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19

Maize for Bioethanol Production in India: Prospects and Strategy

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Preface

The present focus of the Government of India (GOI) is on the use of renewable energy, especially on the production of bioethanol from various sources under National Biofuel Policy. The target set by the Government to achieve ethanol blended petrol of 20% by 2025-26 and 30% by 2030 are strategic and forward looking for making self-reliant and energy secure nation. The GOI have incentivised pan India set up of both grain and dual feed-based bioethanol plants under interest subvention scheme to use agri-commodities for local production and local consumption in realizing energy efficient biofuel chains in the country.

Among the various sources *viz*., sugarcane, maize, broken rice, etc. being increasingly considered for bioethanol production, maize is considered an important source as it not only requires less water and emits less greenhouse gases, but also has pan India presence, which helps in the reduction of transportation cost of bioethanol from one place to another. It is envisaged that 18-20 million tonnes extra maize would be required to meet the additional requirement for bioethanol production in the country.

This strategy paper is the outcome of a brainstorming session (BSS) and provides an in depth analysis of the current status, prospects, and future directions for bioethanol production to address the energy security in India. During BSS, a roadmap was envisaged in association with all stakeholders to achieve the higher maize production to meet out the demand through increased area and productivity from different agro-ecologies. I believe that the maize will emerge as a miracle crop in meeting the energy demand of the country and boost the economy of the farmers as well as the industry.

On behalf of the Academy, I appreciate the efforts of Dr. H.S. Jat for convening BSS and bringing out its recommendations in the form of this strategy paper. My sincere appreciation to the Editors, Dr. V.K. Baranwal & Dr. R.K. Jain and Dr. Ashok K. Singh (Secretary) for their dedicated efforts in bringing this strategy paper to fruition. I trust this publication will help in shaping appropriate policy agenda to encourage maize for continuous bioethanol production.

November 2024
New Delhi

(Himanshu Pathak)
President, NAAS

Maize for Bioethanol Production in India: Prospects and Strategy

1. BACKGROUND

Ethanol's journey in India began in 1938 with recommendations for molasses conversion to alcohol, leading to the establishment of 1948 Power Alcohol Act. The Ethanol Blending Programme (EBP) launched in 2003 mandated 5% blending (E5), but faced supply shortages in 2004-2005, making the blending optional. The importance of biofuel regained in India especially after the announcement of National Biofuel Policy (NBP), 2018. The potential feedstocks envisaged for ethanol production in this policy were sugarcane related feedstock (B-Molasses, sugarcane juice), agriculture residues (rice straw, cotton stalk, maize cobs, saw dust, bagasse, etc.), biomass (grasses, algae, sea weeds, etc.), sugar containing materials (sugar beet, sweet sorghum, etc.), starch containing materials (maize grains, cassava, rotten potatoes, etc.), damaged foodgrains (DFG) unfit for human consumption (wheat, broken rice, etc.) and foodgrains during surplus phase.

Biofuels have gained importance in both the developed and developing economies. During 2023, the USA was on top with 15,550 million gallons followed by Brazil with 8,260 million gallons of biofuels production. In 2023, India ranked third worldwide with 1430 million gallons bioethanol production and achieved E11.7 during 2022–2023. The E11.7 was contributed from various feedstocks such as sugarcane juice (5%), cane molasses (5%), and DFG (1.7%). Traditionally, ethanol production in India has been largely dependent on sugarcane molasses. The NBP 2018 was aimed to promote the use of biofuels in India to reduce dependence on fossil fuels, mitigate greenhouse gas emissions, and enhance energy security. Recognizing the significant progress made in the ethanol fuel blending initiative to promote green transition and *Atmanirbhar Bharat*, the government revised the target to E20 to be accomplished by 2025–26, and set a target of E30 by 2030.

India is the world’s third largest energy consuming economy, but largely dependent on imported oil, which poses significant issues for economic and strategic sustainability. Further, India’s share in global energy consumption will be doubled by 2050. Domestically produced ethanol is a potential way to reduce reliance on imported oil. India started blending ethanol in petrol on a pilot basis in 2001. One crore litres of ethanol blended petrol production and consumption have the relative advantage of reducing 8000-17000 tonnes CO_2 emissions over fossils fuel. A total of 38 crore liters of ethanol was purchased for blending with petrol in 2013-14; this increased to 567 crore liters in Ethanol Supply Year (ESY) 2022-23, reaching E11.7. Government of India (GOI) incentives have led to the establishment of grain or dual distilleries across the country. These initiatives envisage boosting of the agricultural economy, reduced reliance on imported fossil fuel, saving of the foreign exchange used in crude oil import and reduce air pollution.

