SOUVENIR

National Conference
on
Maize for Resource Sustainability, Industrial Growth and Farmers' Prosperity

February 23-25, 2022

Organised by

Maize Technologists Association of India (MTAI), New Delhi

In collaboration with

Indian Council of Agricultural Research (ICAR), New Delhi
ICAR-Indian Institute of Maize Research (ICAR-IIMR), Ludhiana
Maharana Pratap University of Agriculture and Technology, Udaipur
International Maize and Wheat Improvement Center (CIMMYT)

Sponsored by

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त्रिलोचन महापात्र, पीएच.डी.
सचिव एवं महानिदेशक
TRILOCHAN MOHAPATRA, Ph.D.
SECRETARY & DIRECTOR GENERAL

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कृषि अनुसंधान और शिक्षा विभाग एवं
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Message

I am pleased to know that a National Conference on **"Maize for Resource Sustainability, Industrial Growth and Farmers' Prosperity"** is being organized at Udaipur during 23-25 February 2022, by Maize Technologists Association of India in collaboration with Indian Council of Agricultural Research (ICAR), New Delhi, ICAR-Indian Institute of Maize Research, Ludhiana, Maharana Pratap University of Agriculture and Technology, Udaipur and International Maize and Wheat Improvement Center (CIMMYT).

Maize is the future crop for India to further enhance the farmers' income by ensuring sustainable use of natural resources in the long-run. The crop has registered an impressive growth during last decade. It has been projected that the demand for maize will continue to increase in near future due to expanding market size of feed and silage industry in India. In maize, however, there are huge yield gaps between states, districts, blocks within districts and also among farmers. There is a need to develop a strategy for bridging the yield gap. Mechanized maize cultivation along with adoption of single cross hybrids has the potential for enhancing productivity and profitability. Enhanced industrial uses of maize especially for ethanol production might be a boon to Indian farmers. I am happy to note that these issues are going to be deliberated in the conference.

I hope that the Conference will benefit all the participants and bring out recommendations for consideration.

I wish all success to the Conference.

Dated the 21st February, 2022
New Delhi

(T. Mohapatra)

Trust for Advancement of Agricultural Sciences

Avenue II, Indian Agricultural Research Institute, New Delhi – 110 012

Phone: 011-25843243; +91-8130111237

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Progress Through Science

Message

Dr. R. S. Paroda
Founder Chairman

Globally, maize is cultivated in 197.2 mha which produces 1,148 mt with an average productivity of 5,823 kg/ha (FAOSTAT, 2019). Among cereals, maize has registered highest production and productivity growth. India stands 4th in area after China, USA, Brazil and 7th in production after USA, China, Brazil, Argentina, Ukraine and Indonesia in the World. The country is surplus in wheat and rice but not in maize which is the third most important foodgrain crop in the country. Four states, namely, Madhya Pradesh, Andhra Pradesh, Karnataka and Rajasthan produce more than half of the total maize production of india.

Maize is a multi-purpose crop being used as food, Fodder, feed and industrial crop. In India, 15 million Indian farmers are engaged in maize cultivation. It has the potential of generating income while providing gainful employment. Hence, it can help in doubling farmers' income. In spite of wide range of health benefits, maize is a good source of high fibre, antioxidants, vitamins and minerals, besides its quality protein. In India, maize is presently used less for human consumption and more for poultry and animal feed as well as starch production. Unfortunately, its potential for ethanol production, as capitalised upto 40% in USA, has not yet been realised in India.

To bridge the yield gaps in maize, the major focus must now be on: genetic diversification through introgression of exotic including temperature germplasm in the tropical backgrounds to develop specifically single-cross maize hybrids with higher yield potential. Also recycling of lines with tolerance/ resistance to major abiotic and biotic stresses; breeding improved maize hybrids using doubled haploid lines; identifying lines with tolerance to multiple abiotic and biotic stresses using new genetic tools; developing and deploying climate resilient hybrids for rainfed agro-ecologies; greater focus on specialty maize, viz., sweet corn, baby corn, popcorn, specialty corns, single-cross and QPM hybrids. There is need to increase maize production by 50% by 2030 and productivity from present 3.0 t/ha to at least 5.0 t/ha. For this, the hybrid seed coverage has to be further increased from present 70% to >90% of total area as a matter of priority. This would require strong public-private partnership and enabling policy environment. In addition, enhancing rabi and spring maize production through good agronomic practices and increasing area under maize in the north eastern states and in rice-wheat production system to replace rice would help achieving future targets successfully.

Organizing the National Conference on “Maize for Resource Sustainability, Industrial Growth and Farmer's Prosperity” by Maize Technologist Association of India in collaboration with Indian Council of Agricultural Research (ICAR), New Delhi, ICAR-Indian Institute of Maize Research, Ludhiana, Maharana Pratap University of Agriculture and Technology, Udaipur and International Maize and Wheat Improvement Centre (CIMMYT) at Udaipur on 23-25 February 2022 is a welcome initiative. This will provide an opportunity to discuss various options to increase both production and productivity and define future Road Map for much faster growth and development of maize in India.

I congratulate the organizers for a very successful conference.

(R. S. Paroda)
(Padma Bhushan Awardee)
Former Secretary, DARE & DG, ICAR (Govt. of India)
And Chairman, TAAS

भारतीय कृषि अनुसंधान परिषद
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डॉ. तिलक राज शर्मा
उप महानिदेशक (फसल विज्ञान)

Dr. T. R. Sharma, Ph.D.
FNA, FNAAS, FNASc. JC Bose National Fellow
Deputy Director General (Crop Science)

Message

It is a matter of great pleasure to know that a National Conference on **"Maize for Resource Sustainability, Industrial Growth and Farmer's Prosperity"** is being organized at Udaipur during 23-25 February 2022, by Maize Technologist Association of India in collaboration with Indian Council of Agricultural Research (ICAR), New Delhi, ICAR-Indian Institute of Maize Research, Ludhiana, Maharana Pratap University of Agriculture and Technology Udaipur and International Maize and Wheat Improvement Centre (CIMMYT).

Maize is the wonder crop among the cereals to cope-up with climate change and achieve crop diversification. Strengthening of diversification of germplasm base and heterotic grouping of germplasm will equip us to meet the technological challenges in improving and diversifying the crop for food, feed, fodder and industry. Exploiting cutting-edge technologies such as genome-editing, double haploid, speed breeding, etc. will help in developing climate-resilient hybrids in a short span. I hope this Conference will have a great impact in remodeling the cropping system to usher in an ever-green revolution in the country.

I wish the national conference a grand success and extend my best wishes to all the delegates.

Place: New Delhi
Date: 18.02.2022

(T. R. Shrma)

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डॉ. नरेन्द्र सिंह राठौड़
कुलपति
Dr. Narendra Singh Rathore
Vice-Chancellor

महाराणा प्रताप कृषि एवं प्रौद्योगिकी विश्वविद्यालय
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No. PS/VC/MPUAT/2022/101
Date: 18th February, 2022

Message

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Sustainable Development Goals (SDG)-II is meant for attaining nutritional security and Maize is the wonder crop among the cereals to cope-up with climate change and achieve crop diversification. Further, the partnership of the Public Institutions and Private Sector is very much important for the successful Maize Mission. I hope that this conference will encourage more discussions for increasing maize production and productivity in the country.

I extend my best wishes to the organizers and the participating delegates for a successful conference.

(Narendra Singh Rathore)

भा.कृ.अ.प. – भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली–110012 (भारत)
ICAR - INDIAN AGRICULTURAL RESEARCH INSTITUTE
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Message

It is a matter of immense pleasure for me to know that a National Conference on **"Maize for Resource Sustainability, Industrial Growth and Farmer's Prosperity"** is being organized at Udaipur during 23-25 February 2022, by Maize Technologist Association of India in collaboration with Indian Council of Agricultural Research (ICAR), New Delhi, ICAR-Indian Institute of Maize Research, Ludhiana, Maharana Pratap University of Agriculture and Technology, Udaipur and International Maize and Wheat Improvement Centre (CIMMYT).

This conference would be helpful to deliberate the opportunities and challenges in Maize production and prepare a roadmap for Maize research to develop food, feed, and nutritional security in the country. Enhancing Maize production through the adoption of good agronomic and crop protection practices is the need of the hour. Further, breeding for climate-resilient maize by integrating innovative tools such as genomic selection, double haploid technology, gene-editing in ongoing breeding programme will contribute significantly to research and development.

My best wishes to the organizers for the National Conference for a successful event.

(A. K. Singh)

Dr. R. K. Singh
Assistant Director general (CC & FFC)
Indian Council of Agricultural Research
213A, Krishi Bhawan
New Delhi-110001

Dated: 18.02.2022

Message

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Genetic enhancement of maize for yield continued to be the major focus of maize research during 1950-51. India was producing only 1.73 million tonnes (million MT) of maize, which has reached 32.42 million MT in 2021-22. In addition to yield, emphasis on nutritional quality should be given to meet the industrial requirements. Further, an in-depth understanding of the basis of yield, quality and stress resilience through advanced tools and technologies needs to be considered to address the future challenges.

I wish a great success of the conference.

R. Singh

(R. K. Singh)

भारतीय कृषि अनुसंधान परिषद
डॉ. राजेन्द्र प्रसाद रोड़, कृषि भवन, नई दिल्ली–110001
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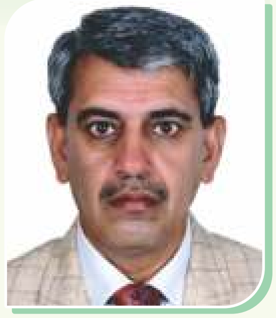
Dr. D. K. Yadava
Assistant Director General (Seed)

Message



Dated: 18.02.2022
No. F. CS.29/2/2021-Seed

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I hope the National Conference will provide a road map for maize-based sustainable agricultural progress in the country. I extend my best wishes to the organizers and the participating delegates for the success of this event.

देवेन्द्र कुमार यादव
(D. K. Yadava)

भाकृअनुप-भारतीय मक्का अनुसंधान संस्थान
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ICAR-INDIAN INSTITUTE OF MAIZE RESEARCH
PAU Campus, Ludhiana-141004, Punjab (India)

Message

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The Indian maize production during 1950-2020 has increased by 16.43 times, which is the highest as compared to rice (4.78 times) and wheat (16.65 times). Maize has recording the record production of 31.65 million MT in 2020, as per the advanced estimates released two days back (16.02.2022), the estimated maize production as gone up further to 32.42 million MT. This has become possible due to 2.12 times increase in area, 4.59 times increase in yield. Despite > 70 per cent maize area is under rainfed condition, the progress made in maize with respect to increase in area, production and productivity is remarkable. Genetic enhancement of maize for yield continued to be the major focus of maize research during this period. In addition to yield, currently the focus has expanded to enhancing the nutritional quality of maize and more emphasis is being given to traits of industrial importance. However, the challenges are numerous ranging from increasing the kharif maize productivity through increasing the area under hybrids of accelerating the genetic gain through application of advanced tools and techniques like doubled haploid technology, genomic selection and even gene editing. In this context, the National Conference would provide an opportunity for deliberations on advances in sciences and also formulating future strategies to face the challenges.

I congratulate the organizer for a successful conference ahead.

(Sujay Rakshit)

Maize Technologists Association of India
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E-mail: maizeindia@gmail.com

Executive Committee
(2020-22)

President
Sain Dass
Ex-Director ICAR - IIMR,
Ludhiana

Message

The growth in maize area, production, and productivity during 1950 to 2020 is comparable to the growth achieved on two major food crops of India viz., rice and wheat. The growth achieved in maize is remarkable as compared to rice and wheat because of the fact that >75% of the total maize area is under short duration and unpredictable moisture condition. Maize has gained popularity and spread to non-traditional areas in Andhra Pradesh, Karnataka, Tamil Nadu, West Bengal and Maharashtra etc. The main driving forces for increased popularity and acceptance by Indian farmers is due to availability of high yielding single cross maize hybrids. The area under single cross hybrids has increased in exponential rate during 2005-2020 and it will continue to increase in near future due its profitability over no remunerative cops in different seasons. The crop with different types with diverse uses, its versatile nature with respect to adaptation has potential to become mainstream crop of India in near future because of its increased importance in the industry. However, there are critical issues which needs scientific attention on priority like addressing increasing the rate of single cross hybrid adoption, addressing the increasing demand for silage maize, maize suitable for ethanol production and even development of hybrids of food-grade maize suitable for various processed food preparation like cornflakes etc. In addition, there are other issues like development of maize cultivars suited to crop diversification in different parts of India, especially in north western plains zone (NWPZ) of India to reduce the burden on the natural resource base like soil and water by replacing resource intensive crops with maize to ensure ecological sustainability. With this background the National Conference on “Maize for Resource Sustainability, Industrial Growth, and Farmers' Prosperity” being organized by Maize Technologists Association of India (MTAI) in collaboration with Indian Council of Agricultural Research (ICAR), New Delhi, ICAR-Indian Institute of Maize Research, Ludhiana, and Maharana Pratap University of Agriculture and Technology, Udaipur and International Maize and Wheat Improvement Centre (CIMMYT) during February 23-25, 2022 with the support of the various industry partners is timely which will bring all the stakeholders together and helps in formulation of the strategies for future to address the emerging challenges in maize improvement and its utilization.

I am looking forward for the best outcome from the National Conference and convey my best wishes for the grand success of the Conference.

(Sain Dass)

भाकृअनुप
ICAR


Maharana Pratap University of Agriculture & Technology, Udaipur


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RCA

Contents

Maize in India by 2030 - prospects and strategies

Sujay Rakshit and Chikkappa Gangadhar Karjagi

ICAR-Indian Institute of Maize Research, PAU Campus, Ludhiana, India – 141 004

Introduction

Maize is one of the most important food, feed, and fodder crop of India with significant importance as raw material in several crop-based industries. It is one of the major ingredients in poultry and other associated livestock feed industries. In addition, several starch and biofuel/ethanol industries across the world are heavily dependent on maize as raw material. Globally, the United States of America (USA) and China are the top producers of maize, which produces 360.25 and 260.67, million MT of maize respectively (FAOSTAT, 2020). However, China is the leading cultivator of maize in the world with largest area (41.26 million ha), followed by the USA (33.37 million ha). India stands distant fourth in total maize area in the world after China, the USA, and Brazil (18.25 million tons) and sixth in total production after the USA, China, Brazil (103.96 million MT), Argentina (58.40 million MT), and Ukraine (30.29 million tons). Presently, India is producing 30.16million MT of maize with an average productivity of 3.06 t/ha from 9.87 million ha area (FAOSTAT, 2020).

The ever-increasing population in the world demands the systematic studies on the future consumption pattern of food and feed grains and their dynamics vis-à-vis several direct or indirect factors which affect the consumption to ensure food and nutritional security of the future generation. The models used for the projections must also be robust for reliable prediction. Further, it also depends on the quality of historical data collected on various factors related to consumption. Similarly, it is also equally important to project the estimated demand for various food, feed and fodder crops based on the historical consumption pattern and dynamics. It is projected that the demand for maize will continue to increase in near future due to several factors. It is estimated that the global maize production may go up by at least 160 million MT during 2018-2030 (Fig.1).

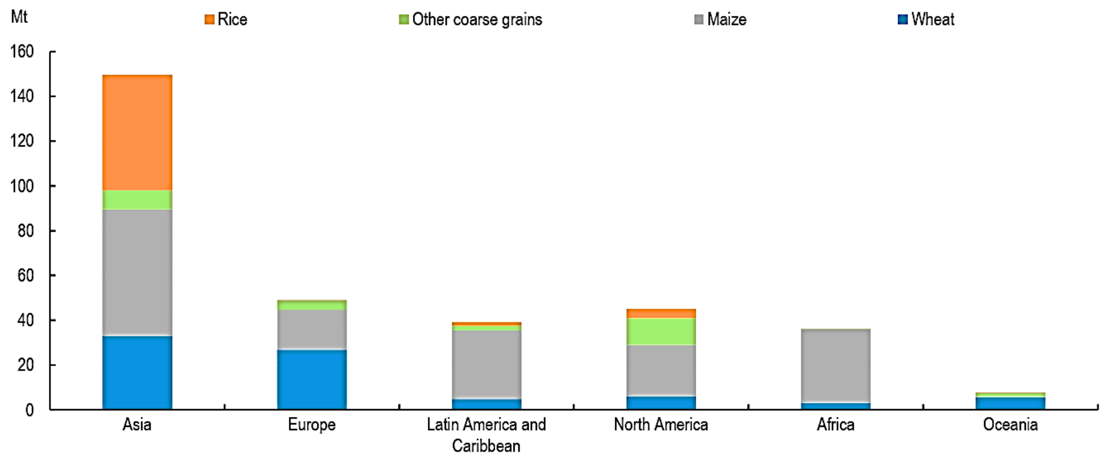

Figure 1. Regional contribution of growth in cereal production, 2018-20 to 2030 (Outlook 2021).

Projected scenarios in major maize producing countries vis-à-vis India

The major countries which would contribute substantially to global increase in maize production are China, USA, Brazil, Ukraine, and Argentina (Fig.2). The main factors which are responsible for increased maize production vary from country to country. For example, the second crop of maize after soybean harvest in Brazil to exceptional fertility along with increased crop rotation in Ukraine are the driving force for increased maize production. In case of Sub-Saharan Africa, the cultivation of improved cultivars of maize, which is enhancing the yield levels, thus would bring the increased total maize production of the region by 22 million MT. Based on the above facts, it is projected that the global maize area and yield would increase by 4 and 10 per cent, respectively during 2018 to 2030 (Outlook 2021).

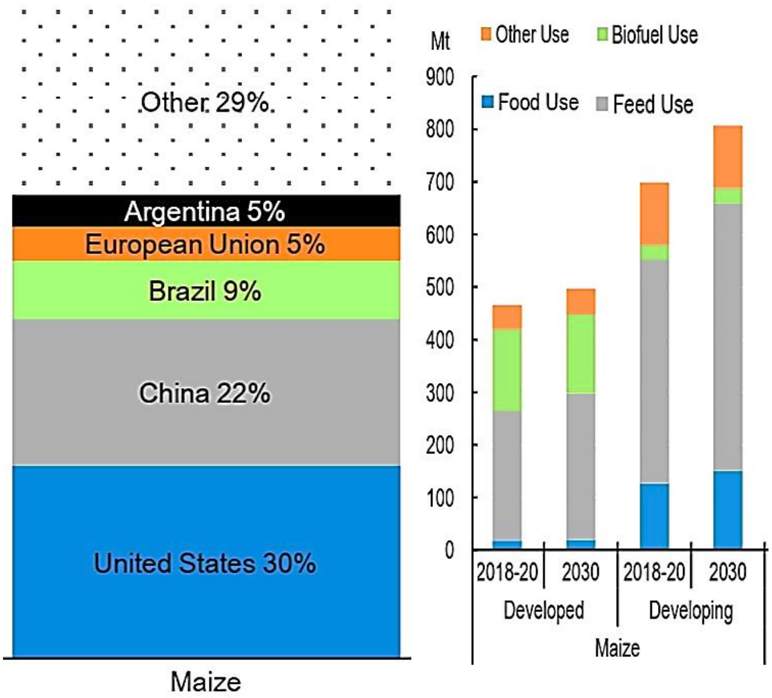

Figure 2. Global production concentration of maize vis-à-vis its projected utilization pattern across different countries in 2030(Outlook 2021).

China, the country with largest maize area in the world and the USA, possessing the second largest maize area after China, have made efforts by undertaking systematic studies to understand the future consumption pattern of major food and feed crops including maize (Chen 2019; Agricultural and Committee 2021). It is projected that the per capita consumption of maize in China would decrease marginally from 9.2 million MT (2017) to 8.4 million MT by 2030 (Fig.3). On the contrary, the total maize consumption as feed and other purposes would increase from 218.4 million MT to 280.9 million MT and 34.2 million MT to 43.4 million MT, respectively during 2017-2030. Thus, the total maize requirement in China would increase from 261.8 million MT to 332.7 million MT which accounts for 39.2% of the total grain consumption.

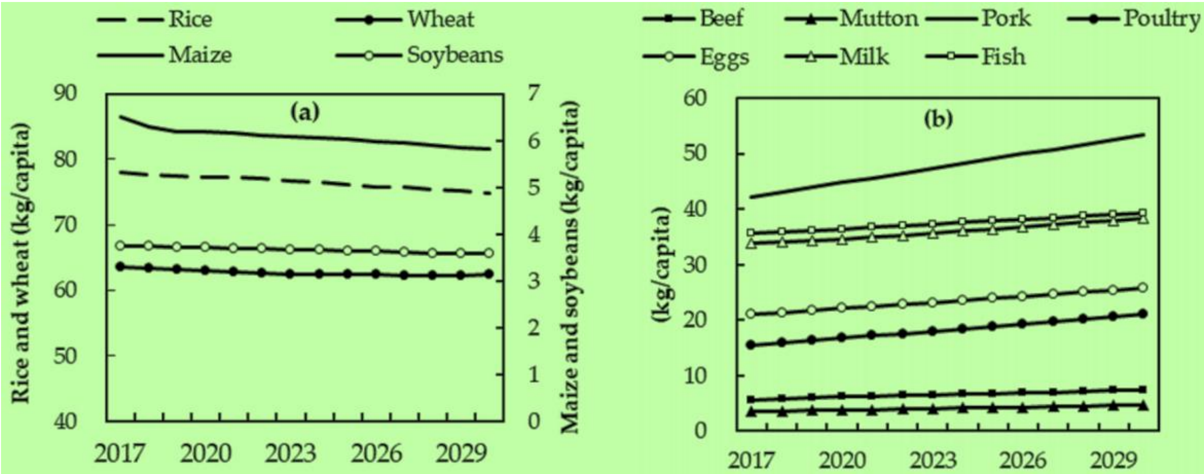

Figure 3. The projected per-capita consumption pattern of major food crops (a) and animal food (b) in China during 2017-2030(Chen 2019).

The USA, the largest maize producers in the world, has projected that the demand for maize would continue to increase in the country. The demand is mainly driven by feed and residual use. It is predicted that it would increase from present 360 million MT of maize (2021) to 380 million MT, which is approximately 15 billion bushels (Fig.4). However, the USA has projected maize production of 410 million MT by 2030.

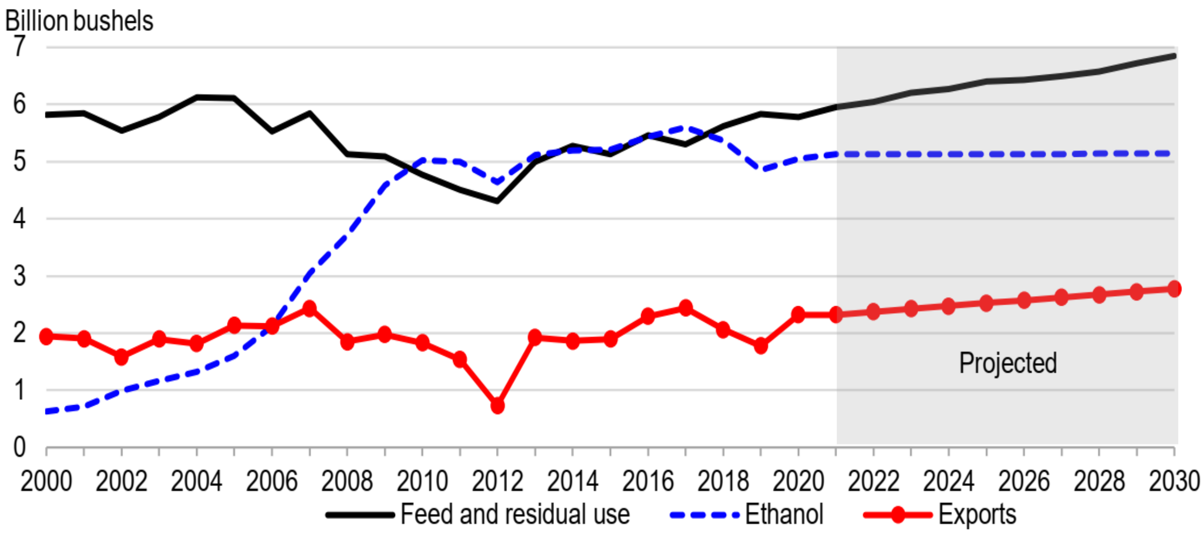

Figure 4. U.S. corn feed and residual use, ethanol, and exports, 2000-30(Chen 2019).

The extensive studies to project and predict the future demand for maize in India by different sectors like poultry feed, pig feed, ethanol production, food and fodder etc. are missing. However, based on the past and present trend in maize area, production, and productivity indicates that the demand for maize and its production and productivity would continue to increase in near future (Fig.5). The major driving forces of maize demand are feed and biofuel industries.

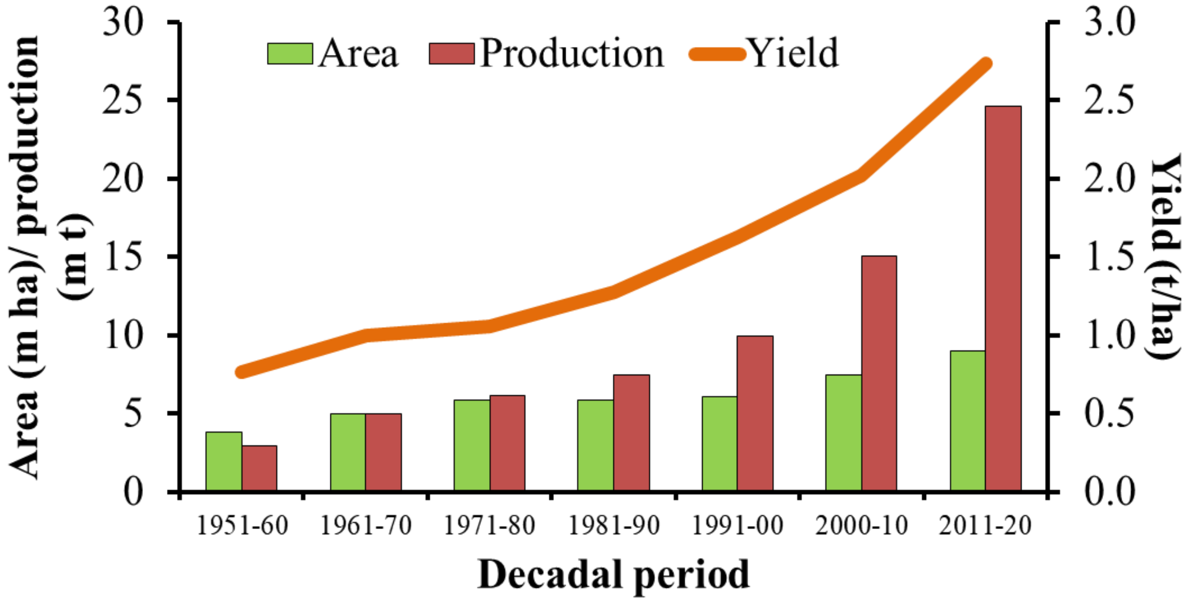

Figure 5. The trend in maize area, production and yield in India during 1951 to 2020.

The future maize demand in India depends on the several factors of domestic and global significance. The major factors which affect the agriculture production in India are also the factor which affects maize production. The major reason for increased demand for maize in near future is due to its diverse uses in different industries. The demand for maize is also governed by dynamics of consumption pattern as well as international trade (Fig.6).

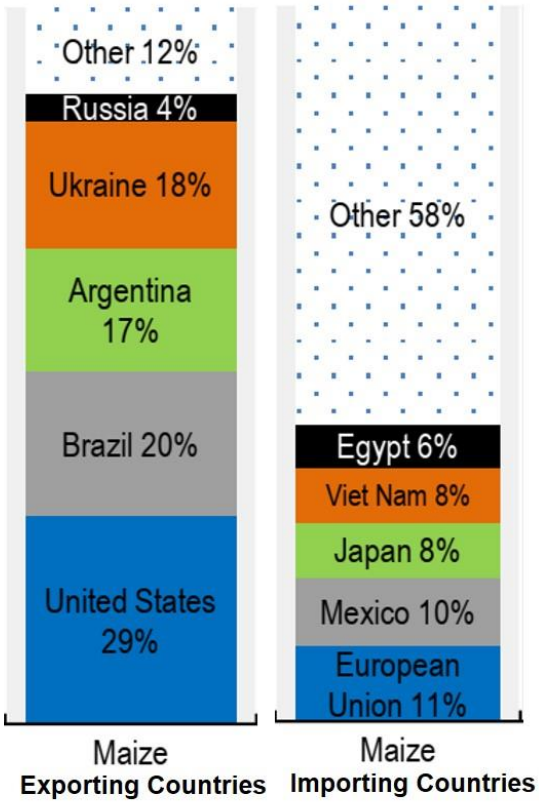

Figure 6. The projected maize trade concentration by 2030 (Outlook 2021).

Strategies to achieve sustainable maize production

Introduction of novel germplasm

The genetic diversity is the core requirement to enhance the yield potential of the new hybrids. In that context, there is a need to introduce new and diverse germplasm from different source. The major sources of novel germplasm could be different folk varieties and landraces collected from different agro-ecological regions across India or otherwise. The very reason for considering landraces or folk varieties for their introduction into active maize germplasm that the significant proportion of those genetic resources have not yet explored. The other factors which demand use of novel germplasm into active germplasm pool are continuous expanding maize uses domain. For example, the USA is diverting approximately 30-40 per cent of its total maize production into biofuel production. Similarly, the expanding the food basket involving different kinds of maize like specialty corn namely baby corn, sweet corn, popcorn also demand for search for germplasm suitable for different purposes. The series of quality traits like high oil, high-methionine, high-starch or its kinds etc. can also be added to the list of other diverse uses of maize to identify and introduce genotypes and germplasm for these traits.

Development of new and productive hybrids

The continuous enhancement of yield is the first objective of any breeding programme. The systematic breeding programme directing towards development of high yielding cultivars is of prime importance. The objective can be achieved through formulating priority traits, identification of germplasm or genotypes for specific traits, understanding the genetics and heredity of the traits, and formulating the suitable breeding methods to improve the traits of interest in both short- and long-run. In India, single cross hybrids have penetrated to remote parts of India in many states like Telangana, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Punjab, Haryana, Odisha, Bihar, Karnataka etc. Presently, several single cross hybrids are available for commercial cultivation, however, there is tremendous scope for development of hybrids which can fit to different cropping systems and seasons in different parts of India. The identification of gaps and formulating the breeding programmes to address the gaps is the need of the hour to bring overall improvement in the national average productivity of the nation. In this regard setting the target yield levels for different parts of India, and also seasons would require focussed research efforts.

Addressing the biotic and abiotic stresses

The continuous expansion of maize area across season and regions especially in the non-traditional areas and seasons has led to increased maize area in the country. The continuous cultivation of maize has led to availability of maize as host-plant to several pests and diseases of maize. Further, due to increased exchange of seed material across continents has also posed serious challenge to government to prevent the movement of cross-boundary pests and diseases. Recently the whole World has witnessed the cross-boundary movement of fall armyworm (FAW) of maize from Africa to Asia to Australia. Earlier FAW which was restricted to America is now the pest of global importance. It was one of the serious insect pests of maize which has the potential to threaten the maize production by causing significant yield losses. Similarly, several diseases and insect pests of maize are slowly gaining ground in different parts of India. For example, post flowering stalk rot (PFSR) in maize has brought down the maize area in Andhra Pradesh and parts of Telangana, the severity of turcicum leaf blight (TLB) is increasing in parts of Karnataka and other states. Similar kinds of examples can be elaborated for each of the states. Therefore, the breeding programme must be developed to address such challenges though developing biotic stresses in long-term.

The abiotic stresses are much more complex than the biotic stresses, and often are unpredictable. The impact of climate change and global warming and, increased concentration of atmospheric CO_2 in the atmosphere has actually increased the frequency as well as severity of abiotic stresses like drought, cold and water-logging. It is reported that in the absence of any adaptation interventions, in spite of increased concentration of CO_2 in the atmosphere due to climate change, it is estimated that the maize yield would reduce by 18% by 2040 in comparison to yield levels of maize during 2000-2007 (Aggarwal et al., 2020). The major factor which affects the maize yield negatively is the increased minimum temperature especially in Telangana region. On the contrary, *rabi* or winter maize in Bihar would be benefitted, which would lead to increased yield levels by 8.4 to 18.2 per cent due to increased temperature (Aggarwal et. al., 2020). Maize being highly sensitive to high as well as low temperature and also low and high moisture stress, it is important to develop the systematic breeding strategy to address these issues and also develop climate resilient genotypes.

Accelerated improvement through use of molecular tools

The increasing population is one of the major reasons for continuous increase in demand and also the requirement of food grains and maize is no exceptional. The need of the hour is to reduce the cycle of cultivar development to meet the challenges of increased production to feed the burgeoning population. The appropriate advanced molecular tools and techniques are available for accelerated development of new and novel cultivars. The integration of molecular markers technology like genomic selection along with doubled haploid technology can sustainably bring increased genetic gain. The success of the application of advanced tools and techniques depend on the robust, accurate, reliable high throughput phenotyping. Presently, attempts are being made and also in some crops the drone aided large-scale, high-throughput phenotyping is followed for precise phenotyping to capture the rare genotypes with immense value in crop improvement. In this context, human resource development in these areas of research plays a significant role in application of such tools and their use for accelerated development of cultivars. Similarly, gene editing technologies can also plays a significant role in precise manipulation of critical defects in the otherwise superior cultivars.

Popularization and spread of hybrid technology

The success of maize improvement in USA is a testimony of the impact of hybrid technology in enhancing the maize yield consistently over five decades. The similar impact is also being witnessed in Indian maize scenario with respect to increase in maize area, production, and productivity. However, according to informal estimates, currently approximately less than 75 per cent maize area is under hybrids. The spread of proven technology like hybrid technology to the tune of 95-100 per cent would bring substantial increase in the maize production and yield of the country. Therefore, careful and effective work-plan or strategy is required to achieve the target. The effective policy intervention in this regard would certainly plays an important and effective role in increasing the maize production in short-term. Further the variety replacement rate, replacing the old and less yielding hybrids with latest hybrids would also bring substantial improvement in the production and yield of maize.

Popularization of improved production technologies

The quantitative genetics has demonstrated that environment plays an important role in the full expression of the genotype. According to recent reports that climate and agronomy are also very important and they can plays much bigger role than the genetics, especially under the scenario of yield plateau (Rizzo et. al., 2022).The several novel concepts have been emerged in crop production technologies like effective integrated nutrient, weed, and water management practices. Therefore, the hybrid specific, site-specific agronomic interventions and their popularization and practices in actual farms would bring substantial improvement in the yield. Thus, would enhance the maize production and productivity.

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Millet Based Value Added Products for Industrial Prosperity and Nutritional Security

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Abstract: The triple burden of malnutrition is now a global challenge. The United Nations has set a target to end hunger by 2030, but we are far from reaching it. There is an urgent need to change the food system to achieve food and nutritional security. One of the approaches to achieve this goal is to provide nutritious and affordable food to all. In this context, millets, one of the ancient grains laden with nutrients, can play a vital role in contributing to global nutritional security. There is a strong need to increase the visibility of millets and create awareness so as to encourage consumption. In order for millet to tap the urban market, there is a need to diversify its product range. This lead paper discusses the potential of millets to meet nutritional security. It also gives an overview of various value-added products which can be made from millets using both the traditional and modern processing techniques and their nutritional benefits. Lastly, it highlights the approaches to boost up millet trade in order to boost up the millet market, leading to industrial prosperity.

Keywords: Nutri-cereals, value addition, millet products, nutritional security, industrial growth

Introduction

The number of people suffering from malnutrition continues to rise globally. In 2020, between 720 and 811 million people in the world faced hunger under the shadow of the COVID-19 pandemic (FAO, 2020). About 2 billion people are overweight and/ or obese, a number which is steadily increasing across all countries of the world (WHO, 2021).Malnutrition has severe effect on individual’s health as it affects growth in children, weakens the immune system and makes the person susceptible to infections, eventually leading to death.

To address the challenge of global hunger and malnutrition, food-based strategies are one of the key recommendations by FAO.It will also help in maintaining the biodiversity in the food systems which is essential for ensuring food and nutritional security. Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2006). While nutrition security refers to the need to secure access to an appropriately nutritious diet, comprising all essential nutrients and water, coupled with a sanitary environment, adequate health services and care to ensure a healthy and active life for all household members (FAO, 2012).

In this context, cereals and grains not only provide more than 50% of the world's caloric and protein intake but are also a good source of other micronutrients (Laskowski et al., 2019) which can be used as a food-based approach for tacking nutritional security. One of the cereal grains laden with essential nutrients such as carbohydrates, proteins, dietary fibre, lipids and phytochemicals, are the millets. Millets are ancient grains which can offer food security and sustainability due to their ease of cultivation, adaptability to grow in arid soils, less water requirement and resistance to pests and droughts. They are also super foods rich in nutrients such as minerals, dietary fiber, proteins and phytonutrients. These grains have been part of traditional diets in tropical communities for many millennia.

With changes in lifestyle and increased focus on other staples such as rice and wheat, consumption of millet grains has declined. There has also been a shift in the dietary pattern of consumer towards convenience foods due to urbanization. Millet processing has been a very slow and tedious process due to the lack of knowledge on processing interventions and processing machinery for millets. With the International Year of Millets 2023 around the corners, these grains have been slowly fueling the start-up revolution to improve the availability and diversity of nutrient rich value-added products, in addition to creating employment.

Various technologies are now available for processing millets into diverse value-added products. They are milling, extrusion, puffing, flaking, baking, instant mixes etc. These processes influence the nutritional content and digestibility of millets. Understanding the changes can help the food industry, researchers, and consumers select a suitable processing technique to optimize the nutritional value of millet-based products, increase the bioavailability of nutrients, and help combat food and nutrition security.

To sustain in the market, there is a need to generate higher demand for millets-based products. This will in turn bring significant revenue to the farming and food industries. With the increasing awareness of consumers on healthy foods, consumption of millets is expected to rise very soon. Expanding the millet industry with a range of value-added products has potential to attract a premium market both nationally and internationally and can serve as a good source of revenue for the country.

Millets and Nutritional Security

Millets possess unique nutritional characteristics. They are superior to major cereals such as wheat and rice, owing to their higher levels of dietary fiber, antioxidant phytochemicals and micronutrients (Bouis, 2000). Nutritional studies indicate presence of balanced protein in millets with significant amounts of the essential amino acids, leucine, phenylalanine and valine and non-essential amino acids, glutamic acid, alanine, proline, serine and aspartic acid (Anitha et al., 2020). Additionally, millet starches offer slow and sustained increases in postprandial blood glucose levels, which are associated with improvement in insulin sensitivity and glucose homeostasis (Kam et al., 2016). Thus, millets can play a major role in addressing malnutrition (both under- and overnutrition-related pathologies), and therefore, form an important crop for food and nutritional security.

The carbohydrates in millets make up around 65 % of the grain, the bulk of which consist of complex carbohydrates. Free sugars account for about 2–3%, non-starch polysaccharides constitute 15–20%, while starch is the major carbohydrate making up about 60–75%. The free sugars include primarily glucose, fructose, and sucrose. The non-starch polysaccharides are the dietary fiber which comprises cellulose, hemicellulose, and pectinaceous material.

Millets contains around 7-12 g of protein, making it a good source of it. The essential amino acid profiles of the millet protein is better than maize. The methionine, a sulphur containing essential amino acid is substantially higher in all millets while lysine is the limiting amino acid in millets, just like other cereals.

Lipids are concentrated in the germ, pericarp and aleurone layers of millet grains. The germ comprises ~24 % of the total grain fat. The average lipid content extracted from millet grain was found to be 7.2 % (Himanshu et al., 2018). It consists of neutral lipids (85 %), phospholipids (12 %) and glycolipids (3 %).

Millets are rich sources of several micronutrients. Part of the reason millets show better micronutrient profiles than the major cereals is that they are typically consumed as whole grains. However, it is also noteworthy that these grains have inherently higher quantities of several micronutrients even compared to the whole grain form of rice and wheat.

Millet based value added products

Utilisation of millets to develop an affordable, palatable and nutrient-rich product is the need of the hour since food and nutritional security is at risk. Therefore, processing techniques such as dehusking, milling, soaking, germination, roasting, etc. is crucial to increase the bioavailability of nutrients, organoleptic quality of the products and decrease the anti-nutrients of the millet grains. Millet based value added products can result from primary processing or secondary processing.

Millet products from primary processing

Primary processing involves processes such as cleaning, washing, soaking, germination, dehulling, milling (into flour and semolina) of the millet grains to remove the undesired seed coat and antinutritional factors (Rao et al., 2017).

Milled products

Milled products from millets include flour, semolina (grits). Semolina can be categorised into coarse, medium and fine semolina based on their particle size. Figure 1 shows the different products resulting from milling.

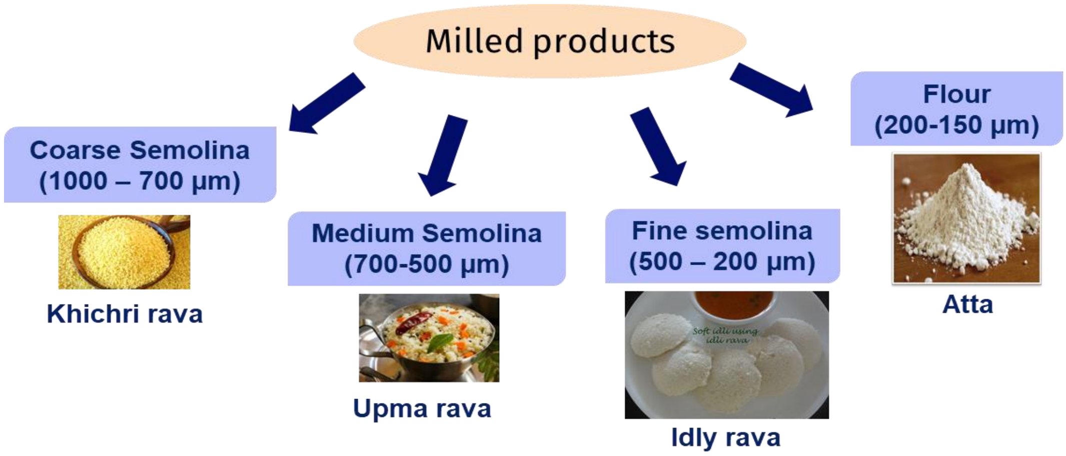

Figure 1. Milled products from millets

Milling reduces the phytic acid levels in millets and enhances the starch digestibility and *in vitro* protein digestibility compared to the whole and semi-refined flours (Pushparaj and Urooj, 2001). Milled grains were reported to cook rapidly to a soft texture, probably due to high hydration rates. In addition, grinding action during the process also causes physical damage to starch granules, thereby increasing the enzymatic action (Singh and Raghuvanshi, 2012).

Flour is one of the main products of milling and is used in aa a base ingredient in various recipes. Millet grains are processed by dry milling. Dry milling starts with cleaning of grains. The cleaned grains are then milled either by hammer, roller or *chakki* (stone) mill to separate the endosperm, germ and bran from each other to get fine flour.

Semolina is also made during the milling process. The endosperm is ground to coarse (1000 – 700 µm), medium (700 – 500 µm) and fine (500 – 200 µm) particle size in a hammer mill. These semolina grits are used to make *khichri rava*, *upma rava* and *idly rava*, respectively.

