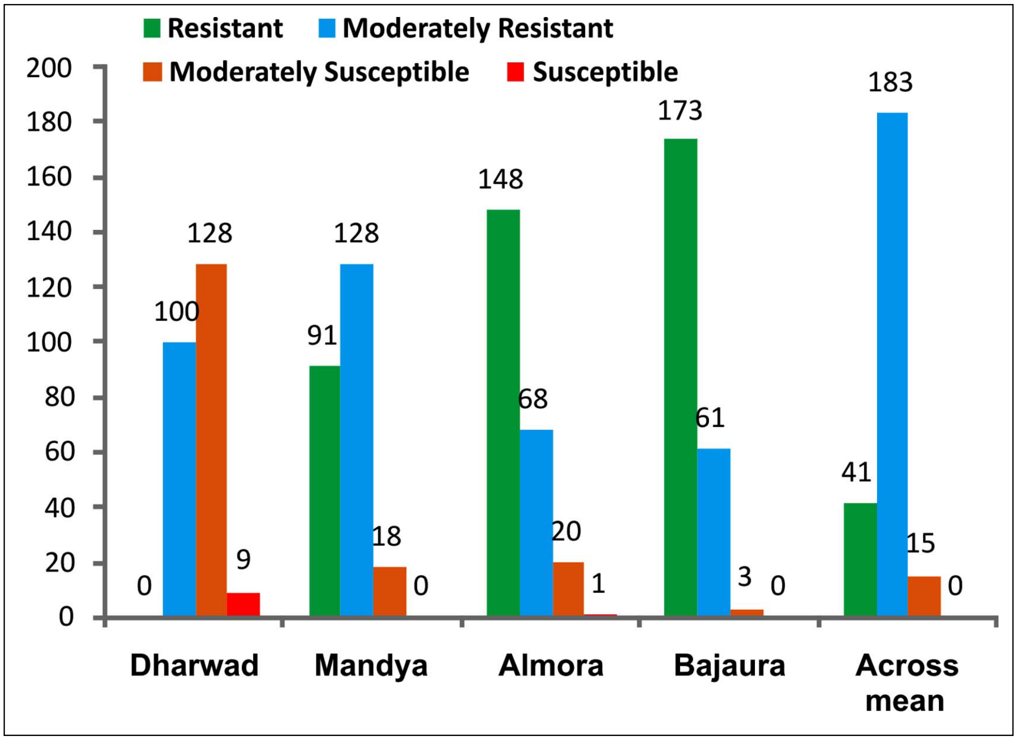

Figure 1. Distribution of 237 maize inbred lines for levels of TLB at 4 locations of India Rating of germplasm reaction: 1-9 (≤3.0 = Resistant; 3.1-5.0 = Moderately Resistant; >5.1-7.0 Moderately Susceptible and >7.0 = Susceptible)

against turcicum leaf blight. Bindhu *et al.* (2018) identified 19 inbred maize lines as resistant out of 128 lines screened for TLB at Mandya. In another study (Mallikarjuna *et al.*, 2018) it was reported that out of 135 inbred lines screened for TLB, 34 inbreds were found moderately resistant, 73 were moderately susceptible and 29 were susceptible. Previous studies have showed that in general, moderately resistant inbreds were greater in number followed by resistant and moderately susceptible. The information generated in this study and resistant lines identified can be used successfully in maize improvement programme in India.

Conclusion

The present study has identified 41 TLB resistant maize inbred lines based on TLB disease phenotyping trial conducted across four locations over two years. The TLB resistant inbred lines namely IMLSB-57-2, IMLSB-119-1, IMLSB-143-1, IMLSB-205-1, IMLSB-244-1, IMLSB-246-2, IMLSB-266-2, IMLSB-282-2, IMLSB-306-1, IMLSB-310-2, IMLSB-317-1, IMLSB-334B-1, IMLSB-343-1, IMLSB-343-2, IMLSB-380-1, IMLSB-428-2, IMLSB-446-2, IMLSB-475-2, IMLSB-568-2, IMLSB-748-1, IMLSB-801-2, IMLSB-807-1, IMLSB-825-2, IMLSB-955-1, IMLSB-956-2, IMLSB-975-2, IMLSB-976-2, IMLSB-1018-1, IMLSB-1041-4-1, IMLSB-1043-1-1, IMLSB-1046-3-1, IMLSB-1047-1-1, IMLSB-1299-1, IMLSB-1299-7, IMLSB-1376, IMLSB-1381, IMLSB-2034, IMLSB-2051, IMLSB-2119, IMLSB-2136 and IMLSB-2166 can be exploited as source of resistance to evolve agronomically desirable, high yielding hybrids with inbuilt TLB resistance. Further, some of the inbred lines can also be used for identification of genomic regions determining TLB resistance through QTL mapping.

References

Ahangar, A. M., Bhat, Z. A., Sheikh, F. A., Dar, Z. A., Lone, A. A., Hooda, K. S. & Reyaz, M. (2016). Pathogenic variability in *Exserohilum turcicum* and identification of resistant sources to turcicum leaf blight of maize (*Zea mays* L.). *Journal of Applied and Natural Science*, **8**(3): 1523-1529.

Bindhu, K. G., Pandurangegowda, K. T., Madhuri, R. & Lohithaswa, H. C. (2018). Identification of resistant sources to turcicum leaf blight caused by *Exserohilum turcicum* (pass.) Leonard and Suggs in maize (*Zea mays* l.). *Int. J. Sci. & Nature,* **7**(3): 569-574.

De-Rossi, R. L., Reis, M. L. & Brustalin, R. (2015). Fungal baseline for mycelia sensitivity of *Exserohilum turcicum*, causal agent of northern corn leaf blight. *Summa Phytopathologica,* **41**(1): 25-30.

Dia, M., Wehner, T. C. & Arellano, C. (2017). RGxE: An R Program for Genotype x Environment Interaction Analysis. *American Journal of Plant Sciences,* **8**: 1672-1698. doi: 10.4236/ajps.2017.87116.

FAOSTAT (2017) http://www.fao.org/faostat/en.

Ferguson, L. M. & Carson, M. L. (2004). Spatial diversity of *Setosphaeria turcica* sampled from the Eastern United States. *Phytopathol*., **94**: 892-900.

Gulzar, S., Dar, Z. A., Ahangar, M. A., Lone, A. A., Bhat, M. A., Kamal-ud-din, M. A. & Majid, A. (2018). Identification of reaction pattern to turcicum leaf blight among early maturing maize (*Zea mays* L.) inbred lines. *Journal of Pharmacognosy and Phytochemistry*, **7**(1): 1657-1660.

Hooda, K. S., Sekhar, J. C., Chikkappa, G. K., Kumar, S., Pandurangegowda, K. T., Sreeramsetty, T. A., Sharma, S. S., Kaur, H., Gogoi, R., Reddy, R. R., Kumar, P., Singh, A., Devlash, R. K. & Chandrashekara, C. (2012). Identifying sources of multiple disease resistance in maize, *Maize J.*, **1**(1): 82–84.

Hooda, K. S., Bagaria, P. K., Khokhar, M., Kaur, H. & Rakshit, S. (2018). Mass Screening Techniques for Resistance to Maize Diseases. ICAR-Indian Institute of Maize Research, PAU Campus, Ludhiana, 93 p.

Joshi, L. M., Goel, L. B. & Renfro, B. L. (1969). Multiplication of inoculum of *Helminthosporium turcicum* on sorghum seeds. *Indian Phytopath.*, **22**: 146-148.

Mallikarjuna, N., Puttaramanaik, N., Kumar, K., Raveendra, H. R. & Kumar, V. B. S. (2018). Evaluation of maize germplasm for resistance to turcicum leaf blight. *Int. J. Pure App. Biosci.*, **6** (2): 1601-1605.

Nwanosike, M. R. O., Mabagala, R. B. & Kusolwa, P. M. (2015). Effect of Northern Leaf Blight (*Exserohilum Turcicum*) Severity on Yield of Maize (*Zea mays* L.) in Morogoro, Tanzania. *Int. J. Sci. and Res.*, **4**(9): 465-474.

Perkins, J. M. and Pederson, W. L. (1987). Disease treatment and yield loss associated with Northern leaf blight of corn. *Plant Diseases*, **71**: 940-943.

Raymundo, A. D. & Hooker, A. C. (1981). Measuring relationship between Northern leaf blight of maize and yield losses. *Plant Disease*, **65**: 325-327.

Reddy, T. R., Reddy, P. N. & Reddy, R. R. (2013). Pathogenic variability of isolates of *Exserohilum turcicum*, incitant of leaf blight of maize. *Indian Journal of Plant Protection*, **41**(1): 72-75.

Tefferi, A., Hulluka, M. & Welz, H. G. (1996). Assessment of damage and grain yield loss in maize caused by northern leaf blight in western *Ethiopia. J. Plant Dis. Prot*., **103**: 353-363.

Wathaneeyawech, S., Sirithunya, P., & Smitamana, P. (2015). Collections, isolations, morphological study of Exserohilum turcicum and screening resistant varieties of corn to Northern Corn Leaf Blight disease. *International Journal of Agricultural Technology*, **11**(4): 937-952.

Yousuf, N., Dar, S. A., Lone, A. A., Ahanger, M. A., Dar, Z. A., Bhat, M. A., Shikari, A., Sofi, P.A., Bhat, Z.A. & Gulzar, S. (2018). Field screening of maize (*Zea mays* L.) landraces for resistance against turcicum leaf blight (TLB) under temperate conditions. *Int. J. Chemical Studies*, **6**(1): 333-337.

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RESEARCH PAPER

Genetic divergence and association studies in inbred lines of maize

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Abstract The present investigation was carried out using 39 inbred lines of maize to analyze their genetic divergence, correlation and path coefficients with a view to select superior high yielding inbreds for utilization in further breeding program. The 39 inbred lines were planted in randomized block design with two replications and observations were recorded on 16 morphological traits. Statistical analysis was carried out using SAS v 9.3 and Windostat v 9.3. Cluster analysis based on UPGMA (un-weighted pair group method using arithmetic averages) classified the 39 inbreds into seven clusters representing high amount of genetic variability among the inbred lines. Maximum number of genotypes (17) were found in cluster VI and minimum number of genotypes were present in cluster II and cluster V, containing single genotype each. Mean performance for grain yield per plant was highest for cluster I whereas cluster III showed lowest mean performance for grain yield per plant. Selection for the genotypes belonging to the clusters showing higher mean performance for yield and yield attributing traits would be rewarding for their further utilization in breeding programme. Correlation studies revealed significant association of cob diameter, number of kernel rows per cob, cob length and number of cobs per plot with grain yield per plant indicating the importance of these traits in selection for yield. Path coefficient analysis put forth the direct and positive effect of number of kernels per row, cob diameter, number of kernel rows per cob and cob length on grain yield per plant indicating the effectiveness of direct selection.