Regarding global fuel ethanol consumption (GFEC), it is projected to increase significantly in the coming years. This is expected to rise by 750 million gallons from 2018 to 2030, which represents 5.7% increment. Additionally, from 2021 to 2030, consumption is anticipated to increase by 950 million gallons, marking a 7.4% rise. It is primarily due to a heightened demand of 234, 276, and 347 million gallons in India, Brazil, and China, respectively during the projected period. At the country level, the consumption of fuel ethanol is mainly determined by the size of the motor gasoline market and the extent to which ethanol is blended within that market. Grains such as maize, broken rice, and other cereals are now being increasingly considered for ethanol production. The government has set up policies and incentives to promote grain-based ethanol production, aiming to reduce dependency on sugarcane. To meet the projected requirement of approximately 1,016 crore liters of ethanol by 2025-26, India is shifting its focus from predominantly sugarcane-based ethanol to increasing the share of grain-based ethanol (Table 1).

Table 1: Realized and projected sugarcane/grain ratio per year

Ethanol Supply Year	Realized				Projected			
	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26
Sugarcane/ grain ratio	95/5	91/9	86/14	83/17	73/27	63/37	55/45	50/50

Source: NITI Aayog, 2021

1.1 Current grain-based distilleries in India

India is witnessing a surge in the establishment of grain-based distilleries, driven by the increasing demand for ethanol (Fig. 1). The pan India presence of the distilleries emphasizes local production and consumption towards transportation cost reduction (Fig. 2). The interest subvention scheme by the GOI aims to support the establishment of distilleries, thereby contributing the country's biofuel targets and reducing reliance on fossil fuels. The current capacity of grain distilleries in the country is 258 crore litres annually and India is heading to have over 150 grain-based distilleries with an installed capacity of 840 crore litres ethanol per year, which would require 16 million tonnes (Mt) of grains annually. This expansion will support the country's biofuel initiatives, aiming to reduce dependence on fossil fuels and enhance energy security. The rapid expansion of grain-based distilleries in India is poised to enhance ethanol supply, promoting energy