Sprouts/ Malt

Millet malt is produced during the malting process. It involves restricted sprouting of cereals under controlled conditions. Malt can be used in the preparation of porridge, infant foods, and alcoholic beverages from millets. Improvement of protein quality and efficiency ratio has been reported during malting (Singh and Saini, 2012). Germinated pearl millet was found to have higher total soluble sugars (6.13 g/100 g), reducing (3.43 g/100 g) and non-reducing sugars (2.70 g/100 g) compared to unprocessed grains (1.76, 0.36, 1.40 g/100 g). Reduction of the starch contentwas observed, which might be due to starch hydrolysis accompanied by release of soluble sugars (Khetarpaul and Chauhan, 1990).Enzymatic hydrolysis of phytate in finger millet during germination was observed by Mbithi-Mwikya et al. (2000) wherein phytate values decreased from 0.35 in the raw sample to 0.02 g/100 g after 96 h of germination.

Fura, a Nigerian cereal food, prepared by germination of pearl millet grains, displayed higher nutritional and energy profile compared to raw pearl millet grains (Inyang and Zakari, 2008). There was also a 29% increase in the concentration of γ-amino butyric acid (GABA) content after germination of the native millets. The increase could be attributed to the γ-decarboxylation of L-glutamic acid present in millets by enzyme glutamate decarboxylase that gets activated as a result of the germination process (Guzmán-de-Peñas et al., 2015).

A

B

Figure 2. (A) Finger millets sprouts, (B) Foxtail millets sprouts

Fermented products

Products such as *dosa* and *idly* are made as a result of fermentation. Fermentation is a metabolic process which converts sugar to acids, gases or alcohol. Fermentation is known to significantly improve the nutritional properties of the product. Fermentation of finger millet flour using endogenous grain microflora showed a significant reduction of the content of antinutrients - phytate (20%), phenols (20%), tannins (52%), and trypsin inhibitor activity (32%) at the end of 24 h. There was a simultaneous increase in HCl-mineral extractability (Ca, 20%; P, 26%;

Fe, 27%; Zn, 26%; Cu, 78%; Mn, 10%), soluble protein, *in vitro* protein digestibility (23%), and starch digestibility (Antony and Chandra, 1998). Fermented products also exhibit a wide variety of flavors and is a method of preservation.

A B

Figure 3. Fermented products from millets (A) Foxtail millet dosa, (B) Multi millets idly

Millet products from secondary processing

Secondary processing involves converting the primary processed products into ready-to-cook (RTC) and ready-to-eat (RTE) products using technologies such as flaking, puffing, extrusion, baking etc. These processing techniques help in enhancing the shelf life, improving the palatability, texture, nutritional quality and digestibility (Yousaf et al., 2021).

Flakes

Flakes are prepared exclusively with100% millet grainsusing theroller flaking machine. It is a ready-to-eat (RTE) product. It can be consumedby both traditional and non-traditional consumers across the country with minimal cooking at home. Sorghum flakes are a soft textured product and hydrate easily after being sprinkled with cold or hot water and can be seasoned with spices and garnishes to prepare very tasty snacks or breakfast items. The flakes can be consumed after mixing with milk and sugar or with buttermilk or curd. Thinner flakes can just be seasoned with a little oil and spice and may be used as delicious dry snacks. Sorghum flakes can partially or fully substitute rice flakes in the traditional flake-based products, such as bisibele bath, imli poha, idli, dosa, and so on.Sorghum flakes was found to be rich in nutrients, such as protein (7.23 g), dietary fiber (5.97 g), calcium (10.94 mg), iron (8.77 mg), and magnesium (68.9 mg) (Rao et al., 2019).

Figure 4. (A) Ragi flakes, (B) Jowar flakes

Puffs

Puffs are products resulting from an explosive puffing or gun puffing where the millet grain is expanded to maximum expansion consistent with the grain identity (having similar shape of the grain). It is a ready-to-eat snack. The highly expanded end product has pleasing texture, appealing flavour, and is less dense with low bulk density.Studies on puffing of proso and pearl millet have shown increased protein content and *in vitro* digestibility (Ramakrishnan et al., 2019).

Expanded rice or *murmura* is a very popular product. But similar products from other cereals are rare. The reason being preparation of such products need elaborate processing of cereals viz. parboiling and pearling of the grain before subjecting to HTST treatment. Expanded grains of millets are possible by using same method.

Figure 5. (A) Barnyard sweetpuffs, (B) Jowar puffs, (C) Bajra puffs

Cold Extruded Products

Cold extruded products such as vermicelli and pasta are generally made from durum wheat or refined wheat flour using the cold extruder. These products can also be prepared with millets using the same machine. Millet suji is used to make vermicelli and pasta by using suitable dies. The mixed material is extruded through dies and dried till the required moisture is reached.Cold extrusion is very useful due to its low cost and continuous processing capability. It has been accepted as one of the most useful technologies during the recent years in the field of food processing. Millet vermicelli can be used to make semiya upma or kheer. Finger millet vermicelli can be stored for six months at ambient temperature.

Hot Extruded Snacks

Extruded snacks (e.g., *Kurkure*, extruded flakes) are ready-to-eat products prepared using twin hot extruder which combines heating with extrusion to create a shaped cooked product through a round minus shaped die. Extruded snacks can be made from millet grits and wheat and corn flour. The mixture is combined through and passed through the twin screw extruder to produce expanded snacks. These can be further coated with the desired spice to create variations in taste and flavour. The hot extruded products have a crunchy texture. Their ready-to-eat nature gives them greater scope for use as weaning and supplementary foods.

Figure 6. Cold extruded products (A) Ragi vermicelli, (B) Sorghum pasta

In a study on the development of extruded weaning foods based on sorghum, pearl millet and finger millet, hot extrusion process enhanced the *in vitro* protein digestibility, but no marked difference occurred in the in vitro carbohydrate digestibility among the unprocessed blends and the extruded foods (Malleshi et al., 1986).

Figure 7. Sorghum extruded snacks

Bakery products

Bakery products, such as bread, biscuits, or cookies, are popular convenience food products in almost all countries. Internationally, refined wheat or *maida* is the main cereal product used as raw material for these products. *Maida* is a fully refined wheat product and does not contain any of the nutrients from its seed coat or wheat bran and the germ. On the other hand, sorghum flour provides a considerable proportion of dietary fiber and complex carbohydrates. Hence, sorghum flour as a raw material for bakery products is a nutritionally superior option to refined wheat flour (Ratnavathi and Patil, 2013).

The procedure of making biscuits includes creaming (fat and sugar powder) and addition of the millet flour then mixing to make dough. It is then rolled, cutting into biscuits, and baked. Cake, bun, bread, rusk, muffins, brownie and other bakery items can also be prepared with millets.

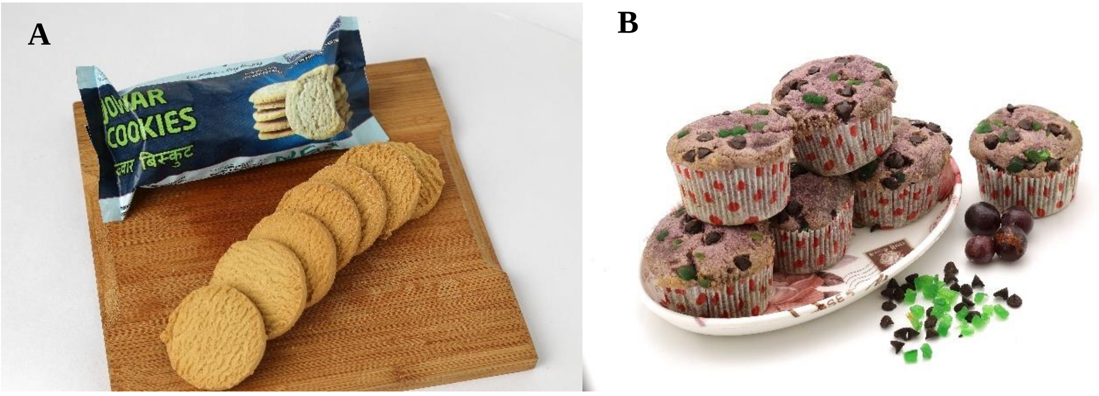

Figure 8. (A) Sorghum cookies, (B) Ragi muffins

Instant Mixes

In the contemporary scenario, where life is at a fast pace, 'Instant Foods' play an important role in the day-to-day life. Instant and ready-to-constitute foods have become well established products in the western countries. It is need of the hour to also develop traditional foods as convenience foods. Ready to cook products made from millets instead of using rice and wheat adds to the health value of the product. Millet based instant mixes such as upma, pongal, khichidi, payasam, bisibelli bath, idli and dosa have been developed at the Indian Institute of Millets Research.

Instant jowar idli mix is made through milling of the sorghum to fine semolina and roasting of ural dal to fine flour and mixing with other dry ingredients.

Figure 9. (A) Instant sorghum *idli* mix, (B) Instant sorghum *upm*a mix, (C) Instant sorghum *pongal* mix

Novel value-added products from millets

One of the emerging areas of research is the plant-based proteins from millets. Millets are known to be a good source of protein, which can be extracted and used in various product developments as a more sustainable protein source. Proso millet, which is one of the richest protein sources (~12 %) among the various millets can be used as a protein source for producing millet protein concentrates. Extraction procedure to optimise yield either using wet method or dry fractionation method is still at its infancy. Trials are ongoing at ICAR-IIMR to increase the yield of protein concentrates. The protein concentrate can be used in development of high protein vegan foods.

Figure 10. Plant-based meat substitute products

Challenges in development of value-added products:

1. The major challenge for development of value-added products from millets is lack of gluten content in protein that is required for binding during processing.
2. Though millets are known for their unique nutritional profile and various health benefits, its utilization is limited to traditional consumers. There is a need to tap the urban, nutritional and functional market.
3. There is a dearth of ready-to-eat/ ready-to-cook convenience products of millets in the market. With fast-paced lifestyle, there is a need to develop more of RTC/RTE products.
4. Millet grains have a tough fibrous outer covering, unique fatty acid profile, flavor, low shelf-life etc. These properties tend to decrease the consumer acceptability and hence may not sustain in the market.
5. At present, the market is witnessing an increase in the millet-based products claiming certain health benefits without proper validation. There is a need for validating the health claim to sustain in the market.

Millets and Industrial Prosperity

Increasing interest in reviving the consumption of millets across various countries is favoring the growth prospects of this market in the recent years. A number of initiatives are being undertaken toward enhancing millet cultivation and consumption to reduce health risks caused due to diabetes, obesity, cardiovascular diseases, etc. Unified approaches among millet suppliers and food and beverage manufacturing companies to fulfil the demand of millets has been crucial to proliferate its industry size.

With an annual global output of 25 million tons, millet has been one of the basic nutrients of humans for 4 thousand years in Africa, Asia and Europe until the end of the Middle

Age.The global millet consumption has declined at a rate of 0.9% and expected to witness positive movement during 2019-2024.The millets market is set to grow from its current market value of more than $9 billion to over $12 billion by 2025.

The growing inclination of urban population towards healthy food is expected to drive the millet trade in 2025. Millets contains calcium, iron and fibres which helps to fortify essential nutrients for the healthy growth in children. The usage of millets in infant food and nutrition products is increasing and many manufacturers are expanding their business.

Another reason which will drive the millet trade relates to its sustainable nature. Rice and wheat production are water intensive and are likely to be unsustainable, as freshwater resources are depleting around the globe. Millet grows easily in dry climate, have smaller harvesting period and require minimal water quantity. They are also nutritionally superior to the highly consumed cereals such as rice and wheat. Their high content of nutrients and phytochemicals can also aid in the management of non-communicable diseases such as diabetes, obesity, cardiovascular diseases etc. However, their high product prices in comparison to wheat and rice is acting as a hindrance to penetrate the urban food market.

The demand for gluten free products, especially in the offshore markets can also be one of the drivers to promote millet trade. Stringent regulations in North America & European market towards labelling of gluten free food will increase consumer awareness related to millet products.

Millets based products such as flour, flakes, cookies, etc. are more than ever increasingly visible in consumer market. The high protein content of these grains makes them ideal for vegetarian and vegan population, largely based in the U.S., Europe and Asia Pacific. Breakfast cereals such as flakes and local recipes have seen an ascending trend of adoption by African and Asian population Thus, millets-based breakfast foods generated revenue over USD 2 billion in 2018 and likely to witness maximum gains due to increasing pattern of fibrous and gluten free food consumption.

Millets based infant food such as porridge are ideal for infant growth and will help to lower the occurrence of malnutrition in infants and babies. Bakery products such as packaged cookies are slowly gaining prominence owing to its easy availability in supermarkets and e-commerce sites, especially in Asia Pacific. Millet Beer is a traditional part of African culture and ventures related to millet beer production are also finding place in Asia Pacific, Europe and North American beverage market.

Conclusion

Millet plays an important role in nutritional security and economy of many countries, esp. in Africa and Asia. They are gaining prominence in Europe and North America due to their gluten-free and hypoglycaemic properties. It also maintains its importance in human nutrition due to its abundance of macro- and micro-nutrients. Value added products from millets are gaining increasing visibility in the market in view of the upcoming International Year of Millets, 2023. This is an excellence opportunity to tap and further expand the technologies to bring in diversity in the millet products. Further, expanding the shelf life of these products will also contribute to spread out the reach of millets to the international market.

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Improving nutritional quality of maize: progress and prospect

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Introduction

Malnutrition caused due to consumption of an unbalanced diet contributes to increased morbidity, disability, stunted mental and physical growth, and reduced national socio-economic development (Hossain *et al*., 2021a). Globally, 2.37 billion people do not have access to adequate food, while 768 million people are undernourished (FAO, IFAD, UNICEF, WFP and WHO, 2021). Among children (<5 years), 149.2 million are stunted while 45.4 million possess wasting (Global Nutrition Report, 2021). Undernutrition causes ~45% of death among children (<5 years) mainly in low and middle-income countries (Global Nutrition Report, 2018). Around 20-25% of all deaths in adults have been associated with imbalanced diets (Mark *et al*., 2020; WHO Global Nutrition Targets-2025). 29.9% of women (15-49 years) are affected by anaemia (Global Nutrition Report, 2021). In India, 15.3% of the population are undernourished (WHO Global Nutrition Targets-2025), 35.5% of the children (<5 years) are stunted and 19.3% are wasted (National Family Health Survey-5, 2019-21). 57.0% of all women (15-49 years) are anaemic, while 25.0% of men (15-49 years) are affected due to anaemia. India loses over US$12 billion in GDP per year to vitamin and mineral deficiencies (www.harvestplus.org). Malnutrition contributes to a loss of 11% GDP in Asia and Africa, and it could cost society up to US$3.5 trillion per year (Global Nutrition Report, 2018).

Considering the paramount importance of alleviating malnutrition, world leaders at United Nations framed ‘Sustainable Development Goals’ (SDGs) for meeting the current needs without affecting future generations (Global Nutrition Report, 2016). Of the 17, 12 goals are highly associated with nutrition. Various approaches *viz*., (i) food-fortification (ii) medical-supplementation and (iii) dietary-diversification are generally used for alleviating micronutrient malnutrition (Neeraja *et al*., 2017; Hossain *et al*., 2021b). However, these avenues have not been successful in the long run. Lack of purchasing power, poor infrastructure, crop seasonality, expense, and lower bioavailability are some of the reasons that affect their successful implementation (Lieshout and Pee, 2005). ‘Biofortification’, a strategy of increasing micronutrient density in edible parts of plant through plant breeding, is a viable, sustainable and cost-effective mean for enhancing required levels of micronutrients in food (Bouis *et al.,* 2011).

Maize assumes worldwide significance as a source of food, feed and diverse industrial by-products (Prasanna *et al.,* 2020). Together with rice and wheat, it provides at least 30% of the food calories to more than 4.5 billion people in 94 developing countries (Shiferaw *et al.,* 2011). It is an important staple cereal food crop for billions of people in South America, Africa and Asia with an estimated world production of 1162 million metric tonnes from 202 million hectares (FAOSTAT, 2020). In India, maize is an important cereal too, and is grown on an area of >9.0 million hectares with a production of 31.7 million tonnes (2020-21, www.indiastat.com). In India 20% of the maize produced, is used for human food, while nearly 60% is used for poultry and animal feed (Rakshit and Chikkappa, 2018). The demand for maize will be doubled by 2050 in the developing world (Rosegrant *et al.*, 2009). Considering the growing importance of maize as both food and feed, biofortification of maize for enhancement of protein quality, provitamin-A, vitamin-E and reduction of anti-nutritional factors like phytic acid assumes immense significance.

Enhancement of protein quality

Among various micronutrient deficiencies, protein-energy malnutrition (PEM), now known as protein energy undernutrition (PEU) caused the highest number of deaths during 2016 worldwide (Nyakurwa *et al.,* 2017). Hoseini *et al.* (2015) reported that about 146 million children under the age of five, lack adequate protein in their diet. Pregnant women, the elderly and children are the most vulnerable groups to PEU, thus warrants urgent attention (Mpofu *et al.,* 2014). The human body requires 0.66 g protein/kg body weight/day for proper growth and development (WHO/FAO/UNU, 2007). The daily requirement of lysine is 30 mg/kg and 35 mg/kg body weight for adults and children, respectively. Similarly, the same for tryptophan is 4 mg/kg and 4.8 mg/kg of body weight in adults and children, respectively. The deficiency of these amino acids causes fatigue, poor concentration, irritability, nausea, red eyes, hair loss, anorexia and inhibited growth (Galili and Amir, 2013). Therefore, the adequate quantity of these two amino acids in human diets is essential to avoid health disorders.

Protein content of common maize generally varies from 9-10%, however maize protein is deficient in two essential amino acids, lysine (~2.0% in protein) and tryptophan (~0.4% in protein) (Mertz *et al.*, 1964). Monogastric animals such as poultry birds and human cannot synthesize these amino acids in their body and has to be provided externally. Of the various kernel mutations, *opaque2* (*o2*) possessing significantly higher lysine (4.0% in protein) and tryptophan (~0.8% in protein) has been utilized the most in breeding programme for enhancement of kernel quality (Vivek *et al.*, 2008; Hossain *et al.*, 2007; Hossain *et al.*, 2008a, b). The *opaque2* gene located on chromosome 7L produces leucine-zipper (bZIP) protein that acts as a transcriptional factor for expression of zein family of storage protein genes, especially 22-kDa α-zeins). The mutant protein causes reduction in synthesis of zein protein by 50-70% primarily due to its less affinity of binding to the promoter regions. The enhancement of nutritional quality in *o2* mutant is mainly due to reduction of lysine deficient zein proteins followed by enhanced synthesis of lysine-rich non-zein proteins. Recessive *o2* also significantly reduces transcription of lysine keto-reductase (LKR), the enzyme that degrades lysine in maize endosperm, thereby enhancing the concentration of lysine. Further, *o2* is involved in regulation of various metabolic pathways and causes enhanced synthesis of various lysine-rich proteins and enzymes (Prasanna *et al.*, 2001). Sustained breeding efforts at CIMMYT, Mexico and University of Natal, South Africa could successfully accumulate desirable endosperm modifiers in *o2* genetic background that finally led to the development of nutritionally enriched vitreous maize, popularly phrased as 'quality protein maize' (QPM) (Vasal *et al.,* 1980).

In India, 'Shakti', 'Rattan' and 'Protina', the *o2*-specific soft endosperm-based maize composites were released during 1971 by All India Coordinated Research Project (AICRP) on Maize (Prasanna *et al.,* 2001), and these are perhaps the first set of biofortified varieties developed through targeted breeding approaches across crops in the country. Hard endosperm-based *o2* composite, Shakti1 was released in 1997. Later on a series of QPM hybrids *viz*., Shaktiman1 (2001), Shaktiman2 (2004), HQPM1 (2005), Shaktiman3 (2006), Shaktiman4 (2006), HQPM5 (2007), HQPM7 (2008), HQPM4 (2010), Pratap QPM Hybrid1 (2013) were released in India (Gupta *et al.,* 2015). Further, Shaktiman5 (2018), LQMH-1 (2020), LQMH-2 (2020), LQMH-3 (2020), Malviya Swarn Makka-1 (2021), VLQPMH-59 (2021) and Pratap QPM Hybrid5 (2021) were released. These biofortified hybrids were developed through conventional breeding approaches.

The cloning and characterization of the *O2* gene, followed by detection of gene specific three SSRs *viz*., *phi057*, *phi112* and *umc1066,* offer advantages in molecular marker-assisted conversion of non-QPM lines into their QPM versions (Prasanna *et al.*, 2010; Pandey *et al.*, 2018). Marker-assisted selection (MAS)-derived QPM hybrid, 'Vivek QPM9' was released during 2008 by the ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora (Gupta *et al.*, 2013). Vivek QPM9 is the *'first MAS-based maize cultivar'* released for commercial cultivation in India. Molecular breeding efforts at ICAR-Indian Agricultural Research Institute (IARI), New Delhi have led to the development of QPM version of five normal commercial hybrids, *viz*., HM4, HM8, HM9, HM10, and HM11 using marker-assisted backcross breeding (MABB) approach (Hossain *et al.*, 2018). Among which, three QPM varieties *viz*., 'Pusa HM4 Improved', 'Pusa HM8 Improved' and 'Pusa HM9 Improved' were released and notified during 2017.

A recessive *opaque16* (*o16*) (on chromosome 8) isolated from Robertson's Mutator (Mu) stock was discovered by Yang *et al.* (2005). Research efforts at IARI, New Delhi revealed that genotype with *o16o16* possessed nearly two-fold more lysine (0.247%) and tryptophan (0.072%) in mutants than *O16O16*-based wild types (0.125% lysine and 0.035% tryptophan (Sarika *et al.,* 2017). Sarika *et al.* (2018a) reported that *o16* does not influence the endosperm attributes such as grain hardness and vitreousness. The study of starch and protein complexes in endosperm through scanning electron microscope also revealed the compact packaging and hard vitreous endosperm of *o16* lines as observed in the normal endosperm. Zein synthesis is not affected in the mutant as well. The mechanism of *o16* on nutritional improvement is thus completely different from the *o2*. Genotype with *o16o16*, therefore, offers a great advantage to the breeders over *o2o2* as the accumulation of endosperm modifiers need not be required in QPM breeding (Sarika *et al.,* 2018a). The newly developed *o16o16*-based progenies here would serve as a valuable genetic resource in the QPM breeding programme in India (Sarika *et al.,* 2017). Further, marker-assisted pyramiding of *o2* and *o16* in four *o2*-based QPM hybrids *viz*., HQPM1, HQPM4, HQPM5 and HQPM7 have been undertaken at IARI, New Delhi (Sarika *et al.*, 2018b). The linked SSRs *viz*., *umc1141* and *umc1149* were used to pyramid *o16* in *o2* genetic background, and MAS-derived inbreds possessed as high as 76% and 91% more lysine and tryptophan, respectively over the recurrent parents. Hybrids with *o2o2/o16o16* also showed an average increase of 49% and 60% in lysine and tryptophan, over the original hybrids, with the highest enhancement about 64% and 86%, respectively. This is the first report of enhancement of lysine and tryptophan by *o16* in maize genotypes adaptable to sub-tropics. Multi-location evaluation of the reconstituted hybrids revealed similar grain yield and attributing traits to their original versions (Sarika *et al.*, 2018b). In some areas of the country, white maize is a popular choice as food over yellow maize. Keeping this in view two normal white maize hybrids viz., HM5 and HM12 have now been targeted for marker-assisted introgression of *o2* and *o16* (Chand *et al.*, 2022).

Enhancement of bioavailability of iron and zinc

Among micronutrients, deficiency of iron (Fe) and zinc (Zn) poses serious health constraints worldwide (Bouis *et al.*, 2019). Globally, 70% of children under the age of five are estimated to be Fe deficient, while it is 38% for Zn (www.harvestplus.org). Fe deficiency adversely affects cognitive development, resistance to infection, work capacity, productivity and pregnancy (Scrimshaw, 1984). Zn is involved in cellular growth and differentiation, and deficiency causes impaired growth, immune dysfunction, increased morbidity and mortality, adverse pregnancy outcomes and abnormal neurobehavioral development (Prasad, 1996). Breeding efforts to develop crop varieties with a target level of kernel -Fe (60 µg/g) and -Zn (38 µg/g) were undertaken worldwide including India (Prasanna *et al.*, 2011; Chakraborti *et al.*, 2011; Pandey *et al.*, 2015a,b; Mallikarjuna *et al.*, 2014, 2015). However, much success could not be achieved primarily due to its polygenic nature and high genotype × environment interactions (Gupta *et al.*, 2015). One of the alternative ways to effectively enhance Fe and Zn in maize is to increase their bioavailability through manipulation of anti-nutritional factor such as phytic acid (PA).

PA is composed of myoinositol 1,2,3,4,5,6-hexakisphosphate, and represents approximately 75-80% of the total phosphorous present in the maize grain (Raboy, 2009). PA possessed strong negative charges due to presence of phosphate groups and binds with positively charged mineral ions *viz*., Fe and Zn thereby reduce their bioavailability inside human body to a level of 5% and 25%, respectively (Bouis *et al.*, 2011). Moreover, monogastric animals including humans, poultry and swine cannot digest PA in their gut, since they lack phytic acid hydrolyzing enzyme phytase. So the phytate is expelled directly to the environment along with excreta posing a serious concern in piggery and poultry where the continuous expulsion of high phosphorous load causes pollution in the nearby water bodies (Jorquera *et al.*, 2008). Extensive research in seed PA has led to the isolation of three low phytic acid (*lpa*) mutations in maize namely *lpa-1, lpa-2* and *lpa-3,* and compared to the wild-type kernels, they contain 66%, 50% and 50% less phytic acid, respectively (Shi *et al.*, 2005). These *lpa* mutants can be effectively introgressed to enhance the bioavailability of Fe and Zn.

In India, novel inbreds possessing *lpa-1-1* and *lpa-2-1* alleles were developed on crossing with elite maize genotypes (Ragi *et al.*, 2021, 2022). Based on C (wild) to T (mutant) transition at amino acid position 1432 bp of *lpa1-1* gene, two dominant markers each specific to wild type (*LPA1*) and mutant (*lpa1-1*) allele were developed (Abhijith *et al.*, 2020). Full length sequence alignment between wild type (*LPA2*) and mutant (*lpa2-1*) allele revealed one transition mutation (A to G), and a co-dominant CAPS marker was developed. Fourteen F_2 populations were successfully genotyped using *lpa1*-1 and *lpa2*-1 markers. Segregants with *lpa1-1/lpa1-1* (1.77 mg/g) and *lpa2-1/lpa2-1* (1.85 mg/g) possessed significantly lower phytic acid compared to *LPA1/LPA1* (2.58 mg/g) and *LPA2/LPA2* (2.53 mg/g). Overall, homozygous segregants of *lpa1-1* and *lpa2-1* showed 31% and 27% reduction of phytic acid, respectively. Four elite inbreds (PMIPV5, PMIPV6, PMIPV7 and PMIPV7) that are parents of four provitamin-A rich QPM hybrids (APQH1, APQH4, APQH5 and APQH7) have been targeted for marker-assisted introgression of *lpa1-1* and *lpa2-1* genes from separate donors of exotic origin (Bhatt *et al.*, 2021). Earlier, *lpa2* was successfully introgressed into UMI395 and UMI285 using linked SSR at TNAU, Coimbatore (Sureshkumar *et al.*, 2014; Tamilkumar *et al.*, 2014). Several low phytate hybrids developed by IIMR, Ludhiana and VPKAS, Almora are in AICRP testing.

Enhancement of provitamin A

Vitamin-A deficiency (VAD) affects at least 190 million pre-school children and 19 million pregnant women (WHO, 2009). VAD is prevalent in Africa and South Asia, where people depend on cereals for their dietary requirement. India stands in world map with severe form of VAD (www.harvestplus.org). Vitamin-A is required for functioning of visual system, growth and development, immune system, maintenance of epithelial cell integrity and reproduction in humans (Sommer and West, 1996). Vitamin-A needs to be essentially supplied through diet, as it cannot be synthesized inside the human body. The daily requirement of vitamin-A in non-pregnant and non-lactating women is 500 µg/g, while it is 275 µg/g per day in case of children of 4-6 years (Andersson *et al.*, 2017). Night blindness is the hallmark of the VAD, however it also causes *Keratomalacia* an inflammation that causes irreversible blindness, besides diarrhoea and respiratory diseases (Sommer and Davidson, 2002; Mayer *et al.*, 2008; Bouis and Saltzman, 2017). VAD may also cause disorders like growth retardation, impaired iron mobilization, depressed immune response, and increased susceptibility to infectious diseases (Sommer and Davidson, 2002; WHO, 2009).

Yellow maize possesses tremendous natural variation for carotenoids (Tiwari *et al.*, 2012; Sivaranjani *et al.*, 2013). However, it is predominated by lutein and zeaxanthin-fractions that do not possess provitamin A (proA) activity (Vignesh *et al.*, 2012, 2013; Choudhary *et al.*, 2015; Muthusamy *et al.*, 2015a, b, c). Provitamin A carotenoids such as β-carotene is present in low amount (<2 µg/g) in most of the tropical germplasm compared to targeted level of 15 µg/g (Bouis *et al.*, 2011). In maize, three genes have been proposed to play crucial roles in the final accumulation of provitamin A carotenoids in the endosperm. *Phytoene synthase1* (*Y1* or *Psy1*) catalyses the first committed step in the pathway leading to formation of phytoene from GGPP, and is primarily responsible for the shift from white to yellow maize. Two genes, *lycopene epsilon cyclase* (*lcyE*) and *β-carotene hydroxylase 1* (*crtRB1*) have been shown to regulate the accumulation of provitamin A compounds. Natural *lcyE* converts lycopene into ζ-carotene and eventually to α-carotene through the action of other associated genes. Favourable *lcyE* allele forces pathway flux towards β-carotene branch and its non-provitamin A derivatives (Harjes *et al.*, 2008). Though the favourable *lcyE* allele increases the proportion of β-carotene in the pathway, a large amount is hydroxylated to produce β-cryptoxanthin (with 50% provitamin A activity) and zeaxanthin (0% provitamin A activity). *CrtRB1* is a hydroxylase gene that converts β-carotene into β-cryptoxanthin. However, naturally available favourable *crtRB1* allele blocks the process of hydroxylation of β-carotene into further components, thereby leading to the increase of concentration of β-carotene in the kernel (Yan *et al.*, 2010).

Thus, *lcyE* and *crtRB1* are the two crucial genes responsible for the accumulation of higher β-carotene in maize kernels (Harjes *et al.*, 2008; Yan *et al.*, 2010). However, the frequency of the favourable allele of *crtRB1* and *lcyE* is extremely low (<4.0%) in the available maize germplasm (Muthusamy *et al.,* 2015c).

At IARI, New Delhi, the favourable allele of *crtRB1* gene from CIMMYT-HarvestPlus genotypes was introgressed in the parental inbreds of elite hybrids using MABB approach (Muthusamy *et al.,* 2014). In India, Pusa Vivek Hybrid-27 Improved with higher provitaminA was relased during 2020. IARI-bred proA rich hybrids were analyzed using a simulated *in vitro* digestion/Caco-2 cell model at Indian Council of Medical Research-National Institute of Nutrition (ICMR-NIN), Hyderabad, and it was observed that the consumption of 200 g/day biofortified maize grains would contribute to 52-64% of recommended dietary allowance (RDA) for adult Indian men, after adjusting for cooking losses and conversion factors (Dube *et al.,* 2018).

Enhancement of vitamin-E

It is observed that 20% of the population possesses suboptimal level of vitamin-E worldwide (Li *et al.,* 2012). Vitamin-E deficiency (VED) symptoms include progressive damage to nervous and cardiovascular systems (Traber *et al.,* 2008). Vitamin-E or tocopherol plays essential biological roles in human body by protecting from reactive oxygen species and free radicals (Bramley *et al.,* 2000). It plays vital role in scavenging of various reactive oxygen species (ROS) and free radicals, quenching of singlet oxygen (high energy oxygen), and providing membrane stability by protecting polyunsaturated fatty acids (PUFA) from lipid peroxidation. Vitamin-E helps in preventing Alzheimer's disease, neurological disorders, cancer, cataracts, age-related macular degeneration and inflammatory disease. Recommended dietary allowance for vitamin-E is 4 mg/day for 0-6 months child, 15 mg/day for both males and females and 19 mg/day for lactating mother (Institute of Medicine, 2000).

Vitamin-E is composed of four isoforms (α, β, δ, γ), and among the various tocopherols, γ-tocopherol constitutes ~80% of the total tocopherol, while α-tocopherol accounts ~20% of the total pool. However, γ-tocopherol is less absorbed in the body due to lack of affinity of receptors in the body. On the contrary, α-tocopherol is the most favoured fraction and well absorbed in the body. Li *et al.* (2012) has reported two insertion/deletions (*InDel7* and *InDel118*) within *vte4* (*γ-tocopherol methyl transferase*) gene which significantly affect the accumulation of α-tocopherol. The favourable allele of *vte4* more efficiently converts γ-tocopherol into α-tocopherol.

In India, an effort to enhance vitamin-E level in maize was initiated at IARI, New Delhi (Das *et al.* 2018, 2020). Das *et al.* (2019a) identified one SNP (G to A), and three InDels (14 and 27 bp) in the *vte4* gene that differentiated low and high α-tocopherol accumulating inbreds with favourable haplotype (0/0). These newly identified SNP and InDels in addition to the already reported InDel118 and InDel7 can be useful in selection of favourable genotypes with higher α-tocopherol in maize. Das *et al.* (2019b) developed hybrids using inbreds possessing the favourable haplotype of *vte4*, and reported higher mean α-tocopherol (mean: 21.37 μg/g) than the check hybrids (mean: 11.16 μg/g). In some of the hybrids *viz*., MHVTE-2, MHVTE-18, MHVTE-28, MHVTE-10 and MHVTE-3, α-tocopherol constituted ≥50% of the total tocopherol.

Genetic improvement for multiple traits

At IARI, we have attempted to combine QPM and proA by marker-assisted stacking of *crtRB1* and *o2*. Muthusamy *et al.* (2014) targeted VQL1 and VQL2 as parental inbreds for marker-assisted introgression of *crtRB1* allele. 'Pusa Vivek QPM9 Improved' is the first released variety in country that possesses higher proA (8.15 µg/g), tryptophan (0.74%) and lysine (2.67%). This is also country's first multi-nutrient rich maize hybrid. Several researchers have demonstrated the cumulative and positive effects of *crtRB1* and *lcyE* genes for proA accumulation (Babu *et al.,* 2013; Zunjare *et al.,* 2017). Zunjare *et al.* (2018a) in India stacked the favourable alleles of *crtRB1*, *lcyE* and *o2* for biofortifying four hybrids for proA, lysine and tryptophan. Four elite QPM parental lines (HKI161, HKI163, HKI193-1 and HKI193-2) which are the parents for commercial four QPM hybrids *viz*., HQPM1, HQPM4, HQPM5 and HQPM7 with wide popularity in India, were targeted. The mean proA content of introgressed lines of HKI161, HKI163, HKI193-1 and HKI193-2 was 12.93µg/g, 8.23µg/g, 10.69µg/g and 11.54µg/g, respectively. The mean proA in HQPM1-, HQPM4-, HQPM5- and HQPM7-based reconstituted hybrids was 9.95µg/g, 10.47µg/g, 9.63µg/g and 12.27µg/g, respectively. Original hybrids *viz*., HQPM1, HQPM4, HQPM5 and HQPM7 had lysine content of 0.298%, 0.337%, 0.352% and 0.374%, while the same for tryptophan was 0.078%, 0.084%, 0.082% and 0.086%, respectively. These proA rich hybrids are in various stages of national testing. Besides, proA rich version of recently released QPM hybrid, 'Pusa HM8 Improved' has been developed and is also being evaluated under national trials. Similarly, QPM version of HKI1128, elite parental inbred of popular maize hybrids [HM9 (HKI1105 × HKI1128), HM10 (HKI193-2 × HKI1128), and HM11 (HKI1128 × HKI163)] was targeted for introgression of *crtRB1* (Goswami *et al.,* 2019). HKI1128 was earlier converted into QPM through marker-assisted selection of *o2* allele (Hossain *et al.,* 2018), and other parental lines *viz*., HKI1105, HKI193-1 and HKI163 have been improved for protein quality and proA in earlier programme (Hossain *et al.,* 2018; Zunjare *et al.*, 2018a). The *crtRB1*-based progenies of HKI1128Q possessed higher mean proA 10.75µg/g compared to HKI1128Q (3.38µg/g). Essential amino acids *viz*., lysine (mean: 0.303%) and tryptophan (0.080%) were high among the introgressed progenies (Goswami *et al.*, 2019). This newly derived proA rich HKI1128Q is being used for hybrid development. Das *et al.* (2021) combined *o2*, *crtRB1*, *lcyE* and *VTE4* genes in the genetic background of HQPM-1, HQPM-4, HQPM-5 and HQPM-7 using MABB. These hybrids possess high lysine, tryptophan, provitamin-A and vitamin-E. The reconstituted hybrids showed a 2-fold enhancement in a-tocopherol (16.83µg/g) over original hybrids (8.06µg/g). Improved hybrids also possessed high proA (11.48µg/g), lysine (0.367%), and tryptophan (0.084%) when compared with traditional hybrids.

Impact of biofortified maize in humans and poultry birds

The beneficial effects of QPM are well demonstrated worldwide (Tessema *et al.*, 2016; Gunaratna *et al.,* 2019). Porridge made from QPM resulted into fewer sick days among children compared to those who had porridge from normal maize. Higher rate of growth in weight (12%) and height (9%) were observed in infants and young children fed with QPM compared to the group given only normal maize (Gunaratna *et al.*, 2010). Grains of provitamin-A rich hybrids were analyzed for bioaccessibility studies using *Caco2* cell assay (Dube *et al.*, 2018). The consumption of 200 g per day of provitamin-A rich maize would contribute to 52 and 64% of recommended dietary allowance (RDAs) for adult Indian men, after adjusting for cooking losses and conversion factors. Gannon *et al.* (2014) conducted a study on 133 Zambian children, and found that β-carotene from maize was efficacious when consumed as a staple food in this population and could avoid the potential for hypervitaminosis-A. Another feeding trial of rural 3-5 years old Zambian children were used to determine the impact of provitamin-A rich orange maize intake on serum retinol (Sheftel *et al.*, 2017). The study estimated that maize provided 11% of the recent dietary vitamin-A to these children. These results demonstrated that orange maize is efficacious at providing retinol to the vitamin-A pool in children through maize provitamin-A carotenoids.

When QPM was replaced with normal maize in practical broiler diets, higher body weight gain and feed conversion ratio was noticed (Amonelo and Roxas, 2008; Panda *et al.*, 2010). Rajasekhar *et al.* (2020) reported QPM diet had higher body weight gain, breast yield, better feed conversion ratio, low abdominal fat and, higher ready to cook meat over normal maize. When 'Vanaraja' breed was fed with the provitamin-A rich grains of 'Pusa Vivek QPM9 Improved', better body weight gain and improved feed efficiency than diet made from traditional maize (Prakash *et al.*, 2021). Further, it considerably reduced the abdominal fat and increased breast muscle, which is highly desirable attribute of chicken meat. Replacement of normal maize with QPM in layer diet increased egg production (Osei *et al.*, 1999; Zhai, 2002; Panda *et al.*, 2012). Further, recent international studies suggest the higher accumulation of provitamin-A in egg yolks when fed with provitamin-A rich maize grains in comparison to the traditional yellow maize available in the market. Liu *et al.*, (2012) reported that provitamin-A equivalents increased in eggs of hens fed with high β-cryptoxanthin maize. Moreno *et al.* (2016) observed higher accumulation of provitamin-A (3.09 ppm) in egg yolks when fed with provitamin-A rich maize, compared to 0.33 ppm in commercial yellow variety.

Challenges and future prospects

The germplasm base for nutritional quality is extremely narrow compared to traditional maize germplasm developed for high productivity. Thus, widening of genetic base through systematic crosses, development of diverse inbreds followed by their heterotic grouping should be the priority of quality breeding programme. There is an urgent need to combine drought-, heat- and water logging- tolerance with nutritional quality. Strengthening the seed chain to produce and supply of good quality seeds is an important step for the popularization of biofortified varieties. Providing subsidized seeds and other inputs to the farmers would further contribute to the rapid dissemination of nutritionally improved cultivars among the farmers. Awareness generation on the health benefits of biofortified crops is also a key factor for rapid adoption of biofortified varieties by the farmers. Educational background of the household head and the extent of farmers' participation in demonstration trials and field days are the important factors for the generation of awareness. Further, the decision by households to adopt biofortified crops and the subsequent decision to allocate the nutritious food to young children are also the significant factors for having impacts on children's nutrition and health. The apprehension of low yielding potential of biofortified varieties has also been identified as the other important factor for slow popularization among the farmers. It is now well established that the biofortified varieties are comparable to traditional varieties for their yield potential. Weak linkages between maize farmers and local poultry firms, and limited access to improved technology are the major challenges of the biofortified maize as poultry feed and maize-poultry value chains. Strong policy support is an important factor for success of biofortified crops. Segregation of grains of biofortified crops in the market and assurance of remunerative price through minimum support price and/or premium price in the market would also encourage the farmers to grow more biofortified crops. Inclusion of these biofortified cereals in different government sponsored programmes specially related to nutrition for child development, well-beings of pregnant women and school-going children would help in providing the much needed balanced food for healthy and disease-free future life.

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Breeding maize for high yield potential: challenges and opportunities

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Introduction

Maize (*Zea mays* L., 2n=20) is a versatile cereal crop that is grown worldwide in diverse agro-ecological environments. Even in Asia, a rapid increase in maize acreage has been reported in the last decade. In the past maize was mainly confined to food in India and many other countries however, now it has become the industrial crop. Maize has several industrial applications and more than 1000 products are being developed from maize in India and around 3500 products in the USA and other countries. It is a raw material for many of the important industries *viz*., pharma, textile, paper, film, tyre food, processing, packing, bio-fuel, etc. The growth rate of poultry, livestock, fish, wet and dry milling industries is very high therefore, maize demand will continue to increase in the year to come. The ever-mounting population of the twenty-first century produces a great challenge for the researchers to provide ample food and that has to be achieved within the context of existing challenges such as quality deteriorated arable land along with increased adverse effects of changing climate.

Single cross hybrids which are productive among the other types of hybrids and composite varieties can be a big rider to meet the ever-increasing demand of maize. This technology has shown better adaptability to a new set of cropping systems and management practices. The Indian Council of Agriculture Research (ICAR) launched the first All India Coordinated Research Project on Maize in 1957 to develop and evaluate improved cultivars of maize. The program started with an emphasis on hybrids development. However, due to the non-availability of productive inbreds leading to the uneconomical hybrid seed production the emphasis, in the sixties and seventies, was shifted to composite breeding in the public sector, while the private sector shifted towards multi-parent hybrids approach to address the problem of economic seed production. Shifting to multi-parents and composites varieties, there was a slowdown in the maize productivity (Fig. 1) (Kumar et al., 2021).