Keywords: Association · Genetic divergence · Inbred · Maize

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Introduction

Maize is one of the important crop in India, next to wheat and rice, not only in terms of acreage but also in context of its wider adaptability to diverse agro-climatic zones. It is a wonderful cash crop where each plant part has some economic value. The grains, leaves, stalks, tassels and even pith are being used for the production of many food and non-food products. Further, corn oil, corn starch, corn protein etc. are some important corn products having high industrial utility. With growing industrial importance of maize, development of high yielding superior varieties with good quality parameters has become an essentially important part of any maize breeding program.

Genetic divergence plays an important role in framing a successful breeding program. Maize, being a cross pollinated plant, contains huge amount of genetic variability. Genetic diversity can be best characterized by molecular markers but the importance of morphological traits cannot be neglected as it plays important role in determining the agronomic value and taxonomic classification of maize as well as other crops (Ortiz *et al.*, 2008). Further, morphological traits are important in the handling and maintenance of Plant Genetic Resources and Plant Breeders' Right system (Babic *et al.*, 2016). For efficient selection of high yielding genotypes association studies between yield and its component traits helps in identifying the character or character combinations having high influence on yield. In addition, path analysis provides a better understanding of direct and indirect effect of different characters on grain yield. Hence, the present investigation has been designed to study genetic diversity, correlation and path analysis in maize inbred lines maintained at Department of Genetics and Plant Breeding, Institute of Agricultural Science, Banaras Hindu University.

Materials and methods

The experimental material used in the study comprised of 39 inbred lines, listed in Table 1, maintained under AICRP on maize in the department of Genetics and Plant Breeding, Institute of Agricultural Sciences, BHU, Varanasi. All the 39 inbred lines were planted in Randomized Block Design (RBD) with two replications in single row of 3 m length having row to row spacing of 60 cm and plant to plant spacing of 20 cm. The crop was raised as per recommended package of practices. Observations were recorded on five randomly selected plants for following traits: PH1: plant height at three leaves stage, PH2: plant height at six leaves stage, PH3: plant height at maturity, GT: days to 50% germination, DTT: days to 50% tasseling, DTS: days to 50% silking, ASI: anthesis-silking interval, TL: length of tassel (cm), PP: plant population per plot, NCPP: number of cob per plant, CL: length of cob in cm, CW: width of cob, NKRPC: number of kernel row per cob, NKPR: number of kernel per row, GW: 100 grain weight, GYPP: grain yield per plant (g). The data was subjected to analysis using SAS v 9.3 for assessment of genetic diversity by adopting hierarchical clustering method; UPGMA (un-weighted pair group method using arithmetic averages) concept of dissimilarity matrices however, correlation and path coefficients were estimated by using Windostat v 9.3 software.

Table 1. List of inbred lines used in the study

S.no.	Inbred lines	S. no.	Inbred lines
1	HUZM-36	21	HUZM-716
2	HUZM-58	22	HUZM-719
3	HUZM-148	23	HUZM-721
4	HUZM-350-1	24	HUZM-1
5	HUZM-352-1	25	HUZM-2
6	HUZM-355	26	HUZM-3
7	HUZM-365	27	HUZM-4
8	HUZM-461	28	HUZM-5
9	HUZM-531	29	HUZM-6
10	HUZM-582	30	HUZM-723
11	HUZM-583-2	31	HUZM-217
12	HUZM-628	32	HUZM-72
13	HUZM-655	33	HUZM-152
14	HUZM-253	34	HUZM-186
15	HUZM-329	35	HKI-287
16	HUZM-704	36	HKI-209
17	HUZM-707	37	SEED1105
18	HUZM-708	38	LM-10
19	HUZM-713	39	CML-49
20	HUZM-714		

Result and discussion

Genetic diversity assessment

The cluster analysis based on 16 morphological traits using UPGMA method classified the 39 inbred lines into seven clusters (Figure 1). The cluster II and V contained only one genotype each. Whereas, cluster VI possessed the maximum number of genotypes (17) followed by cluster VII (9). Cluster II, III and IV contained two, four and five genotypes, respectively. Details of genotypes belonging to different clusters are presented in Table 2.

Mean values of seven clusters for sixteen traits have been presented in Table 3. Cluster I comprised of two genotypes and characterized by the highest grain yield per plant (91.33 g), highest number of cobs per plot (15.50), highest number of kernels per row (26), highest cob diameter (4.33) and lowest ASI (1.00) among clusters. The genotype belonging to cluster II (HUZM-152) had highest plant height at maturity (135.0 cm), highest tassel length (37.0 cm) and lowest days to 50% germination (11), days to 50 % tasseling (91) and days to 50% silking (93) i.e. early maturity group. Cluster III was characterized by lowest grain yield per plant (9.76 g), cob diameter (2.68 cm), number of kernel rows per cob (7.25), number of kernels per row (5.88) and highest days to 50% tasseling (108) and days to 50% silking (110). Cluster IV is characterized by highest 100 grain weight (24.92g) and cob length (15.16 cm). Cluster V comprises of maximum mean plant height at three leaves stage (8.25) cm, highest plant population per row (16) and highest number of kernel rows per cob (16). Whereas, cluster VII exhibited lowest mean performance for plant height at six leaves stage (9.86), plant population per row (11.06) and highest mean performance for days to 50% germination (14 days).

Genotypes from the cluster showing desirable performance can be used in further breeding programme for crop improvement. Hence, it is worthy to note that in calculating cluster means, the superiority of particular genotype with respect to a given character gets diluted by other genotypes that are related and grouped in the same

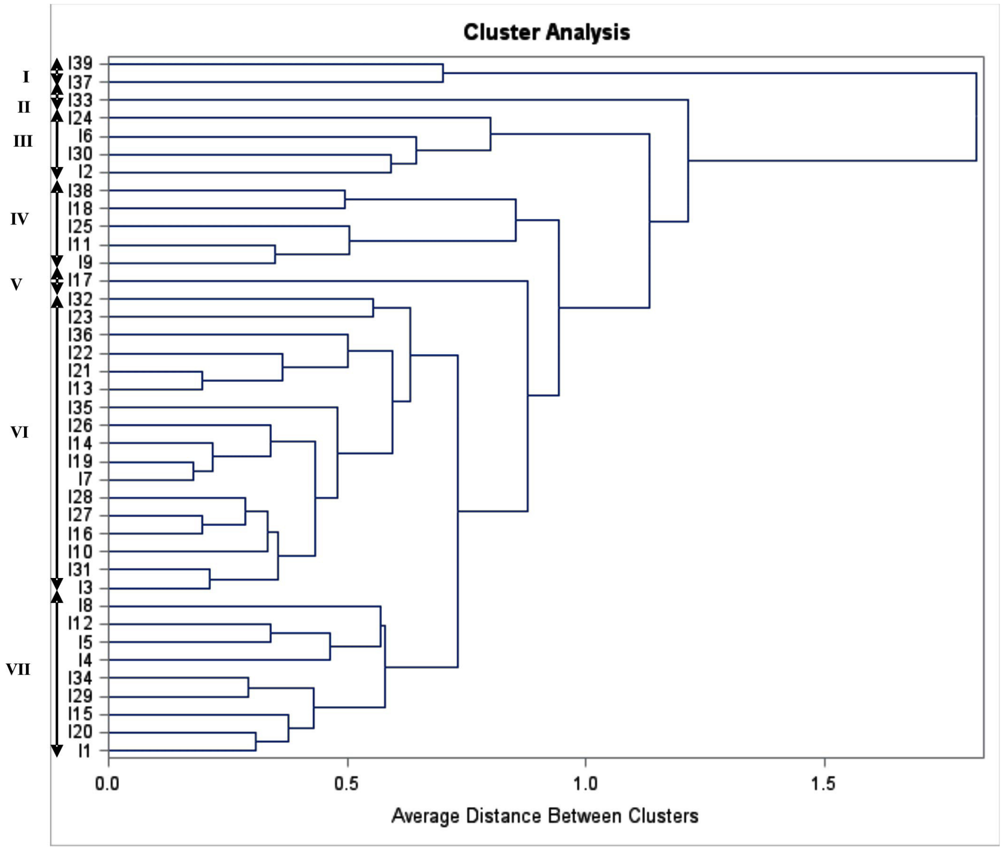

Figure 1. Dendrogram (Cluster diagram) showing different cluster and sub-cluster for 39 genotypes

Table 2. Grouping of 39 Maize inbred lines

Cluster	No. of genotypes	Name of genotypes
Cluster I	2	SEED-1105, CML-49
Cluster II	1	HUZM-152
Cluster III	4	HUZM-58, HUZM-355, HUZM-1, HUZM-723
Cluster IV	5	LM-10, HUZM-2, HUZM-708, HUZM-583-2, HUZM-531
Cluster V	1	HUZM-707
Cluster VI	17	HUZM-148, HUZM-582, HUZM-655, HUZM-253, HUZM-704, HUZM-707, HUZM-713, HUZM-716, HUZM-719, HUZM-2, HUZM-3, HUZM-4, HUZM-5, HUZM-721, HUZM-217, HUZM-72, HKI-209
Cluster VII	9	HUZM-36, HUZM-350-1, HUZM-461, HUZM-628, HUZM-329, HUZM-714, HUZM-6, HUZM-186, HUZM-352-1

cluster but are inferior or intermediary for that character in question. One can also think of selecting parents based on extent of genetic divergence with respect to a particular character of interest.

Association analysis

Correlation between yield and its component traits

Correlation analysis between yield and its component traits revealed that characters *viz*., number of kernel per row (0.68), cob diameter (0.61), number of kernel rows per cob (0.50), length of cob (0.47) number of cob per plot (0.35) and tassel length (0.26) showed significant correlation with grain yield per plant indicating the importance of these traits in selection for yield (Table 4).

Similar results were reported earlier in maize by several workers on different characters *viz*., for the association of grain yield with plant height (Umakanth and Sunil, 2000; Jha and Ghosh, 2001; Mohan *et al*., 2002; Malik *et al*., 2005; Sadek *et al*., 2006), ear length (Choudhary and Chaudhari, 2002; Mohan *et al*., 2002) and ear girth (Sharma and Kumar, 1987; Mohan *et al*., 2002).