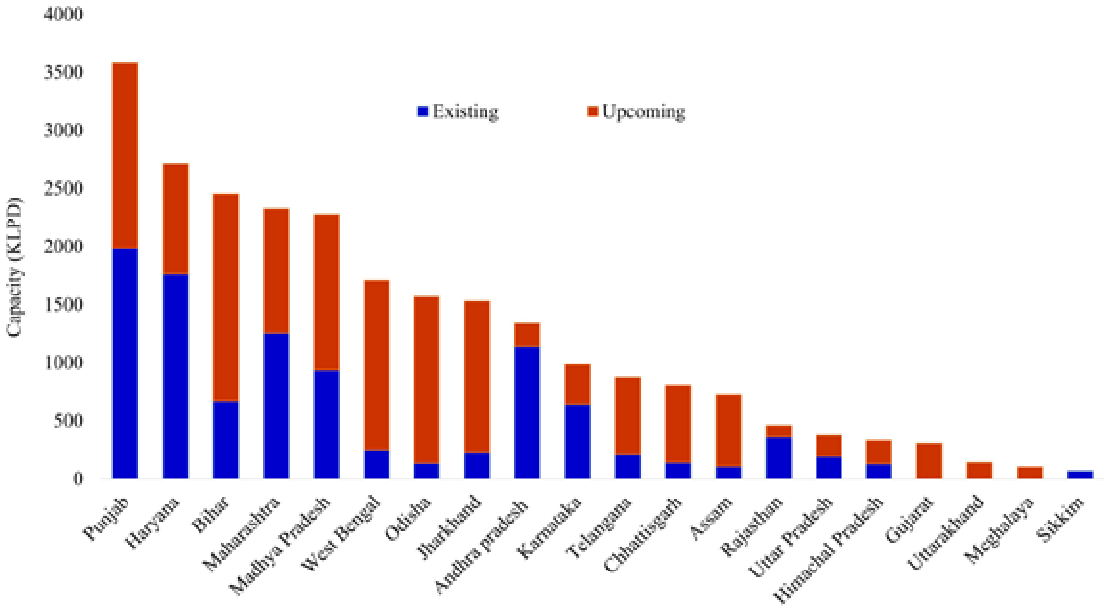

Fig. 1. Existing and upcoming dual/grain-based distilleries in India

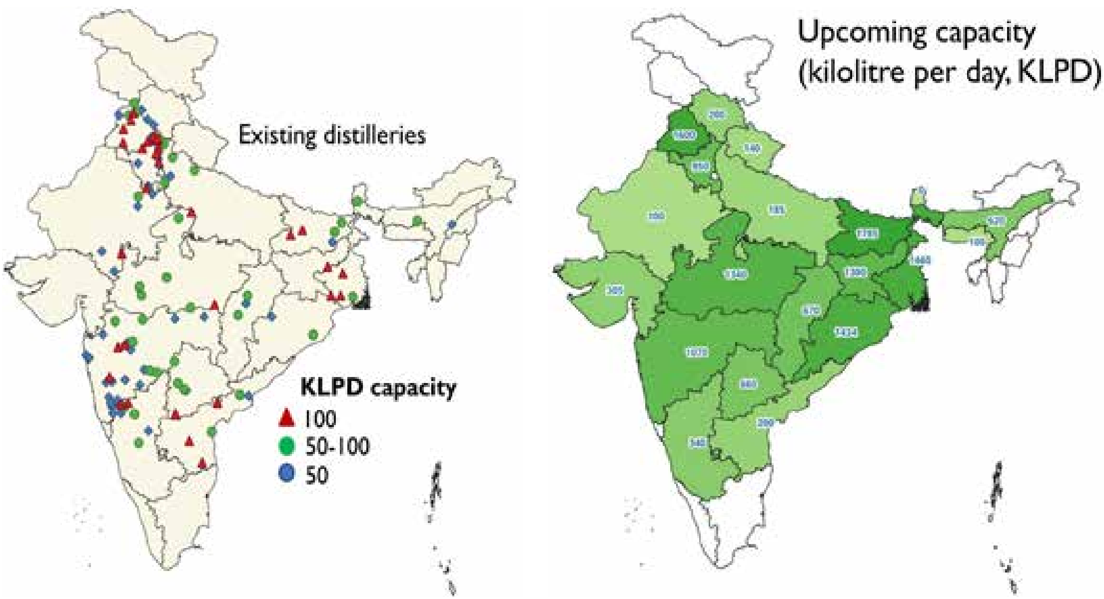

Fig. 2. Location of existing (up to December 2023) and upcoming dual/grain-based distilleries in India

security and agricultural diversification. These distilleries are designed to use grain-based feedstocks like DFG, maize, etc. to produce ethanol. Thus, these industries will play a crucial role in meeting the nation's renewable energy goals and enhancing farm profitability.

1.2 Feedstocks for bioethanol production

The ethanol production process uses yeast to ferment the starch and sugars in the sugar crops (sugarcane and sugar beet), cereal grains (rice, maize, wheat, sorghum, barley and rye) and biomass (crop residue, biomass, sweet sorghum, etc.). Sugarcane, sugar beet and their industrial by-products of these industries are the most common feedstocks used to make fuel ethanol in countries such as Brazil. The suitability of raw materials for ethanol production depends on several factors such as availability and cost, type and quantity/quality of by-products, storage, handling & transportation cost, technology availability, processing cost and sustainability. Considering these factors, the USA is a leading ethanol producer in the world using maize as a primary feedstock.