The impact of single cross hybrid adoption has already been witnessed in the USA, China, and many other countries of the world. Even in India by hardly covering 25-30% of the area under single cross hybrids, the crop growth rate concerning area, production and productivity of maize has increased significantly. Maize, being a hardy crop, has an inherent potential to perform well under sub-optimal environments with minimum crop management. But, still, many challenges in maize research and development need to be addressed.

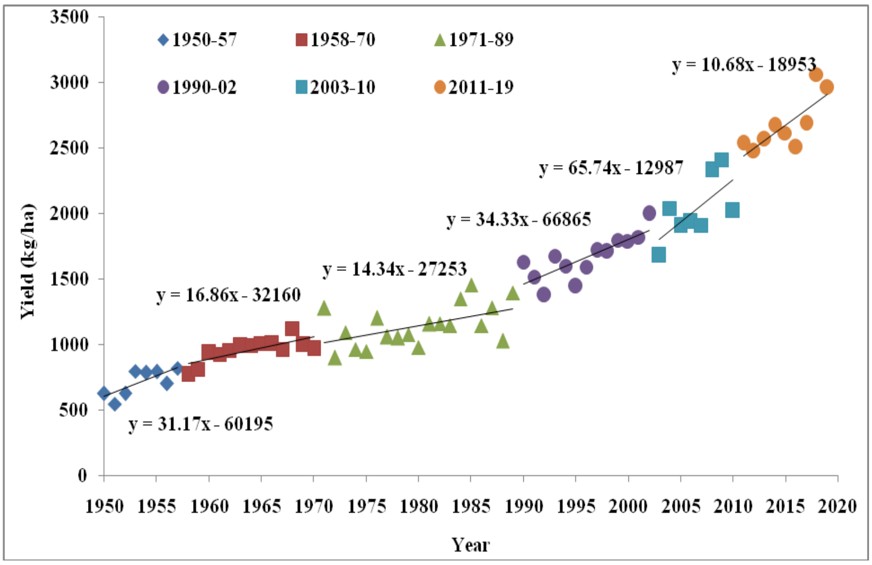

Fig. 1 The year-wise trend of maize productivity in our country since 1950 to till date

Challenges in maize research

Abiotic and Biotic stresses

Improving the genetic potential of Indian maize would continue to be a major challenge. Today, hybrids with a yield potential of up to 12.0-14.0 t/ha are available for the rabi and 8.0-9.5 t/ha in the Kharif. However, it becomes difficult to achieve even half of this potential because of the high incidence of biotic and abiotic stresses in the farmer's field. It is clear that the major challenge in germplasm enhancement lies in introducing stress tolerance traits. The major abiotic stresses in maize include drought, heat, and waterlogging which affects adversely maize productivity. Further, around 80% of maize is being grown as a rainfed crop in India (Kumar et al., 2016; Kumar et al., 2020) which is more prone to major biotic and abiotic stresses. Amongst the biotic stresses, diseases like banded leaf and sheath blight, charcoal rot and in insect-pests, fall armyworm and maize stem borer are the major one (Kumar et al., 2017). These stresses are needed to be addressed on a priority basis.

Systematic characterization and diversification of maize germplasm

Germplasm development evaluation and grouping have been the core competency of maize research and development. Over several years, thousands of maize lines for traits like insect resistance, disease resistance, drought, heat and water-logging resistance, etc. have been evaluated and sources of resistance/ tolerance have been identified. However, very few of such sources have been effectively categorized in different groups and utilized breeding programme. There is an urgent need to diversify and characterized Indian maize germplasm for their effective use in hybrids development programme. Besides, there is the need of efforts to develop and diversify the maize germplasm for long duration. This material will be helpful in developing the potential hybrids for secure ecologies of the country where irrigation facilities are available throughout the time. However, narrowing the genetic base of the elite germplasm is a matter of concern. There is a need to broaden the genetic base, develop new heterotic germplasm and continue to breed newer single cross hybrids with diverse base.

Development of nutritional enriched multi-nutrients maize hybrids to tackle malnutrition

Micronutrients malnutrition is popularly known as "hidden hunger" is a serious health problem particularly in the under-developed and developing countries (Bouis and Saltzman, 2017). Around two billion people worldwide suffer from micronutrients deficiency. Deficiency in any of the essential micronutrients in a food diet leads to abnormal growth and development of humans. Their deficiency also contributes towards the global burden of diseases and hence results in the effect of the overall growth of the country. Maize is a major source of food security and economic development and is among the top three cereals in India (Prasanna et al., 2020). Therefore, the development of multi-nutrients enriched hybrids is always have remained on priority. Markers assisted breeding is an important tool over here which has been explored and further need to be strengthen for increasing efficiency of our breeding programme.

Area extension under single cross hybrids

The single cross hybrids have been the bedrock of the Indian maize programme for the last two decades, which saw a quantum jump in maize productivity. However, still there is only 25-30% of total area under maize in India is under single cross hybrids. This need to be extended further upt to 90-95%. The efforts must be put towards increasing the acreage of single cross hybrids in our country. The development of productive and diverse inbred lines will always be the important activity of hybrid breeding programme.

Meeting out the quality seed demand

Making availability of low cost and good quality seed production to the final stakeholder will be a major issue for enhancing the adoption rate of hybrid maize cultivation. Farmer, private, cooperative and public sector participatory seed production programme needs to be evolved in the future for assuring quality seed availability

Natural resources degradation

The natural resources degradation, fading organic carbon from the soil, declining factor productivity, decreasing farmland due to more land under non-agricultural uses in the future and profitability due to escalating input prices in agricultural production will further aggravate the problem of sustaining maize production systems.

Opportunities

Single-cross hybrids technology

One of the major achievements in maize breeding has been the exploitation of heterosis through the commercial cultivation of maize single-cross hybrids. It is well established and proven technology, therefore, needed to be extended in unreached areas of the country. Still, only 25-30% of the area under maize in India is under single cross hybrids. It can be further enhanced up to 80-90 %. The area coverage under single cross hybrids needs to be coupled with improved packages of agronomical practices to harvest the full potential of maize hybrids.

Double haploid (DH) technology for rapid inbred development programme
The DH technology shortens the breeding cycle significantly by rapid development of completely homozygous lines (in 2–3 generations), instead of the conventional inbred line development process, which takes at least 6–8 generations to derive lines with ~99% homozygosity. In maize, well characterized haploid inducer lines are available in temperate as well as tropical genetic backgrounds. Efforts are required to develop broad genetic base source germplasm for deriving elite DH lines in maize.

Increased demand in poultry and ethanol production
As of now, the United States is already using 30 percent of its maize for biofuel production. Biofuel from maize will help in energy security along with high procurement prices. The expanding spectrum of demand would necessitate focused research tailored for specific segments of the myriad value chains. In India, 65 percent of the total production of maize is used as feed while only 20 percent is used as food. From net return comparisons, it is clear that the use of maize in ethanol production fetches better returns to the farmer. With increasing energy consumption both in India and the world over, the tapping of alternate sources of energy assumes significant importance. In this regard, biofuel from maize holds distinct potential. Maize is the most important natural multiplier and an economical source of starch. Starch comprises about 68-74 percent of maize Kernel weight, which can easily be converted into glucose and subsequently fermented into ethanol (Mahajan & Kumar, 2020).

Enhanced feed and fodder requirements
Fodder is an important issue as the country is presently facing a net deficit of 61% for green fodder. In the absence of nutritious fodder, the farmers are feeding their cattle with low-quality roughage or rice straw, thus adversely affecting the milk production potential of the animals. The competition for land and meeting the feed and fodder need for the support of livestock and poultry production will be another challenge in this scenario.

Availability of advanced tools for maize improvement
Although conventional breeding has been exploited at its fullest for the production of elite maize hybrids but little success has been attained for breeding climate-resilient varieties because stress tolerance is multi-genic or quantitative in nature. Therefore, the best option is to utilize molecular breeding along with the conventional approaches for the development of climate-smart varieties. In the context of molecular mapping, several QTLs (Quantitative Trait Loci) have been mapped for the abiotic stresses such as drought, water-logging and heat in maize. Besides molecular mapping, advanced breeding strategies like genomic selection (GS), and genes editing have also boosted maize breeding. In the era of molecular markers, "omics" has proved its potential through facilitating the identification of abiotic stress associated QTLs in maize along with functional genomics aided identification and characterization of abiotic stress-related genes at the transcriptional level (Tuberosa, 2004). High throughput sequencing tools have further added new dimensions to functional genomics for understanding the molecular basis of tolerance related to abiotic and biotic stresses in maize. Proteomics has also been exploited in maize to understand the expression of proteins under various stress conditions and the regulation of stress machinery through transcription factors. Markers assisted recurrent selection (MARS) has emerged as the novel technique for handling complex traits, especially

where the trait is governed by multiple QTLs. MARS focuses on the accumulation of favorable QTLs in a population by inter-mating of selected individuals in every selection cycle (Bernardo 2008).

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Prospects of specialty corn breeding in India

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Introduction

Since the inception of agriculture, the term maize or corn is well known to humankind because of its vital role in ensuring survival and evolution of human civilization on the earth. The maize is the staple food crop across several countries in almost all the continents in the World. In general maize is produced and marketed in the world as commodity corn. However, the genetic diversity existed in maize crop and also the utility of maize in innumerable number of products or processed and value added products has led to specialized end uses of maize crop for certain purposes. The increased demand for such maize of certain types has led to undertaking production of certain types of maize for specific purposes and its marketing or trading. The production and marketing, most often with premium price of certain types of maize with specific end use has led to term those types of maize as "specialty corn". Thus the term "specialty corn" refers to its type of maize or corn which has specific end use and it differs with the commodity corn with respect to its end use (Scott et al., 2018). In spite of the fact that the specialty corns are being produced and marketed and even being improved scientifically by adopting specific methodologies and protocols under different breeding schemes over several decades in the world, the information on the several aspects are either vague or not available in the public domain. In many instances except sweet corn and to some extent popcorn in some countries, the basic information on the area, production and yield levels is not documented. Perhaps the major reason could be due to dominance of "commodity corn" and also scattered cultivation and marketing of "specialty corn" by specific individual(s) or group(s) for specific market(s) or segment(s).

The United States Department of Agriculture United States Grain Inspection, Packers and Stockyard Administration Grain Inspection Service, defined "commodity corn" with reference to its quality by considering colour (white, yellow, and mixed), grade (flint, dent, flint and dent, waxy, and infested), and density of the corn(Scott et al., 2018; Washington, 2020).In fact, the international trade is also been conducted under these classes and/or grades. Thus, the definition of "commodity corn" is devoid of any reference to the special feature or end use of the corn. The evolution of specialty corn concept can be traced back to identification of novel mutants followed by establishment of associated changes in the biochemical and/or morphological and/or nutritional content and its specific end used of such mutants due to specific changes in the traits or features of corn (Hallauer, 2000). The concept of food-grade corn has also evolved over the period of time, more prominently in USA due to change in the preference and also more so due to development of high yielding hybrids, which are more often not suitable for preparation of many traditional foods and processed foods including corn flakes (Scott et al., 2018).

The specialty corn possesses special features with specific end uses. Maize kernel composed of starch, protein and lipids along with several minor micronutrients like vitamins and minerals. The morphological, biochemical and molecular studies on maize have led to identification of several mutants which affect either kernel phenotype and/or kernel composition. Genetic studies on such mutants have led to identification of heritable changes and establishing association with either morphological and/or biochemical changes. Based on the several studies the following names are given and are being considered under specialty corn class. The list is not comprehensive but limited to current understanding with respect to identification of special feature with specific end uses.

Types of specialty corn

The name of the specialty corn are sweet corn, popcorn, waxy corn (high amylopectin corn), high amylose corn, high quality protein corn, high oil corn, blue corn, baby corn, pipe corn, silage corn etc. (Hallauer, 2000; Pratt, 2001). The alteration in one or the other biochemical components affects kernel morphology and/or the chemical composition of the kernels.

Sweet Corn

Unlike commodity corn, sweet corn is considered as important vegetable rather than field crop. In most part of America especially the United States and Canada, sweet corn is being traded as an important vegetable in large quantity. In recent years, the popularity of sweet corn has spread to India also. The corn is sweeter and consumed as immature ear approximately at milking stage and before dough stage, which comes approximately around 20-24 days after pollination. The mutation in one or the other genes in starch biosynthetic pathway significantly affect and alter the composition of the carbohydrates. The sucrose content, the intermediate component in the starch biosynthesis pathway determines the sweetness in the sweet corn. Approximately eight genes have been identified which are affecting the sweetness in sweet corn and the most widely used genes in the breeding programmes are *su1* and *sh2*. The history of sweet corn breeding dates back to early 1840s in the United States of America (Hallauer, 2000). The significant progress has been made in sweet corn breeding in the USA, the cultivation of sweet corn and its marketing has made generated huge market in the World.

In India, the demand for sweet corn is increasing and is expected to increase further in near future. However, there are no authentic records available in public domain regarding the area, production and productivity of sweet corn. In All India Coordinated Maize Improvement Project on Maize (AICRP-M), the sweet corn trials are the regular trials being conducted at 20-25 centres covering different agro-climatic zones of the country. The number of entries being tested are comparatively lesser that of the commodity corn or general maize.The sweet corn breeding in the past has indicated that the genetic base of the germplasm of sweet corn being available at different breeders are narrow and required diversification of sweet corn germplasm and also broadening the genetic base of the existing germplasm through introduction of new germplasm. With the increase in the demand for sweet corn, efforts are being made through dedicated projects to introduce new and novel exotic sweet corn germplasm from diverse genetic background, and also develop new and productive inbred lines at ICAR-Indian Institute of Maize Research. Further, efforts are also on to enhance the nutritional value of sweet corn by introgressing genes determining enhanced levels of lysine and tryptophan, provitamin A and vitamin E.

Popcorn

Popcorn is the special type of flint corn with a characteristic feature of popping in response to heating. The popping ability in terms of percentage of popping and popping expansion/popping volume, appropriately describe popcorn in relation to commodity corn or any other specialty corn. However, the amount, proportions and distribution pattern of hard and soft endosperm differentiate popcorn and flint corn and also other starchy corn namely dent corn and floury corn (Erwin, 1950). Even though, popcorn do not differ much with either of the commodity corn like flint, dent, and floury corn or of the other specialty corn but in general the popcorn tassel are relatively larger especially as compared to temperate germplasm (Hallauer, 2000).Based on the previous experience, it was observed that the popcorn cultivars are relatively susceptible to many diseases and insect pests as compared to other types of corn.

In contrast to sweet corn, the popcorn improvement programme in terms of breeding by following different methods to enhance the quality and productivity of popcorn is of recent origin. It is postulated based on the available literature that early agriculturists writers overlooked popcorn (Erwin, 1950). Presently the germplasm available in India is not comparable to that of global standards, especially in terms of popping expansion. Based on the available data, it suggests that the popping expansion of Indian cultivars which are released and notified for commercial cultivation till date in India in different agro-climatic conditions is around 20-25 times, whereas the popping expansion of American and Latin American popcorn being sold in India in the Indian markets is around 40-45 times, even >45 times. India has tremendous scope to develop new and improved popcorn cultivars.

Baby Corn

The corn or the maize ear when harvested in the earliest stage or before pollination when the silks are either not emerged or of 1-2 cm long is termed as baby corn. It is the tender cob of maize plant. The quality standards prescribed to consider as de-husked baby corn are the 4-9 cm length and 1.0 to 1.5 cm diameter. Further, the de-husked baby corn should also possess the following traits namely light yellow to cream in colour, straight ovary rows arrangements, unbroken and, uniform ears. The tender cob is nutritious and rich in nutrients and the nutritional composition of baby corn is comparable to most of the vegetables namely cauliflower, cabbage, tomato, eggplant, and cucumber.

The use of unfertilized ear of baby corn and its consumption in its tender stage and identification of its nutritional value when it is harvested at right stage immediately after its emergence as side shoot, is one of the best innovations in maize which evolved into baby corn. In general, any corn/maize plant can be used as baby corn, provided that it possesses the baby corn specific features as given above. Thailand is pioneer which has introduced the baby corn to the world through its cultivation and export to several countries. The breeding methods for baby corn breeding do not differ with any other breeding programme, except the traits attributed to baby corn needs to considered while making selections. One important trait which is primary and needed to be considered is "prolificacy". In India, several baby corn hybrids have been released and notified for commercial cultivation.

Recently the male sterile single cross hybrid baby corn is also released, which would reduce the cost of production of baby corn by avoiding the labours required for detasseling, in male fertile baby corn hybrids. The detasseling is an important operation to maintain the quality of baby corn by avoiding pollination.

High quality protein maize

It is also called quality protein maize (QPM) due to hard endosperm and almost comparable yield potential as that of commodity maize with good storage life. India is one of the country where successful QPM breeding was and continue to be carried out. The seed village concept was successfully demonstrated across several states of India namely West Bengal, Rajasthan, Jammu and Kashmir, Andhra Pradesh and Gujarat. The model adopted for successful commercial cultivation and also hybrid seed production was seed village concept or cluster approach. The strong support from above mentioned State Governments in collaboration with State Department of Agriculture and also State Seed Corporations has made popularization of QPM hybrids in these states. Even though the success and impactful advantages of QPM has been demonstrated, but the dedicated end-to-end value chain is missing in India to promote QPM and bring QPM cultivation on par with commodity maize.

The methionine is also one of the important essential amino acid, more often it is added externally in poultry feed. Since maize is also deficient in methionine, efforts are being made to enhance the level of methionine in the maize kernel through extensive evaluation of germplasm, identification of genotypes with higher levels of methionine and its utilization in breeding programme.

Other specialty corns

In India, the above-mentioned specialty corns are popular and possess huge scope across all states in India. The major constraints in expanding and popularizing the other specialty corns in India are small holding of Indian farmers, lack of organized markets, and also lack of premium price for the produce. The most important thing is that most of the specialty corn traits are governed by recessives genes. The cultivation of specialty corns demands proper time or space isolation. In most of the cases, such isolation is not possible due to small land holding. Further, farmers are not unaware about the availability of latest hybrids for example biofortified hybrids. Recently, ICAR-Indian Institute of Maize Research in collaboration with ICAR-Indian Agricultural Research Institute working in the project on popularization of biofortified hybrids of maize in Eastern and North-Eastern Region through large-scale demonstration in farmers field, organizing field days to provide an opportunity to farmers to understand and assess the importance of biofortified hybrids. The poultry industry in India is growing at >5% CAGR, establishment of linkages among all stakeholders would bring revolutionary changes in the overall impact of specialty maize cultivation, production, marketing benefitting all the stakeholders. This initiative not only a step towards the enhancing the farmers income and farmers profitability but also could boost Indian agriculture export earning forex reserves. The strategic location of India can give big boost if India strengthens and accelerate the specialty corn breeding through dedicated, target oriented breeding efforts.

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Di Haploid Technology for Accelerated Corn breeding

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Di Haploids (DH) are completely homozygous parents that can be utilized for Hybrid Corn breeding. DH technology is a process that leads to faster development of parents in a hybrid breeding program. This is facilitated by the existence of haploid inducer genetic stocks in corn. The inducer breeding efforts have led to enhanced haploid induction from less than 2% in 1960s to over 15% today.

DH technology facilitates parental development in Corn as a paradigm for accelerated genetic gain. This is so in view of shortened parent development time of 2 generations or seasons compared to 8 generations or seasons required to develop an inbred parent in Corn. This leads to reduced lead time in hybrid development subsequently from 10-12 seasons involving inbred development process to 4-5 seasons involving DH parent development process.

In terms of parental quality, a DH line being 100% homozygous for all loci in the genome complement is homogenous and uniform unlike an inbred line that has inherent residual heterozygosity that can lead to developmental variations depending on sample size of increase and the environment or location where it is planted for seed increase.

The technology for dihaploid production involves the various steps like haploid induction, screening of putative haploids, modified ambient conditions for haploid plant growth and subsequent doubling of the haploid complement to generate homozygous diploids (D0). Subsequently the D0 generation is selfed to get the D1 generation. Now the Di haploid parents are available for use as normal parents for hybrid development.

The significance of DH technology to hybrid corn breeding is enormous. In addition to the shortened breeding cycles and quality improvements in seed production, in current cutting edge molecular technology-oriented breeding programs, it sets up the platform for accurate predictive breeding technologies that involve marker- trait association chiefly.

DH technology however does not obviate the fundamentals of hybrid corn breeding viz., the Inbred-Hybrid concept of commercial corn breeding. The necessity of genetic diversity for heterosis or hybrid vigor exploitation to breed hybrid corn commercially remains unaltered.

In conclusion, it can be stated that in the evolving technological interface for crop improvement, DH technology offers one more choice to accelerate breeding efforts. Corn is fortunate to be amenable to this inducer-oriented Di Haploid production. Corn breeders will continue their breeding efforts in a focused manner to target commercial genetic gains facilitated by DH utilization for a long time to come.

Prospect of Genetically Engineered maize in India

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Maize is a versatile crop with wider adaptability and is grown in most of the countries (170) in the world. Among the food cereal crops, maize has the highest genetic potential, production, and productivity. Thus, it is called as "*Cereal Queen*". In India, it is the third most important crop after rice and wheat. Currently, at the national level, it is cultivated in 9.9 million hectares with a production of 31.5 million tons (MT) and a productivity of 3.2 t/ha. India's average maize productivity is almost half of the world average. But per day productivity is comparable with many advanced countries. Owing to its uses as food, feed, fodder as well as a source of starch and biofuel, demand for maize is increasing rapidly. To meet the rising maize demand, it is expected that India would have to increase maize production up to 45 MT by 2030, and that too with limited resources, shrinking arable land, and a changing climate. Further, major challenges ahead including biotic and abiotic stresses are to be tackled by effective deployment of innovative tools such as genomic selection, double haploid technology, and genetic engineering in the ongoing breeding programme. Exploiting genetic engineering-based techniques such as transgenesis, and genome-editing would help in improving the existing traits or introduction of novel traits, hence thereby developing high-yielding climate-resilient maize in a short span. The present article provides an overview of current and potential applications of genetic engineering-based approaches in the Indian maize improvement programme.

Transgenesis for maize improvement

Although conventional plant breeding has played a major role in maize improvement but it has limitations due to the dearth of germplasm diversity. Therefore, it is not possible always to achieve the desired traits through the classical plant breeding approach alone. Many times, the gene(s) or genetic elements or genomic region governing any useful trait are not occurring naturally in the species. In such a situation, for achieving the desired improvement, the gene(s) or genomic region of interest needs to be inserted or introduced in the plant from a sexually incompatible gene pool (species). This is known as transgenesis and the foreign gene/genetic element is called a transgene.

The first transgenic *Bt* maize cultivar – developed by Monsanto – was approved for commercial cultivation in the USA in 1996 (James; 1997). Since then, transgenic technology has been utilized extensively for the genetic improvement of maize worldwide. Among all crops, maize has the highest number of transgenic events approved for commercialization (Kumar et al., 2020). To date, more than 152 transgenic events in maize have been approved in 35 countries either for cultivation or feed/food use (ISAAA, 2019). Transgenic maize is planted by farmers in 14 countries while 15 countries have authorized the import of transgenic maize to meet domestic demand. In the year 2019, transgenic maize accounted for nearly 32% (60.9 million hectares) of the total global maize area (~189 million hectares). The released events belong to six major commercial traits, *viz*., herbicide tolerance, insect resistance, modified product quality, abiotic stress tolerance, altered growth/yield and pollination control system, with the stacking of events being a common phenomenon (https://www.isaaa.org/). The adoption of transgenic technology for crop improvement (including maize) has increased yields, reduced pesticide and insecticide use, reduced CO_2 emission, decreased production costs, and benefited farmers economically (Klumper and Qaim 2014; Brookes and Barfoot 2018).

In India, to date, an indefinite moratorium on transgenic crops is in place, and hence transgenic crops (except *Bt* cotton) are not allowed for cultivation in India. However, a lot of transgenic maize germplasms have been imported previously in India from other countries for introgression breeding purposes (Table 1). Further, the multi-locational field trials [Biosafety Research Level – 1 (BRL-1) and/or BRL-II trials] of transgenic maize have also been done for insect resistance and herbicide tolerance traits. There is also a need to make additional efforts for developing indigenous transgenic germplasm through *de novo* transformation in tropical maize.

Table 1: Details of transgenic maize germplasm imported in India in past for breeding purposes

Accession No.	**Country**	**Transgenic line/ Event name**
EC798082-798111	USA	MON89034XNK603, MON 89034
EC799592	USA	TC1507 x NK603
EC803576-813774	Philippines	BT 11 & GA21
EC814245	USA	Bt11 & GA21
EC815354	Philippines	GA 21
EC829628-829657	South Africa	MON 89034
EC762977-EC762978	Brazil	Cry 1 Ab x MEPSPS x Vip 3a genes (triple stack of Bt11 x GA 21 x MIR 162 events)
EC770247 to EC770250	USA	Event DP-32138-1
EC774805 to EC774834	USA	Event MON89034
EC780916-EC780950	USA	Event MON89034 xNK603 x MON89034
EC787045	USA	Events DP-32138 and NK 603
EC792104 to EC792105	Philippines	Triple stack of Bt11 x GA21 x MIR 162 events
EC730199	USA	DP-32138-1 Inbred
EC732443-732477	USA	Event MON89034
EC732433- 732437	Philippines	Event NK603

EC732438- 732477	USA	Event MON89034
EC736527- 736546	USA	Stacked event MON 89034 x TC1507xNK603
EC736547- 736555	USA	Event TC1507
EC753565	USA	Event DP 32138-1
EC753566- 753571	USA	Events DP406428-8 and DP064226-4
EC757304, 62977	Brazil	Cry 1 Ab x MEPSPS x Vip 3 a genes(triple stack of Bt11 x GA 21 x MIR 162) events
EC757829-EC757853	USA	MON-00810-6, DAS-01507-1, MON-00603-6

(Source: ICAR-NBPGR; http://www.nbpgr.ernet.in/)

The transgenic technology has great potential that might be utilized to address some of the challenges – which could not be done via the conventional breeding approach – faced by maize crops in India. For example, this technology could be useful to develop transgenic Indian maize cultivars which can produce higher crop yield with less water (water use efficient cultivar) and fewer agricultural inputs (nutrient use efficient cultivar) to meet increased maize demand sustainably. Furthermore, the development of transgenic Indian maize cultivars having insect resistance, herbicide tolerance, aflatoxin resistance traits without any yield penalty would have a great impact in enhancing maize production and productivity in the country. Besides, the modern versatile tool of biotechnology like gene stacking/pyramiding can be used to develop multiple pest-resistant cultivars.

Genome-Editing for maize improvement

Owing to public concern and less consumer acceptance of crops developed via transgenic technology, in the past decade, genome-editing technology has been developed for genetic modification of crops. The genome-editing or sequence-specific nuclease, aims to eliminate the public concerns and uncertainties that victimized the transgenic technology in the past. The genome-editing approach utilizes a genetic modification step, but the resulting end products mostly (but not always) do not contain any foreign gene (transgene). Consequently, genome-edited (GEd) transgene-free plants are genetically similar to or maybe even indistinguishable from, conventionally bred plants.

The advent of novel, efficient and precise genome-editing tools has enabled researchers to modify the crop genomes with unprecedented ease and accuracy. These approaches are being successfully employed for crop improvement through interventions like targeted mutagenesis, precise editing of the endogenous gene (both interventions could result in transgene-free GEd plants), and site-specific insertion of a trait gene (end product would be transgenic only). In general, these genome editing technologies make use of engineered site-specific nucleases (SSNs) that recognize and cleave the genomic DNA in a sequence-specific manner (Jinek et al., 2012). The double-strand breaks (DSBs) thus generated are repaired by either homology-directed repair (HDR) or error-prone non-homologous end-joining method (NHEJ), leading to gene modification at the target sites (Agarwal et al., 2018). Several site-specific nucleases such as zinc-finger nucleases (ZFNs), Transcription activator-like effector nucleases (TALENs) and more recently Clustered regularly short palindromic repeats (CRISPR)/CRISPR-associated protein-9 nuclease (Cas9) are now being used to modify the genomes of several crop plants including maize (Shukla et al., 2009; Agarwal et al., 2018).

To date, many endogenous genes in maize have been edited precisely –leading to the development of GEd maize with improved traits or novel traits – using ZFN, TALEN, or CRISPR/Cas systems by various groups globally (Kumar et al., 2020). For example, using ZFN, Shukla et al. (2009) developed low-phytate maize by generating *IPK1* gene knockout via NHEJ. Char et al. (2015) targeted *GL2* gene conferring the glossy phenotype in maize via TALEN approach. Similarly, CRISPR/Cas system has been utilized for targeting *LIG1* gene to develop herbicide-tolerant maize, *GAI* gene conferring yield improvement, *Ms26*/*Ms45* gene to alter male fertility (Svitashev et al., 2015), *Wx1* gene to develop waxy corn having high amylopectin starch content (Walt 2016) and *GA20ox3 gene* to develop semidwarf *maize* (Zhang, 2020), etc.

Since genome-editing has a similar aim to transgenic technology i.e. to produce improved crop genotypes that are difficult to obtain through traditional breeding methods. However, the major advantage is that the final GEd plants would be transgene-free (except in a few cases involving the site-specific insertion of a trait gene). Furthermore, successful employment of these approaches for generating targeted and precise mutations globally proves that Genome-editing tools have immense potential for maize improvement. In many countries, GEd crops are not considered as transgenic/GM i.e., not regulated which in turn resulted in easy and fast commercialization. But In India, to date, the regulatory guidelines for such crops are not finalized. However, it is expected that In India also transgene-free GEd crops might not have stringent regulatory approval or would not be considered as transgenic crops. Therefore, it is hoped that in near future GEd maize would be accepted and adopted by the public in India also.

Conclusions

Considering rising maize demand that too with shrinking arable land area and a changing climate, there is a need to develop high-yielding and nutritionally enriched climate-resilient maize hybrids. However, globally, Transgenic technology has contributed to the development of insect-resistant, herbicide-tolerant, abiotic stress-tolerant maize hybrids. However, in many countries (including India) concerns have been raised regarding the safety of transgenic crops (including maize) to the environment and human health leading to its non-adoption or lesser acceptance in parts of the world. To address some of the major concerns associated with transgenic crops, new alternative techniques, *viz*., genome editing, are being used for maize and other crop improvements. Since most of the GEd plants (transgene-free) developed using genome-editing tools would be quite similar to the traditionally bred plants, it is hoped that such genome-edited crops might be granted faster regulatory approval In India which should lead to their widespread adoption in cultivation.

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Hybrid maize seed production: challenges and prospects

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Abstract: Maize is one of the most important cereal crops after wheat and rice in India as well as in the world. India is producing around 28 million Mt from 9.2 million hectare with productivity around 3.1Mt/hectare. At a global level maize production is around 1060 million MT from 188 million hectares with productivity of 5Mt/hectare. Productivity gap between potential and realization is one of the major concerns of scientific group as well as to the policy makers. Uses and availability of the quality seed in production system is one of the significant components to reduce this gap. This is more critical in cross pollinated crop where the use of the hybrid has been considered as one of the main tools to increase the productivity. Unlike in self-pollinated crop, cross pollinated crop Hybrid seed production is a very wide subject, which has several stakeholders who support the seed production and also influence the seed production, economics and quality. Soon after hybrid introduction, the seed production of hybrid seed also started. In India, hybrid seed production at commercial level started in 1970. Now, this is mature seed production system and India is producing around 140,000 MT seeds of hybrid corn seed every year for domestic uses as well as for export purposes. Around 90% seed production takes place in *rabi* season and reaming 10 % in Kharif season. Hybrid maize seed production engaging around 80 thousand farmers and created around 35 lac man-days jobs for local. Considering India has the capacity to become the major hybrid seed production hub in Asia, having one of most healthy production seasons, supporting infrastructure and one of the best seed economies among the Asian countries. In this article, the highlights are the main points, ways forward and future prospective hybrid maize seed production in India.

Key words: Hybrid, seed, production, productivity, seed economy

Introduction

Maize (*Zea mays* L) is a world-leading crop and widely cultivated in 177 countries from sea level to 3000 meters above the sea level. Maize as cereal grain was domesticated 10,000 years ago in South America. Globally, maize is known as queen of cereals because of its highest genetic yield potential. It is the only food cereal crop that can be grown in diverse seasons, ecologies and uses. Besides, it has many types like normal yellow/ white grain, sweet corn, baby corn, popcorn, waxy corn, high amylase corn, high oil corn, quality protein maize, etc. Apart from these, it is an important industrial raw material and provides large opportunity for value addition. As commercial crop in India, maize occupied third portion in cereal crop after rice and wheat for cultivated in almost all the states of country and with 9.2 million ha area under production and contributes 28 million Mt in food basket of the country with 3.1 MT/ hectare productivity (IIMR director report 2021). Maize has similar potential and strength at globally level and contributing 1060 million MT for 188 million ha with 5.6 MT/ hectare productivity. Like in other countries, India has an introduction of a single cross to increase the productivity but still facing the challenges how to increase the productivity and reduce the gap between potential realizations especially in *kharif* season. This yield gap can be reduced by 1) increasing the productivity rate during Kharif season; 2) increasing the hybridization or area under hybrids mostly tribal valleys and hill regions; 3) introduction of climate resilient hybrids especially in Kharif season; and 4) provide the F_1 hybrid seed to the farmers at an affordable price. Considering the variability in climatic and growing condition, India has huge potential and opportunity to become a hub of hybrid seed production in Asian and African continents.

F_1 Hybrid Seed

Botanically seed is a mature ovule consisting an embryonic plant together a store of food, all surrounded by a protective coat. Seed is being used as basic agricultural input to grow a commercial crop and the quality of the seed has a greater impact of the productivity at farmer field. The genetic constitution in self pollinated is homozygote and will not change by reproducing as long as there is contaminations from other genetic stock and hence it very simple. In cross-pollinated crop or F1 hybrids, the seed is obtained by crossing a designated female with a particular male. The reproduction of F1 seed is also required again to use these two parents and make them crossed each other manually or naturally with help of pollinating agent. Maize is a cross pollinated crop and F1 seed production has to organize by planting the Female and male rows side by side in the same field and ensuring that the female gametes (ovule) will get pollinated with the male gametes (pollen). In maize there are two known practices to make particular parent as female 1) using (CMS) cytoplasmic male sterility gene; and 2) Detasseling (removal of immature male flower) before it will start producing the pollen grain. Detasseling is very simple and practical approach which is commonly used all over the world. Use of CMS provides germplasm security to female lines and reduces the detasseling cost, however it required more effort in breeding front.

Basic of the hybrids seed production

It estimated that India is using around 110,000/Mt seed every year, which can help to plant around 6.1 million hectares, which around 67% of the total corn area in India. To produce this quality a commercial level is required to engage almost 80 thousand farmers and 35 lac labors in field to take care the planning, detesting and harvesting. Quality and seed yield potential of the parental lines has a great impact on seed cost, interest and profitability to the seed growers, farmers and seed companies. Breeder is the 1^{st} link of this chain and to understand a good hybrid has no meaning if it cannot be produced economically at large scale. Breeder needs to insure 1) acceptable female seed yield which >10 quintal per acre; 2) high pollen and load and longer pollen availability in male line; and 3) lesser flowering interval between male and female flower. When a production team go to the field and start negotiating to take the production, these three elements are very critical to the farmer's preference in planting of male and female on the same day, and expect a harvest equal to Rs. 50,000/ (fifty thousand) per acre. Yield potential and overall producibility will determine the cost of goods (COG) which is basic for the seed company to price their F1 hybrids seed to farmers. As role of thumb COG has two components: 50% seed procurement costs and reaming 50% are drying, processing, treatment and packaging cost. It also needs to note COG does not include cost of research or Germplasm royalty, marking cost and other operating expenses which also around 35% of COG.

F_1 Hybrids Seed Production Steps

It is very critical to have some understanding on the step of the hybrids seed production. Good clarity on those steps can help to enable the mindset and process for producing F1 hybrids with good seed economics and good seed health. The first and most important one is to study the producibility of new hybrids often it gets misguided by the information provided by breeder on flowering of male and female parent. Most of the seed company has a full-fledged production research function which help understanding the basic requirements in the field and seed traits of hybrids which include the nicking (the difference between planting of male and female), female and male ratio, germination-ability, uniformity in germination, kernel size or kernel count, percent seed recovery and self-life of the seed, cost of seed production, right planting window and season. The second one is finalizing the growers or farmers and their training based on aspects suggested by the production research team. The third one is negotiating the price and the procurement price, which is critical and based on the seed yield, farmer earning and farmer expectations based on the alternate crop they can opt. The last and fourth one is the most critical, which include creating the batches for planting based on the drying capacity that will help to attain the high uniformity in the seed lot.

Quality assurance in the F1 hybrids seed production

Seed is a basic input in farming system and the efficient use of all other inputs such as fertilizer, crop management, irrigation and etc are based on the quality of the seed. For these two main factors influence the final yield, 1) useable plant population (UPP), and 2) uniformity in the contribution per plant in the final harvest. This is even more critical in the case of single cross hybrid where any genetic impurity in the seed is unwelcome to the farmers. There are three major aspects of the seed quality: first is genetic purity, second physical purity, and third is seedling vigor.

Table 1. Basic parameters to be maintained of these entire aspects of quality are here under:

Quality parameter	**Minimum Standard**	**Precaution to achieve**
Genetic Purity	98%	Purity of parent seed - 99.9%
		Rouging in male and female row before flowering
		Right Nicking between male and female flowering (pollen shading should start before silk emergence)
		Proper isolation (more 200 meters from the production field and 400 meters from the commercial field) or 21 days' time isolation
		Perfect detasseling (all the tassel should be removed before any silk emergence in female row)
		Male chopping - male row should remove from the field after pollination to avoid any admixture
		Ear sorting - any off-type ear needs to be removed before feeding to drying bill or sheller

Germination	90%	Good crop management (health crop for healthy seed)
		Use of low RPM Sheller with rubberized hammer or sheller to produce good seeds
		Best post-harvest management
		low moisture at harvesting <30%
		Gentle dry (use of mechanical drier)
		Proper cleaning and grading of seed
Seedling Vigor	High	Good crop management (health crop for healthy seed)
		Good storage (storing in cold storage)
		Use of authentic and recommended fungicide and insecticide

F_1 hybrids maize seed production potential in India

It is very critical to separate out 3 things, one corn growing area, season, and seed production. Many times, it has been debated that seed production can be taken anywhere, corn can grow and corn cultivation is happening. With these, I also feel that there is a need to debate on the concept of creating local production hub to localize the seed supply. A healthy and viable seed production requires very specific growing and storage conditions. In India 80% of corn grown in Kharif season, imagine if seed production also happens in Kharif season then one need to store the seed in 7 months (from October to April). During Kharif (rainy) season, seed health will also get compromised due to fungal infestation on ear and kernel. Excess rain and cloudy weather during pollination can also have negative effect on the seed settings. With this consideration 80% of the total hybrids maize seed are produced in winter season in Telangana and AP which around 1.0 lac acre. This will ensure the fresh seed supply for Kharif season and a very healthy growing condition in which seeds are always free from fungal infestations. Farmers in theses area are trained by Seed Companies and a number trained field force for planting, detasseling, rouging and harvesting. To maintained this seed production there should be enough infrastructure (around 2.5 lac MT fresh ear) for drying and processing the seed which are available for rental and all the seed company is not required to do this investment. In the past, there were seed production organizer who has module to produce the seed on the agreement that the company shall provide them with parent seed and they will produce, process and provide the pack seed with all the specifications of the company as agreed.

Future prospective of hybrid maize seed production in India

If considered, the domestic requirement of hybridization in India is at the level of 67% and there is possibility of another 20% in area under hybrids may be added in the next 4-5 years. An additional of 1.8 million ha is potential for hybridization for the requirement of additional 35000 Mt seeds. As per my understanding, our industry is enjoying the seed production potential of Telangana and Andhra Pradesh which now start moving toward on saturation and the seed company starts experiencing the difficulty and facing the competition, arranging the seed required and seed production area. I feel there is a need to identify and develop more new locations for seed production which have similar kind of agro climatic condition. Madhya

Pradesh, Chhattisgarh and part of Rajasthan and summer planting in UP can explore as new geography to strengthen the seed production capacity.

On the international front, India is roughly exporting around 20000 MT corn seed every year to Vietnam, Indonesia, Thailand, Myanmar and African country and etc. India offers a very competitive location for seed production (Table 2) and also has bigger cluster which can produce the quality and healthy seed and supply these countries respectively.

Table 2. Location for seed production.

Country	**Seed Procurement ($ US/kg)**	**Limitation and advantage**
India	0.66	Very healthy production season, very high yield and seed recovery
Vietnam	1.09	Small land holding, risky weather and low seed recovery
Indonesia	0.84	Risky weather, very high DM incidence and low recovery
Thailand	1.02	Limited planting window, complete mechanization, staggered planting for male and female is a concern

Conclusion

Indian has very mature F1 hybrids production system with a potential to supply enough F1 seed to Indian farmers at affordable level as well can become the production hub for F1 hybrids seed production in Asia.

Reference

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Conservation agriculture in maize-based systems under changing climatic scenarios

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Maize being a queen of cereals and grown in all the states have immense potential for its cultivation due to its increasing industrial importance lead better price realization. This region is also a centre of biodiversity in maize and has many land races co-evolved with the maize eaters of this region. The crop is annually grown on 9.86 m ha acreage with production of 31.51 m tonnes in India in 2020-21 (4th Advance Estimate, DAC). However, the productivity in this period was 2018 kg/ha which was very less than the national average of 2879 kg/ha. However, this region is the net importer of maize for catering needs of poultry, piggery and livestock. Thus, enhancing production in the NEH region will further boost these sectors in this important strategic region of the country. The favorable rainfall and high organic matter soil provided good opportunity of the cultivation of this crop in these ecologies in multi-season by adoption of high yielding maize cultivars specially hybrids that can tolerate biotic and abiotic stresses for providing resilience and enhancing profitability in the maize systems of the region. Das et al. (2017) in their comprehensive review concluded that though the various studies conducted in last decade provides enough evidences that the conservation agriculture (CA) practices has potential to reverse the trend of land degradation with enhancing input use efficiency for food security of in the degraded hill ecosystem of north east India. Thus, there is an urgent need to deploy a CA based programme in a comprehensive mission mode for food and environmental security in the region.

The CA is adopted over 181 m ha in 78 countries that accounts for 12.5% of worlds cropped area. The main driving force at farm level was cost saving, flexibility in time of planting, less water requirement and favourable support from government. To potentially make the Indo-Gangetic Plains (IGP) productive in a sustainable manner, conservation agriculture (CA) has to be effectively adopted and out scaled into the existing agricultural system. However, the adoption of the CA in India is still very less (1.5 m ha) as it was targeted in a limited number of the cropping systems.

The CA is the set of practices based on three cardinal principles of minimal soil disturbance, retention of residue as soil cover and profitable sustainable crop rotation. The key elements of CA have direct and indirect bearing on the nutrient supplying/availability of soil, which are described as below:

A. Minimal mechanical soil disturbance: The mechanical disturbance of the soil is *completely avoided expect for sowing purposes* and also sowing implement or process must open soil minimally.
B. Permanent covering of sufficient organic matter over the soil surface: The minimal 30% coverage of the residue over the soil surface gives natural environment in the agro-ecosystems.

C. Profitable sustainable crop rotation: Cropping sequences and rotations that include legumes are desirable for CA based system. Inclusion of the diversified crops is key for success of the CA as well.