Table 3. Cluster mean performance for sixteen traits in 39 inbred lines

	PH1	PH2	PH3	GT	DTT	DTS	ASI	TL	PP	NCPP	CL	CW	NKRPC	NKPR	GW	GYPP
cluster I	8.05	12.23	128.75	12.00	99.00	100.00	1.00	32.75	14.50	15.50	14.93	4.33	14.00	26.00	20.01	91.33
cluster II	8.00	12.10	135.00	11.00	91.00	93.00	2.00	37.00	15.50	12.00	12.70	4.10	14.00	25.50	24.73	32.82
cluster III	6.56	10.08	118.00	14.00	108.00	110.00	2.00	23.79	11.50	7.88	10.74	2.68	7.25	5.88	24.03	9.76
cluster IV	7.69	10.98	113.20	13.00	104.00	106.00	2.00	33.50	11.80	10.10	15.16	4.14	14.40	19.50	24.92	56.59
cluster V	8.25	10.90	85.00	11.00	95.00	97.00	2.00	29.50	16.00	7.00	9.50	3.70	16.00	16.00	18.16	19.77
cluster VI	6.80	10.45	108.65	13.00	103.00	104.00	1.00	30.13	13.29	10.91	12.84	3.65	13.00	15.79	22.74	31.58
cluster VII	6.68	9.86	94.56	14.00	104.00	106.00	2.00	29.92	11.06	10.78	12.97	3.46	12.89	17.28	21.59	40.15

PH1= plant height at three leaves stage, PH2= plant height at six leaves stage, PH3= plant height at maturity, GT= days to 50% germination, DTT= days to 50% taseling, DTS= days to 50% silking, ASI= anthesis-silking interval, TL= length of tassel (cm), PP= plant population per plot, NCPP=number of cob per plot, CL=length of cob in cm, CW= width of cob in cm, NKRPC= number of kernel rows per cob, NKPR= number of kernels per row, GW= 100grain weight, GYPP= grain yield per plant (g)

Table 4. Correlation coefficient among yield and component traits in 39 inbred lines

	PH1	PH2	PH3	GT	DTT	DTS	ASI	TL	PP	NCPP	CL	CW	NKRPC	NKPR	GW
PH1	**1.00**														
PH2	0.35**	**1.00**													
PH3	-0.01	0.12	**1.00**												
GT	-0.27*	-0.16	-0.10	**1.00**											
DTT	-0.16	-0.48**	**-0.02**	0.36**	**1.00**										
DTS	-0.07	-0.40	-0.02	0.31**	0.95**	**1.00**									
ASI	0.34**	0.32**	0.04	-0.22*	-0.29**	0.02	**1.00**								
TL	0.23	0.32**	-0.06	0.12	-0.27*	-0.24*	0.15	**1.00**							
PP	0.15	0.53**	0.06	-0.37**	-0.35**	-0.26*	0.34**	0.01	**1.00**						
NCPP	0.20	0.42**	0.04	-0.22*	-0.28*	-0.27*	0.14	0.05	0.51**	**1.00**					
CL	0.08	0.11	0.17	-0.10	0.06	0.10	0.11	0.11	0.12	0.25*	**1.00**				
CW	0.25*	0.28*	0.16	-0.18	-0.18	-0.19	-0.01	0.16	0.25*	0.31**	0.32**	**1.00**			
NKRPC	0.30**	0.26*	-0.20	-0.12	-0.28*	-0.29**	0.03	0.36**	0.10	0.29**	0.13	0.68**	**1.00**		
NKPR	0.17	0.24*	-0.01	-0.15	-0.27*	-0.31**	-0.12	0.29**	0.19	0.37**	0.40**	0.59**	0.60**	**1.00**	
GW	0.11	0.02	0.11	-0.02	0.17	0.12	-0.10	-0.03	-0.34	-0.14	0.15	0.15	-0.14	-0.02	**1.00**
GYPP	0.25*	0.15	0.11	-0.13	-0.07	-0.13	-0.10	0.26*	-0.07	0.35**	0.47**	0.61**	0.50**	0.68**	0.08

*and ** indicates the significant at the level of 5% and 1% respectively

PH1= plant height at three leaves stage, PH2= plant height at six leaves stage, PH3= plant height at maturity, GT= days to 50% germination, DTT= days to 50% anthesis, DTS= days to 50% silking, ASI= anthesis-silking interval, TL= length of tassel (cm), PP= plant population per plot, NCPP= number of cob per plot, CL= length of cob in cm, CW= width of cob, NKRPC= number of kernel row per cob, NKPR= number of kernel per row, GW=100 grain weight, GYPP= grain yield per plant (g)

Table 5. Direct and Indirect effect of component traits on yield in 39 inbred lines

	PH1	PH2	PH3	GT	DTT	DTS	ASI	TL	PP	NCPP	CL	CW	NKRPC	NKPR	GW
PH1	**0.094**	0.0324	-0.0003	-0.0252	-0.0143	-0.0057	0.0318	0.0210	0.0136	0.0184	0.0071	0.0230	0.0276	0.0162	0.0100
PH2	0.022	**0.0621**	0.0076	-0.0097	-0.0299	-0.0248	0.0197	0.0200	0.0331	0.0263	0.0071	0.0172	0.0159	0.0151	0.0014
PH3	0.000	0.0011	**0.0091**	-0.0010	-0.0002	-0.0002	0.0004	-0.0006	0.0006	0.0004	0.0016	0.0015	-0.0019	0.0000	0.0010
GT	0.032	0.0187	0.0125	**-0.1197**	-0.0426	-0.0376	0.0259	-0.0145	0.0441	0.0262	0.0122	0.0220	0.0139	0.0175	0.0022
DTT	-0.085	-0.2669	-0.0112	0.1974	**0.5546**	0.5248	-0.1583	-0.1475	-0.1966	-0.1580	0.0343	-0.0975	-0.1567	-0.1488	0.0925
DTS	0.028	0.1874	0.0097	-0.1476	-0.4441	**-0.4694**	-0.0087	0.1147	0.1233	0.1266	-0.0487	0.0900	0.1352	0.145	-0.0561
ASI	0.021	0.0203	0.0026	-0.0139	-0.0183	0.0012	**0.0640**	0.0098	0.0221	0.0092	0.0073	-0.0008	0.0017	-0.0011	-0.0068
TL	0.022	0.0310	-0.0060	0.0117	-0.0256	-0.0235	0.0147	**0.0963**	0.0006	0.0044	0.0102	0.0157	0.0352	0.0276	-0.0023
PP	-0.059	-0.2187	-0.0268	0.1514	0.1455	0.1078	-0.1415	-0.0026	**-0.4106**	-0.2094	-0.0503	-0.1044	-0.0415	-0.0770	0.0574
NCPP	0.0425	0.0914	0.0092	-0.0474	-0.0616	-0.0583	0.0311	0.0100	0.1102	**0.2161**	0.0538	0.0681	0.0627	0.0798	-0.0302
CL	0.0150	0.0226	0.0345	-0.0202	0.0123	0.0206	0.0226	0.0210	0.0243	0.0494	**0.1983**	0.0644	0.0252	0.0785	0.0303
CW	0.0954	0.1077	0.0629	-0.0713	-0.0683	-0.0744	-0.0047	0.0633	0.0987	0.1224	0.1261	**0.3883**	0.2632	0.2297	0.0571
NKRPC	-0.0310	-0.0269	0.0215	0.0122	0.0297	0.0303	-0.0029	-0.0384	-0.0106	-0.0305	-0.0134	-0.0713	**-0.1052**	-0.0622	0.0144
NKPR	0.0618	0.0865	-0.0009	-0.0521	-0.0958	-0.1109	-0.0060	0.1023	0.0670	0.1319	0.1413	0.2112	0.2112	**0.3569**	-0.0063
GW	-0.0095	-0.0020	-0.0099	0.0016	-0.0149	-0.0107	0.0095	0.0022	0.0125	0.0124	-0.0136	-0.0131	0.0122	0.0016	**-0.0891**
GYPP	0.2489	0.1467	0.1147	-0.1337	-0.0733	-0.1309	-0.1023	0.2570	-0.0678	0.3458	0.4733	0.6142	0.4987	0.6796	0.0755
Partial R^2	**0.0233**	**0.0091**	**0.0010**	**0.0160**	**-0.0407**	**0.0614**	**-0.0065**	**0.0247**	**0.0278**	**0.0747**	**0.0939**	**0.2385**	**-0.0524**	**0.2426**	**-0.0067**

R SQUARE = 0.7067, RESIDUAL EFFECT = 0.5416

PH1= plant height at three leaves stage, PH2= plant height at six leaves stage, PH3= plant height at maturity, GT= days to 50% germination, DTT= days to 50% anthesis, DTS= days to 50% silking, ASI= anthesis-silking interval, TL= length of tassel (cm), PP= plant population per plot, NCPP= number of cob per plot, CL= length of cob in cm, CW= width of cob, NKRPC= number of kernel row per cob, NKPR= number of kernel per row, GW=100 grain weight, GYPP= grain yield per plant (g)

Mutual correlation between characters

As indicated in Table 4, several traits are having very high mutual correlation that can be further utilized for simultaneous improvement of the traits. For example, length of tassel showed positive and significant correlation with number of kernel row per cob (0.36) and number of kernel per row (0.29). Plant population per row exhibited significant and positive correlation with number of cob per plot (0.51) and cob diameter (0.25). However, number of cobs per plot was positively and significantly correlated with cob length (0.25), cob diameter (0.31), number of kernel row per cob (0.29) and number of kernel per row (0.37). These results were in agreement with the findings of Jabeen (2005), Tan *et al.* (2006) and, Sofi and Rather (2007). All these trait combinations can be subjected to simultaneous selection for the development of high yielding varieties.

Path analysis

Yield is a highly complex trait and its expression depends on several mutually associated characters and change in any of the component is likely to disturb the whole network of cause and effect. Each component character has two paths of action *viz.*, the direct influence on grain yield and indirect effect through components which are not revealed from the correlation studies. Direct and positive effect on yield was exhibited by number of kernels per row (0.67), cob diameter (0.61), number of kernel rows per ear (0.49), and cob length (0.47) indicating the effectiveness of direct selection. Among all, number of kernels per row was recorded to have maximum positive direct effect on yield. Singh *et al.* (2003) also mentioned that grain yield of maize was directly influenced by number of kernels per row. However, Sharma and Kumar (1987) reported maximum direct contribution of cob diameter on grain yield. The high direct effect of these traits appeared to be the main factor for their strong association with grain yield. The present findings are in consonance with earlier reports by Mahajan *et al.* (1995); Devi *et al*. (2001); Mohan *et al.* (2002). Geetha and Jayaraman (2000) and, Jabeen (2005) also reported that number of kernels per row had direct effect on grain yield. The results thus emphasized the need for selection, based on plant type with greater number of kernels per row, number of kernel rows per ear, cob diameter and cob length, since they had maximum contribution towards improved grain yield.