In India during ESY 2022-23, sugarcane molasses produced 50% while 25% each was contributed by sugarcane juice and DFG. However, the alarm of low sugar production in 2023-24 raised sustainability issues of ethanol from sugarcane juice. In addition, use of DFGs mainly broken rice for bioethanol production also has very limited potential owing to multiple issues, such as its availability linked to food security, high price, water crisis and future environmental issues. The initiatives for use of broken rice in folic acid fortification programme will make its availability further skewed in coming years. Presently 83% ethanol used in EBP is met through sugarcane which is to be reduced to 50% by 2025-26 by enhancing contribution of the grain-based ethanol. This has led to search for a suitable alternative for the bioethanol production for futuristic EBP. The NITI Aayog estimated that sugarcane and paddy together use 70% of the country’s irrigation water; hence, there is a need for change in crop pattern to reduce dependence on one particular crop and to make ethanol production more environmentally sustainable. Cereals, particularly maize with suitable technological innovations offer promise of a more environmentally benign alternative feedstock for ethanol production. In India, EBP has been implemented in phases. Taking into account the E20 target of the GOI, 8-9 Mt of maize will be needed for bioethanol by 2025-26, and 18-20 Mt for E30 by 2030. Currently, maize production in the country is growing at a rate of 6%, which is higher than that of rice and wheat. With a stable market and good prices for maize, the area, production, and productivity of maize are expected to increase significantly in the future. Furthermore, maize in India is being used as feed (poultry-47%, animal-13%), starch and export (18%), direct food (13%), and processed food (7%). Due to its >85% uses for industrial purposes, the production is increasing @ 6%

annual growth rate (AGR) during the last five years and touched 38.0 Mt in 2022-23. Maize being grown in multiple seasons (*kharif* / *rabi* / spring) and across regions in India, has high yield potential amongst the cereal and can be a potential crop to fulfil the requirement of biofuel.

1.3 Maize-to-bioethanol: comparison of maize *vs* other feedstocks

Bioethanol production from maize in India presents an excellent opportunity to enhance the country's energy security and support rural economy while addressing environmental concerns. Maize, with its high starch content and abundant availability, serves as an efficient and cost-effective feedstock for ethanol production. India produces approximately 36-38 Mt of maize annually, with major contributions from states like Karnataka, Andhra Pradesh, and Maharashtra. This ample production through high yields and sustainable practices, careful planning and prioritization, government policies and incentives, market prices, and coupled with the ability to grow maize multiple times in a year, ensures a steady and reliable supply for ethanol manufacturing.

In addition, utilizing maize for ethanol production not only stabilizes farmers' income by creating consistent demand but also generates employment opportunities across agriculture, logistics, and production sectors. Environmentally, maize-based ethanol reduces greenhouse gas emissions and requires much less water compared to other feedstocks like sugarcane and rice, making it a more sustainable option. Maize, therefore, could be a preferred choice for bioethanol production in India owing to the following advantages:

1.3.1 Rising ethanol production and impact on sugar availability: Increased ethanol production, particularly from sugarcane, can divert resources from sugar production to ethanol. This can lead to reduced sugar availability for domestic and export markets, potentially affecting sugar prices (UNICA, 2020). Conversely, it can stabilize ethanol prices and provide farmers with an alternative revenue stream (OECD-FAO Agricultural Outlook, 2021).

1.3.2 Climate-resilient varieties with high yield potential: Climate-resilient maize varieties are bred to withstand stress conditions such as drought, heat, and diseases and insect-pests (Prasanna *et al*., 2021). These resilient varieties support sustainable farming practices by reducing the need for inputs like water and pesticides, further lowering the environmental impact of maize cultivation. Accelerated breeding and development of such high-yielding and flood/drought-tolerant crop varieties/hybrids can significantly enhance the yield potential of maize, especially in the stress-prone rainfed tropical environments (Prasanna *et al*., 2021; CIMMYT, 2024). Therefore, area under hybrid maize should be increased over composites.

1.3.3 Waxy Corn v/s Normal Field Corn: Waxy corn has been reported to possess higher conversion efficiency (93%) from starch to bioethanol as compared to normal corn (88.2%) (Yangcheng *et al*., 2013). Therefore, a program on maize breeding for developing waxy corn hybrids with higher amylopectin/easily degradable starch should be launched.

1.3.4 Scope for enhanced production: Through the adoption of modern agricultural practices, such as precision farming, integrated pest management, and use of high-yielding and climate-resilient crop varieties, the average yield of crops used for ethanol production can be significantly increased (Gebbers and Adamchuk, 2010). Expanding the acreage dedicated to ethanol feedstock crops, particularly on marginal and underutilized lands, can help meet the rising demand for ethanol without compromising food production. Policies supporting land optimization and sustainable farming practices are crucial in this regard (Tilman *et al*., 2006).

1.3.5 Lesser water and environmental footprint: Crops like maize, used for ethanol production, generally require less water than sugarcane and rice. This makes maize a more sustainable option, with a lower environmental footprint regarding water usage and land degradation (Hoekstra and Chapagain, 2007). Ethanol production from maize and other low-water crops results in lower greenhouse gas emissions and better soil health management, contributing to a more sustainable agricultural ecosystem (Maga *et al*., 2019).