There is a wider choice for the adoption of maize under CA in various cropping system across agro-ecologies in India. The best CA-based maize systems identified in AICRP on maize research and by other researchers are given in Table 1.

Table 1. Conservation agriculture-based maize systems in different ago-climatic zones of India (compiled from various sources).

Agro-climatic region	Potential CA-based Cropping system
Western Himalayan Region	Maize-wheat Maize-oat
Eastern Himalayan Region	Summer rice/maize-mustard Maize-maize-legumes Maize-french bean Maize-mustard
Lower Gangetic Plain region	Autumn rice-maize Jute-maize
Middle Gangetic Plain region Upper Gangetic Plain region Trans Gangetic Plain region	Maize-wheat-mungbean Maize-mustard-mungbean Maize-chickpea
Eastern plateau and hills region	Maize-wheat Maize-chickpea
Central plateau and hills region	Maize-wheat Maize-chickpea
Southern plateau and hills region	Rice-maize Maize-chickpea
East coast plain and hills region	Rice-maize-urdbean
West coast plain and hills region	Maize-pulses Rice-maize
Gujarat plains and hills region	Maize-wheat Maize-mustard
Western dry region	Maize-mustard Maize-chickpea
Island region	Rice-maize

Maize can be successfully grown without any primary tillage under the no-till situation with less cost of cultivation, higher farm profitability and better resource use efficiency. Under such condition, one should ensure good soil moisture at sowing and seed and fertilizers should be placed in-band using a zero-till seed-cum-fertilizer planter with furrow opener as per the soil texture and field conditions. The technology is in place with a large number of farmers particularly under rice-maize and maize-wheat systems in peninsular and eastern India. However, use of appropriate planter having suitable furrow opener and seed metering system is the key to the success of the no-till technology. Happy seeder can be used for seeding the maize under zero-tillage conditions. The seed can also be successfully sown in wet paddy fields by following methods:

The increased area and production may have a threat to nutrient mining due to high nutrient removal with biomass and thus may make the future maize farming under threat. Thus, taking maize to the farmers with the best bet crop production practices involving conservation agriculture (CA) could be a solution for sustainable maize production. The adoption of CA in maize has led to enormous benefits in improving resource use efficiency, crop productivity, profitability and soil health parameters in various agro-ecologies in India.

CA and crop productivity, resource efficiency and profitability in maize systems

- CA gives up to 31% higher net returns with Rs 4300/ha lower production cost compared to conventional agriculture in different maize based cropping systems (Parihar et al., 2016).
- In permanent bed plots, residue retention reduced the water requirement by 50–55 ha-mm, and improved water productivity by 9.4–27.6%, 17.7–30.4%, 21.7–42.6% and 33–57.2% in maize, wheat, mustard and mungbean, respectively compared to no residue plots (Jat et al., 2019).
- Retention of the residues is very important for CA success as a 4-year study showed that crops planted on the permanent bed with crop residue (PB+R) registered 11.7% increase in system productivity compared to PB without residue (PB−R) (Jat et al., 2019a).
- Zero tillage (ZT) gives maximum maize system productivity with reduced irrigation water requirement by 40–65 ha-mm in different maize based cropping systems.
- It improved soil physical and biological health with improved soil nutrient availability (Parihar et al., 2016, Jat et al., 2019).
- The CA gives stable yields against the variable rainfall events (Parihar et al., 2019).
- It is adopted in ~1.0 lakh ha area of Erstwhile Andhra Pradesh and Tamil Nadu.
- The soil faunal activity especially earthworm increased significantly under CA than conventional maize systems (Kumar et al., 2020). We observed higher ant species diversity in CA than CT.

Efficient weed management

One of the most talked about hindrance in the CA adoption is weed management. In maize previously not good chemicals were available for weed management but now good post emergence herbicides are available. The pre-emergence application of Atrazine followed by post emergence herbicide-based weed management is available in maize (Table 2). Now, there is good option available in maize for weed management in maize.

A pre-emergence application of Paraquat @ 0.5-0.6 l ha^{-1} in 500 l of water either one day before the sowing of maize or immediately after sowing will control the regrowth of paddy stubbles as well as monocot weeds. This is to be followed by Atrazine @ 1.0 kg ha^{-1} in 500 l of water to control broad-leaved weeds effectively for 20-30 days. If the broad-leaved weeds are found even after one-month post-emergence application of 2, 4-D sodium salt 80% WP @ 2.5 kg ha^{-1} in 500 l ha^{-1} will be desirable. At present, use of new herbicide molecule viz., Tembotrione @ 120 ml/ha or Topramezone @ 25.2 g/ha provides effective weed control in maize and can be used at the knee-high stage of the maize crop for effective weed management (Radheshyam et al., 2021).

Table 2. Herbicides recommended for maize cultivation in India.

Herbicides	Dose/ha		Dilution in water (liter/ha)
	a.i	Formulation (g/ml)/%	
Atrazine 50% WP	0.5-1Kg	1-2 Kg	500-700
2,4-D Dimethyl Amine salt 58% SL	0.5Kg	0.86 ml	400-500
2,4-D Ethyl Ester 38 % EC (having 2,4-D acid 34 % w/w)	0.9Kg	2.65 ltr	400-450
Halosulfuron Methyl 75% WG	67.5	90 ml	375
Paraquat dichloride 24% SL [pre-plant (minimum tillage) before sowing]	0.2-0.5 kg	0.8-2.0 ltrs	500
Paraquat dichloride 24% SL (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.2-0.5 kg	0.8-2.0 ltrs	500
Pyroxasulfone 85% w/w WG	127.5 g	150 ml	500
Tembotrione 34.4% SC	120g	286 ml	500
Topramezone 336 g/l w/v SC	25.2 to 33.6 g a.i./ha + MSO adjuvant @ 2 ml/l of water	75 to 100 ml + MSO adjuvant @ 2 ml/l of Water	375
Mesotrione 2.27% w/w + Atrazine 22.7% w/w SC	875 gm	3500 ml	500

The layering of the component technology with CA using precision input management leads to further gains in benefits of CA. The precision nutrient management taking benefits of the residue recycling and previous crop nutrition with target yield using Nutrient Expert in maize leads to enhanced yield and resource use efficiency (Parihar et al., 2017) The use of sub-surface drip layered in CA proved to be highly beneficial and the resource use efficiency can be enhanced manifold (CIMMYT, 2019). Similarly, full CA-based MMuMb/MWMb system with the use of proper N sources like Neem/ sulphur coated urea as slow-release coated fertilizers could augment the system productivity, resource-use efficiency, farm profitability while sustaining the natural resources in Western IGP in India and other similar agro-ecologies (Jat et al, 2019). Recently, the green seeker guided N application had shown potential to optimize the N application in maize grown in CA that will help in enhancing nutrient optimization in real-time (ICAR-IIMR, 2018, 2019 and 2020). The point placement of the N fertilizer enhances resource use efficiency under CA in maize (Nayak et al., 2019).

There are various innovations happened in Peninsular India for the adoption of zero-tillage maize (Jat et al., 2009). The wet paddy field after harvest does not allow sowing crop on time, which forced the farmers to adopt the CA, based maize cultivation and the productivity of some districts like Guntur, East Godavari had touched to 10 t/ha and area under ZT maize touched up to 1.5 lakh ha (Jat et al., 2011). The conservation agriculture in maize systems needs to be taken forward by mass awareness, development of locally suited scale appropriated machinery and technology demonstrations at the farmer's field for enhancing natural resource sustainability, profitability and soil health in Indian agriculture. This will lead to environmentally sustainable agriculture for future food security.

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Mechanization for sustainability of maize-based cropping systems

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Today, maize is the third-largest food crop in India in terms of area and is growing fast due to the higher benefits from crop. Maize is considered the queen of cereals because of its huge utility for human consumption, animal feed, and fodder apart from its use as snacks. Not only is the production and consumption of maize steadily increasing, but the pattern of consumption of this edible crop is also changing from year to year. The farmers know maize is a high feeder crop with comparatively higher investment; still, they prefer it due to higher net return. With the growing threats of natural resource depletion, the rising cost of living, shrinking profit margins and emerging climate risks, it is becoming increasingly difficult to "meet food demand" on a "sustainable basis". In this context, farm mechanization helps in the reduction of human drudgery besides ensuring the timeliness of operation and solving the problem of scarcity of labours during peak cropping season.

Major maize based cropping systems in India

As maize has wide adaptability and compatibility under diverse soil and climatic conditions and hence it is cultivated in sequence with different crops under various agro-ecologies of the country (Dixit et al., 2017; Sagar et al., 2019). The predominant maize growing states that contributes more than 80 % of the total maize production are Andhra Pradesh (20.9 %), Karnataka (16.5 %), Rajasthan (9.9 %), Maharashtra (9.1 %), Bihar (8.9 %), Uttar Pradesh (6.1 %), Madhya Pradesh (5.7 %), Himachal Pradesh (4.4 %).

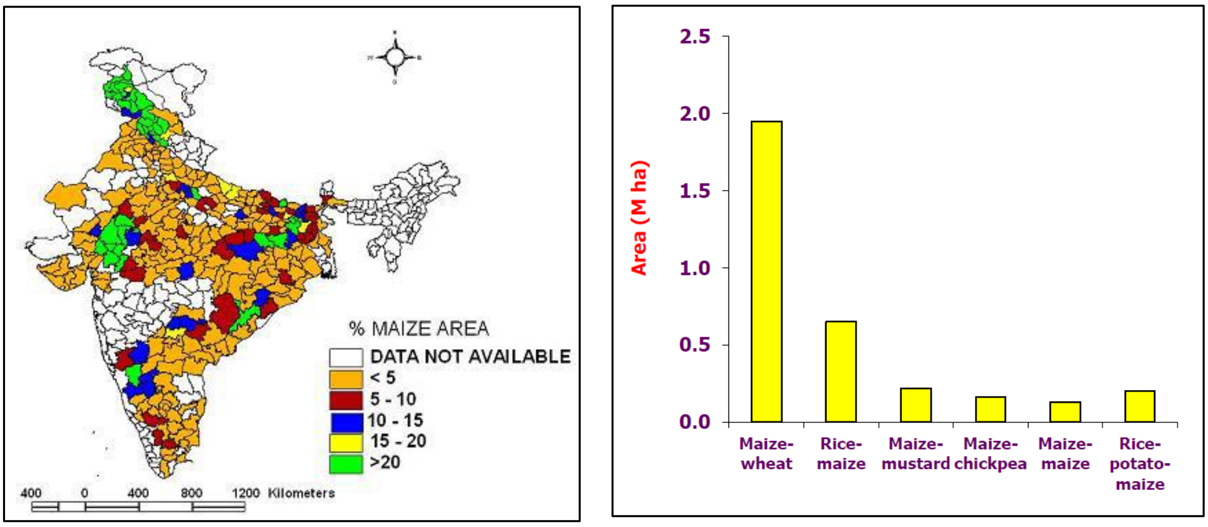

Figure 1. Major maize based cropping systems in India

Apart from these states maize is also grown in Jammu and Kashmir and North-Eastern states (Fig.1).

Among different maize based cropping systems, maize-wheat ranks 1st having 1.8 m ha area mainly concentrated in rainfed ecologies. Maize-wheat is the 3rd most important cropping systems after rice-wheat and rice-rice that contributes about 3 % in the national food basket. The other major maize systems in India are maize-mustard, maize-chickpea, maize-maize, cotton-maize etc. Recently, due to changing scenario of natural resource base, rice-maize has emerged a potential maize based cropping system in peninsular and eastern India. All India Coordinated Research Project on Cropping Systems revealed that compared to existing cropping systems like rice-wheat and rice-rice, maize based cropping systems are better user of available resources and the water use efficiency of maize based cropping systems was about 100 to 200 % higher at different locations (Parihar et al., 2011).

Ecological intensification of maize systems under changing farming scenario

The availability of irrigation water is declining day by day. Due to this in eastern and southern India the rice-rice cropping system is diversified with rice-maize cropping system, while in north-western India rice-wheat cropping system is diversified with maize-wheat cropping system. The terminal heat effect on wheat in the eastern Gangetic plain is affected by climate change. Maize as commercial crop rather than subsistence farming having competitiveness with other crops due to availability of high yield potential genotype, especially in spring maize in north west in Rice-Potato-maize cropping system. A fully automated irrigation system was designed and established for subsurface drip irrigation (SSDI) for conservation agriculture (CA) based cropping systems. This facility will help develop and validate input (water, energy, nutrient) use efficient cereal based systems as an alternative to conventional rice-wheat (RW) and maize-wheat (MW) systems with conventional and non-conventional (solar) sources of energy for irrigation. In MW system on permanent beds, SSDI system with residue retention showed significant grain yield increases of 37% and 7% in maize and wheat compared to furrow irrigation system, respectively. SSDI provided irrigation water savings of 42-68% in maize and 43-59% in wheat, increased NUE compared to conventional system. The maize crop has compatibility with different cropping systems, rational use of resources, increasing cropping intensity and resource use efficiency.

Soil Cover Management

Improvement of applied modern mechanized technologies for growing and harvesting of maize, introduction of hybrids with a low and strong stem, suitable for thicker sowing, irrigation, etc. lead to an increase in average grain yield per hectare. Permanent cultivation of maize is also perceived, but it should not last for more than three consecutive years on the same area. In addition, corn is also eligible for cultivation in the case of reduced soil
and through direct sowing (Fig.2).

Figure. 2 (a) Maize planting with residue; **(b)** Maize planting without residue

Need of mechanization in different operations

The local methods of maize cultivation are labours intensive. High labours demand in each operation adversely affects the timeliness of operations, thereby reducing the crop yield. The extent of farm mechanization is considered to be the indicator of the quality of farm life. Mechanization of farms helps in reduction of human drudgery besides ensuring the timeliness of operation and solving the problem of scarcity of labours during peak cropping season. It is an important means of increasing agricultural productivity through efficient utilization of biological and chemical inputs besides helping to achieve timeliness of operations and improving the quality of crop. Though modernization and technology advancement is taking place at a rapid pace, yet there exist a large mechanization gaps in the region.

Innovative planters for direct drilling of maize Sowing/ Planting Operation

Manual method of seed planting, results in in-uniform spacing, low efficiency and serious back ache for the farmer, particularly the rural women force. Mechanical sowing results in better seed placement and also maintains optimum plant population. Various types of seed metering mechanism has been developed for planting of various sizes of seeds, i.e vertical rotor type, cup feed type, inclined plate type, etc (Fig.3). Some commercially available maize seeding machines are discussed below.

Disking is advisable when there are lumps that have to be scrapped. With high chemistry, the number of treatments can be reduced depending on the physical properties of the soil and the degree of entrainment. The surface of the field should be level with well-grounded soil. Sowing is done with the calibrated and decontaminated seeds of the most suitable for the region hybrids.

The recommended row to row spacing, seed rate/ plant population, plant to plant spacing and depth of seed/ plant placement vary from crop and for different agroclimatic conditions to achieve optimum yield. In hilly areas, most of the farmers are using traditional methods i.e. broadcasting or seed dropping behind plough for sowing maize, which affects germination due to non-uniform placement of seeds at proper depth. Also, farmers apply 30-40 % higher seed rate than recommended to ensure optimum plant population. The placement of seed at proper depth is the most important factor in sowing, which has significant role in crop production particularly under rain fed conditions.

Figure 3. Different views of the seed metering mechanisms used for maize planting. **(a)** Vertical roller type; **(b)** Cup feed type; **(c)** Inclined plate type; and **(d)** Inclined plate type.

Happy seeder

Happy seeder consists of a straw management rotor for cutting the previous crop residues and a zero till drill for sowing of next crop. Flail type straight blades are mounted on the straw management rotor which cuts the standing stubble/loose straw coming in front of the sowing tine and clean each tine twice in one rotation of rotor for proper. The flails pushes the residues as surface much between the seeded rows.

Figure 4. Direct drilling of maize with happy seeder

Zero till planter

In conventional agriculture, one ploughing, 2-3 harrowing followed by planking is done for good seedbed preparation and weed control. These 4-5 runs of tractors and tractor attached heavy tools, press the soil particles affecting soil structure, and create compaction problem which hinder seedling emergence, root penetration, soil aeration and water movement. Further, these conventional tillage operation needs excessive fuel, larger turn around period and labor – enhancing cost of cultivation. Alternative to conventional tillage is no-till planting, under which planting is done in stubble of previous crop without any soil disturbance/tillage operation (Fig.5). This

Figure 5. Zero till maize planter

technology reduces capital investment in land preparation and intercultural operations. It is a viable replacement of conventional and tillage-intensive agriculture. This technology saves diesel, tractor's working time and labor enabling timely sowing of crops. If zero planting is combined with residue mulching, it modifies hydro-thermal properties and protects the crop during adverse conditions.

Zero-till based permanent raised bed is a resource conservation technology with multifaceted benefits. It is a compatible technology with conservation agriculture as it excludes tillage operations and only need bed reshaping before seeding of succeeding crop. This planting method allows retention of residue and also permits inter cropping and crop diversification. Permanent beds also help in increasing the cropping intensity through reduction in the turnaround time. Pneumatic Planter: Uniform sowing depth and precise spacing between seed to seed gives uniform germination and also helps in saving of the costly hybrid maize seed using the pneumatic planters in maize. This gives uniform crop establishment and crop stand which increases the maize yield up to 10-20%. These can be kept in custom hiring centers for maize planting.

Maize planter

Maize planter release constant quantity of seeds and fertilizer throughout the field. Unlike seed-drill, the planter maintains required plant-to-plant distance, resulting in high yield and saving of costly seeds. The machine consists of fluted roller type fertilizer metering system and chisel type furrow openers (Fig.6a and 6b). The machine is provided with seed hoppers for individuals furrows. Provision has been made for the adjustment of depth, spacing of furrow openers and fertilizer rate. Rotors with different size cells are provided to meter various types of seeds. Depth of seed placement was observed 5 to 6.5 cm.

Tractor drawn Raised Bed planter

The traditional method of maize sowing is on flat bed with row spacing of 30-40 cm. Crust formation and failure of crops due to poor germination especially in dry farming are common problems with the existing practices. Ridge furrow system of planting of maize crop offers wider scope not only in rain fed areas but also under irrigated conditions (Fig.6c and 6d).

Weeding and intercultural operation

Weeding/ intercultural operations in maize crops are done manually. The introduction of multi-crop planter has enabled maize planting in rows. Tractor operated earthing up and band placement of fertilizer can be done for efficient weeding/ intercultural operations. The only prerequisite for this operation is that row geometry of the crop should match with the tractor tyre geometry. And use of narrow tyres are recommended to replace the rear tyres to avoid pressing of side walls of ridge and beds. The use of equipment also results in saving of cost of operation by 45 %. Due to shortage of labour for timeliness of operation, farmers liked the equipment for enhancing productivity.

Figure 6. (a) Maize planter with vertical roller type seed metering mechanism; **(b)** Multi crop planter with cup feed type metering mechanism; **(c)** Maize planter with inclined plate metering mechanism at low ground clearance; **(d)** Maize planting on raised beds

Figure. 7. Weeding and intercultural operation in maize

Plant protection

Manually-operated knap-sack sprayer involves drudgery and needs more time to cover the field. Use of mechanical sprayers ensures timely plant protection and efficient use of agro-chemicals.

Tractor operated Boom Sprayer with adjustable height

Boom sprayer can spray larger area with negligible time. It works well in wide space row crops having enough row to row spacing for mobility of tractor. Crop planting needs to be done in rows keeping in view track width of the tractor. The clearance provided in the boom sprayer mounting frame was not sufficient for crop more than 45 cm height so these sprayers are suitable for pre-emergence and early post emergence application of agro-chemicals. It can cover 1.12-1.25 area in an hour (Fig.8).


Figure.8 (a) Tractor operated boom sprayer ; (b) Tractor operated high clearance boom

Maize harvesting

Timely harvesting of a crop is vital to achieve better quality and higher yield especially under bad weather conditions. The traditional practice of maize harvesting consists of stubble cutting with sickles followed by manual picking of mature cobs and requires 80-110 man-h/ha. This traditional method of harvesting is labour intensive, time consuming and also involves lot of drudgery. Mechanized harvesting using combine harvester reduces cost and ensure timely harvesting. According to the harvesting methods, maize harvesters could be classified into two types, one is maize-for-grain harvesters, including pickers and grain harvesters, the other is whole plant harvesters, including forage harvesters and combined grain-stover harvesters.

Shelf propelled Maize Combine Harvester

It is used for direct harvesting and threshing of maize crop (Fig.9). It has specially designed cutter bar for maize. It has a gathering unit to guide the stalks into the machine and snapping rolls to remove the ears from the stalks. It can be used for harvesting other cereal crops in one operation by changing the header. The capacity of this harvester is one ha in an hour.

Figure 9. Maize harvester

Maize Dehusker Sheller/ thresher

Separation of grains from ear/cob is known as threshing. In case of maize, the word shelling is used instead of threshing. Maize is manually dehusked and subsequently sun dried before being shelled. All these operations are time consuming and arduous resulting in huge losses in quality and quantity. Manually operated rotary maize shellers are suitable for small to medium farmers. Ergonomically, these methods of maize shelling create drudgery to the users. With the increase of mechanism, different types of manual or power

Figure 10. Maize dehusker cum

operated maize shellers have been developed to improve quality of work and produce. Multicrop threshers are able to shell maize cobs but dehusking was a prerequisite. PAU, Ludhiana has developed peg type maize dehusker cum sheller having capacity 450 to 650 kg/h at different moisture content (Fig.10). Shelling efficiency was found 98-99.5 % and the maximum percentage of broken grains was 2.0%. This dual-purpose machine is suitable for simultaneous removal of the cobs sheath along with separation of maize kernels from the cobs. It can save 95% shelling time and 60 % shelling cost as compared to traditional method. There are some foot operated standing type maize cob sheller (Dixit et al., 2012) for small holder and hilly area farmers. Two persons are required for pedaling and inserting the cobs in four octagonal maize shelling units.

Maize drying

During harvesting of maize, grain moisture content is quite high (~30-35 %). Due to higher moisture content farmers cannot get good price of their produce. Beside this, storage at high grain moisture creates problems of fungal infection and can cause heating and loss of germination. Hence, after crop harvesting, produce drying is very much essential. PAU portable maize dryer is now commercial available. The govt should have this common crop drying facility at the grain markets so that all category of farmer (small/medium/large) can bring their crop and dry up to the desired moisture to get the best market price.

Figure 11. Maize dryer

Importance of machinery custom hiring centres for medium & small holders

The mechanization plays a very important role in the development of agriculture. All the farmers need not to buy equipment or the machines. The capacity of farmers to buy the tools is also important. Sometimes the institutional support in the introduction of technology and mechanization is to be encouraged. For diversification of agriculture by introducing new crops and cropping systems, there are ample opportunities to develop and introduction of new state-of-art farm tools and machinery for mechanization in maize cultivation. Establishing hi-tech and high productive equipment hub for custom hiring is another opportunity for promotion and strengthening of agricultural mechanization in the country. This will also result in providing employment opportunities, especially entrepreneurship for the farmers to improve their socio-economic status.

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Precision nutrient and water management in maize systems for environmental stewardship

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Abstract: In South Asia, Conservation agriculture (CA)based practices may help in minimizing the losses due to adverse impacts of weather abnormalities and expected climate change effects in maize systems by increasing soil resilience and reducing vulnerability. In conventional system, repeated tillage, over-pumping of ground water and basic recommendation of fertilizer are the major cause of concern for natural resource degradation (soil, water, air, energy), crop productivity and diminishing farm profitability. Developments of better nutrient management practices are important to successful implementation of CA. On average, efficiency of fertilizer N in India is only 30-40% in rice and 50-60% in other cereals. Higher nutrient use efficiency (NUE) under CA can be achieved through fine-tuning of nutrient management practices based on local site-specific conditions developed for conventional till-based agriculture. In north-west IGP, Maize-wheat (MW) system with full CA-based management integrated with micro-irrigation and N-fertilizer through subsurface drip (SDI) recorded 11% higher system productivity, saved 20% of N-fertilizer and 50% of irrigation water as compared to farmers' practice. In MW system, permanent beds layered with SDI increased the system grain yield by ~10% with 52% less irrigation water and saved ~65% electric energy compared to CT based system. Using Solar energy-based SDI in MW system save INR 4540/year/ha and able to mitigate 1041 kg of CO2-e /ha/yr. ZT based management layered with SDI increased the yield by 6.3–21.7% (2 yrs' mean) in 15 best maize genotypes at Ludhiana, India by synergistic interaction between management and genotypes. Site specific nutrient management (SSNM) based various tools, techniques and decision support systems (nutrient expert and optical sensors) are available for soil- and plant-based precision nutrient management, which offer the potential to enhance NUE in maize and helps in mitigating the environmental quality risk by avoiding N losses via volatilization, leaching and denitrification. GreenSeeker (GS)-based SSNM saved ~10-30 kg N ha^{-1} without affecting the grain yield under CA-based systems compared to general recommended dose of fertilizers. Nutrient expert® - and GS-based nutrient management reduced GHG intensity by 5-20%, respectively over farmers' fertilizer practice. There is a need to develop nutrient prescriptions and application strategies in line with the 4R-principles to increase the NUE under CA-based management practices. CSA-based cultivation of MW system integrated with precise water and nitrogen management with SDI helped in dropping groundwater tables and increasing need of energy through solar pumps for irrigation is the way ahead for farmers in the region.

Keywords: Maize systems, Conservation agriculture**,** Bed planting, Subsurface drip irrigation, GreenSeeker, Nutrient dynamics, Nutrient Expert, Nutrient use efficiency, Site-specific nutrient management

Introduction

In India, the cultivated area is static since last 6 decades and there is little chance for further expansion, therefore increase in food grain production (355 Mt by 2030) will have to come from higher system productivity. Indian Agriculture has made spectacular progress on food grain production during past half century and achieved food self-sufficiency on the cost of natural resources (water, soil, and environment) but a large population is still undernourished. The natural resources are severely constrained due to continued mounting pressure to produce more and more, leading to low factor (nutrient) productivity, yield stagnation, lower water and nutrient efficiency, imbalance and inadequate use of external production inputs, diminishing farm profits coupled with climate change (Choudhary *et. al.*, 2018a). Plant nutrients in balanced proportion are essential for getting maximum yield, providing sufficient and healthy food for the growing population and are therefore a vital component of any system for sustainable agriculture production (Jat *et al.,* 2016). Moreover, agricultural intensification requires increased flow of plant nutrients to crops and higher uptake of those nutrients. While depletion of nutrient stocks from the soil is a major but often hidden form of land degradation, excessive applications of fertilizer nutrients or inefficient management can also cause ground water contamination and environmental problems.

In order to reach the required yield levels of any crop, focus on nutrient use is of utmost important to improve the farm profitability to target the "Doubling Farmers' Income by 2022", goal of Govt. of India Mission. The present application rates of fertilizers are very much irregular and varied from region to region and even from farmer to farmer. The current consumption ratio of nitrogen, phosphorus and potassium (NPK) of 6.7:2.4:1 in the country is highly unbalanced. The deterioration in fertilizer mix will not only have an adverse impact on productivity of crops but also on long-term soil health. No wonder, over the years, there has been a decline in the fertilizer response ratio. The environmental damage caused by the inappropriate use of fertilizers is certainly a matter of serious concern in many states. After *Green Revolution* in India, nutrient use has increased by twelve folds in comparison to increase in average yield of total food grains. Therefore, the use efficiency of inputs particularly nutrients has been declining as faster rate, posing a threat to future food security and environmental sustainability. There is still a large knowledge gap in understanding of rhizosphere dynamics and nutrient management in CA systems in South Asia where fertilizer recommendation is largely based on the response trials conducted under CT system and based on a wide geographical area. Improving nutrient efficiency is a worthy goal and fundamental challenge facing by today's agriculture. To cope with the challenges delivery tools are available to accomplish the task of improving the efficiency of applied nutrients. Judicious application of fertilizer best management practices (BMPs), right rate, right time, right place, and right agronomic practice targeting both high yields and nutrient efficiency will benefit farmers, society, and the environment alike.

In India, convergence of different technologies is required to increase the nutrient use efficiency of cereal crops from its current level (N-30-50%; P-15-20%; K-70-80%; S-8-10%; and micronutrients-1-2%). The NPK ratio have been continuously deviating from normal (4:2:1) since last 6 decades and the situation is worst in food basket of the country. Increased nutrient use efficiency through precision nutrient management can substantially reduce production cost thereby increasing economic benefit and also reduce environmental footprints from farming. The challenges for plant nutrition management are to maintain (and where possible increase) sustainable crop productivity to meet out the demands for food and raw materials. The environmental hazards can be minimized by matching plant nutrients with crop requirements. The escalating prices of chemical fertilizers and soil degradation have increased attention to develop SSNM that maintain or enhance soil productivity through a balanced use of mineral fertilizers combined with organic sources (e.g., crop residues, biomass ashes, etc.) of plant nutrients. Current nutrient recommendations are based upon crop response data averaged over large geographic areas without considering indigenous nutrient supplying capacity of the soils. Such blanket fertilizer application, therefore, results into under-fertilization in some cases and over-fertilization in other. This leads to low nutrient use efficiencies, low profits and increased environmental problems.

Inefficient flood-based irrigation and climate change are putting enormous stress on the region's groundwater supplies. Furthermore, by 2050, the share of water for agriculture use will be less than 50% of total water from the present share of 70%. Rice being a water guzzling crop, consumes significant amount (about 50%) of total irrigation water use in Asia that accounts for about 24-30% of the world's total freshwater withdrawal. During 2008-2012, the total fresh water withdrawals in India were about 761 billion m^3 of which about 90% was used for agriculture. Since the early 1970s (Green Revolution era), there has been a steady decline in groundwater table in most of the RW domain area of North-West (NW) India. The decline in ground water table in NW India between 1973 and 2001 was about 0.2 m yr^{-1} which has accelerated by five-fold (1.0 m yr^{-1}) between 2000 and 2006 in central Punjab and parts of Haryana states in India. A conventional cultivation practice with flood irrigation consumes lot of irrigation water for crop production. If sustainable measures are not taken soon to ensure sustainable use of groundwater, the IGP of NW India may soon experience decline in crop productivity and farm profitability, and shortages of potable water leading to extensive socio-economic stresses. Looking to the constraints of water shortages in future, it is imperative that we focused on developing alternative and remunerative approaches for increasing water productivity in the "*Green Corridors*" of NW India.

During the past half century, conventional intensive agriculture practices were successful in achieving goals of production, but in recent years, CA has emerged as an alternative practice of crop production in South Asia. The CA aims to conserve and improve the natural resources through their efficient use and integrated management of available land, water, energy and biological resources combined with external inputs (Jat *et. al.*, 2014, 2019). Fertilizer nutrients play a major role in meeting the plant nutrient demand to sustain yield and quality goals of modern agriculture. Fertilizer best management practices vary from one region to the next and one farm to the next depending on current and historic soil, climate, crop, and management expertise. There is a need to combine CA with good agricultural practices (GAPs), such as integrated soil fertility management and the 4Rs (right source, right rate, right time, and right place), improve fertilizer use efficiency, increase farmer profitability, ensure environmental sustainability, improve food safety and quality, and make farming socially acceptable. The CA-based crop management technologies may be one option to quickly address two critical input i.e. water and nutrients faced by Indian agriculture. The site specific water and nutrient management is the key for higher water and nutrient use efficiency maize based system.

Nutrient Stewardship

The soil organic carbon (SOC) contents in most cultivated soils of India are less than 5 g/kg compared with 15-20 g/kg in uncultivated virgin soils (Bhattacharya, *et. al.,* 2000), attributed to intensive tillage, removal/burning of crop residues, mining of soil fertility and intensive monotonous cropping systems. Fertility fatigue, multiple nutrients deficiency and poor-quality ground water in intensively cultivated area of rice-wheat system in South Asia is a common phenomenon (Kakraliya *et. al.,* 2018). This adds to the challenge of making farming system more and more resilient to climatic risks. To bridge the yield gaps between potential yield and actual yield at farm gate, new innovative technologies and practices are required in the current scenario. Still there is a large *'management yield gaps'* ranging from 14 to 47%, 18 to 70% and 36 to 77% in wheat, rice and maize, respectively, significant portion of which is attributed to agronomic and soil management (Sharma *et al.,* 2015). Soil, water and nutrient are the three key interlinked pillars of good agriculture production. Crop nutrient management in conventional-till (CT) agriculture and conservation agriculture (CA) is directed to link soil, crop and weather production factors with crop management practices to achieve optimal nutrient use efficiency for higher crop productivity and farm profitability while reducing the environmental footprint and nutrient losses. The 4R-Nutrient Stewardship proposed by International Plant Nutrition Institute (IPNI) is an innovative approach centered on four key areas of nutrient management; right rate, right source, right place and right time, for precise fertilizer practice which considers NUE, economic and environmental dimensions of fertilizer management that are important for sustainability of agricultural systems. Managing the 4R- is best accomplished with the right tools for crop-location specific N-management practices. Blanket recommendations of fertilizer nutrients for intensive cereal-based production systems spread over large tracts of the country lead to low nutrient use efficiency due to large spatial (within and between farms) variability coupled with temporal variability in soil nutrient supply due to differences in management practices (e.g., CT and CA) and soil properties. Our efforts led to development of precision nutrient management prescriptions using Green Seeker sensor, Leaf Colour Chart, Nutrient Expert, and Fertigation in addition to 4R- nutrient stewardship considering site and situation-specificity for increasing nutrient use efficiency and farmers' income. Our results proved the feasibility and adaptability of N placement methods (sub-surface point placement) in CA-based systems on permanent beds in standing crops.

Precise irrigation water management

Agriculture remains central to the Indian economy providing livelihood to the majority (> 50%) of its population. Climate change not only affects crop yields but also affects the availability and productivity of natural resources including land and water. To satisfy the growing demand for food, India will need to produce 37% more rice and wheat by 2025, with nearly 10% less water available for irrigation. Puddled transplanted rice requires 2500 L of water to produce 1 kg of rice while maize crop requires only 600 L per kg grain (Bouman, 2009). In order to meet the rising demand for food under current scenario, India needs to mainstream CA interventions that are required to make agriculture production system more resilient and vulnerable to expected climate change effects in the coming years. Water management by proper irrigation scheduling in combination with better crop management techniques and surface mulch are potential options to save water and increase water productivity (WP) (Yadvinder-Singh *et. al.,* 2014a). Another option to increase WP lies in pursuing alternative crops (like maize) and cropping systems, which are more environmentally friendly and efficient in utilizing natural resources (Aulakh and Grant, 2008; Kumar *et. al.,* 2018). A systemic research has been carried out on subsurface drip irrigation (SDI) in bed planting and flat panting system in maize-wheat (MW) systems to enhance the fertilizer and water-use efficiency. Results from our studies showed that fertigation increased N use efficiency by 25% and water productivity by more than two-times in maize-based systems. The approaches for increasing water productivity include diversification of rice-wheat by maize-wheat system and use of micro irrigation system to replace highly inefficient flood irrigation. One of the major reasons of the limited adoption of surface drip is its cumbersome handling before and after each farm operation. Earlier, research efforts have been made for water saving with surface drip and nutrient efficient management practices in cereal-based systems for example CA, precision nutrient management, and micro-irrigation but in isolation.

Sustainable intensification of maize systems

Maize has emerged as the most produced grain in the World and its production is increasing at twice the annual rate of that of rice and three times that of wheat (Fischer *et al.,* 2014). With the changing economy, increasing wealth and dietary patterns leading to higher consumption of animal-based foods and growth in the poultry industry, the demand for maize is likely to increase. Maize being an important crop for food and nutritional security is grown in diverse ecologies and seasons. To meet the rising demand, a quantum jump in maize production can be achieved through sustainable intensification in current dominant cereal-based systems. Increasingly, *sustainable intensification* is being considered as "an important component of the overall strategy for ensuring food security, poverty alleviation, health for all, rural development, enhancing productivity, improve environmental quality and preserve natural resources". With limited scope for further expansion of area under agriculture in India, production gains can be accomplished through intensification of agriculture by pursuing one or more strategies including: (i) increasing yields per hectare; (ii) increasing cropping intensity per unit of land and (iii) changing land use. The sustainable intensification can be achieved through diversification of RW system and integration of mungbean in rice/maize systems in NW India. CA is a farm centric approach to increase crop yields and systems sustainability. CA fits well within the sustainable intensification paradigm of producing more from less purchased inputs; enhancing the resource base and its productivity and ecosystem services. CA-based rice/maize system improved the soil physical, chemical and biological properties of soil (Choudhary *et. al.,* 2018b, c; Jat *et. al.,* 2017), which helps in arresting the soil degradation by increasing the soil organic carbon and other nutrients. Carbon sequestration is key to ecosystem function under different ecological boundaries. Adopting principles of CA-based management practices in MW system layered with precise water and nitrogen (N) through sub-surface drip irrigation (SDI) saves more water, improves water and nutrient use efficiency and accelerates both productivity and profitability in cereal-based systems compared to blanket application of irrigation water and nitrogen. Therefore, CA-based sustainable intensification (tillage, crop establishment, residue management, irrigation scheduling and mungbean integration) of MW system is an alternative to RW system on crop productivity, WP and economic performance in the NW IGP.

Evidences on precise water and nutrient management

System productivity and irrigation water use

A study was conducted to design productive, profitable, irrigation water¸ nitrogen and energy use efficient intensive cereal systems (rice-wheat; RW and maize-wheat; MW) in North-West (NW) India. Bundling of CA with SDI was compared with CA alone and conventional tillage based and flood irrigated RW rotation (business as usual scenario; ScI). In contract to conventional till RW rotation which consumed 1889 mm ha^{-1} irrigation water (2-yr mean), CA+SDI system saved 58.4 and 95.5% irrigation water in RW and MW rotations respectively. SDI with CA practices saved 45.8 and 22.7% of irrigation water in rice and maize respectively, compared to CA with flood irrigation. On a system basis, CA+SDI practices saved 46.7 and 44.7% irrigation water under RW (ScIV) and MW (ScV) systems compared to their respective CA-based systems with flood irrigation. CA+SDI in RW system recorded 11.2% higher crop productivity and improved irrigation water productivity (WP_I) by 145% and profitability by 29.2% compared to business as usual (Farmers' practice; ScI). Substitution of rice with maize (MW system; ScV) recorded 19.7% higher productivity, saved 84.5% of irrigation water and increased net returns by 48.9% compared to Farmer's practice (ScI). CA along with SDI in RW and MW system improved energy productivity by 75 and 169% and partial factor productivity of N by 44.6 and 49.6% respectively, compared to ScI. The SDI system saved the fertilizer N by 20% under CA systems.

Table 1. Grain yield and irrigation water use in different scenarios (2 yrs' mean) (Jat *et. al.*, 2019)

Scenarios	Grain yield (t ha^{-1})			Irrigation water use (mm ha^{-1})		
	Rice/Maize	Wheat	System	Rice/Maize	Wheat	System
I: Conventional based RW system	7.04^{a}	5.68^{b}	13.36^{b}	1889^{a}	435^{a}	2321^{a}
II: Full CA based RW system with flood irrigation	5.87^{b}	6.47^{a}	13.06^{b}	1447b	385^{a}	1832^{b}
III: Full CA based RW system+ SDI	6.30^{b}	6.70^{a}	13.75^{a}	785^{c}	207^{b}	992^{c}
IV: Full CA based MW system with flood irrigation	7.14^{a}	6.51^{a}	14.38^{a}	110^{d}	372^{a}	482^{d}
V. Full CA based MW system+ SDI	7.48^{a}	6.59^{a}	14.81^{a}	85^{d}	198^{b}	283^{e}

Where: CA- conservation agriculture; RW- rice-wheat; MW- maize-wheat; SDI- sub surface drip irrigation

Crop productivity, irrigation water use and energy nexus

In NW India, solar energy-based pumps can be used for irrigating the crop with subsurface drip irrigation to avoid the coal/power-based electricity and to slow down the tube well discharge. As solar power-based irrigation technology makes use of clean, renewable energy possible; provides numerous environmental and financial benefits. Efforts have been made to address these challenges through developing CA based management practices in cereal-based systems using crop diversification-replacement of rice with maize, precise water management-subsurface drip irrigation and green energy- solar energy. Results showed that system (rice grain equivalent) yield differed significantly under different scenarios. On 2' yrs mean basis MWPB-SSD recorded 9.73% higher system productivity (13.19 t ha^{-1}) compared to RWCT-FP (12.02 t ha^{-1}) and it was *at par* with MWPB-Fu (Table 2). Irrigation water consumption under zero tillage layered with SSD based RW and MW scenarios was ~50% less compared to conventional tillage-based farmer's management practices. The irrigation water productivity of ZT based RW and MW systems coupled with SSD was twofold (1.15 and 4.19 kg m^{-3}) compared to CT based systems with flood irrigation (0.59 and 1.86 kg m^{-3}). On 2 years average basis, MWPB-SSD (156571 INR/ha) recorded 43.77 and 17.37 % higher net returns by RWCT-FP (108897 INR/ha) and MWCT-FP (133403 INR/ha), respectively. MW system with CA based management layered with SSD saved ~65% electric energy compared to conventional RW system. Solar energy used for pumping of ground water under RWZT-SSD and MWPB-SSD saved INR 13480/year/ha and INR 4540/year/ha and have potential to mitigate the 3296 kg of CO2-e /ha/yr and 1041 kg of CO2-e /ha/yr, respectively

Table 2. Effect of different management portfolios on system productivity (crop and water) and profitability.

Scenario	System yield (rice equivalent) (t/ha)	System Irrigation Water Use (cm)	System Irrigation Water Productivity (kg grain m^{-3} water)	Net return (INR)
RWZT-SSDI	12.36^{bc}	107.30^{b}	1.15^{d}	138274
RWZT-Fl	11.99^{c}	188.32^{a}	0.63^{e}	118522
RWCT-FP	12.02^{c}	202.09^{a}	0.59^{e}	108897
MWPB-SSD	13.19^{a}	32.87^{d}	4.19^{a}	156571
MWPB-Fu	12.79^{ab}	56.62^{c}	2.37^{b}	149164
MWCT-FP	12.04^{c}	68.14^{c}	1.86^{c}	133403

Where; RW: rice-wheat; MW: maize-wheat; ZT: zero till; CT: conventional till; PB: permanent beds; SSDI: subsurface drip irrigation; Fl: flood irrigation; Fu: furrow irrigation; FP: farmer's practice

Precision nutrient management

SSNM is based on a set of nutrient management principles (crop removal adjusting the soil residual nutrients), which aims to supply a crop's nutrient requirements tailored to a specific field or growing environment. Major technologies focused on the adoption of modern diagnostic tools for SSNM for effectively enhancing the NUE, economic profitability with lower environmental footprints include use of SPAD, LCC, GS and Nutrient Expert® (NE) under both CT and CA systems. The plant-based diagnostic tools provide a valuable estimation of the N status of the crop and develop precision N management practices (Bijay-Singh *et. al.*, 2020). These tools helped in-season estimation of the right time and rate of N application matching the uptake requirement of rice, wheat and maize in a site-specific manner. The SSNM approach does not necessarily aim to either reduce or increase fertilizer use. Instead, it aims to recommend nutrients at optimal rates and times to achieve higher profit for farmers, with higher efficiency of nutrient use by crops across spatial and temporal scale, thereby preventing leakage of excess nutrient to the environment. Nutrient Expert® (NE), an interactive decision support system is developed by IPNI in collaboration with CIMMYT and national agricultural research systems in India for smallholder production system of South Asia (Pampolino *et. al.,* 2012; Satyanarayana *et. al.,* 2014). It can rapidly provide SSNM recommendation for individual farmers' field for maize, wheat, rice and cotton crops in absence of soil testing data. Parihar *et. al.* (2017) reported that combination of CA and SSNM increased MW system productivity by ~23% compared with CT using the farmers fertilizers practices, which might be due to optimum supply of nutrients as per crop demand and indigenous soil nutrient supplying capacity. Majumdar *et. al.* (2013) reported that NE-based fertilizer recommendations provided higher grain yield, lower fertilizer cost and higher gross returns in maize under CA than the applications based on state recommendation (SR) and farmer's fertilizer practice (Table 3). Better efficiency of nutrients applied according to nutrient expert (NE) recommendations than in farmers' practice indicates that location-specific nutrient application rate and better timing of nutrient application (i.e., a greater number of splits and matching physiological demand of the crops) reduced N losses and enhanced efficiency of nutrient utilization.