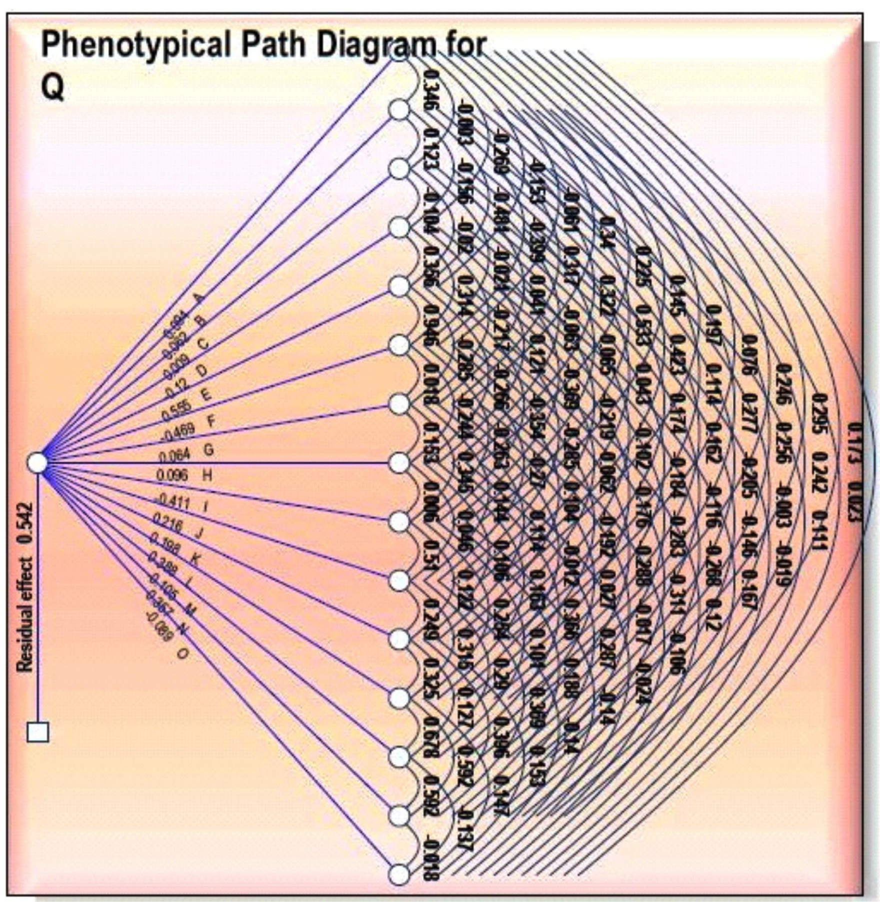

Figure 2. Path diagram for yield per plant A= Plant height at three leaves stage, B= Plant height at six leaves stage, C= plant height at maturity, D= days to 50% germination, E= days to 50% tasseling, F= days to 50% silking, G=anthesis silking interval, H= tassel length, I= plant population per row, J=number of cob per plot, K= length of cob, L=width of cob, M= number of kernel row per cob, N=number of kernel per row, O=100 grain weight, Q= grain yield per plot

References

Babic, V., Nikolic, A., Andjelkovic, V., Kovacevic, D., Filipovic, M., Vasic, V. & Mladenovic-Drinic, S. (2016). AUPOV morphological versus molecular markers for maize inbred lines variability determination. *Chilean J. Agric. Res.*, **76**(4): 417–426.

Choudhary, A. K. & Chaudhari, L. B. (2002). Heterotic pattern of some early generation inbreds derived from two maize (*Zea mays* L.) populations. *Indian J. Genetics,* **62**(2): 159-160.

Devi, I. S. & Mohammed, S. (2001). Character association and path coefficient analysis of grain yield and yield components in double crosses of maize. *Crop Res.,* **21**: 255-359.

Geetha, K. & Jayaraman, N. (2000). Path analysis in maize (*Zea mays* L.). *Agril. Sci. Digest*, **20**(1): 60-61.

Jabeen, F. (2005). Studies on gentic divergence, combining ability and stability for protein, oil and grain yield in Maize (*Zea Mays* L.) genotypes. Ph.D. Thesis, Acharya NG Ranga Agricultural University; Hyderabad.

Jha, P. B. & Ghosh, J. (2001). Variability and component analysis for fodder or dual purpose maize (*Zea mays*). *J. Res. Birsa Agric. Univ.,* **13**(1): 65-68.

Malik, H. N., Malik, S. I., Hussain, M., Chughtai, S. R. & Javed, H. I. (2005). Genetic correlation among various quantitative characters in maize (*Zea mays* L.) hybrids. *J. Agric. & Social Sci.,* **3**: 262-265.

Mahajan, V., Gupta, A. S. & Khehra, A. S. (1995). Path analysis in maize over diverse environments. *International J. Tropical Agric.*, **13**(4): 97-101.

Mohan, Y. C., Singh, D. K. & Rao, N. V. (2002). Path coefficient analysis for oil and grain yield in maize (*Zea mays* L.) genotypes. *National J. Plant Improvement*, **4**(1): 75-76.

Ortiz, R., Crossa, J., Franco, J., Sevilla, R. & Burgueño, J. (2008). Classification of peruvian highland maize races using plant traits. *Genetic Resources Crop Evolution,* **55**: 151-162.

Sadek, S. E., Ahmed, M. A. & El-Ghaney, H. A. (2006). Correlation and path coefficient analysis in five parents inbred lines and their six white maize (*Zea mays* L.) single crosses developed and grown in Egypt. *J. Applied Sci. Res.*, **2**(3): 159-167.

Sharma, R. K. & Kumar, S. (1987). Association analysis for grain yield and some quantitative traits in popcorn. *Crop Improvement*, **14**: 201-204.

Singh, P., Dass, S., Kumar, Y. & Dutt, Y. (2003). Variability studies for grain yield and component traits in maize (*Zea mays* L.). *Annals of Agril. Biol. Res.,* **8**(1): 29-32.

Sofi, P. A. & Rather, A. G. (2007). Studies on genetic variability, correlation and path analysis in maize (*Zea mays* L.). *Maize Genetics Co-operation News letter,* **81**: 26-27.

Tan, H., Wang, G. & Hu, X. (2006). Multiple regression and path analysis of effective factors affecting maize yield. *Acta Agriculturae Zhejiangensis,* **18**(4): 238.

Umakanth, A. V. & Sunil, N. (2000). Character association and heritability studies in Harsha maize composite. *Bioved Journal,* **11**(2): 43-45.

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RESEARCH PAPER

Characterization of resistance to shoot fly, *Atherigona naqvii* Steyskal in spring maize

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Abstract: Shoot fly, *Atherigona naqvii* Steyskal is a serious pest of spring sown maize in north India. The host plant resistance holds a good potential in managing the shoot fly. The antixenosis for oviposition, antibiosis and tolerance components of resistance were studied in six maize hybrids and two inbred lines using fish meal technique during spring season. The antixenosis for oviposition was not observed in any of the test genotypes. On the basis of dead hearts incidence, the genotypes were categorized as least susceptible, JH 3459 (10.49%) & JH 3956 (10.95%); intermediate susceptible, CM 143 (15.16%), PMH 1 (15.35%) & JH 31244 (16.70%) and highly susceptible, LM 16 (21.48%), PMH 2 (21.52%) & Parkash (23.57%) to *A. naqvii*. The proportion of dead hearts due to shoot fly incidence was maximum in susceptible LM 16 (47.43%) and minimum in least susceptible JH 3956 (32.45%), providing evidence for tolerance mechanisms of resistance. The susceptible LM 16, PMH 2 and Parkash had comparatively lower larval and pupal periods; more larval survival, pupal weight and fecundity suggested the prevalence of antibiosis mechanism also. Among various morphological and biochemical traits of seedlings at 5th leaf stage the leaf length and width, stem girth and reducing sugars were more in the susceptible genotypes.

Keywords: *Atherigona naqvii* · Antixenosis · Antibiosis · Resistance · Spring maize · Shoot fly

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Introduction

Maize, *Zea mays* (L.) (Poaceae), ranks 3rd in area after wheat and rice and is one of the important cereal crops in the world. The large scale adoption of spring maize in Punjab emphasized the need to develop integrated pest management (IPM) strategies for the management of its key pest shoot fly, *Atherigona naqvii* Steyskal (Kumar and Kanta, 2012). The losses of up to 35-40 per cent in spring maize was reported by Jindal (2013) and deadhearts incidence of even up to 85.8 per cent was reported in Punjab (Sajjan and Sekhon, 1985). The seed treatment and soil application of insecticides have been recommended for its control. However, the management strategy for any pest must involve more than one control tactics. The exploitation of host plant resistant has a good potential for the management of shoot fly. In India, number of genotypes with low to moderate resistant has been identified by various workers from different locations (Siddiqui *et al.*, 1988; Panwar, 2005; Jindal *et al.*, 2007; Kumar and Kanta, 2012) but, the mechanisms of resistance in the promising maize cultivars have not been identified under north Indian conditions. To develop insect pest resistance cultivars, it is important to identify germplasms with diverse combinations of factors associated with resistance to the target pests and then to combine them in the same genetic background. So, the present studies were planned to study the mechanism and factor associated with the resistance to shoot fly, *A. naqvii* in maize cultivars.

Material and methods

The seed of eight maize genotypes i.e. 6 hybrids (JH 3459, PMH 2, JH 31244, JH 3956, PMH 1 and Parkash) and 2 inbred lines (LM 16 and CM 143) were procured from Senior Maize Breeder, PAU, Ludhiana. The experiments on these genotypes to find their relatively susceptibility, mechanism and role of various morphological and biochemical plant characteristics in resistance to *A. naqvii* was conducted during spring season. The test genotypes were sown in R.B.D. with 3 replications in plots of 5 rows with 3 meter length. The optimum shoot fly population in field was ensured by broadcasting the moistened fish-meal @ 50 g per m^2 on emergence of seedlings (Jindal *et al.*, 2007). The following observations were recorded:

Incidence of shoot fly, Atherigona naqvii

To assess the antixenosis for oviposition, observations were made on number of eggs laid per plant by *A. naqvii* from 15 plants per treatment plot at 3 days interval from 3 to 15 DAG (days after germination). The leaf injury and dead hearts incidence was recorded at 20 DAG on whole plot basis to work out per cent infestation. The proportion of deadhearts incidence out of total shoot fly incidence (leaf injury and deadhearts) was also worked out to calculate the recovery of seedlings for assessing the tolerance in different genotypes, as given below.

$$\text{Proportion of dead heart incidence in total shoot fly incidence} = \frac{\text{No. of dead hearts}}{\text{Total shoot fly incidence}} \times 100$$

Expression of antibiosis to A. naqvii

To study antibiosis, potted plants of test genotypes were exposed to shoot fly adults under field conditions. The survival and development of shoot fly on different genotypes was studied in Maize Entomology Laboratory. 75 plants of each genotype sown in fish meal baited small pots (dia. 12 cm) in 3 replications were observed daily for egg laying and dead hearts formation. The plants with eggs were tagged after ensuring that the laid eggs were of *A. naqvii* species only. To quantify antibiosis, dead hearts formed in tagged plants in field and pots were labelled on the day of their appearance to compute the larval period (Meksongsee *et al.*, 1981). Ten dead hearts per replication, 6 days after its formation were taken per replication and placed in 50 ml vials. These seedlings were dissected carefully to ensure the presence of the maggot; and on drying the seedling was replaced with the fresh one of the same age. The observations were recorded on larval and pupal periods and pupal survival; pupal weight, fecundity (number of eggs laid/ female) and longevity as per Dhillon *et al.* 2005b.

Studies on morphological and biochemical characteristics of the test maize genotypes

The observations on various morphological and biochemical characters were recorded at 5th leaf stage of seedlings (14 days old seedling) in 3 replications. The data on chlorophyll content, seedling vigour, leaf glossiness, trichomes, leaf sheath pigmentation, leaf length, leaf width, leaf area and stem girth were recorded under field conditions, while the data on leaf surface wetness was recorded in seedlings grown under screen house conditions as per Dhillon *et al*, 2005b. While the estimation of proteins (AOAC 2000), phenols (Swain and Hills 1959), tannins (Sadasivam and Manickam 1992), reducing sugars (Nelson 1944) and free amino acids (Elahi and Khan 1973) were carried out as per standard analytical procedures in Quality Laboratory, Department of Plant Breeding and Genetics, PAU, Ludhiana.

Statistical analysis

The data on infestation and biological parameters of *A. naqvii* of plants were analyzed using ANOVA and the different treatment means were separated by least significant differences test (LSD) at p=0.05 (Gomez and Gomez, 1984). The correlation of infestation and biological parameters with morphological and biochemical parameters were also worked out.

Results and discussion

Oviposition by shoot fly, A. naqvii on the test maize genotypes in the field conditions

The mean number of eggs per plant in the test genotypes differed non significantly in all the observations during both the test years (Table 1). Thus, antixenosis for oviposition was not observed in any of the test genotypes. The non-significant differences in oviposition might be due to high shoot fly pressure in fish-meal baited treatment plots. Panwar and Sarup (1988) and Rao and Panwar (1996) also reported the non-significant differences for oviposition by shoot flies on various maize germplasms. Dhillon *et al.*, 2005a reported that in sorghum also the mechanism of antixenosis for oviposition to *A. soccata* was not stable and tended to breakdown under no choice conditions.

The shoot fly, A. naqvii incidence in the test maize genotypes in the field conditions

The mean leaf injury and dead hearts incidence of two years in test genotypes ranged from 18.18 to 33.07 and

Table 1. The incidence of shoot fly, *Atherigona naqvii* on different test genotypes in the field conditions during spring season

Genotype	Mean egg count/plant	Mean incidence LI (%)	Mean incidence DH (%)	Mean proportion of dead hearts out of total incidence
JH 3459	0.38	20.45	10.49	33.51
PMH 2	0.47	26.62	21.52	42.25
JH 31244	0.43	26.06	16.70	35.90
JH 3956	0.40	21.84	10.95	32.45
PMH 1	0.41	25.97	15.35	36.47
PARKASH	0.45	33.07	23.57	40.49
LM 16	0.46	23.13	21.48	47.43
CM 143	0.38	18.18	15.16	45.09
CD (p=0.05)	NS	4.47	2.87	5.19

10.49 to 23.57 per cent, respectively (Table 1). The leaf injury was maximum in Parkash (33.07%) followed by PMH 2 (26.62%) and minimum in CM 143 (18.18%), which was also on par with JH 3459 (20.45%) and JH 3956 (21.84%). The leaf injury incidence was overlapping in different genotypes and did not give any clear-cut differentiation for their susceptibility. However, the differences were evident from dead hearts. Moreover, dead hearts counts are easy, quick and provide the assessment of the yield loss. On this basis Parkash (23.57%), PMH 2 (21.52%) and LM 16 (21.48%) were categorized as highly susceptible, JH 3459 (10.49%) and JH 3956 (10.95%) as the least susceptible. While CM 143, PMH 1 and JH 31244 (15.16 to 16.70%) were intermediate. The moderate susceptible inbred CM 143 is a female parent of least susceptible hybrid JH 3459. It can be further used in resistant breeding programme. The hybrids JH 3459 and JH 3956 with relatively less susceptibility to shoot fly are important in implementation of integrated strategies for the management of this pest.

Recovery of seedlings or tolerance in the test genotypes after infestation of shoot fly, A. naqvii

The overlapping in leaf injury incidence in different genotypes may to be due to the inherent capacity of cultivars to recover from shoot fly infestation (Table 1). The mean proportion of dead hearts out of total incidence was more in highly

Table 2. Variations in biological attributes of shoot fly, *A. naqvii* reared on different test genotypes under the laboratory conditions during spring season

Genotype	Larval period* (days)	Pupal period* (days)	Adult longevity** (days)	Larval survival* (%)	Pupal survival* (%)	Male pupal wt.*** (mg)	Female pupal wt.*** (mg)	Fecundity**
2011								
JH 3459	18.17	7.50	8.44	47.17	65.22	3.25	3.99	6.44
PMH 2	17.72	7.66	6.95	51.04	62.23	3.97	4.44	7.33
JH 31244	17.78	7.61	7.50	47.28	73.22	3.52	4.18	7.00
JH 3956	17.89	7.50	7.32	46.39	72.59	3.08	4.02	7.45
PMH 1	17.72	7.88	6.91	50.49	60.28	3.92	4.30	5.89
PARKASH	17.22	7.55	6.77	57.57	66.67	3.00	4.16	7.67
LM 16	17.16	7.39	6.32	54.31	64.46	3.79	4.68	6.67
CM 143	17.33	7.28	6.45	50.12	65.49	3.63	4.39	6.11
CD (p=0.05)	0.62	NS	0.77	NS	NS	0.38	NS	1.01
2012								
JH 3459	18.57	8.10	8.62	46.94	61.80	3.44	4.13	8.11
PMH 2	18.10	7.76	7.83	55.41	62.64	4.14	4.74	9.78
JH 31244	18.62	8.24	7.14	50.93	71.69	3.63	4.46	8.00
JH 3956	18.14	8.05	7.31	52.92	65.28	3.15	3.95	8.78
PMH 1	18.24	8.80	7.39	51.39	63.54	3.46	4.09	8.00
PARKASH	17.52	7.87	7.26	63.87	65.56	2.85	4.15	9.33
LM 16	17.48	7.76	6.92	59.23	68.50	4.02	4.79	9.00
CM 143	17.19	7.43	6.76	55.87	67.37	3.55	4.28	8.11
CD (p=0.05)	0.91	NS	NS	NS	NS	0.28	NS	NS

*Mean based on 10 individuals per replication; ** Mean based on 3 pairs per replication; *** Mean based on 3 individuals per replication susceptible genotypes LM 16 (47.43%), CM 143 (45.09%), PMH 2 (42.25%) and Parkash (40.49%). Whereas, it was less in least susceptible JH 3956 (32.45%) and JH 3459 (33.51%) showing comparative tolerance in these genotypes. Pandey and Sharma (1980) also reported that the per cent increase in dead hearts in subsequent observations was lower in the least susceptible maize genotypes in comparison to the susceptible ones. Thus, the resistance to shoot fly in maize is primarily dependent on degree of tolerance i.e. ability of plant to recover from injury.

Expression of antibiosis component of resistance to shoot fly, A. naqvii

The larval and pupal periods; adult longevity; per cent larval and pupal survival; male and female pupal weights; and fecundity on 8 maize genotypes ranged from 17.16 to 18.17 and 7.28 to 7.88; 6.32 to 8.44 days; 46.39 to 57.57 and 60.28 to 73.22 per cent; 3.00 to 3.97 and 3.99 to 4.68 mg; and 5.89 to 7.67 eggs per female, respectively in 2011; and 17.19 to 18.62 and 7.43 to 8.80; 6.76 to 8.62 days; 46.94 to 63.87 and 61.80 to 71.69 per cent; 2.85 to 4.14 and 3.95 to 4.79 mg; and 8.00 to 9.78 eggs per female, respectively in 2012 (Table 2). The susceptible LM 16, PMH 2 and Parkash had comparatively lower larval and pupal periods; more larval survival, pupal weight and fecundity than less susceptible JH 3459 and JH 3956 indicated the presence of antibiosis mechanism in addition to tolerance. Dhillon *et al.* (2005a) also reported that the slow larval development, prolonged pupal period; and reduced larval/ pupal survival on the resistant genotypes provided an evidence of antibiosis to *A. soccata* in sorghum.

Variations in morphological and biochemical traits of the test maize genotypes in relation to expression of resistance to shoot fly, A. naqvii

Among various morphological characters seedling vigour score (1= highly vigorous, 5 = poor vigour) was correlated with the tolerance in different test genotypes. The per cent dead hearts out of total incidence showed positive and significant correlation with seedling vigour score (r = 0.84*) thus, revealing that more dead hearts formation in less

Table 3. The correlations of shoot fly, *A. naqvii* damage parameters under field conditions with morphological and biochemical parameters

Parameters	The correlation coefficients of different parameters			
	Mean egg counts	Leaf injury (%)	Deadhearts (%)	Proportion of deadhearts out of total incidence
Morphological plant parameters				
Leaf surface wetness score	-0.05	0.14	0.32	0.48
Seedling vigour score	0.06	-0.45	0.24	0.84*
Leaf glossiness score	-0.14	0.02	0.06	0.09
Leaf sheath pigmentation score	0.20	-0.05	0.15	0.25
Leaf length	0.54	0.79*	0.28	-0.43
Leaf width	0.53	0.89*	0.34	-0.40
Leaf area	0.45	0.85*	0.26	-0.48
Stem girth	0.48	0.76*	0.36	-0.21
Trichome length	0.01	0.08	0.21	0.11
Trichome angle	-0.06	-0.28	-0.41	-0.35
Trichome density	-0.36	-0.33	-0.55	-0.41
Biochemical plant parameters				
Chlorophyll (CCI)	-0.10	0.39	-0.32	-0.81*
Moisture	-0.05	-0.24	-0.23	0.13
Protein	0.17	0.01	0.41	0.51
Tannins	-0.37	-0.06	0.23	0.26
Phenols	-0.26	0.13	-0.14	-0.42
Amino acids	-0.01	0.16	0.34	0.38
Reducing sugars	0.81*	0.77*	0.88*	0.41

* Correlation coefficients significant at 5 per cent level of significance

Table 4. The correlations of shoot fly, *A. naqvii* biological parameters reared on different test genotypes with plant morphological and biochemical parameters

Parameters	The correlation coefficients of different parameters							
	Larval period (days)	Pupal period (days)	Adult longevity (days)	Larval survival (%)	Pupal survival (%)	Pupal wt. (mg)		Fecundity
						Male	Female	
Morphological plant parameters								
Leaf surface wetness score	0.67	0.65	0.59	-0.73*	-0.14	0.21	-0.27	-0.06
Seedling vigour score	-0.57	-0.54	-0.51	0.19	-0.20	0.71	0.66	-0.25
Leaf glossiness score	-0.23	-0.07	-0.28	0.14	0.63	-0.29	-0.05	-0.41
Leaf sheath pigmentation score	-0.48	-0.20	-0.78*	0.29	0.63	-0.05	0.17	0.12
Leaf length	0.48	0.55	0.45	0.07	-0.15	-0.14	-0.15	0.57
Leaf width	0.42	0.56	0.32	0.10	-0.03	-0.16	-0.17	0.51
Leaf area	0.48	0.60	0.39	0.05	-0.05	-0.23	-0.26	0.46
Stem girth	0.38	0.54	0.28	0.04	-0.38	0.19	0.03	0.37
Trichome length	-0.52	0.09	-0.40	0.60	-0.14	-0.49	-0.22	0.08
Trichome angle	0.45	0.40	0.27	-0.47	-0.39	0.31	-0.06	-0.01
Trichome density	0.67	-0.05	0.66	-0.73*	-0.21	0.17	-0.20	-0.07
Biochemical plant parameters								
Chlorophyll (CCI)	0.73*	0.74*	0.46	-0.47	0.36	-0.37	-0.58	-0.17
Moisture	-0.42	0.14	-0.54	0.29	-0.02	-0.14	-0.03	-0.13
Protein	-0.37	-0.58	0.09	0.45	-0.58	0.13	0.33	0.41
Tannins	-0.49	-0.16	-0.18	0.42	-0.32	-0.36	-0.23	-0.30
Phenols	0.26	0.16	0.66	0.03	-0.29	-0.63	-0.57	0.07
Amino acids	-0.18	-0.05	0.11	0.23	-0.64	0.26	0.23	-0.19
Reducing sugars	-0.51	-0.09	-0.44	0.87*	0.12	-0.13	0.35	0.71*