Table 3. Agronomic and economic performance of farmer fertilizer practice (FFP), state recommendation (SR), and nutrient expert (NE)-based nutrient prescriptions in wheat across sites (n=27) under conservation agriculture practice in IGP, India (Majumdar *et. al.*, 2013)

Parameter	Unit	FFP	SR	NE	P>F†
Grain yield	Mg ha^{-1}	4.4	4.7	5.2	<.001
Fertilizer N	kg ha^{-1}	157	139	165	<.001
Fertilizer P	kg ha^{-1}	24	27	25	0.387
Fertilizer K	Kg ha^{-1}	0.9	39.0	69.7	<.001
Fertilizer cost	USD ha^{-1}	57	62	73	-
Gross profit	USD ha^{-1}	1034	1102	1214	<.001

Grain yield of maize yield under permanent beds (PB) along with SDI was significantly higher than conventional tillage and flood irrigation (Jat *et al.*, 2018). Grain yield of wheat with PB+SDI (120 kg N/ha) was significantly higher by 7% compared to conventional flood irrigation system with similar N rate. In maize, PB+SDI saved 68.4% and 60.5% of irrigation water compared to CT-FI (conventional till-furrow irrigated), during two consecutive years. Irrigation water productivity (WP_I) of maize in PB+SDI (11.36 kg m^{-3}) was 3 times higher compared to CT-FI treatment (3.68 kg m^{-3}). The partial factor productivity of applied N (PFP_N) was significantly higher by 41.0, 86.4 and 83.3% under PB+SDI (60 kg N/ha) compared to PB+SDI (90 kg N/ha), PB+SDI (120 kg N/ha) and CT-FI with 120 kg N/ha, respectively in maize. Similarly, PFP_N in maize was significantly higher by 35.3, 58.6 and 76.9% under PB+SDI (60 kg N/ha) compared to PB+SDI (90 kg N/ha), PB+SDI (120 kg N/ha) and CT-FI with 120 kg N/ha, respectively.

In eastern Indo-Gangetic plains of India, maize is grown under conventional-till management system with sub-optimal nutrient management (rate, method, time etc). Therefore, CA- based management system may address the probability of maize crop failure due to poor crop establishment, inappropriate input use and sub-optimal agronomic management under monsoonal risks. A study was carried out with nutrient management options i.e., i) farmers fertilizer practices (FFP); ii) state recommended dose of fertilize (SR); iii) precision nutrient management using Nutrient Expert®; iv) NE + Green Seeker (GS) based nitrogen rates applied with two methods; broadcasting and drilling. Nutrient management through NE, NE+GS and SR along with drilling method significantly increased yield, nutrient use efficiency as well as net returns compared to broadcasting method under respective management practices. Cultivation of MW system on permanent beds (PBs) with NE+GS-drilling increased the system productivity and net returns by 31.2% and 49.7%, respectively compared to FFP. Significantly, higher (11-18%) NUE was observed under NE+GS treatment with drilling method compared to FFP. Global warming potential (GWP) of maize and wheat production was lower with NE-drilling compared to FFP-broadcasting. NE-drilling recorded 15.2 percent (2 yrs' mean) carbon sustainability index compared to FFP-broadcasting.

Layering CA with drip irrigation systems for increasing nutrient use efficiency

Water is becoming increasingly scarce worldwide and more than one-third of the world population would face absolute water scarcity by the year 2025 (Rosegrant *et. al.*, 2002; Yadvinder-Singh *et. al.*, 2014b). Wide scale adoption of RW in north-west India has resulted in decline in water level at an alarming rate. So, for the sustainable food production, the irrigation water productivity needs to be increased significantly in the near future by adoption of innovative micro-irrigation (fertigation) practices. Subsurface drip irrigation (SDI) system allows simultaneous delivery of water and nutrients directly to the crop root zone, while minimizing nutrient (N) losses. Integration of CA with drip irrigation system has potential to improve water productivity and nutrient use efficiency. The SDI system is considered economically viable option for row crops, such as maize, rice and wheat under CA (Sidhu *et. al.*, 2019; Jat *et. al.*, 2019). Integrating CA, decision tools/sensors and fertigation can boost the NUE significantly. Field experiment conducted at BISA, Ladhowal, Punjab showed that fertigation using SDI in CA-based RW system significantly increased N use efficiency in both rice and wheat compared to both flood irrigated ZT and CT (Sidhu *et. al.*, 2019). Results from another study by Jat *et al.* (2019) showed that SDI system resulted in 25% saving of fertilized N in rice, maize and wheat without any yield penalty. On system basis, SDI system saved 47 and 45% irrigation water under CA-based RW-mungbean and MW-mungbean systems compared to their respective flood irrigated CA-based systems (C.M. Parihar, personal communication). Fertigation increased N use efficiency by about 47% compared with farmer's practice of flood irrigation. Above-mentioned studies showed that SDI system provided tangible benefits for substantial saving in irrigation water and energy and increasing NUE and net income for CA-based RW and MW systems in NW India.

SDI layered with CA-based RW and MW systems has potential to save both irrigation water and fertilizer use with significant reduction in GHGs while producing same or even higher yields of major cereals. The CA layered with SDI in rice (ScV) and maize (ScVI) improved the partial factor productivity of nitrogen (PFP_N) by 20 and 33% compared to farmers' practice (ScI). Like rice and maize, the PFP_N of wheat was significantly higher with the SDI compared to the flood irrigation in both partial CA (ScII) and CT (ScI) (Table 4). The CA + SDI system in wheat improved the PFP_N by 46% compared to the CT in rice (37.8 kg grain kg^{-1} N applied). The CA-based RW-mungbean (ScV) and MW-mungbean (ScVI) recorded 45 and 50% higher PFP_N compared to those of ScI and ~31% higher compared to their respective CA-based systems (ScIII and IV), respectively.

Table 4. Partial factor productivity of nitrogen (PFP_N) under different CA-based RW and MW systems (Jat *et. al.,* 2019).

Scenarios	PFP_N (kg grain kg^{-1} N applied)		
	Rice/Maize	Wheat	System
ScI	40.2	37.9	41.1
ScII	47.5	39.3	52.1
ScIII	36.7	43.1	45.2
ScIV	40.7	43.4	47.2
ScV	48.4	56.8	59.4
ScVI	53.4	54.9	61.5

Where; ScI: conventional-till (CT) rice-CT wheat (farmers' practice); ScII: CT rice-Zero tillage (ZT) wheat-ZT mungbean with flood irrigation; ScIII: ZT rice-ZT wheat-ZT mungbean with flood irrigation; ScIV: ZT maize-ZT wheat-ZT mungbean with flood irrigation; ScV: ZT rice-ZT wheat-ZT mungbean with SDI; and ScVI: ZT maize-ZT wheat-ZT mungbean with SDI.

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Conservation agriculture based innovative strategies for weed management in maize (*Zea mays*) based cropping systems of eastern Indo-Gangetic Plains (E-IGP)

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Abstract: To achieve the sustainable food production, maintain natural resources and environmental safety. Adoption of conservation agriculture (CA) based management practice is gaining popularity around the globe due to its sustainable approaches. Efficient weed control is the biggest challenge to CA adoption. The weed ecology and management are different in CA than in conventional agriculture. To mitigate climate change and feed the rapidly growing population we have to identify the new management options. Adoption of modified tillage operations, crop establishment method, bioherbicides, chemical herbicides, and crop nutrition has been identified as suitable weed management tools. None of these offers complete control but the integration of these tools in suitable combinations works efficiently in CA based maize production system.

Keywords: Conservation agriculture, maize, weed management, optimization, integration

Introduction

South Asia is the most populated regions of the world will have to address the twin challenges of bridging management yield gaps and sustaining natural resources for future food security. The sustainable crop production is a critical factor of agriculture which is responsible for global food security. Continuous intensive tillage management practices lead to increase production cost, degraded soil and environmental sustainability (Edwards and Smith, 2005). To mitigate the climate change (SDG 13) and feed the rapidly growing global population (SDG 2) conservation agriculture (CA) is the sustainable alternative option. Recent agricultural management system gaining more popularity of CA based management practices is significantly increased globally. FAO (2001) define that adoption of (i) minimal soil disturbance, (ii) permanent soil cover, and (iii) crop rotations.

The efficient weed management has been recognized as essential component of CA and, thus, requires special attention. Traditional tillage practices play an important role in weed control (Wicks et al., 1094). Weed population significantly negatively influenced by the CA based management practices. CA requires dedicated efforts to control weeds initially; however, after maintaining a certain threshold level, it is easier to manage weed infestations in these systems. Heavy weed infestation in maize is one of the major production systems constraints which leads to large yield losses (~60%), particularly in rainfed ecologies. Lack of effective post-emergence herbicide molecules and repeated soil inversion as a weed management strategy leading to exposure of deeper soil weed seed bank to near the soil surface which provide favourable conditions of light, aeration, and less depth for the germination and emergence of weeds (Brenchley and Warington, 1933; Bilalis et al., 2010).

Under the emerging challenges of natural resource degradation and frequent climatic extremes, maize has been emerging as potential cereal crops with accelerated growth in area, production, and productivity in the region. Maize is also rapidly emerging as a favourable option for farmers in South Asia as a non-traditional component crop of rice and wheat-based systems. Drivers of this change are higher productivity and profitability, lesser water requirement, and better resilience of maize to biotic and abiotic stresses than rice or wheat. In E-IGP various maize systems such as maize-wheat, maize-maize and intercropping systems potato + maize practiced on wide scale, whereas rice-maize and soybean-maize are the emerging ones. Adoption of integrated strategies including herbicide molecules and CA based management practices have demonstrated potential benefits in terms of yield gains and reducing weed pressure over time.

How was this addressed?

BISA along with partners developed several maize based cropping systems and implementing in large number of demonstration plots at BISA Farm and at farmers' fields to showcase different stakeholders' farmers, technical staffs, scientists, and policy planners. Also organised several exposure visits and training for farmers on different components. Raised bed planting and permanent raised bed planting popularizing among the maize growing farmers it provides opportunities for inter-cropping of different crops including vegetables.

Weed flora of maize- based cropping systems

In general, weed flora varied between the two nearest fields due to differentiated management practices as well as cropping and herbicide use history. *Cyprus rotundus*, *Bracharia reptans*, *Dactyloctynium aegyptium*, *Digera arvensis*, *Digitaria ciliaris*, *Cucumis* spp. are the dominant weed flora of maize during rainy season (Table 1). The weed pressure during winter season is comparatively less than that appears during the rainy season. The major winter season maize weeds are *Cyprus rotundus*, Cannabis *sativa*, *Anagallis arvensis* and *Chenopodium album.*

Weed control measures under CA

The CA is on priority to sustain the productivity of cropping system in India. Different management practices such as (i) zero tillage reduced weed seed bank as compared to disturbed soils, and less weeds emerged in succeeding year if, the further multiplication of weed seeds is checked, (ii) residue retention or inclusion of cover crops like sesbania, cowpea, mung bean has added the advantage of weed control in zero tillage. Crop residues and cover crops reduced weed germination and emergence by altering the soil temperature, release of phytotoxins, and (iii) diversified crop rotations result into better crop growth and effectively suppress the parasitic weeds and crop associated weeds and opens the avenues to use wide range of herbicides in different cropping systems. Inter cropping of leguminous and gramineous grain crops and mixed cropping of these fodder crops produced more biomass, less weed problem and improved soil fertility. Employing the combinations of these CA principles can reduce the entire reliance on herbicides and can delayed herbicide resistance development.

Table 1. Weed Spectrum in maize-based cropping system in E-IGP (R= rice, W= wheat, P= potato, M= maize, PP = pigeon pea, L = lentil, F= Fallow, C=Chickpea)

Botanical Name	Cropping Systems and Seasons	
	Kharif Season	**Winter Season**
Grassy Weeds		
Brancharia reptans	M^2-W,R^4-M	
Cynodon dactylon	M^{5-}W ss	M-W^9
Dactyloctynium aegyptium	M^3-W,	
Digitaria ciliaris	M^4-W, M^3-P+M, M^3-P	
Echinochloa colonum	M^9-W	
Eleusine indica	M^6-W	
Eragostis tenella	R^6- M	
Panicum repens	R^7- M	
Broadleaf weeds		
Anagallis arvensis		M-W^3, M-P+$M^{3,}$ M-P^3
Cannabis sativa		M-W^4, M-P+$M^{2,}$ M-P^2
Celosia argentea	M^7-W	
Circium arvense		M-W^5
Caesulia axillaris	R^9- M, M^8-W	
Chenopodium album		M-W^1, M-P+$M^{4,}$ M-P^4
Commelina bengalensis	M^7-W, R^9- M,	
Cucumis spp	R^4- M, M^4-W	
Digera arvensis	R-M^3, M^8W	
Eclipta alba	M^{10}-W,	
Euphorbia hirta	M^7-W	
Launaea nudicaulis		M-W^5
Melilotus indica		M-W^6
Phylanthus niruri	M^4-W	
Physalis minima	R^3-M	
Parthenium hysterophorus		M-W^7
Solanum nigrum		M-W^2,
Sedges		
Cyperus iria	R^2- M, M^3W	
Cyperus deformis	R^2- M, M^5W	
Cyperus rotundus	M^{1-}W, R^8- M, M^1P+M, M^1M	M-$W^{6,}$ M-P+$M^{1,}$ M-P^1
Fimbristylis milicea	R^5W/ M	

Zero tillage (ZT) and permanent beds (PB)

The composition and density of arable weed floras are, in general, a reflection of the agricultural systems employed. In on station experiments and farmers participatory demonstrations, it was observed that weed problem is less under ZT and PB plots as compared to conventional plots. Perennial weeds were managed by application of pre-plant herbicide Glyphosate @ 1L a.i./ha and followed by seeding with ZT drill which provided less soil disturbance and less weed seed bank on soil surface. Using of ZT drill also help in application of fertilizer in crop root zone at the time of planting provided initial better initial crop growth and vigour which suppress the weeds. In traditional practices, farmers generally broadcast the fertilizer during tillage operation which gives equal opportunity to absorb to crop and weeds. Permanent practicing zero tillage reduced weed seed bank as compared to disturbed soils, and less weeds emerged in succeeding year if, the further multiplication of weed seeds is checked.

Permanent soil cover

Residue cover on soil surface alter the soil temperature, moisture content and sun light (intensity and quality) that may change the weed emergence pattern of sensitive species. Since residue cover change soil micro-climate may also increase the beneficial insects than consume weed seeds.

Rice-maize, which is an emerging cropping system in peninsular and eastern India, diversifying respectively winter rice and wheat with maize owing to adverse effects on winter rice due to water scarcity and wheat due to terminal heat. Under such conditions, the RCTs are serving as potential drivers for realizing the potential benefits of this diversification.

Results of the studies carried out at Long-term Research trial at Pusa Bihar revealed that continuous no till and crop residue retention significantly reduced the population of weeds in winter maize. In long-term experiment after 10 years, we recorded that the treatment permanent raised bed with residue retention have 60% less weed population as compared to the treatment permanent raised bed without residue retention and 80% less weed population as compared to the treatment conventional tillage. Legume cover crops in cereal-based cropping systems improved soil fertility, nutrient availability and use efficiency and suppress weed establishment and growth, thereby reducing the number of weed seeds and vegetative propagates infesting succeeding crops. The purpose of using cover crops for weed control is to replace unmanageable weed populations with a manageable cover crop. Weed suppression will be effective when crop establishment occurs before weeds appear. Furthermore, harvest and deposition onto the soil also facilitates weed control because of the germination inhibition of cover vegetal residues.

Crop diversification

Intercropping is receiving increasing attention as it offers potential advantages for increasing sustainability in crop production. Intercropping of short duration legume crops with long duration and wide spacing cereals increased initial ground cover and suppress the emerging weeds. However, intercropping can increase competition between crops and weeds. Maize-legume intercropping led to a higher soil canopy cover (leaf area index) than sole crops. Thus, in maize-legume intercrops the decrease in available light for weeds led to a reduction of weed density and dry matter, compared to sole crops. Intercropping maize and legumes considerably reduced the weed density in the intercrop compared with the maize pure stand. Weed suppression by crops was also greater on a low-productivity site than on a high-productivity site. Intercrops that are particularly effective at suppressing weeds capture a greater share of available resources than sole crops.

Crop rotations are highly effective against parasitic, and crop associated weeds. Rotating crops with different life cycles favours the natural loss of weed seeds across time because producers can prevent new seeds being added to the soil. With less seeds in the soil, fewer seedlings emerge in following crops. Growing of summer mungbean in March-April help in reducing the weeds in *kharif* maize, because most of the rainy season weeds emerged in April-May which controlled by applying Imazethapyr @ 65g a.i./ha. In eastern IGP, Soybean-winter maize is also an important cropping system. We observed that there are 40% less weed population in maize under soybean-winter maize copping system as compared to rice-maize cropping system.

Herbicidal weed management

Based on the on-station experiment and large number of farmers participatory demonstrations we found several combinations chemical weed management effective for controlling the weeds in maize. *Kharif* maize has more weed problem as compared to *rabi* maize. The major weed during *kharif* season in *Cyperus* spp. Stale seed bed technique with Glyphosate (1.0kg a.i./ha) found effective in reducing the *Cyperus* spp population in *kharif* maize. In stale seed bed technique, before sowing of maize crop, weeds are allowed to germinate by applying irrigation or pre monsoon rains and killed by applying the Glyphosate. The herbicide Halosulfuron @ 67.5g a.i. /ha effectively controlled the *Cyperus* species and major broadleaf weeds. Pre-emergence application of Pendimethalin @ 1.0L a.i./ha effectively controlled the grassy and broad-leaf weeds but less effective on *Cyperus spp*. Similarly, Atrazine @ 1000g a.i. /ha and Tembotrion @ 125g a.i./ha effectively controlled the major grassy and broadleaf weeds but less effective on *Cyperus* spp. We found several combinations which effectively control the complex weed flora of maize. Pre-emergence application of Pendimethalin @ 1000g a.i./ha followed by post-emergence application of Atrazine @ 1000g a.i./ha Topramizone @ 12g a.i./ha at 20-25 DAS or Atrazine as pre-emergence followed by Tembotrion @ 125g a.i./ha or Tembotrion + Atrazine as post emergence effectively control the complex weed flora in maize.

Integration of CA approaches

The individual CA component has its ability to affect weed dynamics. The integration two or more component can be proving more effective in handling weed issues. ZT keeps soil undisturbed allowing seeds to remain exposed to high temperature, and for predators. If other component i.e., residue retention or cover crops or inter crops or crop rotation imposed on ZT, than further weed emergence and seed multiplication can be checked. Long-term ZT and residue retention reduced the weed seed bank and less weed problem. Stale seed bed technique, crop residue retention, and cover crops like mungbean or cowpea helped in reducing broadleaf and sedges weeds. For season long and broad-spectrum sustainable weed management, integration of different herbicides and weed control measures is needed as part of IWM strategy. Continuous monitoring of weed flora is needed to identify shifts in weed flora due to shift from conventional tillage to conservation tillage and to focus on the emerging problematic new weed species which are even more difficult to control and competitive in nature. Hence, cropping system-based weed management strategies like better water management, Laser levelling, timely planting and competitive cultivars were found helpful in managing the complex weed flora in maize-based systems.

Conclusion and future scenario

Adoption of conservation agriculture (CA) based production system have potential to provide sustainable agriculture worldwide. Therefore, optimize the weed management practices have significant role in maintain food production under changing climatic conditions. In, Bihar, weed management appears to be the major factor that requires an adaptation of their practices and strategies. Based on large plot long-term experiment and farmers participatory demonstration results suggested that adoption of integrated approach is most effect weed management in CA based maize production system.

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Intercropping in maize for enhancing income of small holders

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Abstract: Maize has shown its higher yield potential as compared to other cereals, pulses and oilseeds in Haryana. Intercropping with maize makes *rabi* and *kharif* maize more profitable as compared to sole maize. Substantial advantage in yield from intercropping compared with sole cropping occurs from complementary effect of different crops on each other, making better use of resources when grown together. In North India, maize becomes more popular owing to high productivity. In *kharif* maize unfavorable factors like erratic distribution of rainfall, unfilled cobs, infestation of diseases, insect- pest, weeds are the responsible for the low yield of maize (*Zea mays* L.). However, these factors show less effect when maize grown with various intercrops. Hence, this offers yet another possibility of substantially increasing the production potential of maize. In winter season, the growth of maize crop up to the middle of December remains normal and thereafter due to low temperature it almost ceases till middle of February. Therefore, during this phase there is ample scope for growing intercrops in between the rows of maize to get more returns from a unit area of land. There are many winter vegetable crops which may be suitably adjusted in between the winter maize.

Keywords: Intercropping, Maize, income, small holders

Introduction

World population is growing exponentially and it has to fulfill their food requirements. The average size of the landholding has declined by more than half to 1.08 ha during 2015-16 from 2.28 ha in 1970-71. If this trend continues, the average size of holding in India would be mere 0.68 ha in 2023 and would be further reduced to 0.32 ha in 2030 (Agriculture Census, 2015-16). An attractive strategy for increasing productivity and labour utilization per unit area of available land is to intensify land use. This can be increased by growing several crops simultaneously or in succession with each other in farms devoted to short maturing annual crops. Maize (*Zea mays* L.) is the second most important cereal crop in the world in terms of total food production. It is grown for fodders as well as grain. The grains of maize are used in a variety of ways by human beings. Recently with the release of improved cultivars and hybrids, grain yield has been increased but still the maize crop faces many problems. Weeds are the one of the important factors in maize production. In conventional farming and mono-cropping systems, although high yield per unit area is been able to provide the nutritional needs of growing populations in some areas, but these systems require direct and indirect to abundant costs and energy that arise from fossil fuels. In terms of ecology and environment, mono-cropping has been caused a series of serious problems. Human by excessive use of resources such as water, soil, forests, pastures and natural resources not only put them at risk of extinction, but also with the creation of pollution caused by industrial activities, chemical fertilizers and pesticides, threatens the earth. If farming activities be conducted based on ecological principles, in addition to preventing the destruction of natural ecosystems, the result is stable condition. Also, agricultural systems must provide needs of people today and future generations; therefore, it seems that is essential achieving to sustainable agriculture. One of the key strategies in sustainable agriculture is restoration diversity to agricultural ecosystems, and its effective management. Intercropping is a way to increase diversity in an agricultural ecosystem. Intercropping as an example of sustainable agricultural systems following objectives such as: ecological balance, more utilization of resources, increasing the quantity and quality and reduce yield damage to pests, diseases and weeds. Success of intercrops in comparison with a pure cropping can be determined by a series of agronomic operations. These operations are including ultimate density, planting date, resources availability and intercropping models.

Cropping system

Cropping system is a combination of various crop on a given area within a year, it varies in local climate, soil, economics and social system. Water balance, radiation, temperature and soil conditions are main component to determine physical ability of crops to grow and cropping system (Beek and Bennema, 1972 and Hayward, 1975). Cropping system is the crop production activity of a farm. It comprises all components required for the production of the set of crops of a farm and relationship between them and the environment. These components include all necessary physical and biological factors as well as technology, labour and management (Zandstra et. al., (1981). So, cropping system varies with change in locations throughout the world. It used to improved system for given agro ecological situation based on their superiority over existing system which is adapted by the farmers of a specific area in terms of biological productivity and stability of production which is least affect the ecosystem.

Intercropping

Intercropping is a part of mixed cropping and describes cultivation of two or more crops in same place and same time (Andrew and Kassam, 1976). The intercropping of two or more crops increases the productivity per unit of land. In intercropping all resources are used to get maximum crop production per unit of time. Risk of failure of crop also minimized while taking an intercropping (Woolley and Davis, 1991). Intercropping is the growing of two or more crops simultaneously on the same field such that the period of overlap is long enough to include vegetative stage (Gomez 1983). Intercropping refers to growing of two or more dissimilar crops simultaneously on the same piece of land, base crop necessarily in distinct row arrangement. The recommended optimum plant population of the base crop is suitably combined with appropriate additional plant density of the associated crop. The objective is intensification of cropping both in time and space dimensions and to raise productivity per unit area and inputs by increasing the pressure of plant population. It also entails better utilization of soil moisture, nutrients and solar radiation than sale cropping of the base crop. Legumes and non-legumes are generally intercropped with one another/each other. Cropping and more seeds of the succeeding crop are required to obtain a good stand.

Why intercrop?

Stability: Intercropping provides diversity to the cropping system and diversity tends to lead to stability.

Reduced chemical use: Intercropping may allow for lower input levels in a cropping system by reducing fertilizer and pesticide requirements.

Over yielding: Over yielding occurs when the yield produced by an intercrop is larger than the yield produced by the component crops grown in monoculture on the same total land area.

Over yielding is calculated using the Land Equivalency Ratio (LER). The LER is a measure of how much land would be required to achieve intercrop yields with crops grown as pure stands. When the LER is greater than 1, over yielding is occurring and the intercrop is more productive than the component crops grown as sole crops. When the LER is less than 1, no over yielding is occurring and the sole crops are more productive than the intercrop.

It can be defined as the relative area of sole crop that would be required to produce the equivalent yield achieved by inter cropping.

$$LER = La + Lb = Ya/Sa + Yb/Sb,$$

Where, La and Lb are LER's of individual crop in the mixture.

Ya and Yb are individual crop yield in an intercropping situation

Sa and Sb are yield of species a and b as sole crops.

LER provides:

1. Standardized basis so that crop can be added to form combined yields.
2. It can be used to assess the competitive abilities of component species of any intercropping situation.

Intercropping Concepts

When two or more crops are growing together, each must have adequate space to maximize cooperation and minimize competition between them. To accomplish this, following four things need to be considered:

Spatial Arrangement

There are at least four basic spatial arrangements used in intercropping. Most practical systems are variations of these.

Mixed intercropping

In mixed intercropping, two or more crops are grown together without and definite row proportion. Sometimes it is also called as mixed cropping (Vons et. al., 2019). In pasture-based cropping system, grass-legume intercropping is an ideal example of mixed intercropping (Gulwa et. al., 2017). The mixed intercropping is commonly observed to fulfill the requirement of food and forage where the land resource is a limiting factor (Undie et. al., 2012). Furthermore, a review work clearly described perennial polycultures as an agro ecological strategy in cropping system with enough potential for the sustainable intensification of agricultural systems spatially and temporally (Weibhuhn et. al., 2019).

Row intercropping

The row intercropping is rising of one or more crops sown in regular rows, and growing intercrops in a row or without row at the same time. The row intercropping is a usual practice targeting maximum and judicious use of resources and optimization of productivity (Verma et. al. 2019).

Strip intercropping

The strip-intercropping is a type of intercropping where two or more crops are cultivated together in strips on sloppy lands. Strip intercropping is known to enhance radiation use efficiency in marginal and poor lands (Yang et. al., 2015). A combination of soil conserving and depleting crops are taken in alternate strips running perpendicular to the slope of the land or the direction of prevailing winds. An important objective of strip cropping is the reduction of soil erosion and harvesting of yield output from poor lands.

Relay Intercropping

Relay intercropping is raising two or more crops at a time during a portion of the growing period of each. In this system, the second crop is seeded when the first crop completes a major part of its life cycle and reaches reproductive stage or close to maturity but before harvest. The areas with limitation of time and soil moisture are more appropriate for relay cropping (Balde et. al., 2011). Before harvesting of the preceding crop, the next crop is sown and both the crops remain in the field for some period of their cycle. However, the succeeding crop yields less compared to normal sowing in sequential.

Aspects for consideration in intercropping system

Plant Density

To optimize plant density, the seeding rate of each crop in the mixture is adjusted below its full rate. If full rates of each crop were planted, neither would yield well because of intense overcrowding. By reducing the seeding rates of each, the crops have a chance to yield well within the mixture. The challenge comes in knowing how much to reduce the seeding rates. Low plant population per unit land area in sole crop has low yield as compared to intercropping (Jeyakumaran and Seran, 2007). The planting pattern of the maize intercropped with legume did not affect the yield of maize. Prasad and Brook (2005) reported that with increase in plant density had significant effect on Leaf Area Index in soybean intercropped with maize. The field should produce near top yields of peas even from the lower planting rate and offer the advantage of corn plants for the pea vines to run on. If you wanted equal yields from both peas and corn, then the seeding rates would be adjusted to produce those equal yields.

Maturity Dates

Planting intercrops that feature staggered maturity dates or development periods takes advantage of variations in peak resource demands for nutrients, water, and sunlight. Having one crop mature before its companion crop lessens the competition between the two crops. Enyi (1977) reported that crop mature at different times because of demand of nutrient and moisture with differ with arial space and light.

Selecting crops or varieties with different maturity dates can also assist staggered harvesting and separation of grain commodities. By this, the time of peak nutrient demands of component crops should be differed. Crops which mature at different times thereby separate their periods of maximum demand to nutrient, moisture, space and light. (Reddy and Reedy, 2007) reported that maize intercropped with green gram has maximum demand for light at 60 days after planting.

Compatible crops

Selection of a crop as intercropped with main crop has a vital role. Plant geometry, shading and nutrition competition between plants depend on choice of intercropped. Plant completion could be minimized not only by spatial arrangement, but also by choosing those crops best able to exploit soil nutrients (Fisher, 1977). Barker and Norman (1975) stated that increased yield from better use of space in mitue are complimentary to utilizing time with crops in sequences. So it revealed that maximum production should be obtained with sequences of high yielding crops in compatible mixture.

Time of planting

Time of planting has a major role for establishment of an intercrop. Amede and Nigatu (2001) reported that simultaneously planting maize with potato not influenced maize grain yield, whereas late planting of potato have negative effect on maize yield.

Plant Architecture

Plant architecture is a commonly used strategy to allow one member of the mix to capture sunlight that would not otherwise be available to the others. Widely spaced corn plants growing above an understory of beans and pumpkins is a classic example of intercropping concepts.

Advantage of intercropping

Resource utilization

The main reason for higher yield is due to the better utilization of natural resources by component crop in a unit area. Barhom (2001) reported that biological basis for intercropping involves complementary effects between the crops. Poor farmer are not able to recover poor soil fertility soil, so that crop intercropped with leguminous crop can enhance soil fertility and get additional income. Integrated nutrient management adopts a holistic approach to plant nutrient management by considering the totality of farm resources that can be used as plant. Vesterager et. al. (2008) found that maize and cowpea intercropping is beneficial on nitrogen poor soils. Maize-cowpea intercropping system enhances nitrogen, phosphorus and potash contents as compared to sole cropping (Dahmardeh et. al., 2010). Different root and leaf system systems are able to harness more light and make use of more water and nutrients than when the roots and leaves of only one species are present. When only one species is grown, all the roots tend to compete with each other.

Weed control

Intercropping is a better option for control of weeds, pests and diseases. In intercropping the weed not able to get grow due to dense canopy of both crop. (Makindea et. al., 2009) revealed that leafy vegetable can intercropped with maize to control weeds in tropics and increase yield. Intercropping maize and legumes considerably reduced the weed density compared with the monocropping maize by decrease in available light for weeds compared to monocrops (Dimitrios et. al., 2010).

Pest and disease

Maize crop is a host of many insect pest and disease, intercropping appears to be a very promising cultural practice for this purpose. It is generally believed that one component crop of an intercropping system may act as a barrier or buffer against the spread of pests and pathogen. Sastrawinata (1976) reported that maize-groundnut and maize soya bean mixed crop reduced the number of corn borer in maize.

Erosion control

Intercropping controls soil erosion by preventing rain drops from hitting the bare soil where they tend to seal surface pores, prevent water from entering the soil and increase surface erosion. In Maize-cowpea intercropping, cowpea acts as best cover crop and reduced soil erosion (Kariaga, 2004).

Yield advantage

Intercropping gave higher maize equivalent yield and land equivalent ratio as compared to sole crop. One of the most important reasons for intercropping is to ensure that an increase and diverse productivity per unit area is obtained compared to sole cropping. Yield is taken as primary consideration in the assessment of the potential of intercropping practices. The crops are grown together because of higher yields and greater biological and economical stability in intercropping system. The LER value also exceed than unity in intercropping as compared to sole crop.

Table 1. Pooled data of yield parameters and economics of *rabi* maize intercropping for year (2018-19 & 2019-20)

Treatment	**Maize yield (q/ha)**	**Intercrop yield (q/ha)**	**Maize equivalent yield (q/ha)**	**Land equivalent ratio**	**Return over variable cost**	**B: C ratio**
T1 - Maize: Potato	76.4	187.1	142.4	1.39	1,11,226	1.85
T2 – Sole potato	0.0	229.6	81.1	1.28	15,940	1.13
T3 – Maize: Green pea	74.1	41.9	123.3	1.32	1,47,002	3.27
T4 – Sole green pea	0.0	60.8	71.6	1.24	74,191	2.56
T5 – Maize: Fenugreek	76.7	63.4	114.0	1.38	1,33,259	3.12
T6 – Sole Fenugreek	0.0	80.5	47.4	1.20	42,143	2.10
T7 – Maize: Spinach	70.6	77.3	116.1	1.41	1,37,764	3.24
T8 – Sole spinach	0.0	91.1	53.6	1.00	54,290	2.47
T9 – Maize: Coriander	74.1	44.2	98.3	1.76	1,10,685	2.80
T10 – Sole coriander	0.0	54.7	30.0	1.00	17,774	1.48
T11 – Maize:	72.9	94.9	156.7	1.57	1,95,958	3.70
T12 – Sole Cauliflower	0.0	149.1	131.6	1.00	1,61,682	3.61
T13 - Maize: Cabbage	72.5	120.4	136.3	1.54	1,66,229	3.46
T14 – Sole Cabbage	0.0	195.5	103.5	1.00	1,22,262	3.28
T15- Maize: Garlic	73.4	49.8	146.7	1.40	1,80,422	3.54

T16 - Sole Garlic	0.0	108.3	159.2	1.00	1,80,742	3.01
T 17 – Sole Maize	78.9	0.0	78.9	1.00	90,810	2.99
CD at 5%	5.7	14.8	12.8	0.13		

Intercropping in maize

It is the third most important cereal crop of the world and used as food, feed and forage. Intercropping with maize is a way to grow a staple crop while obtaining several benefits from the additional crop. Intercropping of short duration legumes/ flowers/vegetables crops can be grown successfully with long duration maize. Maize-legume intercropping system led to higher soil canopy cover than the sole crop. So, in maize intercropping systems, weed density and weed dry matter get reduced due to unavailability of light to weeds. The yield of maize in intercropping system is not less than that of sole maize; rather intercrop yields are bonus to the farmers. Due to erect growth habit and different growth periods, maize is well suited to different intercrops of different growth habits and growing duration. During Rabi season crops like garlic, onion, cabbage, knol-khol, cauliflower, potato, fenugreek, coriander, spinach, gladiolus, lentil and pea can be grown successfully with maize whereas in *kharif* season suitable intercrops with maize are mung bean, urd bean, soybean, groundnut, pigeon pea, cow pea and various vegetable and flowers. A Research finding at CCS HAU, Regional Research, Karnal concluded that intercropping in *rabi* maize was conducting during 2018-19 and 2019-20. There were seventeen treatments, among all treatment the maximum maize equivalent yield (156.7 q/ha) and land equivalent ratio (1.57) was observed in Maize: cauliflower followed by maize + spinach, maize + garlic, maize + potato, maize + cabbage maize + coriander, maize + green pea and maize + fenugreek during both the year.

Conclusion

An ideal intercropping should aim to produce higher yields per unit area through better use of natural resources, offer greater stability in production under adverse weather conditions to meet the domestic needs of the farmers and provide an equitable distribution of farm resources. With particular reference to dry land agriculture, an intercropping system needs to be designed in such a way that in the case of unfavorable weather, at least one crop will survive to give economic yields. Thus, intercropping system should provide for the necessary insurance against unpredictable weather. In case the year happens to be normal with respect to rainfall, the intercropping system, as a whole, should prove to be more profitable than growing either of the crops alone.

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Winter maize-based cropping system: strategies to improve productivity and profitability of farming community of Bihar

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Abstract: Agriculture production system in Bihar needs to sustain productivity and improve profitability under changing climatic scenario. Bihar state is called capital of marginal farmers (~91%), all such farmers are vulnerable to climate change impacts and crop losses due to climatic changes affect livelihood and farmers income. In India Bihar state is the second largest growers of winter maize (*Zea mays* L.) after Andhra Pradesh state. This is an important cereal crop in world after wheat and rice. Climate resilient production technologies have potential to sustain productivity to meet the growing demands of rapidly growing world population and improve profitability of farming community. Winter maize could also be a sustainable option to improve system productivity. We hypothesized that winter maize-based cropping system would promote sustainable intensification, productivity, and profitability. We also predicted that winter maize would maintain total system productivity. Farming community of Bihar may expect higher revenues but also higher income volatilities in the future. Seven project sites (Purnea, Katihar, Nalanda, Nawada, Munger, Samastipur and Vaishali) were consider for this study. Winter maize was planted after harvest of Kharif rice. Results showed that rice grain and maize yield varied from 42.20 to 63.76 q/ha and 67.0 to 106.38 q/ha, respectively. However, in case of rice and maize profitability registered in range of 43300 to 94600 INR/ha and 74624 to 99000 INR/ha, respectively in different project sites. We conclude that winter maize-based cropping system has the potential to increase system productivity and profitability of Bihar farmers.

Keywords: Winter maize, Raised bed planting, Profitability, Weed management, food security

Introduction

South Asia faces great challenges in achieving food security in the coming decades as there is a need to 2-time food production by 2050 by using resources more efficiently while minimizing environmental problems (Ladha et. al., 2016). In many regions, demand for food is increasing with population and dietary changes creating increased competition for input (water, nutrients, energy) inputs into food production (Garnett et. al., 2013). Moreover, climate change poses additional challenges to agricultural development in developing countries such as India with food security, economic and political ramifications (Dagar et. al., 2012; Dubash, 2013). In many regions and countries, current farming practices are not sustainable and are also a major source of greenhouse gas emissions (Ladha et. al., 2016; Tongwane et. al., 2016).

The agriculture is one of the most climate vulnerable sectors of the Indian economy and the agricultural production system is highly sensitive to extreme events such as floods and drought, as well as long-term changes in climatic conditions such as rainfall and temperature that can lead to reduction in yields and shifts in cropping patterns of the region. This is particularly problematic for small hold farmers; these farmers are in the front line of climate change impacts. There is evidence of negative impact of changing climate on yield of wheat, rice and other crops with variable magnitude in diverse ecologies of Bihar. The climate projections of Bihar for 2050 have further revealed increasing trends in both maximum and minimum temperatures (2-4°C), coupled with much more variability (± 25%) in monthly rainfall pattern, that are bound to have large implications on agriculture, food security and livelihoods of the rural masses. This situation in the state of Bihar points to the need for call to action to counter adversities of climate change in a proactive and pre-emptive manner. Bihar is called capital of marginal farmers, approximately 91% of all farmers belong to marginal category with land holdings less than 1 hectare along with scattered land holding. These challenges vary by geographic location and are particularly challenging in the eastern Gangetic plains, especially in the state of Bihar, one of India’s most populous and poorest states that urgently needs to develop its agricultural potential and ensure food and nutritional security (Erenstein and Thorpe, 2011; GOB, 2015).

Climate-resilient agriculture (CRA) is one such multi-benefit approach for transforming and reorienting agricultural development under the new realisms of climate change. Under the Bihar government’s initiative of Agriculture Road Map, climate change is identified as one major challenge for a sustainable agricultural growth in the state. Accordingly, the State Government has started a series of innovations such as *Jal-Jivan-Hariyali*, *Organic Agriculture Mission*, *Hariyali Mission*, *Crop Residue Management and The Climate Resilient Agriculture Programme*. Based on literatures discussed above and question raised here, we hypothesized that in adoption of winter maize could increase or decrease the productivity and profitability of farming community. Consequently, we intend to clarify the impact with following objectives (i) to quantify the rice – winter maize productivity and profitability, (ii) to identify the suitable project site for rice – winter maize cropping system by adopting climate resilient technologies.

Methodology

Experimental sites

Seven project sites (Purnea, Katihar, Nalanda, Nawada, Munger, Samastipur and Vaishali) were consider for this study (Fig. 1), selected site is being managed by CIMMYT-BISA in collaboration with respective Krishi Vigyan Kendras (KVKs) under the CRA Program. Based on the existing climatic situations of Bihar, different ecologies (low, mid and upland soils) and available resources, 14 different cropping systems (Rice – Wheat – Mung bean; Rice – Wheat; Rice – Potato + Maize; Rice – Winter maize; Rice – Mustard – Mung bean; Rice – Lentil; Maize – Wheat – Mung bean; Maize – Mustard – Mung bean; Maize – Lentil – Mung bean;

Soybean – Winter maize; Soybean – Wheat – Mung bean; Pearl millet – Mustard – Mung bean; Pearl millet – Lentil – Mung bean; and Pearl millet – Wheat – Mung bean). For this study we have consider winter maize-based cropping systems.

Planting method and time

Zero tillage (ZT) maize through ZT machine and raised bed panted maize by the raised bed planter and manual seeding after preparation of bed-by-bed shaper. Planting was done during 15 October to 5 November 2020. Two maize hybrids (P-3355 and P-3388) were considered for this study. Nutrient, water and weed management followed by the recommended management practices.

Economic analysis

All fixed and variable costs (excluding land rent) were considered in the economic analysis. The cost of human labour used for tillage, seeding, irrigation, fertilizer, and pesticide application, weeding, and harvesting of crops was based on person-days ha^{-1} (Standard working hours as per the labour law of the Indian government). The cost of labour was calculated using the minimum wage rate as per the labour law (Minimum Wage Act, 1948). Gross returns (GR) were calculated by multiplying the grain yield of each crop by the minimum support price offered by the Government of India (Economic Survey of India, various years), while straw value was calculated using current local market rates. Net returns (NR) were calculated as the difference between GR and total cost (TC) (NR = GR − TC). System net returns (SNR) were calculated by adding the net returns of crops for the crops harvested within an individual calendar year.

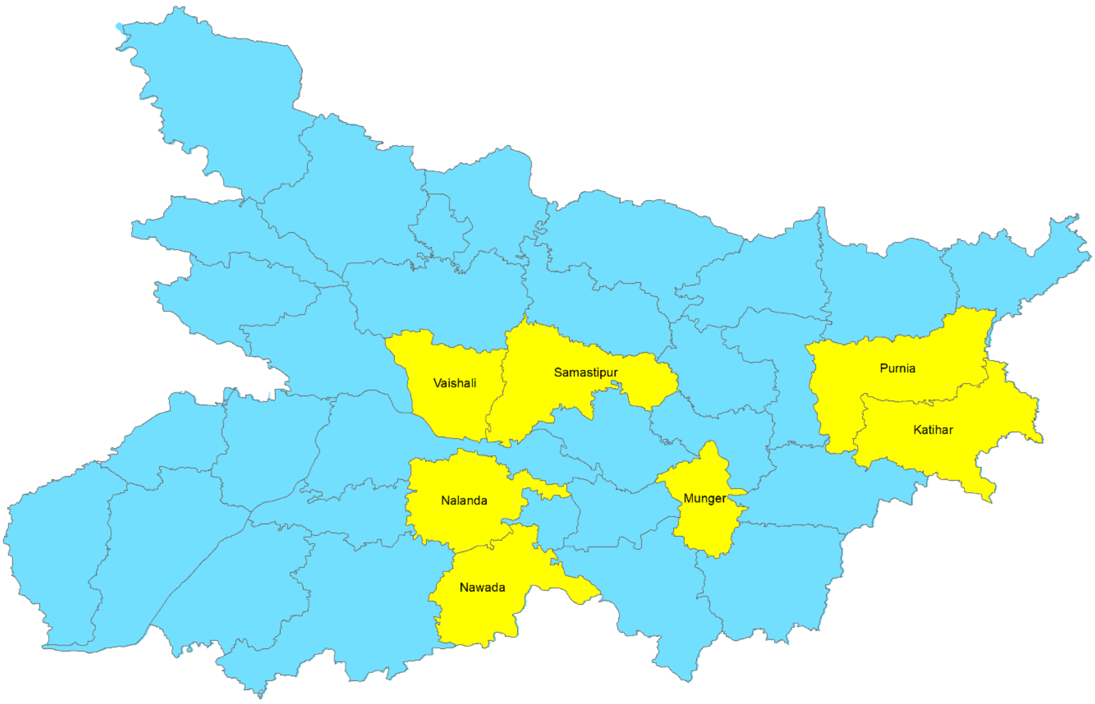

Figure 1: Winter maize-based cropping system experimental sites.

Data analysis
Data on different cropping system were analyzed using the analysis of variance (ANOVA) technique for randomized complete block design.

Results

Rice productivity
Results showed that rice grain yield varied from 42.20 to 63.76 q/ha in different project sites (Figure 2). The highest productivity was registered in Vaishali (63.76 q/ha), followed by the Nalanda (55.37 q/ha), Purnea (53.91 q/ha), Katihar (50.10 q/ha), Munger (49.35 q/ha), Nawada (48.24 q/ha) and lowest with Vaishali (42.20 q/ha).

Maize productivity
In Bihar winter maize is have most significant importance in cropping system and it have huge productivity potential due to long duration crop varieties and productive soils (Figure2). Data showed that maize grain yield varied from 67.0 to 106.38 q/ha in different project sites. The highest productivity was registered in Katihar (106.38 q/ha), followed by the Nalanda (92.0 q/ha), Samastipur (90 q/ha), Vaishali (88.0 q/ha), Purnea (86.10 q/ha), Munger (77.60 q/ha) and lowest in Nawada (67.0 q/ha).

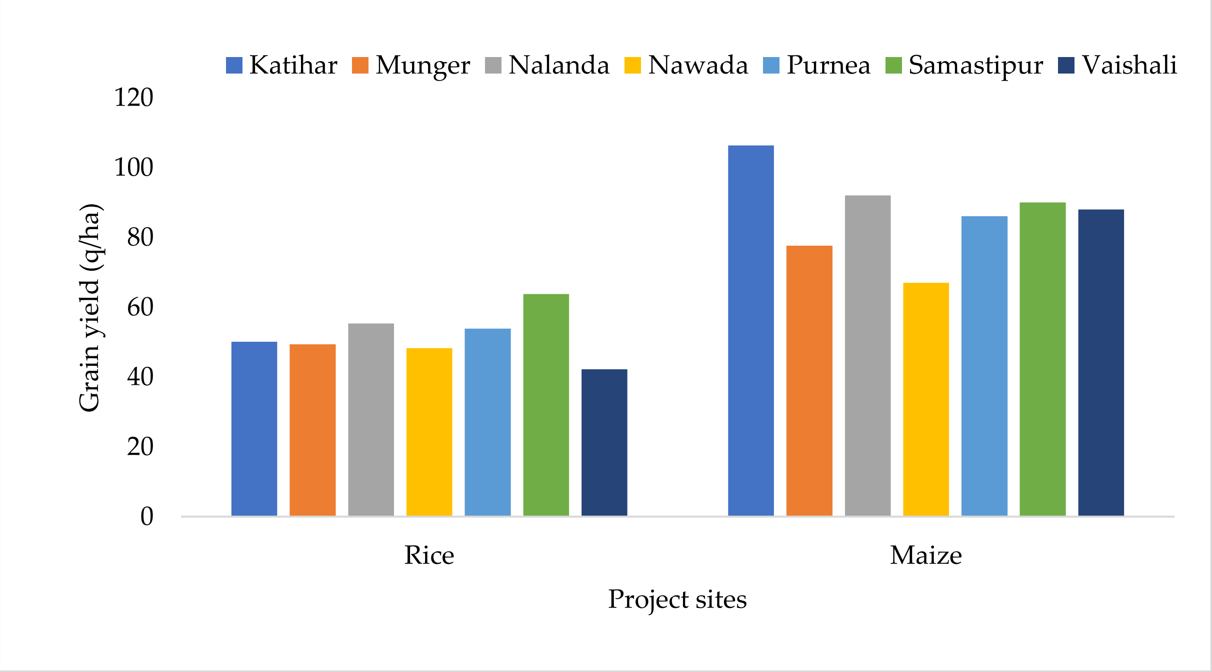

Figure 2: An average productivity of Rice–Winter maize cropping systems of different project site.

Rice profitability
Rice – winter maize systems are rapidly expanding in South Asia, India, Bihar, Telangana and Andhra Pradesh due to higher yield and profit potential from *rabi* (winter) maize, its reduced water requirement compared to rice–rice systems and increasing demand from poultry and fish feed industries (Figure 3). The rice profitability ranged from 43300 to 94600 INR/ha. Results

showed that highest rice profitability was observed in following order Munger > Purnea > Katihar > Nalanda > Samastipur > Nawada and Vaishali.

Maize profitability

The maize profitability ranges from 74624 to 99000 INR/ha under different project sites (Figure 3). The highest profitability was registered with Nalanda (99000 INR/ha), followed by the Samastipur (95000 INR/ha), Katihar (94600 INR/ha), Purnea (89950 INR/ha), Munger (83480 INR/ha), Vaishali (79400 INR/ha). Meanwhile, lowest maize profitability was observed in Nawada (74624 INR /ha).

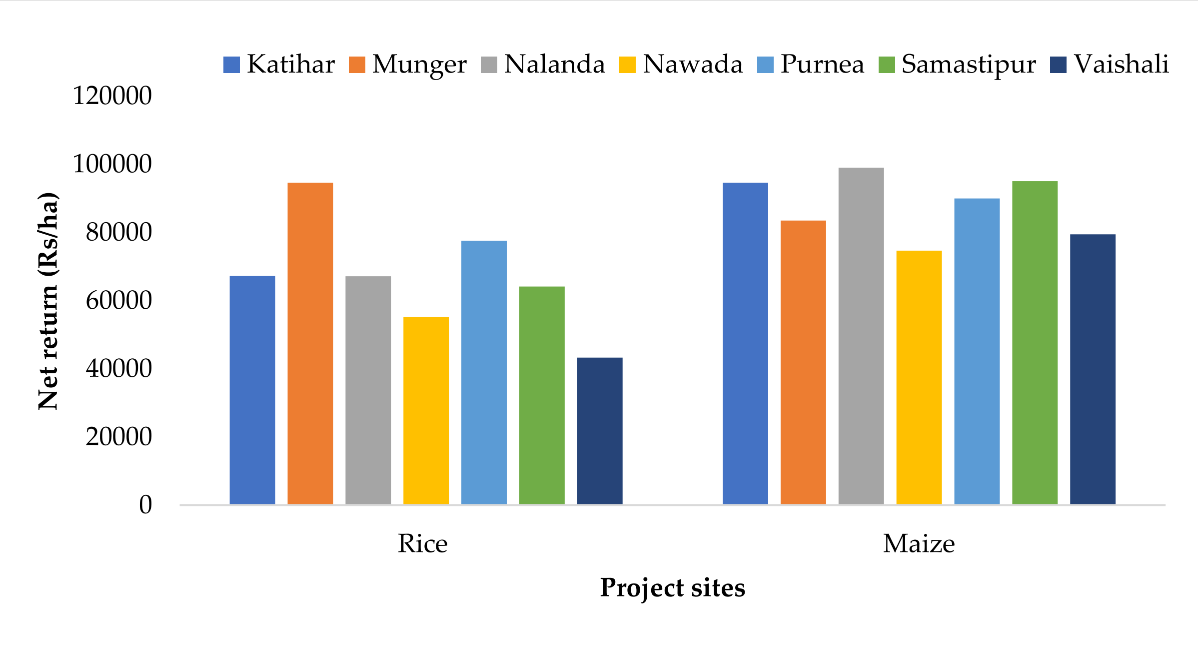

Figure 3. An average profitability of Rice–Winter maize cropping systems of different project site.

Conclusion

Climate change repercussions on agricultural systems in EGIP differ due to agro-ecological zones and socio-economic aspects. Due to more abiotic (rainfall & temperature) variations farmers in Bihar adversely affected. The adoption of climate resilient agriculture production system has led to rise in farmer's income. This rise has come both from reduction in cost of cultivation and increase in productivity. Results showed that the rice – winter maize system productivity ranges from 115.24 to 153.76 q/ha whereas profitability ranges from 129838 to 178080 INR/ha. Overall, results suggested that by adopting climate resilient agriculture technologies in rice – winter maize cropping system ensure food security and enhance farmer's profitability of Bihar state.

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Challenges in biotic stress management in maize

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Maize (*Zea mays* L.) is a multi-faceted cereal crop, commonly known as "Queen of Cereals" and can be grown in varied agro ecological regions. Maize is a potential crop for enhancing the farmers' income and is one of the most important crops next to rice and wheat. In India, maize is grown in an area of 9.2 million ha in varied agro-climatic conditions with a production of 30.2 million MT (DES, 2021). It is widely valued for its extensive use as feed (poultry and animal), fodder and as a raw material for large number of industrial applications (Rakshit *et. al*., 2017). It is cultivated for several purposes like quality protein maize, baby corn, popcorn, sweet corn, silage, fodder and for other industrial products. Global losses in maize production associated with biotic stresses are ~ 10.9% due to diseases, 14.5% due to insects, and 13.1% due to weeds. An additional 10% postharvest loss brings the total estimated loss to 48.5% (García-Lara and Serna Saldivar, 2016).

Insect pests

Insect pests are the major biotic constraints affecting productivity of maize, which in turn threatens food security under changing climate scenarios. In tropical and sub-tropical regions, climate is highly favorable for rapid multiplication of wide range of insect pests. Maize is attacked by large number of insect pests at different stages of crop growth in field and also during storage. Before May 2018, spotted stem borer (*Chilo partellus* Swinhoe), pink stem borer (*Sesamia inferens* Walker) and shoot fly (*Atherigona* sp.) are the predominant insect pests of maize. In 2016, a new invasive pest, fall armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) prevalent in Americas for several decades was reported for the first time in Africa. Subsequently, in 2018 it was first reported in India (Sharanabasappa *et. al*., 2018) and its temporal spread has been documented (Rakshit *et. al*., 2019).

Spotted stem borer is the most important insect pest during *kharif* season causing 26-80% yield loss in different agro-climatic regions of India (Panwar, 2005). The favorable conditions for rapid multiplication are warmer temperatures, high relative humidity and abundance of host plants. Female moth prefers 3-5 leaf stage maize for egg laying. The moth laid eggs preferably on lower surface of leaves. Eggs hatch in 3-4 days and the newly hatched larvae crawl inside the leaf whorl and feed in groups. Pin holes and papery windows are the first symptoms of spotted stem borer attack. After a week onwards, larvae move out of whorl and bore upwards the developing stalk. The leaf whorl dries resulting in 'dead heart' formation and often gives rise to tillers. Pink stem borer is the most important insect pest during *rabi* season causing yield losses in the range of 25.7 % to 78.9 % (Chatterjee *et. al*., 1969). Mild winters and high relative humidity favors the multiplication of PSB. The most critical damage has been found to be the destruction of growing point which results in dead heart formation. After hatching, pink borer larvae feed inside the leaf sheath in groups and feed on the epidermal layer of the leaf sheath preferably on first three leaf sheaths. The larva bores into the central shoot as a result; growing point dries up resulting information of dead heart in young plants. The larva feed in groups forms circular shaped tunnels inside the stem and exit holes at the surface. Due to larval feeding, circular ring like cuts occur on lower inter nodes.

FAW is a highly polyphagous migratory lepidopteran insect pest reported to feed more than 350 plant species with a preference to cereal crops across the globe (Montezano *et. al*., 2018). FAW has now become predominant pest of maize causing substantial damage to the crop. Its invasion, nature, distribution, management and potential impact has been described (Suby *et al*. 2020). Warm and humid conditions are favorable for multiplication of FAW. In the absence of any control measures, FAW is predicted to cause 21-53% loss in annual maize production (Day *et al*. 2017). Early instars feed in and around the whorl by scraping and skeletonizing the upper epidermis of leaves leaving a silvery transparent membrane resulting into papery spots. The damage results in pinhole symptoms on the leaves. The dispersal of early instar larva occurs by suspending in its silk known as ballooning. Later instars remain and feed inside the whorl. The damages by late instars (4^{th} instar onwards) result in extensive defoliation of leaves and presence of large amounts of faecal pellets in the plant whorl. During reproductive stage the larvae damage tassels or may bore inside the corn ear and feed on kernels, making control very difficult. Shoot fly is economically an important pest for spring maize which infests maize seedlings between the first and fourth weeks after emergence by ovipositing eggs on the abaxial surface of the third to sixth basal leaves. Grain yield loss due to *A. soccata* is 21.28%, while it is 20% by *A. orientalis* (Pathak *et. al*., 1971). Mild to moderate temperatures (20-30^{o}C) and high relative humidity favour multiplication of shoot fly. It infests seedling stage of maize as it is the most vulnerable stage. Infestation starts from two days after germination. Its infestation can extend up to three weeks old crop, which is less vulnerable to the pest. Eggs are laid on the abaxial surface of basal leaves, shoot and in soil. Maggots bore into shoot while feeding, gradually killing the growing point leading to withering of central shoot results in formation of dead heart, which is formed within two weeks of germination.

Among several insect pest management measures, chemical control is predominantly being practiced to manage maize insect pests. The toxic nature of pesticides causes different environmental and human health hazards. Thus, keeping in view the negative aspects of chemicals, alternative management strategies against major insect pests of maize are urgently needed. In this context, host plant resistance (HPR) based approaches are very promising as these are sustainable, eco-friendly and essential component of integrated pest management (IPM).

Identification of resistant sources

Utilizing diverse crop genetic resources that confer insect resistance in crop breeding programme has long been one of the most effective strategies for the integrated pest management in maize. It was reported that Antigua group 1 & 2, CML 139, CML 67, PFSRS 2, AEBYC 534-1-1, P 390AM/CML C4F230-B-2, AEBCYC 534-3-1, CML 384 × 176 F3-100-9, P 63C2-BBB-17B were found to be promising against spotted stem borer (Kumar *et. al*., 2005; Sekhar *et. al*., 2014). Genotypes CML 421, CAO 3141, CAO 3120, CAO 0106, WNZPBTL 9 (3.2), WNZPBTL 8 (3.5), CML 338 (3.6), WNZ EXOTIC POOL DC2 (3.1),

CML 424 (3.2), WNZPBTL 9-1 (3.4), BGS 86, CM111/*Zea diploperennis*/CM111, CML 141, CML 33#-4 (2.4), DML 1432 (3.0), EC 619101 (2.5) were resistant to pink stem borer based on 1-9 scale of LIR (Sekhar *et al*. 2008, 2014; Lakshmi Soujanya *et. al*., 2019). Five genotypes CML 420 (8.3), ACC 263214 (9.1), WINPOP 8 (9.1) AEB (Y) (10.0%), and CML 49 (10.0) recorded less than 10.0 percent dead hearts when screened against shoot fly (AICRP Annual Report IIMR, 2015).

Studies on FAW-resistant lines from Antigua indicated the importance of general combining ability in FAW resistance suggesting prevalence of additive effects. The details of maize lines developed resistant to FAW were Mp 496, Mp 703, Mp 704, Mp 705, Mp 706, Mp 707, Mp 701, Mp 702, Mp 713, Mp 714, Mp 716, Mp 708 (Williams *et al*. 1990); CML 333, CML 336, MP 708 (Ni *et al*. 2008); Mp 708, FAW 7061 (Ni *et al*. 2011); UR 11003:S0302, CUBA 164-1; DK 7 (Ni *et al*. 2014); CML 338, CKSBL 10008, CKIR 04002, CKIR 04005 (Prasanna, 2019). Since onset of FAW attack in India a large set of diverse maize germplasms are currently being screened for their resistance to FAW at the Winter Nursery Centre of ICAR-IIMR at Hyderabad under artificial infestation. Genotypes DMRE 63, CML 44BBB, CML 345, IML-15-243, IML 16-248 were found promising based on Davis score under artificial infestation (ICAR-IIMR, Unpublished data).

Screening techniques against major pests

The ability to develop resistant cultivars depends on the precision of resistance screening techniques. At hot spot locations screening can be done under natural pest infestations. In these locations, planting date of the crop should be adjusted in such a way that the susceptible stage of the crop coincides with the peak activity period of the pest. This can be determined by conducting population dynamic studies either by using attractant traps or by monitoring pest infestation at regular intervals. Screening under natural infestation is unreliable and takes longer time to identify lines with stable resistance. Therefore, artificial infestation techniques have been standardized for evaluating maize germplasm against insect pests.

For screening against stem borers, 10-12 neonate larvae should be released slowly into the whorl of the plant with camel hair brush in plant whorls by pinning on the leaf of 10-12 day old maize plants. There is often an accumulation of water in the plant whorl and in order to avoid larval drowning, the whorl should be gently tapped before infestation. Artificial infestation in the field is generally carried out in the evening times to avoid larval mortality due to high temperatures. Leaf Injury rating on 1-9 scale is recorded 30-35 days after infestation for categorization of maize genotypes. The resistant, moderately resistant and susceptible entries are classified by LIR 1-3, >3.1-6 and >6.1-9 respectively. In case of FAW, the most reliable method of screening maize genotypes against fall armyworm is through artificial infestation technique under confinement. During screening under artificial conditions, 15–20 neonate larvae per plant will be released manually or with modified bazooka insect applicator into the whorls of each maize plant at V5-V6 stage. The degree of leaf feeding damage are visually rated thrice *i.e*. at 7th, 14th and 21st day after infestation based on the rating scale described by Davis and Williams (1992) (1-9). Ear damage rating to be taken based on Davis and Williams (1992) at harvest (1-9). In case of shoot fly, damage rating scale based on percent dead hearts formed, modified from Sharma *et al.* (1992) is a good indicator of resistance.

Host Plant Defenses

Morphological and biochemical defenses in plants are considered as direct defenses and play a major role in imparting resistance to insect pests of maize. To withstand the effects of herbivore attack, plants respond to insect pests by various structural, biochemical, and molecular mechanisms. Morphological traits include trichomes, spines, thorns, epicuticular wax, tissue toughness, etc., form the first physical barrier to feeding by the insects. It was reported that trichomes on the upper leaf surfaces of the resistant genotypes resulted in oviposition reduction by SSB (Dubey and Sarup, 1982). Morphological traits attributed to FAW resistance include higher amounts of leaf cuticular lipids (Yang *et. al*., 1993) and thicker cell wall complex of epidermal layer (Davis *et. al.,* 1995) acts as a barrier to prevent insect feeding. Several biochemicals in maize have earlier been reported to be associated with resistance/susceptibility to insect pests of maize (Dhillon and Chaudhary, 2015). Resistant maize genotypes contain lower reducing and total sugars and were positively related to infestation by stem borer. Phenolic compounds and hydroxamic acids are the most common group of secondary metabolites and play a major role in imparting resistance to stem borers. Cell wall-bound phenolic constituents' *p*-CA and FA contribute resistance to pink stem borer infesting maize (Lakshmi Soujanya *et. al*., 2020). A higher concentration of amino acids, *viz*., aspartic acid, and tyrosine, abundance of crude and acid detergent fiber imparts resistance to FAW (Hedin *et al*. 1990). Indirect defenses such as Herbivore-induced plant volatiles (HIPVs) defend plants with the help of natural enemies of the insect pests. Volatiles are also released by secondary metabolites that attract the insect's natural enemies. It was reported that maize induces volatiles after applying synthetic volicitin, caeliferin, and inceptin which in turn attract natural enemies of insect pests (Alborn *et. al*., 1997). In some maize landraces, oviposition by SSB induces the release of volatiles which attract egg parasitoid *Trichogramma* spp and larval parasitoids (*Cotesia sesamiae*) (Tamiru *et. al*., 2011).

Breeding for insect resistance

In breeding programmes, utilization of resistant sources is the first step in the process of development of resistant cultivars to various insect pests. Higher yield is the most important trait to be considered for breeding for insect resistance under infested conditions (Butron *et. al*., 1999). The purpose of breeding for insect pest resistance is to reduce yield losses and selection for resistance should be based on criteria for yield loss. In any breeding programme selection against insect pest attack under artificial infested condition will be more rewarding for development of insect resistant germplasm. Historically, conventional breeding has been followed for breeding for insect resistance. Development of hybrids and their evaluation under artificial infestation condition is also being practiced for development of resistant cultivars. QTL mapping is a powerful tool for efficient identification and characterization of novel insect resistant genes. Development of powerful molecular genetic tools allows genome - wide association studies to dissect the molecular variation underlying variation in insect resistance. Several studies have been conducted on QTL mapping of resistance traits to different insect pests in maize depending on the importance of pest. In an attempt to decipher quantitative trait loci (QTL) determining FAW resistance, Brooks *et. al*. (2005, 2007) identified the key genomic regions on chromosomes 1, 5, 7, and 9 in Mp704 and Mp708 (these have combined resistance to both FAW and southwestern corn borer). Subsequently, using composite interval mapping

(CIM) and multiple interval mapping (MIM), 24 QTL explaining up to 26.5% of the total phenotypic variation and 36 QTL and 10 interactions for FAW leaf-feeding damage in Mp704 were identified (Womack et. al. 2018). QTL mapping facilitate the development of molecular markers and enhance marker-assisted breeding in order to introgress resistance traits into economically important cultivated crops (Varshney *et. al.*, 2005). The whole-genome based selection is bringing lots of excitement towards increasing efficiency of MAS by targeting all sets of genes *viz.*, minor as well as major genes determining resistance, which looks promising towards developing resistance to various insect pests**.**

Conclusion

Utilization of modern breeding techniques to transfer target traits in cultivated maize lines is required for improved resistance to biotic stresses. The components of resistance should be exploited and morphological traits that contribute to resistance should be given importance in selection. Exploitation of wild relatives for identifying new insect-resistant genes such as *R* genes is also essential as defense-related genes exhibit higher expression levels. Secondary metabolites responsible for insect resistance can be enhanced by recapturing from wild relatives of maize through conventional breeding techniques. Genotypes with higher capacities of tritrophic interactions with their natural enemies can be utilized in breeding programs.

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Conservation biological control of fall armyworm *Spodoptera frugiperda* (JE Smith)

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Fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) evolved in Americas has become the dominant pest of maize outside its native range since its invasion in 2016 in Africa, followed by 2018 in Asia. Tillage practices, cropping pattern and, fertilizer and pesticide management influence the incidence and severity of pest and diversity of its natural enemy fauna in agro ecosystem. Hence the present study was carried out to study the effects of contrasting tillage practices and fertilizer management on fauna in maize ecosystem under two long term experimental setups at ICAR-IARI, New Delhi. The first experiment was established in the year 2008 had diversified cropping systems [Maize-Wheat-Mungbean (MWMb), Maize-Chickpea-Sesbania (MCS), Maize-Mustard-Mungbean (MMuMb) and Maize-Maize-Sesbania (MMS)] under different tillage practices viz., [permanent bed with crop residue (PB), Zero tillage (ZT) and Conventional tillage (CT)] Parihar et al. (2016). The second experiment on the tillage practice of permanent bed with crop residue (PB+R) and without (PB-R) was established in the year 2012, had MWMb and MMuMb cropping system under four nitrogen management practices viz., recommended dose of N (RDN), and three green seeker based application of N preceded with basal application of 33% (33+GS), 50% (50+GS) and 70% (70+GS) of urea Jat et al. (2019).

Pest dynamics

Infestation of FAW during *kharif* 2020 and 2021 ranged from 92-99% and 88-98% respectively and the damage severity was less in conventional tillage both the years. Significantly higher damage was observed in high N applied plots across cropping system and residue management during *kharif* 2020. Maize plants were scored for leaf injury rating (LIR) when the plants at V6 stage during kharif 2020-21. FAW infestation was low in ZT and more in CT, especially in MCS and MMuMb system, however severity was more in CA plots. CT recorded low severity, especially in MCS and MMuMb. One pesticide spray was given after scoring at V6 stage and later no control measures were applied further. All the harvested ears were infested by FAW. FAW infested tip more frequently than the middle part of the corn. Tillage and fertilizer management was found to have a role in severity of ear damage too.

Natural enemy dynamics and diversity among different maize ecosystem

Several natural enemies were observed in maize ecosystem, where ants and parasitoids were visibly having an impact on FAW.

Ant dynamics and diversity

Ants are ecosystem engineers by virtue of modulating trophic levels and soil properties. They serve as ecosystem indicators owing to high sensitivity to ecological and environmental variables. Ant activity was recorded during 2019-21 *kharif* seasons by observing their nesting i.e. ant burrows (AB). CT recorded significantly highest AB during 2019, whereas PB recorded the highest during 2021. About 3.5 times more AB was recorded during kharif 2020, however, no significant differences were found across cropping system and tillage practices. Least ant activity was recorded in MWMb system. More ant activity was observed in the experimental system where only one pesticide application was done. Total of 13 ant genera were found in the maize ecosystem viz., *Tapinoma, Meranoplus, Pheidole, Trichomyrmex, Paratrechina, Monomorium*, *Crematogaster*, *Lepisiota*, *Messor*, *Plagiolepis*, *Trichomyrmex*, *Cardiocondyla* and *Camponotus*. During *kharif* 2020, highest ant diversity with total of 13 species was observed in PB among tillage practices and MCS among cropping system with 11 species. However, species richness was less under residue retention in the exp.2. Different scenario was observed during 2021, where one genus dominated in both the experiments with more than 5 species of it, suggesting high sensitivity of ants to environment. Two years of data showed ants would be antagonistic to parasitoids, but play a positive role in better plant health in CT. However, cropping system differences in ant activity and FAW infestation levels in both significantly negative and positive manner suggests their interaction with other fauna.

Parasitoid dynamics and diversity

During 2020, about 52% parasitization was observed across tillage, cropping and fertilizer management practices, where, CA plots recorded higher parasitization compared to CT. During 2021, 87% parasitization was observed and there were no significant differences between the cultural and crop management practices. Around the same period, only 28% parasitization was observed in no-spray maize-intercropping trials, the plot situated amidst a contiguous 15 ac. plot, where continuous spraying was undertaken. This suggests the negative role of plant protection chemicals in sustainable natural control of pests. During 2020, over 80% of the parasitization was contributed by the egg larval parasitoids *viz.*, *Chelonus formosanus* and *Chelonus blackburni*. Rest of the parasitization was constituted by *Temelucha* sp., *Coccygidium* sp., *Charops bicolor* and one species of Tachinidae and their share increased during 2021, along with new ones, suggesting faster adaption of native species on FAW.

Conclusion

Conservation agriculture helps in conservation biocontrol of FAW in addition to its inherent advantage of sustainability.

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Plant Biosecurity Prespectives in India

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The globalization of food production and distribution has shown a massive increase in international movement of people and goods (Sahli, 2006) leading to biosecurity concerns jeopardizing the global food security mission. Biosecurity is defined as safeguarding of resources from biological threats (Sharma et al., 2008). It is designed to reduce the risk of transmission of infectious diseases in crops and livestock; quarantined pests, invasive alien species, and living modified organisms. With increasing international trade of plants and plant materials, the risk of introducing exotic pests along with imported material also rises. Potential productivity of agricultural and horticultural crops is challenged by insect pests, diseases, weeds, nematodes and some vertebrates. Their impacts on farmers, consumers and all organisms down the food web are significant and often devastating. The impact of alien agricultural pests on yields may be around 50 per cent in the poorest countries (Oerke et al., 1994). During each cultivation cycle of agricultural and horticultural crops, production, and productivity losses of ~15.7 per cent occur in India owing to pests (Dhaliwal et al., 2015) accounting to ~US$ 36 billion. Plant biodiversity in India is particularly critical, as the country is home to one of the world's most biodiverse ecosystems. Of the 173 invasive alien species documented in India, 54, 25 and 22 represent terrestrial plant species, pathogens, and insects, respectively till 2018 (Sandilyan, 2016). India has faced at least 10 major invasive pest and weed attacks in the past 15 years. The most recent was the fall armyworm (FAW) that destroyed almost the entire maize crop in the country in 2018. India had to import maize in 2019 due to the damage caused by FAW in 2018 (Jitendra, 2019). The continuous entry of exotic pests in the country is necessating the revamping of the present legislative and regulatory framework for agricultural sustainability, food safety and environmental protection.

In compliance to recommendation of National Farmers' Commission headed by eminent agriculture scientist M.S. Swaminanathan (2004), various taskforces, committees and FAO (2008), India attempted to revise their archaic quarantine laws so as to mitigate the onslaught of invasive alien species (IAS). Consequently, the Agricultural Biosecurity Bill, 2013 was introduced in the Lok Sabha on March 11, 2013 by the then Honourable Minister of Agriculture, Shri Sharad Pawarji (https://prsindia.org/files/bills_acts/bills_parliament/Bill Summary-Agriculture biosecurity) for setting up a centralised National Agricultural Biosecurity System (NABS) covering four sectors of biosecurity *viz*. human, animal, and plant life and health, and associated risks for the environment. However, attempts to legislate on the issue through the Agricultural Biosecurity Bill 2013 ultimately failed. Bill aimed to establish an integrated national biosecurity system covering plant, animal and marine issues repealing the Destructive Insects and Pests Act, 1914 and the Livestock Importation Act, 1898. One of the biggest criticisms about the Bill is that it did not include epizootics/zoonoses (disease causing organisms that can hop from one vertebrate to another). Famous examples of such diseases are COVID-19, SARS, avian flu and mad cow disease which can easily be transferred from their primary hosts to humans. Another criticism for the Bill has been in the area of domestic quarantine. While the bill, does forbid individuals to "possess, move, grow, raise, culture, breed or produce any plant, animal and plant product", it does not clarify how states should act to contain the spread of disease. India's past record in imposing domestic quarantine has not been worth mentioning. India needs to relook into its biosecurity preparedness and plug all the big gaps to prevent dangerous biological agents- either man-made or natural. A number of biosecurity preparedness measures applicable for zoonotic and human diseases, have implications for plant quarantine in the management of invasive pests affecting field and horticultural crops. Numerous diseases that made a localized appearance earlier have now spread all over the country. Prof. Shashi Sharma (the then Chair in Biosecurity and Food Security at Murdoch University, Australia and former Professor and Head at the Nematology Division of Indian Agriculture Research Institute), says, "There is a need to consider and establish proper agreements between the Central and State Governments to ensure commitment in implementation of quarantine measures that are compliant with the Sanitary and Phytosanitary (SPS) Agreement". State and Central governments must have clear arrangements and agreements regarding roles and responsibilities and actions to be taken in case of suspect detection of a biosecurity threat. Contingency plans for key high priority exotic biosecurity threats must be prepared in advance so that they can be implemented when such threats are detected. Dr. Ravi Khetrapal (the then Director of the Inter-governmental Agriculture and Environment Organization CABI), India says that the emergency action plan is not clearly laid out. Dr. Khetrapal further suggests that apart from professors and researchers, experts from the ministry of Home and Defence should also be roped in to draw a clear action plan. He also insists on raising public awareness on the subject and help farmers understand what they can do at their level.

Presently, border quarantine is the mainstay of protection from exotic pests and diseases in India. Since biosecurity is emerging as one of the most pressing issues of global importance, investments in coordinated training and research, policy and development efforts are needed to enable scientists and farmers to competitively participate in addressing biosecurity issues in India. In the light of entry of invasive pests (Table 1) in the past (Jitendra, 2019) and sharp critism of our biosecurity legislation at national and international fora, it is urgent requirement to formulate new biosecurity policy with regional approach. Some of perspectives for revamping the Indian Biosecurity set up as per FAO guidelines are discussed in the paper.

Biosecurity Continuum Approach

The enhanced risk of invasion by biosecurity threats is necessitating the need for implementation of a continuum of biosecurity approach to manage pest and disease risks where they can be most effectively managed. Hence, India should adopt biosecurity continuum approach comprising of a coordinated system of pest risk analysis, inspection, surveillance and control using risk mitigation measures at pre-border, border, and post-border to prevent the entry, establishment, and spread of harmful organisms rather than focusing primarily on interventions at the border as per Destructive Insects and Pests (DIP) Act, 1914 (2 of 1914) with PQ Order 2003. An effective biosecurity continuum is also required to facilitate safe movement of goods and people and maintain the health status of human, animal and plants and the environment in general. It provides the necessary regulatory framework that governs trade within and between countries. The biosecurity continuum reduces the probabilities of incursions of harmful organisms and increases the probability of successful eradication of pest and disease incursions. Biosecurity policies and regulations across the continuum help to maintain existing markets and create new and improved trade opportunities. Communication, education and awareness of quarantine issues are integral parts of the biosecurity continuum.

Table 1. Recent invasion of major transboundry pest and their outbreak

S.No.	Pest	States	Year	References
1.	Desert locust	Rajasthan, Madhya Pradesh, Uttar Pradesh, Punjab, Haryana Gujarat, and Telangana	2020	FAO, 2020 a, b
2.	Cassava mealybug (CMB)	Thrissur, Kerala	2020	Joshi et al., 2020
3.	Fall armyworm (FAW)	Karnataka	2018	AFFRC, 2019
4.	Rugose spiralling whitefly (RSW)	Tamil Nadu and Kerala	2016	NCIPM, 2019
5.	South American tomato moth (SATM)	Karnataka and Tamil Nadu	2014	Sridhar et al., 2014
6.	Papaya mealy bug (PMB)	Coimbatore, Tamil Nadu.	2011	Shekhar et al., 2011
7.	Cotton mealy bug (CMB)	Gujarat	2005	Dhawan an et al., 2007
8.	Eucalyptus gall wasp (EGW)	South Indian states	2001	Jacob et al., 2007,
9.	Silver leaf whitefly	Tamil Nadu and Kerala	2000	Ananthakrishnan, 2009
10.	Coconut eriopyhid mite	Karnataka and Tamil Nadu	1998	Sathiamma et al., 1998

Pre-border Biosecurity

Pre-border biosecurity risk management includes the use of international agreements such as the SPS Agreement or the IPPC for the imposition of import standards, pre-border checks and treatments of goods to be imported, as well as information-sharing and international networking between research and development and biosecurity agencies. Pre-border activities seek to prevent biosecurity risks reaching borders of a country or region. Following are the main activities under pre-border biosecurity:

1. Risk assessments- level of biosecurity risk with imports and their management measures. Off-shore verifications, inspections and audits.
2. Collaborating- international partners on plant health issues and standards.
3. Regional capacity building through collaborative activities.

4. Intelligence gathering- determines and assesses potential biosecurity risks.

For example, it may include overseas fumigation certification for full containers and pre-clearance of some fruits and thus maintaining the quarantine pest risk off-shore. All the pre-border activities should come under domain of Union Government.

Border Biosecurity

Border biosecurity risk management includes checks by the border quarantine authorities of incoming goods and passengers that have potential to be pathways for pest and disease introduction. There is a need to strengthen the present border quarantine. The border biosecurity involves the following activities:

1. Screening and inspecting international vessels, passengers, cargo, mail, animals, plants, and plant products
2. Managing the high biosecurity risks of live plants and animals through containment, observation and treatment at quarantine facilities.
3. Identifying and evaluating the specific biosecurity risks facing northern, eastern and western India through Land Frontier Biosecurity Strategy.
4. Raising awareness of IB requirements among travellers, importers and industry operators.

Like pre-border activities, these border activities should also be under control of Union Government only.

Post-border Biosecurity

Post-border biosecurity risk management includes the use of subnational (States and UTs) boundaries to monitor and restrict the movement of biosecurity risk materials, surveillance, and monitoring activities for pests and diseases and incursion response planning. Monitoring and surveillance for pest and disease incursions, pest and disease spread and establishment in new regions are some of the key activities of post-border biosecurity program. Post-border biosecurity programs develop best-practice procedures and contingency plans to deal with incursions of exotic pests and diseases for eradication, containment or appropriate control. The approach involves preparation of biosecurity plans for each industry, including farm biosecurity plans where appropriate. Following activities can be part of post-border biosecurirty:

1. Post-entry quarantine (PEQ) and domestic quarantine
2. Pre-emptive biosecurity planning to combat pest incursions and to manage market access.
3. Pre-emptive breeding of varieties to improve pest resistance
4. Surveillance for exotic species.
5. Diagnostics and pest management
6. Farm biosecurity

Biosecurity can involve Union Ministries of Science and Technology (MoST), Health and Family Welfare (MoHFW), Environment, Forests and Climate Change (MoEFCC), Agriculture & Farmers Welfare (MoAFW), Finance (MoF), and States and Union Territories. In addition to these Union Ministries, one not-for-profit public company like Plant Health India (PHI) needs to be registered under company registration act. Then Union Government, PHI, State/UT Governments and Industries can join hands for the management of pest incursion in the country.

Stakeholders in Indian Post-border Biosecurity

Biosecurity impacts everyone, and everyone has a role to play. This is why Indian biosecurity can be delivered through a partnership approach. Following different groups should be stakeholders with an interest in keeping a strong plant biosecurity system for India:

i. Union Government:
   a) Coordinates national plant biosecurity policy
   b) Delivers border quarantine services to reduce the risk of pest entry

ii. General Public:
   a) Report any unusual plant pests
   b) Comply with quarantine by not moving fruit, vegetables and other plant products where not permitted

iii. Growers:
   a) Implement best biosecurity practices to protect their farm from pests
   b) Report pest detections to the relevant agency

iv. PHI:
   a) Coordinates the government-industry partnership to improve India's plant biosecurity system and to build capability to respond to plant pest emergencies

v. Plant Industry Representatives' Bodies:
   a) Coordinate biosecurity activities within the industry
   b) Raise awareness of pests and biosecurity best practice

vi. State/ UT Governments:
   a) Responsible for the management and eradication of pests within their borders
   b) Regulate pathways that may allow the introduction of pests. For example, placing restrictions on the importation of fresh produce.

Thus, biosecurity would be the management of risks to the economy, environment and community, of pests and diseases entering, emerging, establishing or spreading, and is delivered in partnership between governments, industries and a variety of stakeholders.

Biosecurity Responses

Any plant pest suspected of being an EPP need to be reported. This provides the best chance to respond appropriately to the detection and minimising its potential impacts. Reporting of the (suspect) EPP to the relevant State/UT Governments' authority can be ensured through one of these methods:

a) Exotic Plant Pest Hotline: There should be a hotline e.g. 1800 103 8181 where anyone in the country can call for reporting of the Exotic Plant Pest.
b) Directly to the state or union territory governments: We can contact our state/UT government departments of agriculture directly through designated telephone number.

The *modus operandi* of government responses to suspect emergency plant pest (EPP) should include:

a) The national agreements between central government, states and PHI should be passed in legislature so as to facilitate a rapid response
b) The response process, decision making and key players
c) The approach to national sharing of biosecurity response costs
d) Managing communications and confidentiality

The Response Deed for Emergency Biorisk (RDEB)

For establishing proper agreements between the governments and industries there should be a Response Deed for Emergency Biorisk (RDEB) on the pattern of Emergency Plant Pest Deed (EPPRD) in Australian Plant Biosecurity System between the Union Government, the State/UT Governments, PHI as well as plant-based industries.

The RDEB will serve as a cost sharing agreement for plant pest emergency responses between governments and industries. It would be a legally binding document that includes mechanisms for formal government/industry consultation on resource allocation, funding, training and risk management in the response to an EPP Incident.

Responding to EPP

The following briefly outlines the key aspects that should be initiated by the reporting of a plant pest.

Notification to Relevant Government Personnel

Plant Protection Officer (PPO) of the state or UT should be informed about the EPP. He will be the person responsible for plant biosecurity in each state. Once the PPO has confirmed the EPP, it must be notified to the chair of the Consultative Committee on Emergency Biorisks (CCEB), within 24 hours. The Plant Protection Advisor (PPA), Government of India can be the chair of the CCEB in the country.

All signatories affected by the EPP (both government and industry) would then be notified immediately, and a CCEB meeting would be convened. Membership of the CCEB is Incident dependent, as only Industry Parties that are affected by the EPP need to be represented. PHI will provide advice to the CCEB Secretariat, based on the host list provided, as to who the Affected Parties are and this information is used to convene the CCEB. The role of the CCEB is to coordinate the national technical response to EPPs. The CCEB would provide a link between the Union Government, states/territories, Industry, PHI and the National Biorisk Management Group (NBMG) during an Incident.

The CCEB membership should be based on the following:

1. PPA to Government of India as the Chair
2. PPOs from each jurisdiction
3. A representative from each Affected Industry Party
4. Plant Health India (PHI)
5. Indian Government representatives with expertise in border operations and import/export markets.

Members may be accompanied at CCEB meetings by advisors with relevant expertise. These individuals are considered as observers and cannot contribute to decisions. Notification of Affected Industry and government Parties would be sent to the representatives and will occur via email. It is the responsibility of all potential participants to read and respond to these emails.

CCEB members would arrange online meetings and decisions will be made in this format. Hence, it would be mandatory that all Affected Parties, government and Industry, read their emails and respond accordingly. No response by the due date will be taken as abstaining from the decision(s). At the beginning of any Incident the CCEB has a number of key questions that need to be addressed. The decisions made should be based on the available information at that point in time.

Key Decisions:

i. Does the Incident relate to an EPP?
ii. Should the EPP be eradicated?
iii. What additional information needs to be collected?
iv. What should be communicated?
v. What is the recommendation that should go to the NMG?

National Biorisk Response Management

All signatories affected by the EPP play a part in the national management of EPP responses. This is primarily through the two national decision making committees:

a) The Consultative Committee on Emergency Biorisks (CCEB) which provide technical expertise on the response
b) The National Biorisk Management Group (NBMG) which acts on recommendations from the CCEB and make the final decisions about EPP responses and funding.