*Correlation coefficients significant at 5 per cent level of significance

vigorous genotypes. The seedling vigour and high rate of recovery were reported to be important characteristics of resistant cultivars in sorghum also (Dhillon *et al.*, 2005b). The leaf injury showed significant and positive correlations with leaf length (r = 0.79*), leaf width (r = 0.89*), leaf area (r = 0.85*) and stem girth (r = 0.76*) revealing that more infestation occurred on seedlings of cultivars having broad and long leaves with more stem girth, while larval survival was negatively correlated (r = - 0.73*) with leaf surface wetness and trichome density (Table 3 & 4). Among biochemical characters only reducing sugars content were positive and significant with per cent leaf injury (r = 0.77*), dead hearts (r = 0.88*), oviposition (r = 0.81*) and larval survival (r = 0.87*) by shoot fly revealing the role of reducing sugars in imparting susceptibility in the different test maize genotypes to shoot fly (Table 3 &4). Singh *et al*. (2004) reported the phagostimulatory role of sugars for feeding by the shoot fly maggots resulting in more dead hearts formation. Thus, these characters can serve as reliable marker in shoot fly resistance breeding and help in understanding the factors affecting the resistance.

References

AOAC (2000). Official methods of analysis: Association of Official Analytical Chemists, 17th edn. Gaithersburg, MD, USA.

Dhillon, M. K., Sharma, H. C., Singh, R. & Naresh, J. S. (2005a). Mechanisms of resistance to shoot fly, *Atherigona soccata* in sorghum. *Euphytica*, **144**: 301–12.

Dhillon, M. K., Sharma, H. C., Reddy, B. V. S., Singh, R., Naresh, J. S. & Kai, Z. (2005b). Relative susceptibility of different male-sterile cytoplasms in sorghum to shoot fly, *Atherigona Soccata*. *Euphytica*, **144**: 275–83.

Elahi, M. & Khan, N. (1973). Free amino acids of Pakistani wheat varieties. *J. Agric. Food Chem.*, **21**: 743–44.

Gomez, K. A. & Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd edn. Pages 653. Wiley Interscience, New York.

Jindal, J. (2013) Incidence of insect pests and management of shoot fly, *Atherigona* spp in spring sown maize. Ph.D. dissertation. Punjab Agricultural University, Ludhiana, India.

Jindal, J., Hari, N. S., Grewal, M. S. & Chawla, J. S. (2007). Evaluation of different genotypes against shoot fly, *Atherigona naqvii* Steyskal in spring sown maize. *Crop Improv.*, **34**: 160–62.

Kumar, V. & Kanta, U. (2012). Management of insect pest complex in maize. Pages. 338–69. In: Arora, R., Singh, B. and Dhawan,

A. K. (eds) *Theory and Practice of Integrated Pest Management.* Scientific publishers, Jodhpur, India.

Meksongsee, B., Chawanapong, M., Sangkasuwan, U. & Poonyathaworn, P. (1981).The biology and control of the sorghum shoot fly, *Atherigona soccata* Rondani in Thailand. *Insect Sci. Applic.*, **2**: 111–16.

Nelson, N. (1944). A photometric adoption of somogyi method for determination of glucose. *J. Biol. Chem.,* **15**: 375–80.

Pandey, K. C. & Sharma, V. K. (1980). Comparative susceptibility of some released and elite maize germplasm against shoot fly, *Atherigona* spp. in spring sown maize. *Indian J. Ent.,* **42**: 21–23.

Panwar, V. P. S. (2005). Management of shoot fly (*Atherigona* spp.) in spring sown maize in tropics. Pages 376–95. In: Zaidi, P. H. & Singh, N. N. (eds) *Stresses on Maize in Tropics.* Directorate of Maize Research, New Delhi

Panwar, V. P. S.& Sarup, P. (1988). Differential reaction of promising maize germplasm to shoot fly species (*Atherigona soccata* Rondani and *A. naqvii* Steyskal). *J. entomol. Res.,* **12**: 41–44.

Rao, K. R. & Panwar, V. P. S. (1996). Location of sources of resistance among maize germplasm against shoot fly species (*Atherigona soccata* and *A. naqvii*) during spring. *Ann. Pl. Prot. Sci.,* **4**: 47–49.

Sadasivam, S. & Manickam, A. (1992). Phenolics. Pages 187-88. In: *Biochemical Methods for Agricultural Sciences*. Wiley Eastern Ltd., New Delhi, India.

Sajjan, S. S. & Sekhon, S. S. (1985). Control of shoot fly, *Atherigona naqvii* Steyskal (Diptera: Anthomyiidae) on maize through soil and seed treatment. *Indian J. Entomol.,* **47**: 371–75.

Siddiqui, K. H., Marwaha, K. K. and Sarup, P. (1988). Differential response of maize germplasm to shoot fly species, *Atherigona soccata* Rondani and *A. naqvii* Steyskal under natural conditions. *J. entomol. Res.* **12**: 160–65.

Singh, B. U., Padmaja, P. G. & Seetharama, N. (2004). Stability of biochemical constituents and their relationships with resistance to shoot fly, *Atherigona soccata* (Rondani) in seedling sorghum. *Euphytica,* **136**: 279–89.

Swain, T. & Hills, W. E. (1959). The phenolic constituents of *Prunus domestica*: The quantitative analysis of phenolic constituents. *J. Sci. Food Agric.,* **10**: 63–68.

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RESEARCH PAPER

Performance of hybrid maize in *rabi* season with different levels of nitrogen and phosphorus

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Abstract: Field experiments were conducted during *rabi* season 2015-16 to 2016-17 at Main Maize Research Station, AAU, Godhra and Regional Research Station, AAU, Anand to assess performance of new single cross hybrids, GAYMH-1 and GAWMH-2 under different levels of nitrogen and phosphorus under irrigated conditions. The results indicated that application of 150 kg N/ha and 40 kg P_2O_5/ha (soil having medium phosphorus status) in Middle Gujarat Agro Climatic zone in Panchmahal district and application of 150 kg N/ha and 60 kg P_2O_5/ha (soil having low phosphorus status) in Anand district significantly increased the grain yield, fodder yield, ear length, ear girth, test weight and grain rows/ear. Overall pooled results of both the centers show significant effect of nitrogen on grain yield of maize. The treatment 200 kg N/ha gave significantly higher grain yield (7,111 kg/ha) than 100 kg N/ha but, it was at par with application of 150 kg N/ha (6,947 kg/ha). The effect of phosphorus was found non-significant in overall pooled analysis. The result revealed that the grain yield of both the hybrids differed significantly. Hybrid GAYMH-1 gave significantly higher yield (6,724 kg/ha) than GAWMH-2 (6,312 kg/ha) in overall pooled analysis. The overall pooled results of fodder yield showed that, increase in the level of nitrogen, increased the fodder yield of the maize. The higher levels of nitrogen 200 kg N/ha and 150 kg N/ha recorded significantly higher fodder yield 10,196 and 9,619 kg/ha, respectively as compared to 100 kg N/ha. However, hybrid GAYMH-1 gave higher fodder yield (9,540 kg/ha) than GAWMH-2 (8,667 kg/ha). Economics of different treatments results revealed that at Godhra location, the treatment of 150 kg N + 40 kg P_2O_5 per ha gave maximum net realization of Rs. 1,24,630/- and Rs. 1,18,655/-, respectively and at Anand location indicated that the treatment 150 kg N + 60 kg P_2O_5 per ha gave maximum net realization of Rs.1,02,670/- per hectare.

Keywords: Hybrid maize · Nitrogen · Phosphorus· Yield

Introduction

Maize (*Zea mays* L.) is a very important cereal crop of middle Gujarat grown in *kharif* and *rabi* season. In Gujarat *rabi* Maize is grown in 1.00 lakh hectare. It has 3.5 lakh ton production with a productivity of 3500 kg/ha during the year 2013-14. The cereal food grain crops require high dose of chemical fertilizers. As the soils of middle Gujarat area low in available nitrogen and medium to high in available phosphorus and potash. The continuous use of high-grade fertilizers has generated problems like deterioration of soil fertility, soil health and nutrient imbalance as well as decrease the productivity. There is sufficient amount of phosphorus in the soil in many places and phosphorus application can be avoided or reduced because of natural endowment of soil. Identification of popular maize genotypes having adaptability and responsiveness to input is considered first step for development of production technology (Parihar *et al*., 2011). Hence there is need to test early maturing hybrids under prevailing rainfed agro-climatic condition of middle Gujarat. Further, grain and fodder yield potentials of the released hybrids can be realized fully when they are grown under adequate fertilization. There is a need to work out optimum combination of nitrogen and phosphorus fertilization for early maturing

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hybrids for Middle Gujarat Plain in *rabi* season. Considering these facts and paucity research findings on these aspects, a study entitled "Performance of hybrid maize in *rabi* season with different levels of nitrogen and phosphorus" was carried out for two consecutive *rabi* season in Middle Gujarat Plains.

Materials and methods

The field experiment was conducted during *rabi* 2015-16 to *rabi* 2016-17 at two different locations of middle Gujarat *i.e.* Godhra and Anand. Two newly released hybrids *i.e.* GAYMH-1 and GAWMH-2 were tested against different three doses of nitrogen *i.e.* at 100 kg N per ha, 150 kg N per ha and 200 kg N/ha accompanied with 40 kg P_2O_5/ha, 60 kg P_2O_5/ha and 80 kg P_2O_5/ha. The experiment was laid out at both locations in RBD (factorial) by keeping gross plot size of 4.5 m × 6.0 m and net plot size of 3.0 × 5.6 m in three replications. The texture of soil is sandy loam at Godhra and medium black type at Anand. The phosphorus was applied at as basal and nitrogen in 4 splits as 25% at basal, 25% at 4 leaf stage, 25% at 8 leaf stage and 25% at tasseling stage.