All decisions made in a response should be by consensus, with the exception of decisions about cost sharing (funding) which must be unanimous. Overall, the CCEB and NBMG provide advice and agree on the response activities to eradicate the EPP, including the financial contributions. The state/UTgovernments would be responsible for implementing the on-ground activities to eradicate the EPP.

Technical Response Recommendations

The CCEB will provide technical guidance to the response and makes recommendations to the NBMG. Information about the EPP, and regular situation updates, are provided to the CCEB, allowing the committee to make recommendations regarding:

a) Whether a suspect pest is an EPP or not
b) Determining the feasibility of eradicating the EPP
c) Development of an appropriate biorisk response strategy
d) Monitoring the ongoing response actions and providing advice where required
e) Whether the EPP has been eradicated
f) Determine whether a transition to management phase is appropriate, if a response plan is in place and the EPP is no longer technically feasible to eradicate
g) Appropriate communication messages

National Decision Making and Commitment

The NBMG will manage the national policy and resourcing needs throughout a response. It would be the responsibility of the NBMG to consider the advice from the CCEB, approve the response actions and agree on the commitment and sharing of funds to a response, through the approval of a response plan. Membership of the NBMG will consist of the following:

a) Secretary of the Department of Agriculture, Cooperation & Farmers Welfare (DACFW), as the Chair.
b) CEOs from each state and territory government (or their representative).
c) The President/Chairman (or their representative) of each affected industry party.
d) The Chairman of PHI (or their representative).

The recommendations formed by the CCEB will be presented to the NBMG to make the decisions. The decisions made by the NBMG would be implemented and the CCEB monitor the response actions.

Phases of a Response

There can be three phases on an EPP response:

i. *Investigation and alert phase*: A suspect pest is detected and reported to the Plant Protection Officer (PPO) of the state or UT agriculture department. The process of initial and confirmatory identification or diagnosis of the pest will be initiated. The Plant Protection Advisor (PPA) is notified and an outbreak is declared. The PPA will notify the affected parties from government and industry, who are signatories to the Emergency Plant Pest Response Deed, and will convene a meeting of the Consultative Committee on Emergency Biorisks (CCEB).

If the pest is considered potentially serious, then the relevant state or territory agriculture department may adopt precautionary measures. These measures, depending on the pest, may include:

a) Restriction of operations in the area
b) Withdrawal of people, vehicles and machinery from the area and disinfection
c) Restricted access to the area
d) Interim control or containment measures.

The CCEB will determine the feasibility of eradication and makes a recommendation to the NBMG. If the NBMG decides to proceed with eradication, the CCEB will oversee the preparation of a Biorisk Response Plan by the lead agency (ies). The resources and costs required for the eradication are identified. The NBMG approves the Biorisk Response Plan and national cost sharing arrangements to fund the response.

ii. *Operational phase:* The aim of this phase is to eradicate the pest. The lead agency (ies) in the states or territories in which the incursion occurs implement and manage the Biorisk Response Plan, overseen by the CCEB, providing regular reports to the committee on the progress of the campaign. Meetings of the CCEB and NBMG are convened as required during implementation of the Biorisk Response Plan.

iii. *Stand down phase:* After the response is complete, or a review determines that eradication is not feasible, records of expenditure and technical reports will be provided to PHI so that final costs can be calculated. In the stand down phase, all operations are wound down.

Confidentiality in a Response

Confidentiality should be a key commitment of all participants of an emergency response. It applies to responses carried out under the RDEB. The release of inaccurate or incomplete information could affect the international and domestic markets immediately for no reason. To limit this negative behaviour, it is essential that consistent messages are delivered from the EPP response team through the appropriate channels.

Release of Talking Points to Media

The communication of relevant, accurate and up-to-date information to key stakeholders, such as growers and the general public is important to deliver an effective response. This information should be consistent and appropriate to the audience. Talking points are released from the Consultative Committee on Emergency Biorisks (CCEB) for general communications use by participants for generation of their own media release. All other information should remain confidential.

Talking points may include generalised information on:

a) What has happened
b) How it happened
c) Implications
d) What is being done about it
e) What we want the public to do
f) Sources of further information

Paying for the Response

Affected industries and governments invest in the eradication of EPPs and share the costs of an agreed response plan, this is referred to as 'cost sharing'. The costs to be shared are clearly shown in this budget and include items such as the cost of additional staffing, operations, capital and Owner Reimbursement Costs (ORCs). Responses incur a large number of costs from a wide range of activities and these are classified as either normal commitments or Cost Shared costs.

<table>
<tr><th>Category of Pest</th><th>Pest which if not eradicated would</th><th colspan="2">Funding</th></tr>
<tr><td>Category 1:
Very high public impact</td><td>Cause major environmental damage to natural ecosystems; and/or
Potentially affect human health or cause a major nuisance to humans; and/or
Cause significant damage to amenity flora; and
Have relatively little impact on commercial crops.</td><td colspan="2">100% Government</td></tr>
<tr><td>Category 2:
High public impact</td><td>Cause significant public losses either directly through serious loss of amenity and/or
Environmental values and/or effects on households or indirectly through very severe economic impacts on regions and the national economy, through large trade losses with flow on effects through the economy; and</td><td>80% Government</td><td>20% Industry</td></tr>
</table>

	Also impose major costs on the industries concerned so that these industries would significantly benefit from eradication.		
Category3: Moderate public impact	Primarily harm the industries concerned but there would also be some significant public costs as well (that is, moderate public benefits from eradication). In this case the pest could adversely affect public amenities, households or the environment, and/or could have significant, though moderate trade implications and/or national and regional economic implications.	50% Governmen t	50% Industry
Category 4: Mostly if not wholly private impact	Have little or no public cost implications and little or no impacts on natural ecosystems. The affected commercial industries would be adversely affected primarily through additional costs of production, through extra control costs or nuisance costs; and Generally, there would be no significant trade issues that would affect national and regional economies.	20% Governmen t	80% Industry

Division of Costs

The cost shared costs of a biorisk response should be divided between affected industries and governments in an equitable manner based upon category of EPP (https://www.planthealth-australia.com.au/biosecurity/emergency-plant-pests/pest-categorisation/) directly related to the benefit of eradicating the same. The government portion can be first divided (50:50) between the Union Government and the states and UT governments. The state and UT portion is further divided based on the benefit of eradication to each jurisdiction. When there are multiple industries involved, division of the industry portion will be based on a combination of the level of impact as mentioned in above table and the size of each industry. In the event that a response plan is endorsed for an uncategorised EPP, cost sharing will commence using the default category (*category 3*), and may be revised later.

Owner Reimbursement Costs

Owner Reimbursement Costs (ORCs) should be provided as an incentive for growers to report suspect EPPs. ORCs are included in the shared costs of a response and will be available to eligible growers to alleviate the financial impacts of crops or property that are directed to be destroyed under an agreed response plan. The values of ORCs to individual are determined based on the value of the crop destroyed under the direction of the Response Plan at the time of destruction.

Conclusions

The risk of introducing exotic pests along with trade of plant materials always rises. Plant biodiversity of India is home to one of the world's most biodiverse ecosystems. Since biosecurity is emerging as one of the most pressing issues of global importance, the present legislative and regulatory framework of India needs to be revamped through new Agricultural Biosecurity Legislation so as to safeguard our biodiversity from onslaught of IAS including epizootics/zoonoses in line with those of USA, Australia, New Zealand, Belize, Norway, Canada, and Finland. Under the new legislation, India should adopt biosecurity continuum approach comprising of a coordinated system of pest risk analysis, inspection, surveillance and control using risk mitigation measures at pre-border, border, and post-border to prevent the entry, establishment, and spread of harmful organisms rather than focusing primarily on interventions at the border repealing the Destructive Insects and Pests Act, 1914 and the Livestock Importation Act, 1898. Revised biosecurity policies and regulations across the continuum will also help us to maintain existing markets and create new and improved trade opportunities. The novel biosecurity plan can involve Union Ministries of Science and Technology (MoST), Health and Family Welfare (MoHFW), Environment, Forests and Climate Change (MoEFCC), Agriculture & Farmers Welfare (MoAFW), Finance (MoF) and States and Union Territories and one not-for-profit public company like Plant Health India (PHI). Affected industries and governments will invest in the eradication of EPPs and share the costs of an agreed response plan referred to as 'cost sharing'. The costs to be shared will be clearly shown in the budget and include items such as the cost of additional staffing, operations, capital and Owner Reimbursement Costs (ORCs). Responses incur a large number of costs from a wide range of activities and these are classified as either normal commitments or Cost Shared costs. The cost shared costs of a response should be divided between affected industries and governments in an equitable manner based upon category of EPP directly related to the benefit of eradicating the same.

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Host plant resistance in maize

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Genetic resistance in plants is divided into two major classes- qualitative and quantitative resistance. Qualitative or major-gene resistance is based on single major-effect resistance genes (R genes) and generally provides race-specific, high-level resistance. It is generally effective against biotrophic pathogens. Quantitative resistance has a multigenic basis and generally provides durable, non-race-specific intermediate levels of resistance and is more often associated with resistance to necrotrophic pathogens. The vast majority of genetic resistance used by maize breeders is quantitative. The reason being maize an outcrossing species, is substantially more genetically diverse and comparatively fewer commercially important biotrophic pathogens attacking this crop. Indian subcontinent is prone to foliar diseases, ear rots and stalk rots caused by fungi and bacteria. Foliar diseases include southern leaf blight, northern leaf blight, banded leaf and sheath blight, rusts and downy mildew. Banded leaf and sheath blight has emerged as a major threat, especially where rice-maize rotation is followed, with no good sources of resistance against this disease. Among stalk rots, *Fusarium* and *Macrophomina* spp. are prevalent after a dry spell.

The first classical example included a new race (race T) of the southern corn leaf blight pathogen *Cochliobolus heterostrophus* that emerged in 1969 and was very pathogenic on cms-T maize, causing disease epidemics in 1970 and 1971. Susceptibility to this disease was due to specific interaction of a fungal metabolite with the product of a unique susceptibility gene in the host, and it was averted by simply avoiding the use of cms-T germplasm containing this gene. Secondly, the *Hm1* gene that confers specific resistance against a leaf blight of maize, caused by *C. carbonum* race 1 (CCR1). The exceptional virulence of race 1 on susceptible *hm1* maize is due to production of a host specific toxin, HC-toxin, a cyclic tetrapeptide. *Hm1* was first gene to be cloned by transposon tagging and was found to be an NADPH dependent HC-toxin reductase, which reduces a key carbonyl group on HC-toxin, thereby inactivating it (Johal and Briggs, 1992). For HC-toxin, plant resistance is an active function, requiring the production by the plant of an enzyme to detoxify a fungal pathogenicity factor. Contrastingly, in case of T-toxin, plant susceptibility is an active function, requiring production by the plant of a toxin binding protein.

Resistance to leaf blights

Southern leaf blight (SLB)

Genetic resistance to SLB is quantitative, and the gene action is primarily additive or partially dominant or epistatic. Our AICRP (Maize) programme has identified several resistant sources - JCY_2-7-1, LM 19, LM 23, CM 143, LM 16, LM-5, CM 139, JCY 3-7, LM 13, LM 14, LET DR-49 and LMDR 2 and being used for developing potential hybrids (Hooda et al., 2012). The monogenic recessive resistance gene, *rhm1* to race O of *C. heterostrophus* mapped to the short arm of chromosome 6, was fine mapped to 8.56kb region harbouring only one putative candidate gene *lysine histidine transporter 1* (*LHT1*). However, it is effective only at the seedling stage. At the adult plant stage, *rhm1* confers a low level of quantitative resistance.

Recently, study conducted at PAU revealed that four major QTL from the resistant parent LM5 found on chromosomes 3, 8 and 9 were associated with large and consistent effects on SLB reactions and accounted for most of the genetic variation seen among the RILs (Kaur et al., 2019).

Northern leaf blight (NLB)

The fungus *Exserohilum turcicum* causing this disease spreads biotrophically during the initial infection process before switching to a necrotrophic lifestyle. Infections manifest as local lesions and necrosis, which lead to reduced photosynthetically active leaf area and yield losses. In All India Coordinated Maize Programme, Mandya centre has identified 19 stable TLB resistant inbred lines *viz*., NAI 137, 175, 181,187, 204, 207, 176, 197, MAI 2, 214, 264, CML 226, 300, 451, HKI 163, CAL 1443, SKV 50, KUI 1411 and KUI 1411-A and contributed to Winter Nursery Center, Hyderabad. Partially dominant qualitative genes viz; *Ht1*, *Ht* 2, *Ht* 3, *Htn* 1 and *Ht* P have been described that confer race-specific resistance. *Ht* genes have unusually high environmental dependence, particularly with regard to light and temperature and they tend to confer delayed lesion development rather than complete resistance. QTL for northern leaf blight resistance identified in at least nine different populations seem to be distributed throughout the genome and tend to be insensitive to light and temperature variations. The Htn1 resistance reaction is different from the other known resistance genes Ht1, Ht2, and Ht3, which confer qualitative resistance. In contrast, Htn1 leads to a delay of sporulation without chlorotic lesions (Balint-Kurti and Johal, 2009). It was originally introgressed into modern maize cultivars from the Mexican landrace Pepitilla in the 1970s.

Banded leaf and sheath blight (BLSB)

Identifying genotypes with genetic resistance to BLSB is quite difficult among maize germplasm as experienced in rice against the same fungus. However, national programmes in India are making efforts towards screening for BLSB resistance. In All India Coordinated Research Project on maize, both inbreds and hybrids are evaluated for their reaction against BLSB and few lines with moderate level of resistance have been identified. Recently, Sanjay et al (2021) studied the virulence of 44 isolates of *Rhizoctonia solani* on four hybrids and seven inbred maize lines and revealed that maize hybrid JH3459 and inbred LMDR-2 were less susceptible to Punjab population of *Rhizoctonia* species. Inheritance studies have indicated digenic and oligogenic nature of disease resistance. Recently, a study revealed that two amino acid substitutions in ZmFBL41 determine a *R. solani*-resistant phenotype, suggesting that *zmfbl41* is a recessive gene responsible for BLSB resistance in maize. *ZmFBL41*B73 over-expression results in susceptibility to *R. solani*, and knockout of *ZmFBL41* results in enhanced resistance, indicating that *ZmFBL41*B73 functions as a negative regulator in BLSB resistance. This locus is the first cloned BLSB-related QTL and it therefore represents a crucial target for developing *R. solani* resistance through maize breeding (Li et al 2019).

Stalk rots

Bacterial stalk rot

Partial resistance against *Erwinia chrysanthemi* pv. *zeae* has been reported in CM 600, CM 104, CM- 101, CM- 110, Basi and CM 105 maize lines and their crosses in the field. **S**usceptibility of maize varieties was due to enhanced proteolytic enzyme activity and change in protein and total amino acid contents of stalk and leaf tissues of plant in middle and old age of crop. It was also observed that the susceptibility of maize plants was dependent on the induction of cellulose activity by the bacterium in the infected tissues. Pathogenic variability was observed in 62 Punjab isolates of *Dickeya zeae* after inoculation on ten maize cultivars. Out of these, CM140 was found to be highly susceptible with almost 85% of the isolates virulent on this inbred, whereas LM16 was found to be least susceptible as only five isolates of were virulent on this line (Adesh et al., 2017).

Post flowering stalk rots

Post-flowering stalk rots are complex diseases, due to probable combined infection with multiple pathogens, accentuated by abiotic stresses and further compounded by secondary infections. Resistance to different stalk rots is highly polygenic in nature and related to abiotic stresses, additive effects were found to be more significant than non-additive effects. Hooda et al. (2017) identified 12 stable disease resistance sources (PFSR/51016-1, CM144, HKI 193-1, PFSR-R2, PFSR-R9, JCY2-1, CM117-3, 42048-2, JCY3-7, JCY2-7, LM13 and CM117-3) that could be used for developing promising maize hybrids with inbuilt resistance to PFSR disease for different maize agroecologies in India. Genetic mapping studies for resistance to *Gibberella* stalk rot identified two QTL, namely *qRfg1* and *qRfg2*, fine-mapped to ~ 500 kb region on chromosome 10 and ~ 300 kb region on chromosome 1 (Zhang et al., 2012). Another QTL *Rgsr8.1* was fine mapped, conferring broad-spectrum resistance to *Gibberella* stalk rot on chromosome 8 (Chen et al., 2017). Similarly, two QTLs on chromosomes 6 and 8 identified in GWAS for charcoal rot resistance were also validated in biparental mapping populations. *Rcg1* gene that confers resistance to anthracnose stalk rot of maize segregates as a major gene in certain populations while in others it was identified as a QTL.

Rusts

Rigorous screening of Polysora Rust at Mandya AICRP centre identified stable resistant inbred lines *viz*., NAI 138, 161, 175, 197, 204, 207, 209 and CML 410. To date, at least 18 race-specific resistance genes have been identified, and most have been widely used in commercial maize varieties, such as Rpp1-11 (Storey and Howland, 1957; Ullstrup, 1965; Brewbaker et al., 2011), Rpp25 (Zhao et al., 2013), RppQ (Chen et al., 2004; Zhou et al., 2007), RppD (Zhang et al., 2010), RppC (Yao et al., 2013), RppS313 (Wang et al., 2019a), RppS (Wu et al., 2015), and RppCML496 (Lv et al., 2020). Common rust another important disease can cause up to 49% yield losses in susceptible genotypes. The rp1 complex, a cluster of resistance genes, is located on the short arm of chromosome 10 (Hulbert, 1997). Sixteen different genes were identified in the rp1 cluster by examining their responses to an extensive collection of rust biotypes, and fourteen of which were given the Rp1 designation (Rp1-A to Rp1-N) (Hooker, 1969; Hulbert, 1997).

Ear rots

Fusarium ear rot (FER)

The inheritance of resistance to *Fusarium* spp. causing ear rots is complex. Very little fumonsin accumulation was detected in kernels with low starch or where the amylase:amylopectin ration was high. QTL mapping studies in maize indicated that resistance to FER is a quantitative trait determined by polygenes having small effects; however, a few studies detected QTL with moderate effects on chromosomes 3 and 4. GWAS identified SNPs associated with Fusarium ear rot and fumonisin content, some of which were located close to QTLs detected in biparental populations. Several elite lines from CIMMYT with low accumulation of fumonisin content have been reported. The Kenyan maize inbred line CML495 found to be more resistant to FER, *F.verticillioides* colonisation and fumonisin accumulation is also considered to have broad adaptability. It has also been characterised as a late maturing line (CIMMYT 2005), which dries down slower than early maturing lines, thereby potentially extending the conditions conducive for fumonisin deposition.

Aspergillus ear rot

Resistance to *A. flavus* was found to be highly quantitative and inherited in an additive manner. Many sources of resistance including Mp313E, SC54, Mp420, and Tex6, were identified in temperate maize germplasm, but resistance in the majority of them was highly environment-dependent. Mp313E, released in 1990, was the first line released as a source of resistance to *A. flavus* infection. Subsequently, germplasm lines Mp420, Mp715, Mp717, Mp718, and Mp719 were released as additional sources of resistance (Williams et al 2015). New breeding lines with repeatable and stable resistance were identified, majority of them with tropical germplasm background, especially using the Tuxpeno landrace (Prasanna et al., 2021). Inbred CML495 was found promising not only to *F. verticillioides* and fumonisin contamination but also provided comprehensive resistance to *A. flavus* and aflatoxins.

In addition, continuous efforts are being done to identify downy mildew resistant maize lines and their utilization in breeding programme. Outbreak of new diseases and evolution of more virulent strains pose a major challenge to the available host-plant resistance. Therefore, host-plant resistance breeding programs require close monitoring of changes in the virulence of pathogens and the identification of new resistance sources. In nutshell, identifying resistance genes and understanding their molecular mechanisms, coupled with advanced biotechnology, help us to breed new maize cultivars with high disease resistance and ideal agronomic traits.

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Prospects of maize-based silage for sustainability of dairy industries in India

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The economics of milk production is largely dependent upon the quality of nutritious fodder fed to milch animals. Green forages are considered to be the backbone of dairy farmer as feeding of green forages compared to concentrates lowers the cost of milk production substantially. Inadequate supply of quality fodder has been identified as one of the reasons for poor livestock productivity. For the optimum milk production around 40 kg of green fodder is required to feed per animal per day. However, a huge deficit exits between the demand and supply of green fodder in India. At present, there exists around 63 per cent deficiency of green fodder and 23.5 per cent deficiency of dry fodder in India. Therefore, to meet out the needs of the ever increasing livestock population, the production as well productivity of fodder is to be increased. The increasing cultivation of cereal and cash crops, however, contributed towards a decline in the area under fodder cultivation. There is a tremendous pressure of livestock on the available total feed and fodder, as the land available for fodder production has been decreasing. Moreover, green forages are rich and cheapest source of carbohydrates, protein, vitamins and minerals for dairy animals. Therefore, by providing sufficient quantities of fodder instead of costly concentrates to the milch animals, the cost of milk production can considerably be reduced. Maize is one of the most important non-legume green fodders. It is tall, leafy plant having biomass yields to the tune of 400-500 q/ha. It is highly nutritious, palatable fodder free from any unwanted anti-quality components. Green maize is rich in protein and possesses sufficient quantities of soluble sugars required for proper ensiling. Silage is as nutritious as green fodders as it preserves the nutrients in its original form and hence it is as good for animal feeding as green fodder itself. From a practical view, the three most important things that must occur in order to make good silage are 1) the rapid removal of air, 2) the rapid production of lactic acid that results in a rapid drop in pH, and 3) continued exclusion of air from the silage mass during storage and feed out. In certain forage crops such as maize has relatively low buffering capacity and high concentrations of fermentable carbohydrates; therefore, pH decline is rapid and final pH is usually low, approximately 3.5, thus are more suitable for silage making. In general, the pH of silage at the final stage should be within the range of 3.5-4.3. Proper dry matter is the most important criteria for ensiling so that chaffed fodder can be packed well and more lactic acid is produced. Delayed filling of silo pit results in excessive amounts of air trapped in the forage mass can have detrimental effects on the ensiling process. Longer filling time of chaffed fodder in silo might have not maintained anaerobic conditions properly leading to increased aflatoxins in silage. The container in which silage is made is of greatest importance and will determine to the large extent the nature and quality of final product. The most common silo is the trench silo. One cubic meter space can store 5-6 quintals of green chopped fodder. During silage making, loss of dry matter, carotenes, carbohydrate and proteins occur due to respiration, fermentation and aerobic deterioration. The field losses may occur due to shattering of leaves and other nutritious portions because of poor harvesting managements. Various types of additives can be used to improve or inhibit the fermentation or supplement nutrients needed by ruminants to be fed as silage. Silage quality is determined mainly by the odour, physical state, pH, ammonia nitrogen, volatile acids and lactic acid. It should he of pleasant smell and semi dry in nature. It should be of green colour.

Key Words: Silage, Maize, Lean period, Silo pit, Dry matter, Protein

Silage

Silage is the product from a series of processes by which cut forage of high moisture content is fermented to produce a stable feed which resists further breakdown in anaerobic storage. Silage is as nutritious as green fodders as it preserves the nutrients in the original form and hence it is as good for animal feeding as green fodder itself. One time harvesting of fodder crop for silage making is beneficial, since we can harvest the crop at appropriate time when the crop is nutrient rich. During silage making, the palatability of fodder crop increased as hard stem on fermentation in silage becomes soft, this helps in easy digestion by dairy animals and the anti quality components are either destroyed or lowered during silage fermentation (Chaudhary *et al*, 2012). The fermentation process is governed by microorganism present in fresh herbage or by additives to maintain anaerobic conditions and discourage clostridial growth with minimum loss of nutrients.

Ensiling Process

From a practical view, the three most important things that must occur in order to make good silage are 1) the rapid removal of air, 2) the rapid production of lactic acid that results in a rapid drop in pH, and 3) continued exclusion of air from the silage mass during storage and feed out. Lactic acid producing bacteria (*Lactobacillus plantarum*) present on fresh forage and on silage equipment, are responsible for most of the acid production during fermentation. There is a positive correlation between the number of bacteria present at the time of ensiling and the rate of pH decline (Thomas, 2008). In short, for a rapid and extensive fermentation to occur, the forage must have high concentrations of fermentable carbohydrates, low buffering capacity, relatively low dry matter content (30-40 %) and adequate lactic acid bacteria present prior to ensiling. Certain forage crops such as maize has relatively low buffering capacity and high concentrations of fermentable carbohydrates; therefore, pH decline is rapid and final pH is usually low, approximately 3.5. In general, the pH of silage at the final stage should he within the range of 3.5-4.3 (Roth and Heinrichs, 2001). Because of the biochemical changes involved in silage making, the colour of chlorophyll changes to greenish brown due to a pigment called phaeophytin (a magnesium free derivative of chlorophyll).

After chopping, plant respiration continues for several hours (and perhaps days if silage is poorly packed) and plant enzymes (e.g., proteases) are active until air is used up. Rapid removal of air is important because it prevents the growth of unwanted aerobic bacteria, yeasts, and molds that compete with beneficial bacteria for substrate. If air is not removed quickly, high temperatures and prolonged heating are commonly observed. Air can be eliminated by wilting plant material to recommended dry matters (DM) for the specific crop and storage structure, chopping forage to a correct length, quick packing, good compacting, even distribution of forage in the storage structure, and immediately sealing the silo. When air is removed lactic acid bacteria utilize water-soluble carbohydrates to produce lactic acid, the primary acid, responsible for decreasing the pH in silage. A quick reduction in silage pH will help to limit the breakdown of protein in the silo by inactivating plant proteases. In addition, a rapid decrease in pH will inhibit the growth of undesirable anaerobic microorganisms such as enterobacteria and clostridia. Airtight silos and removal of sufficient silage during feed-out can help to prevent aerobic spoilage due to limitation of yeast.

The dry matter content of the forage can also have major effects on the ensiling process. Proper dry matter in forage should be there so that it can be packed well and more lactic acid is produced. Undesirable bacteria called clostridia tend to thrive in very wet silages and can result in excessive protein degradation, DM loss, and production of toxins. Where weather permits, wilting forage above 30-35% DM prior to ensiling can reduce the incidence of clostridia. Delayed filling of silo pit results in excessive amounts of air trapped in the forage mass can have detrimental effects on the ensiling process. Longer filling time of chaffed fodder in silo might have not maintained anaerobic conditions properly leading to increased aflatoxins in silage (Brar *et al.*, 2017). Wittenberg (2004) also reported that with rapid elimination of oxygen, as the corn herbage enters the silo, is critical for the prevention of storage moulds, as subsequent aeration of silage can cause fungi to proliferate and if conditions are suitable, mycotoxin may be produced. Another factor that can affect the ensiling process is the amount of water-soluble carbohydrates present for good fermentation to take place. WSC decreases and DM losses increased when forage was not immediately packed into silos after chopping.

The end products of silage fermentation are often monitored to assess silage quality and the composition of “normal silages” is presented in Table 1.

Table 1. Common end products of silage fermentation.

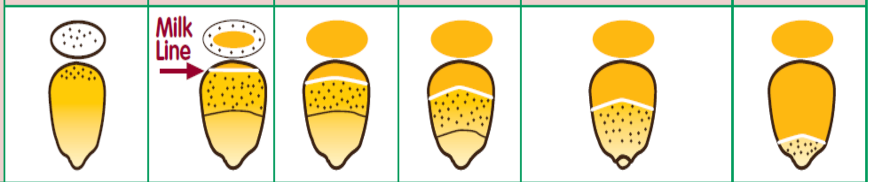
Item	Positive or Negative	Action(s)
pH	+	Low pH inhibits bacterial activity
Lactic acid	+	Inhibits bacterial activity by lowering pH.
Acetic acid	- +	Associated with undesirable fermentations. Inhibits yeasts responsible for aerobic spoilage.
Butyric acid	-	Associated with protein degradation, toxin formation, and large losses of DM and energy.
Ethanol	-	Indicator of undesirable yeast fermentation and high DM losses.
Ammonia	-	High levels indicate excessive protein breakdown

Acid detergent insoluble nitrogen (ADIN)	-	High levels indicate heat-damaged protein and low energy content.

Harvest time of maize for making good quality silage

To prepare best quality silage, maize is preferred because of higher concentration of soluble sugars as sugar is utilized in fermentation process to make lactic acid by microorganisms. Time of harvest has a major impact on the nutritive value of silage. Protein content, available energy, daily nutrient intake and digestibility decrease with advancing crop maturity (Mojumdar and Rakib, 1980), while later cutting represents lower carbohydrate and more lignin. Since dry matter yield per unit area are lowered by early harvest, time of harvest is a compromise between nutritive value and yield. High prices for energy and protein tend to favor early harvest despite of lower dry matter yield. Griffiths *et al*. (2004) used Milk line score (MLS) to determine the proper stage of harvesting of maize crop. The MLS varies from 0 (no visible milk line at the tip of kernel) to 5 (the milk line reaches the base of the kernel and a black or brown layer forms across it). Maize is best suited to be ensiled when the grains are in the milking stage or at 2.5 milk line score (MLS) i.e. the milk line is halfway down the grain, is considered best stage to harvest maize for silage (Fig. 1). Brar *et al*., (2017) reported that, for making of good quality silage, harvest the crop at proper stage, when the nutrient contents are at peak i.e. when the grains are in dent stage or near 2.5 MLS. However, in the recent practice being adopted throughout Punjab, the hard dough stage is utilized as criteria for best quality ensiling of maize.

Figure 1. Right stage for harvesting maize for grain based silage making

Grain description	Milky	Milky doughy	Doughy milky	Doughy	Hard dough, top is hard and glassy	Hard and glassy
						
Milk line	None	Beginning to show from top	¼ way down grain	⅓ way down grain	½ way down grain	At bottom
Husk	Green	Green	Green	Yellowing	Yellowing	Desiccated
Whole plant DM (%)	Less than 25	25-28	28-30	30-32	32-35	Over 35
Status	Not ready	Not ready	Not ready	Ready	Ready	Too late

Some important management practices that will help in making high quality silage are listed in Table 2.

Table: 2. Some good silage management practices

Silage practice	Reasoning
Harvest crop at correct maturity and DM *Maize* : Grains in milk stage (70-75 DAS) 35% DM	1. Optimizes nutritive value (protein, fiber, energy, etc.) 2. In some cases optimizes DM content 3. Ensures good packing, elimination of excess oxygen 4. Minimizes seepage losses 5. Prevents clostridial (butyric acid) fermentation
Check that all equipment which are required for silage making are in good working order	1. Sharpen knives of the chaffer 2. Be sure that silos are free from leaks, breakage and holes.
Chop material to correct length: about 5 to 7 cm	1. Promotes good packing and elimination of oxygen 2. Promotes cud chewing by animals
Wilt and chop during dry weather	1. Prevents extensive DM losses from forage 2. Helps in inhibiting the clostridia bacteria
Harvest, fill, and seal quickly	1. Quick elimination of oxygen reduces DM losses from respiration and prevents growth of undesirable aerobic organisms 2. Sealing minimizes exposure to air 3. Pack to proper density to eliminate air
Allow silage to ferment for at least 45 days	1. Properly ensiled silage will minimize production losses during silage change over

Advantages of silage making: Silage has numerous advantages which are listed as follows:

a) For daily cutting, transporting & chaffing of fodder in traditional way requires more labour and time but in case of silage, fodder cutting, transport, chaffing is done at one time only, so it is cheap and quick practice. Land under fodder can immediately be used for plantation of other crops. So farmers' can grow more crops in same land in a year.
b) Due to lactic acid in silage, it is easily digestible to animals, so energy required for digestion is used for other purposes like milk production etc. An increase in milk yield of HF crossbred cows by 15.47% (on an average) when green fodder was replaced by maize silage was reported by Brar *et al.* (2016).
c) Silage is tasty & flavored, so it increases appetite of dairy animals.

d) Lower field losses particularly of leafy portion which is relatively rich in protein and minerals.
e) Lower probability of rain damage and thus leaching of nutrients
f) Storage over longer period, if properly packed under optimal ensiling conditions
g) Provide more succulent feed to livestock
h) Ideal technology for preserving nutrients in temperate conditions
i) Less dependence over weather conditions, particularly availability of sun lights

Silos and Method of silage making:

Types of silos: The container in which silage is made is of greatest importance and will determine to the large extent the nature and quality of final product. The size of container will generally depends on the number and kind of animals to be fed from it and the length of the feeding period. The different kinds of silo designs are given below.

1. Stacks
2. Clamp silo
3. Pit silo
4. Trench silo
5. Bunker silo
6. Tower silo

The most common silo is the trench silo. One cubic meter space can store 5-6 quintals of green chopped fodder. Generally a trench of 10 m x 4 m x 1.5 m near the cattle shed can store 350-400 quintals of chopped green fodder or one cubic feet pit can accommodate roughly 15 Kg of green fodder. The length and width of trench can vary depending on the number of animals and fodder available for making the silage. The pressing of the material may be carried out manually or mechanically by using a tractor. In case of pressing with tractor, the width of pit should be at least double the width of tractor i.e. 12-15 feet. Depth of pit should be 6-8 feet. Care should be taken that material on the sides and edges are properly compressed. The trench should be high spot so that rain water cannot stagnate near the silo pit. Trench silo has advantages like less air infiltration, less power required for filling the trench, loading and carrying silage is easier. Silo pit should have slanting walls with narrow base and broad opening as such shape helps in maximum exclusion of the air.

The silage is made by 1) Direct cut method 2) Wilting method. Wilting method is preferred over direct cut method which as under:

1. Harvested green fodder should be wilted to 65-70 % moisture.
2. Chop the fodder to make pieces of 2-3 inches so that material is packed well.
3. The walls of the silo pit should be plastered or lined with straw. The chopping should be done near the silo so that the chopping of fodder and filling of silo pit is done simultaneously.
4. Filling should be done in layers of one feet as soon as possible.

5. Pressing of the fodder in the pit should be done regularly to exclude the air.

6. The silo should be filled 1 meter above the ground level and arranged it in the semicircle with dome shaped at top.

7. Cover the pit with one feet thick layer of straw and plaster it with the mud mixed with wheat *bhusa* to make it air tight and protect it from rains. Alternatively plastic sheet can be used to cover the cut forage.

8. Check the filled pit once a week to avoid cracking of the plaster because any crack in the plastered layer will affect the fermentation process. Silage will be ready within 45 days.

9. Open the silo pit from one side only and take out 25-30 kg silage per animal/day for feeding. The remaining silage kept covered stays good till used.

Nutrient losses during ensilage and ways to Reduce Nutrient Losses

Generally loss of dry matter, carotenes, carbohydrate and proteins occur due to respiration, fermentation and aerobic deterioration. The other losses of nutrients arise from field, harvesting and affluent losses. The field losses may occur due to shattering of leaves and other nutritious portions because of poor harvesting managements. The extent of loss in dry matter depends on the time at which the forage is ensiled. Over the period of 48 hours, losses of DM may occur which may be as high as 6.4 percent after 5 days. Loss of carbohydrates and protein also occur due to respiration and proteolysis by plant enzymes. Studies revealed that the loss of nutrients during ensilage was drastically minimized with increasing dry matter content of ensiling material (Honig, 1968; Chaudhary *et al.*, 2014). The fermentation losses chiefly depend upon the moisture content. The clostridial type fermentation is deleterious for most of the nutrients. The clostridia are responsible for the loss of protein. Losses thus are dependent upon pH, moisture content of fodder and type of micro-organism growing during course of fermentation. Forages of low dry matter content (less than 22.9 %) lead to effluent production with a considerable loss of nutrients (Castle and Watson, 1993). After the silo is opened for feeding to livestock, the silage surface is exposed to air and thus leading to aerobic secondary fermentation. During aerobic degradation, the temperature and pH rises while lactic acid content reduces. Loss of DM and nitrogenous substances occur due to escape of volatile fatty acid, lactic acid and ammonia. Loss of nutrients arising out of secondary fermentation could be 0-15 % and could be minimized by management practices such as use of cover, propionic acid etc (Wyss, 2000). The Table 3 below summaries the losses of nutrients during preservation of herbages as silage.

Reduction in the nutritive value of silage fermentation with respiratory losses, silage heating and clostridial fermentation is minimized by limiting air and moisture contact with silage (Bolsen *et al.*, 1996). Minimizing oxygen exposure to silage is essential for obtaining good quality silage. Air allows the respiration process to continue using soluble carbohydrates essential for acid production, which generates heat and increases the temperature. The process of respiration results in loss of valuable dry matter and energy. Air exposure during preservation tends to progress towards mould formation and leading to rottened silage. The increase in the temperature of silage as a result of heating also reduces its palatability when fed to livestock (Pelz and Hoffman, 1997). Uniformly compacted silage and properly sealing aid in air exclusion.

Dry matter concentration of the forages plays a vital role in minimizing the nutrient losses during ensilage. High moisture silage leads to clostridial fermentation, which cause excessive dry matter loss, high butyric acid concentration and lower nutrient intake (Henderson and Mc Donald, l971). Proper stage of harvesting and dry mater content maximizes the nutritive value of silage (Mojumdar and Rekib, 1980; Brar *et al.*, 2017). Chahine *et al*. (2009) reported that 30.0-40.0% dry matter content is optimum for corn silage for better quality and for the production of livestock. Wilting of high moisture forage to 30% dry matter is a safe way, which inhibits the clostridial fermentation. Clostridia bacteria degrade sugars and also convert lactic acid to butyric acid and elevate ammonia concentration and thus causing pH to rise. They also break down protein to amines. Thus, clostridial fermentation has an undesirable effect on the nutrient leading to their decomposition to undesirable end products, dry matter loss and reduced palatability (Nikolic and Jovanovic, 1986).

The heat caused during fermentation plays vital role in preservation of nutrients. Higher temperature silage (100ºF) has been found to be poor in quality. The overheated silage produced at a temperature above 120ºF have been found to be resulting into heat damaged protein having brown to dark brown colour with a tobacco type fowl smell. Protein of heat-damaged silage forms a complex with carbohydrates and is not digestible. The part of protein and energy is not available to livestock and resulting into lower DCP and TDN values (Rodriguez *et al.*, 1985). Higher temperature also increases aerobic spoilage and reduces stability of silage.

Water soluble carbohydrate content of forages constitutes the primary nutrient that is fermented to lactic acid and acetic acid by *Lactobacillus* bacteria to produce a low pH (4.5) and stable silage. Maize, sorghum, oat and other cereal fodders usually have higher soluble sugar concentration and a good stable silage having lactic acid as percent of total acid to the tune of 60 is obtained, while legume forages having low soluble sugar content are not repeated to produce stable and good quality silage chiefly because of low lactic acid production mostly below 3% of dry matter (Singh and Rekib, l986a). Carbohydrates in the forages may be naturally occurring or may be added as a separate ingredient such as molasses obtained as sugar industry by-products (Evers and Carrell, 1998), which act as a fermentable substrate. Relatively more lactic acid is produced from glucose present in the ensiling forage than fructose. Hemi-cellulose after acid hydrolysis produces pentoses, which is then fermented to lactic acid and acetic acid. Besides carbohydrates, the protein content of the ensiling forage plays an important role in determining the quality and feeding value of silage. High CP content in the leguminous forages leads to ammonia production during fermentation leading to rise in pH (5 and above), buffering action and temperature. The high moisture content (more than 75%) causes more protein loss due to proteolysis by clostridia. Nitrates present in the plant are reduced to nitrites which in turn release ammonia (Singh *et al.*, 1983).

Additives for Effective Ensiling of Nutrients

Various types of additives can be used to improve or inhibit the fermentation or supplement nutrients needed by ruminants to be fed as silage. Adding acids such as sulfuric acid, formic acid and other acids decreases the pH of the forage ensiled and helps to preserve it. But corrosiveness of these acids is the limiting factor for their use. Propionic acid reduces aerobic deterioration, heating and mould formation at the top of silage layers. The use of acids has also financial implications for the economic viability of their use. Formaldehyde has been used for effective preservation as it inhibits the fermentation. Addition of formaldehyde @ 5.0 litre per ton of fresh maize fodder has been found to produce good quality silage with higher feeding value when fed to cross-bred calves (Verma and Mojumdar, 1984). Addition of formaldehyde has also been reported to improve the DM1 when fed to ruminants (Barry et al, 1973). Forages with marginal concentration of soluble carbohydrate may benefit from enzymes such as cellulase, pectinase and amylase that can break down complex plant structural carbohydrates such as cellulose, pectin and starch present in forage to simple sugar which then can be fermented to lactic acid. An increase in soluble sugar content resulted in more lactic acid (10%) and lower ammonia- N (less than 6 % of total nitrogen) and pH 4.5 in enzyme treated silage (Van Vauran et al., 1989). Commercial bacterial inoculants have also been used in developed countries which increase the rate of lactic acid fermentation and produce stable silage but such system may not be profitable.

Carbohydrate sources such as mo1asses, whey, yeast and other energy rich ingredients, have also been used as additives to increase the fermentation and feeding value of silage. Most commonly used carbohydrate sources are molasses which is used to add fermentable sugars to forage low in sugar. It can he added 5-10% depending upon the sugar content of ensilage forage. Urea is the most important source of non-protein nitrogen used to elevate CP content of cereal forage silage low in protein. Addition of urea @ 0.5-1.0 % has been found to increase CP content and lactic acid content of silage (Verma *et al.*, 1982, Singh and Rekib, 1986b). Nutritive value, particularly CP content of graminaceous forage silage can be improved by mixing legumes forages such as cowpea, berseem and *Leucaena leucocephala* leaves (Verma and Mojumdar, 1985).

Silage Quality

Silage quality is determined mainly by the odour, physical state, pH, ammonia nitrogen, volatile acids and lactic acid. It should he of pleasant smell and semi dry in nature. It should be of green colour.

There are number of factors which affect the quality of silage i.e. crop used for silage making, variety of crop, stage of harvesting, method of storage and period of ensiling etc. It is very essential to harvest the crop at a proper stage to ensure good yield, quality and ensiling characters of fodder. Farmer's knowledge regarding stage of harvesting of crop for silage making is very important as it determines the moisture content of the crop. Dry matter content of silage is important as it indicates the adequacy of wilting. Forages ensiled below 30% DM will produce effluents which can result in a significant loss of nutrients. On the contrary, when forages are too dry, it is difficult to achieve anaerobic conditions and the silage will be more susceptible to heating and mould growth (Chaudhary *et al*., 2016). Chahine *et al.* (2009) reported that 30.0-40.0% dry matter content is optimum for corn silage for better quality for the production of livestock. Chaudhary *et al*. (2016) observed variable dry matter content (22.0-35.5) of silages prepared from different maize hybrids and composite due to their morphological variation and plant characteristics. Brar *et al.* (2017) also reported the value of dry matter content in silages prepare at farmers field under different management practices between 16.5 to 31.8 %.

Protein content of the silage is very important and its estimation is very essential for sound nutrient management and animal production. A large proportion of the crude protein, often 90% known as degradable protein (RDP). Ruminants need adequate RDP in the diet to sustain normal microbial activity and digestive function in the rumen (Kaiser and Piltz, 2004). A range of 7.0-9.0% crude protein is optimum for corn silage as reported by Chahine *et al*. (2009; Brar *et al.* 2017; Kumar *et al.,* 2016).