Result and discussion

Growth and yield attributes

The overall mean result for growth and yield attributes are presented in Table 1. It revealed that, treatment effect of nitrogen was non-significant on plant height, however Treatment 200 kg N/ha gave higher plant height 229 cm at Godhra and 259 cm at Anand. The effect of phosphorus on plant height was found non-significant at both locations. The plant height difference of both the hybrids was non-significant. However, GAWMH-2 recorded more plant height 203 cm at Godhra and GAYMH-1 236 cm at Anand. The results were in conformity with the findings of Reddi and Reddy. (2007). Results of the experiment presented in table 1 revealed that at Godhra, treatment 200 kg/ha gave higher ear length 19.48 cm but, it was non-significant, while, at Anand it was found significant. Treatment 200 kg N/ha gave significantly higher ear length 22.99 cm. Effect of phosphorus on ear length was non-significant at Godhra and it was significant at Anand. Treatment 80 kg P_2O_5/ha gave higher ear length (21.87 cm) but it was at par with 60 kg P_2O_5/ha. GAYMH-1 gave significantly higher

Table 1. Effect of nitrogen, phosphorus on yield of two maize hybrids (mean of two years)

Treatment	Godhra					Anand				
	Plant height (cm)	Ear length (cm)	Ear girth (cm)	No. of rows per ear	Test weight (g)	Plant height (cm)	Ear length (cm)	Ear girth (cm)	No. of rows per ear	Test weight (g)
N_1 100 kg N/ha	177	18.56	13.68	14.24	307	210	17.96	13.87	14.47	285
N_2 150 kg N/ha	197	18.98	14.19	14.29	311	255	21.44	14.89	14.62	294
N_3 200 kg N/ha	229	19.48	14.59	14.82	314	259	22.99	15.66	15.20	298
SEm ±	7.9	0.84	0.35	1.28	28	15.8	0.35	0.13	0.18	3.4
CD (0.05)	NS	NS	NS	NS	NS	NS	0.99	0.37	0.52	9.7
P_1 40 kg P/ha	196	18.77	14.11	14.30	307	220	19.63	14.21	14.38	285
P_2 60 kg P/ha	201	19.05	14.17	14.44	310	246	20.89	14.99	14.91	295
P_3 80 kg P/ha	206	19.19	14.18	14.65	315	258	21.87	15.22	15.01	297
SEm ±	4.10	0.15	0.05	1.26	26	8.2	0.35	0.13	0.18	3.4
CD (0.05)	NS	NS	NS	NS	NS	NS	0.99	0.37	0.52	9.7
N × P										
SEm ±	3.9	0.26	0.10	0.47	47	7.3	0.60	0.23	0.31	5.9
CD (0.05)	NS	NS	NS	NS	NS	20.6	NS	0.65	NS	NS
V_1 GAYMH-1	199	19.42	14.52	14.80	313	246	21.89	15.27	14.41	253
V_2 GAWMH-2	203	18.59	13.79	13.90	309	236	19.71	14.34	15.12	332
SEm ±	1.8	0.12	0.29	0.11	1.0	14.2	0.29	0.10	0.15	2.8
CD (0.05)	NS	0.35	NS	3.31	3.0	NS	0.81	0.31	0.43	7.9

ear length (19.42 cm) than in GAWMH-2 (18.59 cm) at Godhra while 21.89 cm and 19.71 cm respectively for GAYMH-1 and GAWMH-2 at Anand. Kunjir *et al*. (2007) observed the similar kind of results. Experimental results showed that the ear girth was significantly influenced by application of nitrogen at Anand. Treatment 200 kg/ha gave higher ear girth (15.66 cm) but, it was at par with 150 kg N/ha (14.89 cm). The treatment effects were found non-significant on ear girth at Godhra while in case of the hybrid, GAYMH-1 gave significantly higher ear girth (15.27 cm) than GAWMH-2 (14.34 cm) at Anand while it was non-significant at Godhra. The treatment effects were found significant for nitrogen application on number of rows per ear (15.20) at Anand while non-significant at Godhra. The treatment effects of phosphorus were found significant at Anand. 80 kg P_2O_5 /ha gave higher rows/cob (15.01) but, at par with 60 kg P_2O_5/ha (14.91) while non-significant at Godhra. Chaudhary *et al.* (2002) reported the same kind of results in maize. The treatment effect was found significant for hybrid. GAYMH-1 have more rows per ear (14.80) at Godhra while GAWMH-2 have more no. of rows per ear (15.12) at Anand. The overall pooled result of test weight showed that, application of nitrogen significantly influenced test weight of maize. Treatment 200 kg N/ha gave higher test weight (298 gm) but, it was at par with 150 Kg N/ha) that is 294 gm at Anand. The treatments effects were found non-significant effect of Nitrogen and phosphorus on taste weight at Godhra while significant at Anand. At Anand, 80 kg P_2O_5 /ha gave higher test weight (297 gm) but it was at par with 60 kg P_2O_5 /ha. The observance are in accordance with the results findings of Mahesh *et al.* (2010). The difference in the test weight between two hybrids was found significant, GAWMH-2 (white hybrid) having higher taste weight (332 g) at Anand while GAYMH-1 (313 g) at Godhra. The research findings are in similar fashion as observed by Kumar *et al.* (2002) (Table 1).

Yields

Overall pooled results of both the centers show significant effect of nitrogen on grain yield of maize (Table 2). The treatment 200 kg N/ha gave significantly higher grain yield (7111 kg/ha) than 100 kg N/ha but, it was at par with 150 kg N/ha (6947 kg/ha). The effect of phosphorus was found non-significant in overall pooled analysis at both the centers (Table 2). The result presented in Table 2 showed that grain yield of both the hybrids differed significantly. Hybrid GAYMH-1 gave significantly higher yield (6724 kg/ha) than

Table 2. Effect of nitrogen and phosphorus on grain yield of two maize hybrids

Treatment	Grain yield kg/ha				Over all pooled (kg/ha)
	Godhra		Anand		
	2015-16	2016-17	2015-16	2016-17	
N_1 100 kg N/ha	7658	5870	4227	4231	5497
N_2 150 kg N/ha	9077	7229	5829	5654	6947
N_3 200 kg N/ha	9388	7424	5936	5697	7111
SEm ±	149	301	137	111	95
CD (0.05)	428	865	396	319	265
P_1 40 kg P/ha	8826	6733	4655	4341	6139
P_2 60 kg P/ha	8564	6755	5610	5477	6602
P_3 80 kg P/ha	8733	7033	5726	5764	6814
SEm ±	149	301	137	111	200
CD (0.05)	NS	NS	396	319	NS
N X P					
SEm ±	258	521	238	192	288
CD (0.05)	NS	1497	NS	NS	NS
V_1 GAYMH-1	8743	7037	5650	5468	6724
V_2 GAWMH-2	8672	6645	5011	4920	6312
SEm ±	122	245	112	90	77
CD (0.05)	NS	NS	323	260	216

Table 3. Effect of nitrogen, phosphorus and hybrids on fodder yield of maize

Treatment	Fodder yield kg/ha				Over all pooled (kg/ha)
	Godhra		Anand		
	2015-16	2016-17	2015-16	2016-17	
N_1 100 kg N/ha	10238	7133	6196	6414	7495
N_2 150 kg N/ha	12738	9001	8586	8152	9619
N_3 200 kg N/ha	13720	9930	8933	8201	10106
SEm ±	201	436	251	277	152
CD (0.05)	579	1255	722	796	425
P_1 40 kg P/ha	12440	8456	6990	6544	8607
P_2 60 kg P/ha	11964	8697	8341	7717	9180
P_3 80 kg P/ha	12291	8912	8384	8507	9524
SEm ±	201	436	251	277	268
CD (0.05)	NS	NS	722	796	NS
N X P					
SEm ±	348	756	435	479	264
CD (0.05)	NS	NS	NS	NS	NS
V_1 GAYMH-1	12226	9630	8374	7929	9540
V_2 GAWMH-2	12237	7747	7437	7249	8667
SEm ±	164	356	435	226	277
CD (0.05)	NS	1025	NS	NS	NS

Table 4. Economics under different treatment combination at two locations

Godhra					Anand				
Trt. No.	Treatment	Gross Realization Income Rs./ha	Total Cost Rs./ha	Net Realization Income Rs./ha	Trt. No.	Treatment	Gross Realization Income Rs./ha	Total Cost Rs./ha	Net Realization Income Rs./ha
N_1	100 kg N/ha	123173	24143	99030	T_1	$N_1P_1V_1$	67670	25543	42127
N_2	150 kg N/ha	149470	24840	124630	T_2	$N_1P_1V_2$	62105	25543	36562
N_3	200 kg N/ha	155653	25537	130116	T_3	$N_1P_2V_1$	89285	26243	63042
P_1	40 kg N/ha	142805	24150	118655	T_4	$N_1P_2V_2$	84338	26243	58095
P_2	60 kg N/ha	140725	24850	115875	T_5	$N_1P_3V_1$	105010	26943	78067
P_3	80 kg N/ha	144748	25550	119198	T_6	$N_1P_3V_2$	89095	26943	62152
V1	GAYMH-1	145670	22750	122920	T_7	$N_2P_1V_1$	115800	26240	89560
V2	GAWMH-2	139865	22750	117115	T_8	$N_2P_1V_2$	83510	26240	57270
	Fix cost	Rs.22750			T_9	$N_2P_2V_1$	129610	26940	102670
	N_1	Rs. 1393	P_1	Rs.1400	T_{10}	$N_2P_2V_2$	95828	26940	68888
	N_2	Rs.2090	P_2	Rs.2100	T_{11}	$N_2P_3V_1$	121940	27640	94300
	N_3	Rs.2787	P_3	Rs.2800	T_{12}	$N_2P_3V_2$	114333	27640	86693
					T_{13}	$N_3P_1V_1$	94148	26937	67211
					T_{14}	$N_3P_1V_2$	110675	26937	83738
					T_{15}	$N_3P_2V_1$	119908	27637	92271
					T_{16}	$N_3P_2V_2$	117623	27637	89986
					T_{17}	$N_3P_3V_1$	126183	28337	97846
					T_{18}	$N_3P_3V_2$	107855	28337	79518

GAWMH-2 in overall pooled analysis. Similar kind of trend was observed by Patel *et al.* (2017) (Table 2).

The overall pooled results of fodder yield showed that, increase in the level of nitrogen, increased the fodder yield of the maize (Table 3). The higher levels of nitrogen 200 kg N/ha recorded significantly higher fodder yield 10196 as compared to 100 kg N/ha (7495 kg/ha) and 150 kg N/ha (9619 kg/ha). The effect of phosphorus on fodder yield was found non-significant at both the locations. The individual hybrid was also found non-significant for fodder yield (Table 3).

Economics

Economics of different treatments were presented in Table 4. At Godhra indicated that the treatment $N_2P_1V_1$ and $N_2P_1V_2$ (150 kg N + 40 kg P_2O_5/ha) gave maximum net realization of Rs.1,24,630/- for nitrogen and Rs. 1,18,655 for phosphorus application. At Anand indicated that the treatment $N_2P_2V_1$ (150 kg N + 60 kg P_2O_5/ha) gave maximum net realization of Rs.1,02,670/-. The similar trend was observed by Reddi and Reddy (2007).