Fibre content in forage is also very important. Fibers (measured by NDF, ADF & ADL) are a strong predictor of forage quality, since it is the poorly digested portion of the cell wall. Neutral Detergent Fibre (NDF) values are important in ration formulation for the livestock because they reflect the amount of forage the animal can consume (Kumar *et al*., 2016).). NDF is an inverse predictor of intake (high NDF values low intake of feed and vice versa). The optimum range of NDF in corn silage is 35-55 % (Chahine *et al*., 2009). Acid Detergent Fibre (ADF) values relate to the ability of an animal to digest the forage (Kumar *et al*., 2016). High ADF content is an issue for the same reason as like high NDF content. ADF is negatively correlated to digestibility and energy (Chahine *et al*, 2009; Kumar *et al*., 2016; Chaudhary *et al*., 2016). ADL is non digestible portion of cell wall, having optimum range of 2.8-4.1% in corn silage. Increased fibre content of forage is associated with decreased digestibility and intake, and subsequently lower animal production.

Roth and Heinrichs (2001) reported the optimum range of pH values for corn silages in between 3.5 to 4.3. Kaiser and Piltz (2004) reported that, when dry matter is low, pH values of well preserved silages are usually in the range of 3.5-4.2. They further stated that if the silage pH exceeds these limits, there is a high probability that the silage had been poorly preserved. The preferred lactic acid fermentation will produce silage with a low pH. All forages contain chemical compounds, called buffers which resist changes in pH. There is an increase in risk of poor fermentation when ensiling forages with a high BC (Piltz and Kaiser, 2004).

Ammonia-N (% of total nitrogen) in silage is an important guide to fermentation quality of silage. High ammonia-N is seen in poorly preserved silages and indicates extensive degradation of the forage protein during ensiling process (Kaiser and Piltz, 2004). Wilkinson (1990) reported that silage having ammonia-N (% total silage N) < 5% is excellent, 5-10% is good, 10-15% is moderate and 15< is poor, fermentation quality.

Good quality silage should have

a) pH: 4.5 to 5.0
b) Ammonical nitrogen of total N: less than 10%
c) Lactic acid: Above 3 %
d) Acetic acid: up to 5 %
e) Butyric acid: less than 0. 2%

Voluntary intakes of silage has been a limiting factor and lower than that of green forage (Pachauri and Mojumdar, 1994) which is more prevalent with high moisture silage. The main reason of low intake could he ascribed to low pH and high lactic acid content. Wilting has been reported to increase intake of silage considerably (Singh and Rekib, 1986b). Use of formic acid as additive has been reported to increase intake, body weight gain as well as milk production (Waldo and Derbyshire, 1971). Quality of oat silage was decreased considerably when silage was reused after one year from the once opened silo pit as compared to freshly made silage of oat (Kumar *et al.*, 2009).

Conclusion

Inadequate supply of quality fodder has been identified as one of the reasons for poor livestock productivity. Therefore, there is urgent need for preservation of nutrients from green forages including maize during the flush period for feeding livestock during lean period so that high yielding animals can be sustained for profitable dairy farming. Silage is as nutritious as green fodders as it preserves the nutrients in the original form and hence it is as good for animal feeding as green fodder itself. Out of all non leguminous fodder crops, maize has relatively low buffering capacity and high concentrations of fermentable carbohydrates; therefore, pH decline is rapid and final pH is usually low, approximately 3.5, thus more suitable for silage making. For quality silage, the pH of silage at the final stage should he within the range of 3.5-4.3. At time of harvesting, proper dry matter should be there so that it can be packed well and more lactic acid is produced. It is also very important to fill the silo pit as soon as possible, as delayed filling of silo pit results in excessive amounts of air trapped in the forage mass can have detrimental effects on the ensiling process. The container in which silage is made is of greatest importance and will determine to the large extent the nature and quality of final product. The most common silo used for silage making is the trench silo. In one cubic meter space, we can store 5-6 quintals of green chopped fodder. In process of silage making, the field losses may occur due to shattering of leaves and other nutritious portions because of poor harvesting managements can be avoided by proper planning in advance. Quality of silage is also very important, is determined by mainly the odour, physical state, pH, ammonia nitrogen, volatile acids and lactic acid. It should have pleasant smell, semi dry in nature and should be of green colour.

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Prospects of maize-based ethanol in India in the present scenario

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Need for biofuels

Energy is a very important parameter for the development of a nation. Fossil fuel-based energy is non-sustainable and environmentally unsuitable. Transportation sector is a major consume of energy and producer of Green House Gas (GHG) emissions. Government of India's National Policy on Biofuels envisages the development of sustainable fuel options for the growing Indian economy. India, being deficient in oil resources, needs strategic reserves for better operability. Blending of petroleum with bioethanol for use in transportation can provide a strategic edge to the country. Government of India is actively working to promote biofuels with the twin objectives of energy security and environmental protection. For this purpose, National Policy on Biofuels provides the directives, under which flagship programmes like Ethanol Blended Petrol (EBP) of Ministry of Petroleum and Natural Gas works. In view of the ongoing climate change scenario, every country is trying to reduce GHG emissions, the Intended Nationally Determined Contribution of India aims to decarbonize one-third of its Gross Domestic Product between 2005 and 2030.

Technological options for bioethanol

For the EBP programme, Government of India has the target of achieving 20% blending. Bioethanol can be generated through the use of first generation (1G) and second generation (2G) feedstocks. 1G feedstocks includes sugar-rich substrates like sugarcane, sweet sorghum, sugar beet etc. and starchy crops, among which corn is the main cereal. Corn is the most important and economical source of starch. Starch is the major carbohydrate storage product in maize kernel, comprising of 70-72% of its weight. Starch (a glucan biopolymer) serves as a major reserve of energy, is readily converted into glucose and fermented into ethanol. It is a polymer consisting of two major structural elements, amylose, essentially a linear polymer in which glucose residues are linked by α 1-4 and amylopectin, a branched molecule with α-1-4 and α-1-6 glycosidic links.

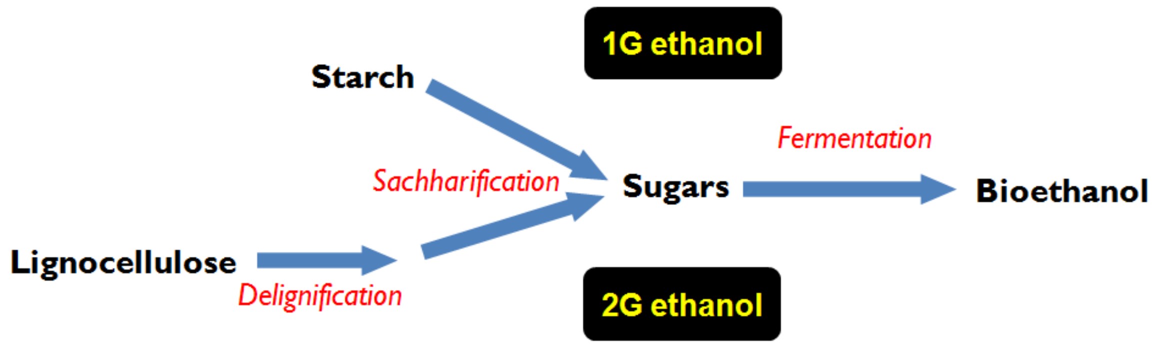

Figure 1. 1G and 2G ethanol technologies differ in the feedstock nature and the steps required for releasing fermentable sugars for ethanol production

2G feedstocks include agricultural residues and municipal solid wastes. Among the agricultural residues, maize lignocellulose is a prominent substrate. It includes maize stover and cobs.

In place of starch, maize stover and cobs contain lignocellulose, where lignin-bound cellulose is first freed of lignin, enzymatic action to convert cellulose to glucose, followed by fermentation to yield ethanol. Although 2G ethanol is desirable, however, the breaking of lignocellulose structure for optimal enzymatic action renders this process technically difficult and economically unviable at present. Government of India has implemented a Viability Gap Funding to promote domestic 2G ethanol production. Apart from this, microalgae can also be used for production of biofuels. However, large scale cultivation of microalgae is challenging due to issues of contamination, hence, they are not being used commercially at present.

By far, 1G ethanol from maize appears to be a very suitable option for upscaling of bioethanol capacity of the country. Instead of relying of rice and sugarcane, both of which are water-guzzling crops, maize provides a better feedstock. The technology for 1G maize ethanol is being upgraded along with advances in distillation technology for higher productivity of ethanol production and processing. Due to its wider suitability in different agro-ecological zones, maize ethanol is not expected to suffer from seasonal cycles of availability, as is the case with sugarcane currently. Efficient utilization of maize in the bioethanol programme is must to meet the blending targets set by the Government.

Status of technology in maize-based ethanol

New technologies are being implemented which are adding values to co-products so as to make it more economical. Internationally a number of new processes have been incorporated in the new phases of research and development. Back-end oil extraction has emerged as a potential option for dry grind ethanol process to improve economic efficiency. The modification of Quick-fiber technologies (Singh *et al.,* 1999), enzymatic milling (Johnston *et al.,* 2003) and the COPE process (Cheryan, 2002) may allow cost-effective removal of co-products such as corn oil, zein, germ, pericarp fiber and endosperm fiber. Singh *et al.* (1999) worked on recovery of fiber in the corn dry-grind ethanol process and concluded that this recovery can reduce the cost of ethanol production by increasing the revenue from these co-products. Improved enzyme formulations are now being introduced commercially. Enogen® maize hybrids have been developed that contain efficient alpha-amylase, eliminating the need to add extraneous amylase enzyme and reducing process costs. In addition to improvements in the feedstock and process technologies, improvements in distillation technology have also been made. A number of hybrid distillation and membrane-based technologies for efficient recovery of bioethanol are in different stages of research and implementation. It is necessary to determine the industrial potential of the newer distillation technologies being developed.

Future perspectives

Variability has been observed with respect to amylose to amylopectin ratio in maize (Hao et al., 2015; Liu et al., 2007). The ratio of amylose to amylopectin and the starch protein matrix of the maize kernel is responsible for varying rate and extent of starch fermentation leading to variability in the fermentation characteristics. A large number of maize hybrids are available for commercial cultivation. Being a cross pollinated crop, a significant variability is observed in the carbohydrate profile of the available maize hybrids. Moreover, the damaged/cut grains, which are least preferred for food and feed purpose, may efficiently be exploited for ethanol production. Maize produce, infested by aflatoxin due to inefficient storage conditions, may also be utilized for ethanol production and thus could fetch a reasonable market price. More work is required for exploring the ethanol production potential of high yielding maize hybrids in light of newer development in the related technologies like availability of improved enzyme formulations and yeast strains. In addition, proper policy interventions to allow integration of diverse technologies towards sustainable production of bioethanol are required to develop it for energy security of the country. Till the development of commercial successes in 2G ethanol technologies, maize-based 1G ethanol represents a viable and one of the most suitable platforms for increasing the biofuel capacity of the nation.

Maize technologies targeting in NEH region

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Maize is one of the most widely grown cereal grains in the world, second only to rice and wheat in terms of production. India is the world's fifth largest maize producer, accounting for 3% of global production, despite productivity being significantly lower (2.60 t ha^{-1}) than global productivity (5.6 t ha^{-1}) and other potential maize-growing countries such as the United States (12.08 t ha^{-1}), Canada (10.33 t ha^{-1}), Australia (8.3 t ha^{-1}), Argentina (8.20 t ha^{-1}) and China (6.55 t ha^{-1}) (FAOSTAT, 2016).The North Eastern Hill (NEH) region of India is comprises of eight states (Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and Assam's hilly tracts) and ~ 18 m ha of land, accounting for 5.47% of the country's total geographical area (329 M ha).Maize is the second most important crop in India's Eastern Himalayan Region (EHR), occupying a significant net cultivated area. The area under maize cultivation in the NEH Region is 0.23 million ha, with a yield of 0.37 million tonnes and a very low productivity of ~1.5 t/ha when compared to the national average productivity*i.e.* 2.6 t/ha (NECS, 2015).The Secondary origin of maize is assumed to be the North Eastern region of India, which has a large number of germplasms. Maize is a vital ingredient in animal, fish, and poultry feeds, and the cost of feed has skyrocketed, therefore its importance is growing by the day.As a result, maize is the EHR's most significant emerging crop. As a result, there is a pressing need to fulfil the farmers' demand for increased output.

Maize cultivation has a vital role in providing food security in the North Eastern Himalayan Region (NEHR), and it is used both for direct consumption and for second cycle products in piggery and poultry farming. The majority of the land in the NEHR is made up of terrace and sloppy lands, with low land productivity and resource use efficiency (water and nutrient productivity; other resources and energy efficiency). Rainfed agriculture is possible in the diverse and complicated climate of the North Eastern Himalayan Region (NEHR), which differs in crop phenology from the rest of the country. The resource use efficiency vs. productivity can be evaluated to the utmost with the increasing evidence of reduced seasonal rainfall, terminal heat, frequent occurrence of extreme weather events, and intensive rainfall pattern over the region. Successful maize production, on the other hand, necessitates the use of appropriate technology and the precise application of production inputs in order to protect the environment as well as agricultural productivity. The success and profitability of maize farming are determined by the technology used (Ansari et al., 2016; 2017). Better spatial and temporal management strategies have the potential to create 2 to 3 times greater productivity than farmers' practices. As a result, it is clear that pulses have the potential to be a significant to accommodate with maize either in as intercrop or sequential crops in a system. Therefore, environmentally sustainable maize-based technologies are important in maintaining soil quality and improving the productivity along with farm income. The ICAR-Research Complex for

NEH region implemented a pilot project in collaboration with ICAR-Indian Institute of Maize Research, Ludhiana under NEH fund of the ICAR-IIMR, sanctioned by ICAR on “Promoting Improved Technology of Maize in NEH region”. The programme was started in 2015-16 in Manipur in collaboration with ICAR-Indian Institute of Maize Research, Ludhiana with objectives to developed location specific technology, participatory dissemination of technology and strengthening of awareness among farming community through capacity building programme. After successful achievement in Manipur, this programme was extended in other North east states like Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura in collaboration with regional stations of ICAR NEH in respective states in 2018-19. Many researchers along with us have popularized and recommended following maize based technologies in north Eastern region.

Introduction of high yielding varieties

Ansari et al. (2016) studied the performance of maize genotype in Manipur during 2012- 2013. They have reported that the mean maize grain yield varied from 2081kg ha^{-1} to as high as 5022kg ha^{-1}. They have also found that the Vivek QPM-9 followed by Prakash recorded the highest grain yield while Chakhaochujak (hill) recorded the lowest grain yield. Similar to grain yield, oil and starch yields were also maximum in Vivek QPM-9 followed by Prakash while protein yield was maximum in HM-4 and Prakash followed by Vivek QPM-9. The minimum grain yield, oil yield, protein yield and starch yield were found in Chakhaochujak (hill), Chakhaochujak (plain) and Vijay composite (Ansari et al., 2018).

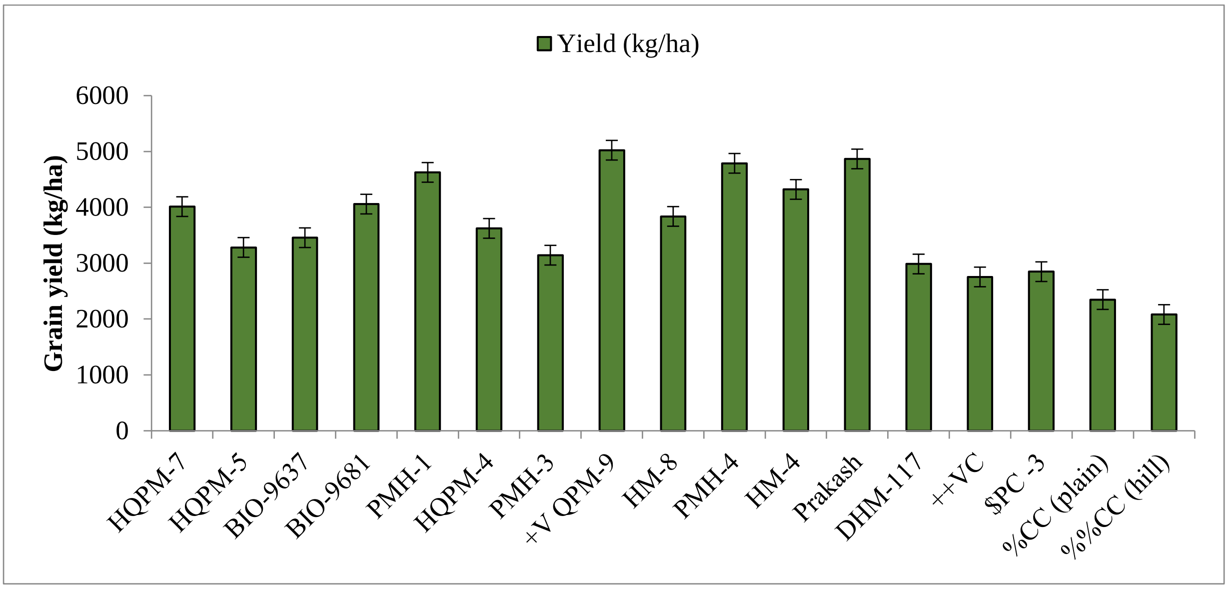

Figure 1. Evaluation of maize genotypes and their performance in Manipur.
Vertical bar represents significant level at 5%. $^{+}$V QPM-9= Vivek QPM-9; $^{++}$VC= Vijay composite; $^{\$}$PC -3= Pusa composite-3; $^{\%}$CC (plain)= Chakhaochujak (plain), $^{\%\%}$CC (hill)= Chakhaochujak (hill)

Similarly, they Ansari et al., (2017) reported that the temperature plays important role in production. They recorded the highest and significant ($p<0.05$) HUE was in Prakash followed by Vivek QPM-9 in. The lowest HUE was found in Chakhaochujak (hill). Temperature influences plant growth and development including emergence, flowering and maturity (Liu et al., 2010). The maximum heat units in the long duration genotypes were largely due to the longer duration of the reproductive phase. The heat units required for seedling emergence were almost same at different sowing dates. The duration from seedling emergence to maturity increased conspicuously and therefore, the heat units showed a marked increase under the higher duration genotypes. The heat use efficiency is the proportion of grain yield and GDD. With the increase in GDD, the grain yield should also increase for maximization of economical harvest. Increase in HUE enhanced the maximum utilization of solar radiation across maize genotypes (Ansari et al., 2017). Further, heat use efficiency is positively and significantly correlated with LAD in 2012.

Upscaling of high yielding varieties under participatory demonstration

Supportive technology demonstrationwas conducted over1283 ha area with 3324 farmer beneficiaries up to 2018-19 (Ansari et al., 2019b, Das et al., 2019). The front-line demonstrations (FLDs) emphasized on quality protein maize production, crop diversification i.e. intercropping (with groundnut, pea, rice bean, frenchbean etc.),row planting, crop rotation, soil liming and integrated nutrient/water management etc against the farmers' practice (FP).The yield gap varied from 32.7 % (at Tripura) to as high as 96.3% (at Nagaland), with an average yield gap of 57.4% in NEH region (Figure 1) (Ansari et al., 2019b).The result indicatedthesubstantial possibility for the maize production enhancement with available crop production technologies across the least explored North East Indian hills.

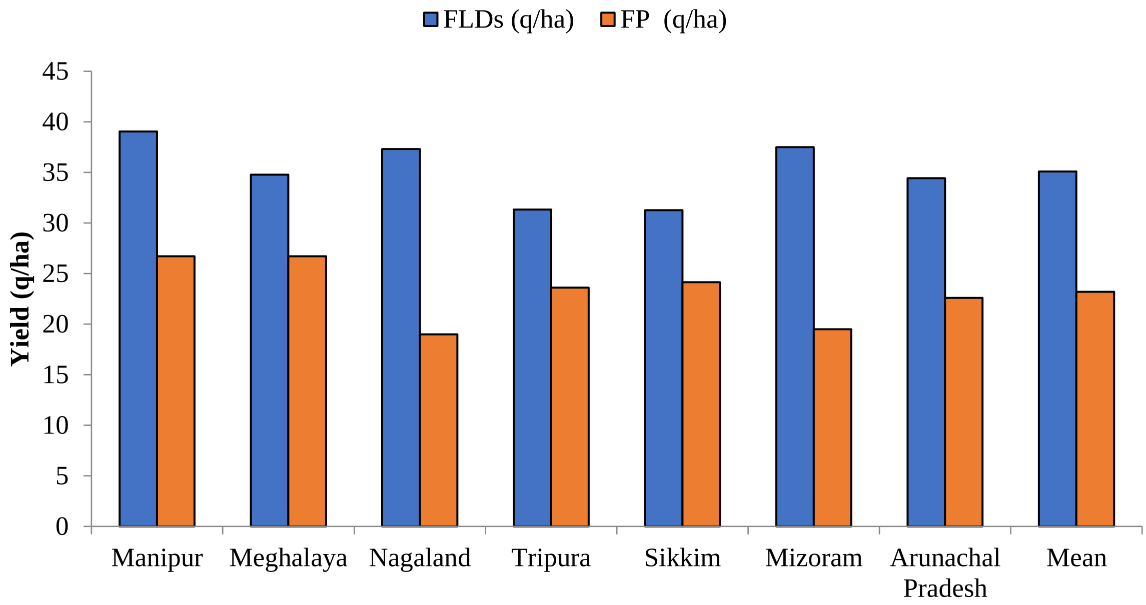

Figure 2. Maize yield gaps assessed across the seven north eastern hill states of India

We have also created awareness of suitable technologies for crop and soil management. In 2019, the sudden and first-time attack of fall army warm (FAW) created panic among the maize growers in north east India, particularly at Mizoram and Manipur. Real time support from the collaborative efforts from the scientists working at ICAR Research Complex for NEH Region, ICAR-Indian Institute of Maize Research (IIMR), Ludhiana and National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru was provided to the respective State

Governments for extensive sensitization and supportive awareness development on FAW infestation in maize over the seven North East Indian Hill States. State level workshop/brainstorming session/awareness/officials trainings and farmer-scientist interactions on FAW management were organized with the line department officials for the farmers and other stakeholders under the ongoing collaborative project of ICAR NEH and ICAR-IIMR with other associated partners (Technical expertise from Central Integrated Pest Management Centre (CIPMC), Imphal and Directorate of Plant Protection, Quarantine & Storage (PPQS, Faridabad) and the respective State Governments in all the seven north east Indian states. Total 1897 officers/progressive farmers were trained across the NEH states. 23 numbers of national/state/district level workshop/brainstorming session/awareness campaigns on Fall Armyworm management in maize (Ansari et al., 2020).

Diversification through sequential cropping system

Maize-Sweet corn-pea cropping system: ICAR Research complex for NEH Region, Manipur Centre conducted an experiment on maize based cropping system (Maize-Sweet corn-pea) with 300% cropping intensity under agrotextiles based ground cover and open field. We have observed that 60, 34 and 36 percent higher yield of maize, sweet corn and pea under ground cover crop than open field, respectively. The system productivity in terms of maize was recorded 15.2 tonnes/ha in ground cover as compared to10.7 tonnes/ha under open field. Under ground cover higher water use efficiency and very less weed infestation were recorded as compared to open field (Ansari et al., 2019a).

Maize- vegetable pea cropping system: ICAR Research complex for NEH Region, Manipur Centre demonstrated and up scale the maize- vegetable pea cropping system in collaboration with ICAR-IIMR, PAU Punjab, at farmers field and farmers yield varied from 8 to 11 t/ha in terms of maize equivalent yield as compared to sole cropping (3.5 to 4.0 t/ha).

Maize- rapeseed and mustard cropping system: ICAR Research complex for NEH Region, demonstrated the maize- rapeseed and mustard cropping system in collaboration with ICAR-IIMR, PAU Punjab, at farmers field and farmers yield varied from 7 to 10 t/ha in terms of maize equivalent yield (Saha et al., 2019).

Diversification through vertical intensification

In intercropping, the crops are arranged in definite rows. Sowing of both crops may be done simultaneously or in staggered manner. Similarly harvesting time may also differ. Intercropping is an improved system of mixed cropping which ensures desired plant stand, ease in cultural operation, spraying of chemicals and harvesting, and higher returns. The major considerations for intercropping are the contrasting maturities, growth rhythm, height and rooting pattern and variable insect pest and disease associated with component crops so that these complement each other rather than compete for the resources and guard against weather adversities. Growing of crops in intercropping systems is found more productive particularly under rainfed conditions. More than 70% area of pulses in India is covered under intercropping systems. Pulses are intercropped with oilseeds, cereals, coarse grains and commercial crops. Maize is the most suitable crops to intercrops with pulses and oilseeds. Intercropping of pulses with maize is more popular in terrace cultivation and mixed cropping of pulses with rice/maize is more popular in jhum cultivated areas of Manipur. Maize + rice bean, Maize + soybean, Maize + Urdbean/Mungbean and are more remunerative in Kharif season.

ICAR Research complex for NEH Region, Manipur Centre demonstrated the maize based intercropping system on farmer's field in various districts of Manipur. Among the various maize based cropping system, on an average maximum maize equivalent yield was found in Maize + groundnut (R) (6.33 t/ha) followed by Maize + Soybean (A) than Maize sole cropping (3.4 t/ha) (Figure 2). Maize + Groundnut (A), Maize + Greengram (A), Maize + Urdbean (A), Maize + Rajma (R), and Maize + Ricebean (R) were fetched higher economic returns as compared to sole cropping of maize. Based on MSP fixed by Govt. of India, across the targeted area farmers earned net returns from Rs 25410 to 60555ha^{-1} from HYVs (After deducting the cost of cultivation) as compared to farmers grown local genotype Chaochujak (1.9 tha^{-1}).

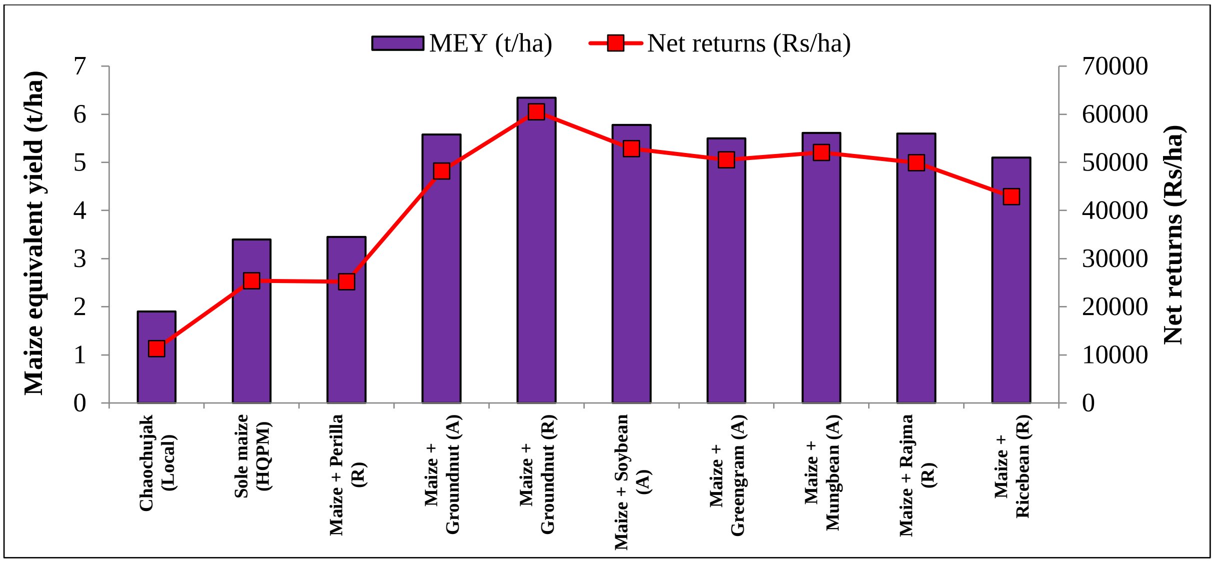

Figure 2. System productivity under various maize based intercropping

Improvement of soil quality through conservation agriculture

ICAR Research complex for NEH Region, Manipur Centre conducted an experiment under collaborative project with ICAR-IIMR, PUA Campus, Ludhiana of "Promoting improved technology of maize production in NEH Region" on maize based cropping system (Maize (QPM-1)-baby corn/sweet corn- vegetable pea) at ICAR Lamphel with 300% cropping intensity and recorded more than up to 24 t/ha maize equivalent yield due to intervention of soil and crop management. The residues were recycled under conservation agriculture, which have improved the soil quality indicators and enhanced the crop yields as compared to traditional practices.

Biomass recycling to restore the soil health

In an experiment of biomass recycling with green gram (*Vigna radiata*), cowpea (*Vigna unguiculata*), sesbania (*Sesbania aculeata*) along with recycling of crops taken under cropping system (maize + groundnut–pea, maize-pea and maize-groundnut), Ansari et al. (2022) reported that the green manuring along with residues recycling enhanced the system productivity and stabilized soil quality. They have reported that the system productivity expressed in terms of maize equivalent yield (MEY) varied from 10.2 to 14.2 Mg ha^{-1} across treatment combinations and the green manure significantly (p<0.05) increased the MEY. Among them, *Sesbania* incorporated plots produced the highest system productivity (MEY: 13.5 Mg ha^{-1}) followed by cowpea and green gram, respectively. Similarly, intercropping of maize+ groundnut -pea produced the highest MEY (14.2 Mg ha^{-1}) followed by groundnut-pea and lastly, the maize-pea system (10.2 Mg ha^{-1}). Residue retention treatment had 11% higher (p<0.05) system productivity compared to residue removed plots (MEY: 11.7 Mg ha^{-1}). They have confirmed that green manure with Sesbania and retention of crop residues in the maize-based inter-cropping with legume (maize + groundnut–pea) system could able to enhance the system productivity in the low-productive hill agriculture. Incorporation of legumes as green manures, especially *Sesbania aculeata* considerably improved key soil quality properties like microbial biomass carbon, labile carbon, nutrient availability (nitrogen, phosphorus, and potash),and soil aggregations. Crop residue retention additionally improved carbon inputs, particularly the total organic carbon stock, which facilitated crop intensification and improved the system productivity. Therefore, legume green manure like Sesbania in maize + groundnut –pea cropping system with crop residue retention is recommended to enhance the crop intensification, soil quality, and system productivity in single-crop maize fallow system in the Eastern Himalaya region and other similar agro-ecosystems.

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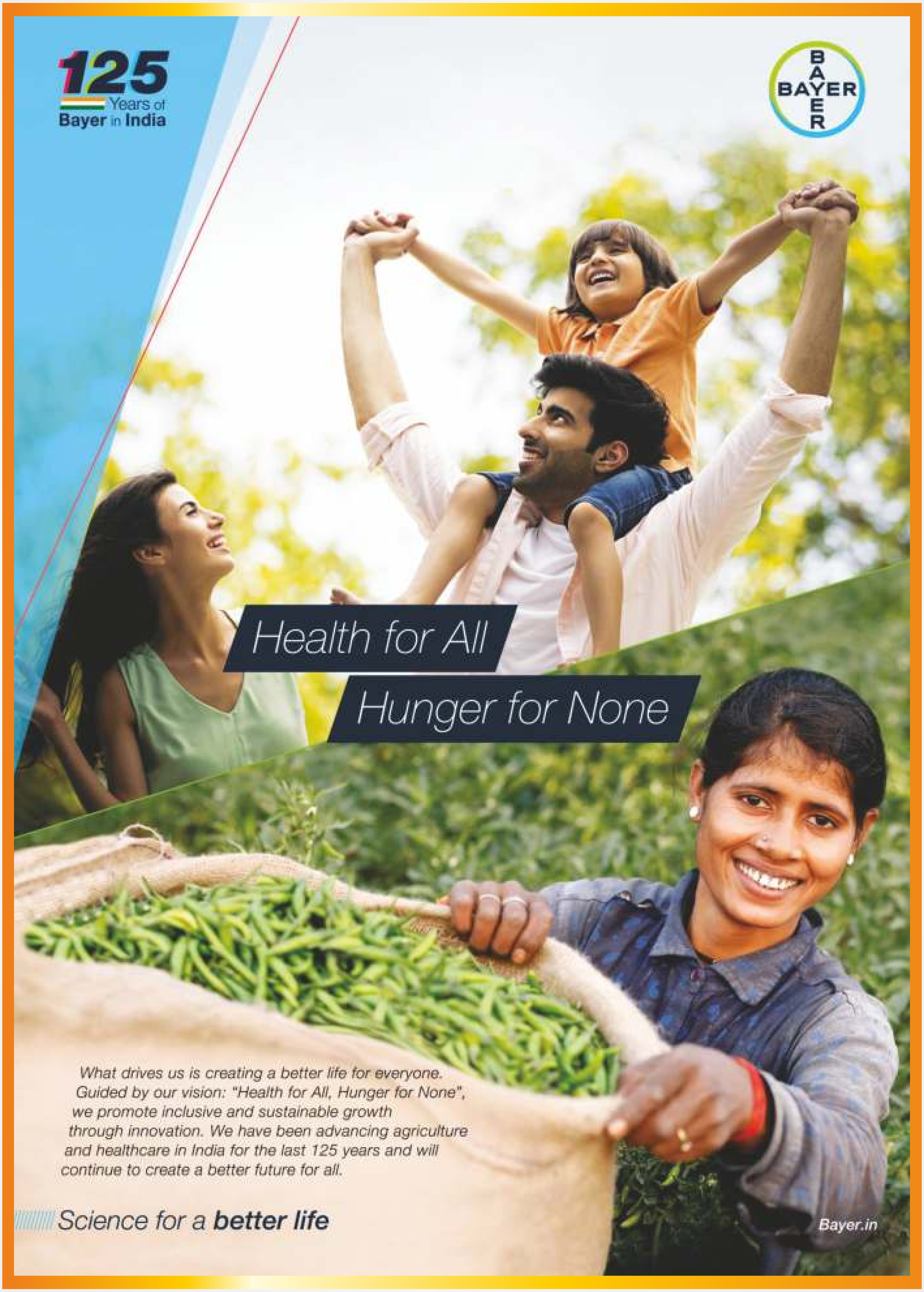
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Climate Resilient Agriculture (CRA) Programme

The *"Climate Resilient Agriculture (CRA) Programme"* was a combined approach of Bihar Agricultural University (BAU), Sabour, Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa-Samastipur, ICAR-Research Complex for Eastern Region (ICAR-RCER), Patna along with nodal organization at Borlaug Institute for South Asia (BISA) as a follow-up of the instructions of the **Hon'ble chief minister of Bihar, Shree Nitish Kumar ji**, for preparing a workable plan to cope up with current future climatic risks and demonstrate climate resilient technologies in all districts of Bihar, to provide climate resilient science based solutions to the hard working farmers of Bihar.

Project Goal

To develop and introduce evidence-based response strategies for addressing the principal climate-based threats to the productivity and resilience of staple crop production systems in Bihar.

Project Objectives

To achieve the project goal, climate resilient agriculture (CRA) programme, new futuristic cropping system (crop cycle) relevant to needs of resource poor farmers that can address climatic risks is to develop, validated and deployed through a community-led approach to make farming relevant, remunerative, and stable. The engagement model is being working around principles of convergence with multi-stakeholder, multi-disciplinary, and multi-institute teams contributing to innovation and knowledge generation.

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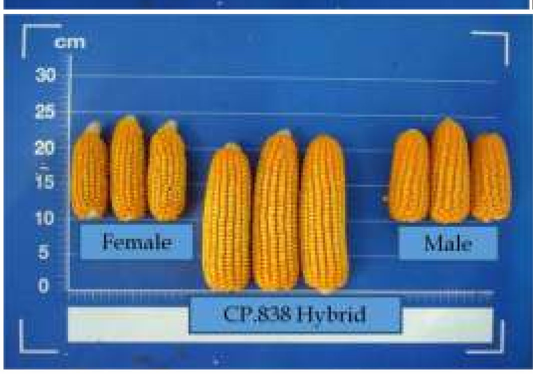

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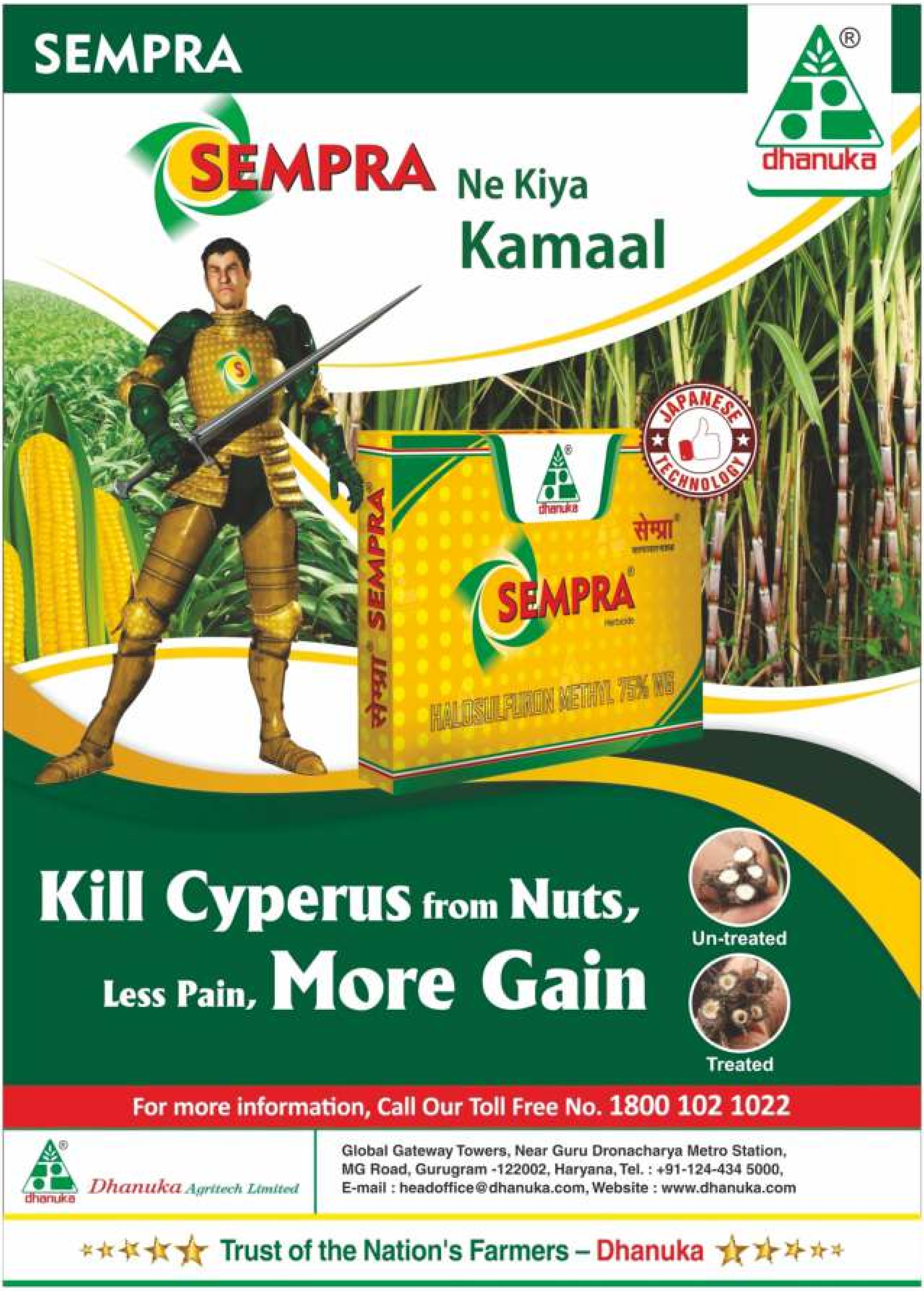

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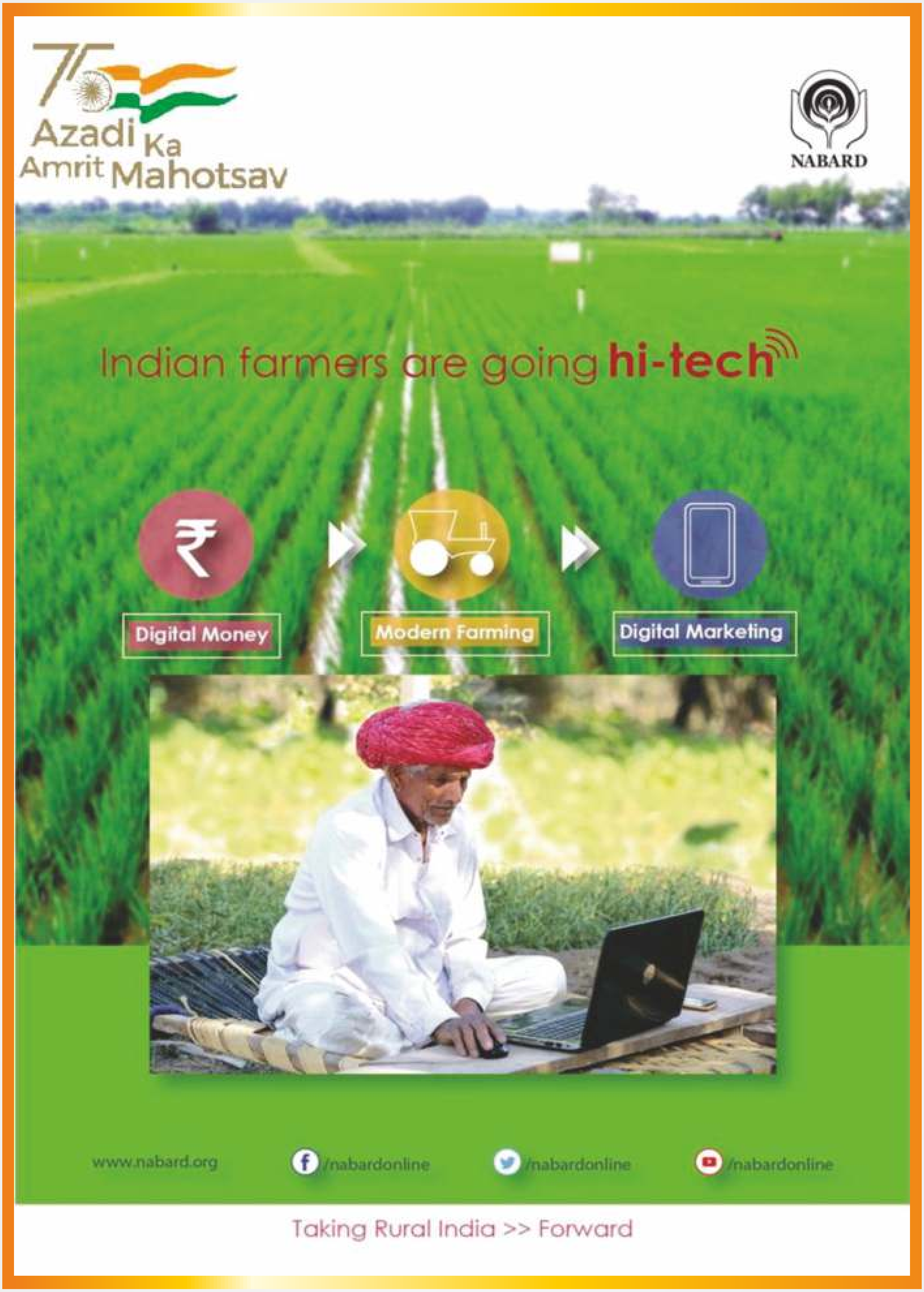
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