Conclusion

The farmers of middle Gujarat Agro climatic zone of Panchmahal District growing *rabi* maize hybrid GAYMH-1 and GAWMH-2 are advised to fertilize the crop with 150 kg N/ha and 40 kg P_2O_5/ha (Soil having medium phosphorus status) for securing higher grain yield with higher net return and the farmers of middle Gujarat agro-climate zone of Anand district growing *rabi* maize hybrid GAYMH 1 are advised to fertilize the crop with 150 kg N/ha and 60 kg P_2O_5/ha (Soil having low phosphorus status) for securing higher grain yield with higher net return.

References

Chaudhary, R. S., Rana, K. S. & Kantwa S. R. (2002). Effect of cropping system and nitrogen on growth and yield of maize (*Zea mays* L.). *Ann. Agril. Res.*, **23**(3): 461– 464.

Kumar, A., Thakur, K. S. & Sandeep, M. (2002). Effect of fertility levels on promising hybrid maize (*Zea mays* L.) under rainfed conditions of Himachal Pradesh. *Indian J. Agron.*, **47**(4): 526-530.

Kunjir, S. S., Chavan, S. A., Bhagat, S. B. & Zende, N. B. (2007). Effect of planting geometry, nitrogen levels and micronutrients on the growth and yield of sweet corn. *Crop Prot. Prod.,* **2**(3): 25-27.

Mahesh, L. C., Kalyanamuthy, K. N., Ramesha, Y. M., Yogeshappa, H., Shivakumar, K. M. & Prakash, H. (2010). Effect of Integrated Nutrient Management on growth and yield of Maize (*Zea mays* L.). *International J. Agril. Sci.*, **6**(1): 275-277.

Parihar, C. M., Jat S. L., Singh, A. K., Hooda, K. S., Chikkappa, G. K., Singh, D. K. & Kumar, R. S (2011). Maize production technologies. DMR Technical bulletin 2011/3. Directorate of Maize Research, Pusa Campus, New Delhi-110012. pp. 36

Patel, K. H., Parmar, P. K., Patel, M. B., Singh, S. K., Rathod, D. M. & Thakkar, B. N. (2017). Performance of single cross hybrid maize at varying levels of nitrogen and phosphorus under rainfed conditions of Middle Gujarat plains. *Maize J.,* **6**(1&2): 40-46.

Reddi Ramu, Y. & Reddy, D. S. (2007). Effect of micronutrient management on growth, yield, quality and economics of hybrid maize. *Crop Res.,* **33**(1,2&3): 46-49.

Maize Journal (October 2018) 7(2): 90-92

RESEARCH TECHNOLOGY INVENTORY

Landmark maize research papers in 2018*

S.No.	Authors, title and journal details	Key finding
1.	Kistler *et al.* (2018). **Multiproxy evidence highlights a complex evolutionary legacy of maize in South America.** *Science* 362(6420): 1309-13.	The authors use genomic, linguistic, archaeological, and paleoecological data to unravel complexity of maize domestication in South America. Landrace and archaeological maize genomes suggest that the origin of modern maize cultivars may have involved a "semidomesticated" lineage that moved out of Mexico which became isolated from the wild teosinte gene pool, before traits of domesticated maize were fixed.
2.	Kremling *et al.* (2018). **Dysregulation of expression correlates with rare-allele burden and fitness loss in maize.** *Nature* 555(7697):520.	The paper reports a multi-tissue gene expression resource from diverse modern inbred maize, including transcriptomes in an average of 255 lines in seven tissues. It characterizes the effect of rare alleles and evolutionary history, including long term effects of plant breeding, on the regulation of expression.
3.	Pan *et al.* (2018) **Structure of the maize photosystem I supercomplex with light-harvesting complexes I and II.** *Science* 360(6393):1109-13.	A major advance in our understanding of the photosysthesis process in maize revealing previously unseen paths for energy transfer between the antennas and the photosystem I core. The authors solved structures of photosystem I supercomplex bound to two light-harvesting complexes.
4.	Zhan *et al.* (2018). **Opaque-2 regulates a complex gene network associated with cell differentiation and storage functions of maize endosperm.** *The Plant Cell* 30(10): 2425–2446.	The authors have mapped *in vivo* binding sites of bZIP transcription factor, Opaque-2 (O2), in B73 endosperm. They identified 186 putative direct O2 targets and 1677 indirect targets, encoding a broad set of gene functionalities. Two distinct mode of gene activation by O2 was observed. Results from this study provide novel insights into the complexity of the O2-regulated network and its role in regulation of endosperm development and function.
5.	Zhang *et al.* (2018). **A pectin methylesterase gene at the maize Ga1 locus confers male function in unilateral cross-incompatibility.** *Nature Communications* 9(1):3678.	The authors cloned *ZmGa1P*, a pollen-expressed pectin methylesterase (PME) gene from gametophyte factor1 (Ga1) locus that can confer the male function in the maize unilateral cross-incompatibility (UCI) system. Homozygous transgenic plants expressing ZmGa1P in a ga1 background can fertilize Ga1-S plants and can be fertilized by pollen of ga1 plants. ZmGa1P protein is predominantly localized to the apex of growing pollen tubes and may interact with another pollen-specific PME protein, ZmPME10-1, to maintain the state of pectin methylesterification required for pollen tube growth in Ga1-S silks. This study discloses a PME-mediated UCI mechanism and provides a tool to manipulate hybrid breeding.
6.	Schaefer *et al.* (2018) **Integrating coexpression networks with GWAS to prioritize causal genes in maize.** *The Plant Cell* 30(12): 2922–2942.	The authors developed a computational approach, Camoco, that integrates loci identified by Genome-wide association studies (GWAS) with functional information derived from gene coexpression networks to identify highly promising candidate genes. Using Camoco, authors prioritized candidate genes from a large-scale GWAS examining the accumulation of 17 different elements in maize (*Zea mays*) seeds. Two candidate genes identified by their approach were validated using mutants. This study demonstrates that coexpression networks provide a powerful basis for prioritizing candidate causal genes from GWAS loci but suggests that the success of such strategies can highly depend on the gene expression data context.

**Compiled and edited by: Pranjal Yadava, Krishan Kumar, Bhupender Kumar and Ishwar Singh*

S.No.	Authors, title and journal details	Key finding
7.	Ziemann *et al.* (2018) **An apoplastic peptide activates salicylic acid signalling in maize.** *Nature Plants* 4(3): 172-180.	The authors discovered an immune signalling peptide, *Z. mays* immune signalling peptide 1 (Zip1), which is produced after salicylic acid (SA) treatment. *In vitro* studies demonstrated that PLCPs (Papain-like cysteine proteases) are required to release bioactive Zip1 from its propeptide precursor. Conversely, Zip1 treatment strongly elicits SA accumulation in leaves. Moreover, transcriptome analyses revealed that Zip1 and SA induce highly overlapping transcriptional changes. Consequently, Zip1 promotes the infection of the necrotrophic fungus *Botrytis cinerea*, while it reduces virulence of the biotrophic fungus *Ustilago maydis*. Thus, Zip1 represents the previously missing signal that is released by PLCPs to activate SA defence signalling.
8.	Feng *et al.* (2018) **High-efficiency genome editing using a *dmc1* promoter-controlled CRISPR/Cas9 system in maize.** *Plant Biotechnology Journal* 16(11): 1848–1857	In this study, using the *dmc1* promoter-controlled Cas9 system, high-efficiency and stable / heritable genome editing at the target site was achieved in maize. The T_0 plants regenerated were highly efficiently edited at the target sites with homozygous or bi-allelic mutants accounting for about 66%. The study showed that the dmc1 promoter-controlled CRISPR/Cas9 system is highly efficient in maize and evolutionary conservation of the *dmc1* gene suggests its potential for use in other plant species.
9.	Dong *et al.* (2018) **Parent-of-origin-dependent nucleosome organization correlates with genomic imprinting in maize.** *Genome Research* 28: 1020-1028.	The authors found that Parent-of-origin-dependent nucleosomes were significantly associated with the allele-specific expression of imprinted genes, with nucleosomes positioned preferentially in the promoter of nonexpressed alleles of imprinted genes. They also found that most of the paternal specifically positioned nucleosomes (pat-nucleosomes) were associated with parent-of-origin-dependent differential methylated regions, suggesting a functional link between the maternal demethylation and the occurrence of pat-nucleosome. Maternal specifically positioned nucleosomes (mat-nucleosomes) were independent of allele-specific DNA methylation but seem to be associated with allele-specific histone modification. This study suggested a mechanistic connection between chromatin organization and genomic imprinting.
10.	Sun *et al.* (2018). **Extensive intraspecific gene order and gene structural variations between Mo17 and other maize genomes**. *Nature Genetics* 50: 1289–1295.	This study reports a high-quality reference-genome sequence of Mo17 maize inbred, and the intraspecific gene order and gene structural variations identified should have implications for heterosis and genome evolution. The comparative genomics analysis uncovered extensive intraspecific gene-order variation: approximately 10% of genes were mutually nonsyntenic between B73 and Mo17. In addition, more than 20% of the annotated genes had large-effect mutations or large structural variations in B73 compared with Mo17.
11.	Springer *et al.* (2018). **The maize W22 genome provides a foundation for functional genomics and transposon biology.** *Nature Genetics* 50:1282–8.	The authors sequenced and de novo assembled a W22 reference genome. The generation of this reference genome enables accurate placement of thousands of *Mutator* (Mu) and *Dissociation* (Ds) transposable element insertions for reverse and forward genetics studies. This study shows that significant structural heterogeneity exists in comparison to the B73 reference genome at multiple scales, from transposon composition and copy number variation to single-nucleotide polymorphisms.

S.No.	Authors, title and journal details	Key finding
12.	Lappe *et al.* (2018). **Functions of maize genes encoding pyruvate phosphate dikinase in developing endosperm.** *Proc Natl Acad Sci USA* 115:E24–E33.	This study shows that maize endosperm pyruvate phosphate dikinase (PPDK) affects glycolytic flux without impacting net biomass deposition. It reported that PPDK deficiency in isolation causes the negative phenotype associated with reduced kernel hardness. The data indicates that PPDK modulates endosperm metabolism, potentially through reversible adjustments to energy charge, and reveal that o2**-** mutations can affect the opaque phenotype through regulation of PPDK in addition to their previously demonstrated effects on storage protein gene expression.
13.	Wang *et al.* (2018). **A comparative transcriptional landscape of maize and sorghum obtained by single-molecule sequencing.** *Genome Research* 28: 921–932.	The comparative analysis in this study revealed a large numbers of novel isoforms in maize and sorghum. Evolutionarily young genes were likely to be generated in reproductive tissues and usually had fewer isoforms than old genes. The maize subgenomes exhibited no bias in isoform generation; however, genes in the B genome were more highly expressed in pollen tissue, whereas genes in the A genome were more highly expressed in endosperm. Overall, this study revealed considerable splicing and expression diversity between sorghum and maize, which together are likely to explain the extensive morphological and functional differences between maize and sorghum.

AUTHOR INDEX

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