1.3.6 Increased cropping intensity, round the year industry functioning and food security independence: Many parts of India have favourable climatic conditions that allow for multiple cropping cycles per year. This can enhance the availability of ethanol feedstocks and improve overall agricultural productivity (Azad *et al*., 2024).The ethanol industry can function year-round, providing consistent economic activity and employment. This is feasible with proper planning and use of various feedstocks available in different seasons, ensuring a stable supply of raw materials (Renewable Fuels Association, 2021).This approach ensures that food production remains independent and unaffected by the increasing demand for ethanol (Bentivoglio and Rasetti, 2015).

1.3.7 Reduced transport cost for oil marketing companies (OMCs): Locally produced ethanol reduces the need for long-distance transportation, cutting down on logistics costs and emissions. This benefits OMCs by providing a cost-effective and environmentally friendly fuel alternative (IEA Bioenergy, 2019).

1.3.8 By-Product for feed industry: Distiller's Dried Grains with Solubles (DDGS), a by-product of ethanol production, is rich in protein and energy, making it an excellent animal feed component. This not only adds value to the ethanol production process but also supports the livestock industry (RFA, 2021). Utilizing DDGS as animal feed reduces waste and lowers feed costs for farmers. It also contributes to reducing the environmental impact of feed production by recycling by-products efficiently (Jacob-Lopes and Zepka, 2017).

2. PRESENT STATUS OF MAIZE IN INDIA

Maize is indeed the largest produced cereal crop globally, with its global average grain yield reaching 5.7 tonnes per hectare (tha^{-1}). Over the past twenty-five years, maize production has more than doubled, driven by substantial increases in yield and the expansion of cultivation areas. Based on 2022-23 figures, the USA leads global maize production (contributing nearly 30%), followed by China, Brazil, and Argentina. Amongst the top 15 producers, USA leads in productivity (10.9 tha^{-1}) which is much higher than global average (5.7 tha^{-1}). The production of maize in India has touched to 38.0 Mt in 2022-23 from sizeable area of 10.7 Mha. The year-wise trends of maize area, production and productivity in India are depicted in Fig. 3.

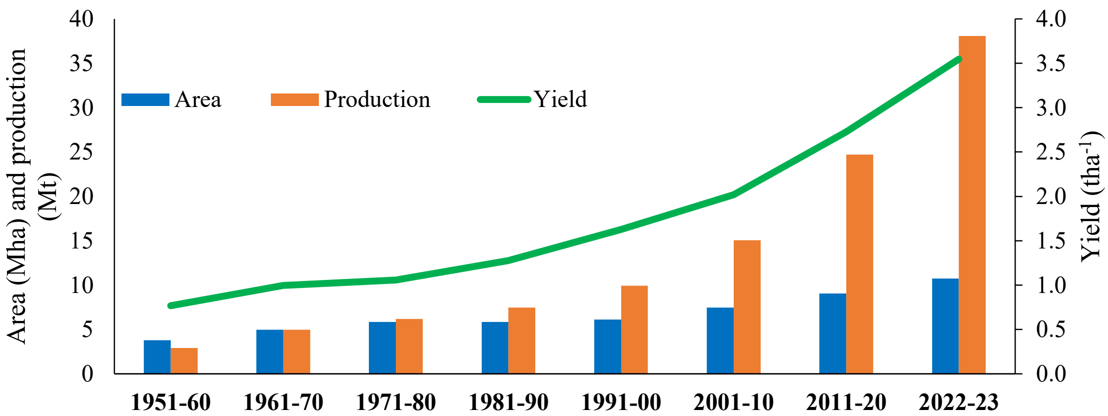

Fig. 3. Year-wise area, production and yield of maize cultivation in India

There has been a significant improvement in overall productivity of maize in India since 1951. The major maize producing states in India are Madhya Pradesh, Karnataka, Rajasthan, Andhra Pradesh, Bihar and Maharashtra. The country exported Rs. 9000 crores worth maize during 2022-23. Maize cultivation is done in two production environments namely traditional maize growing areas (Bihar, Madhya Pradesh, Rajasthan, and Uttar Pradesh) and non-traditional maize areas, (Karnataka and Andhra Pradesh). Karnataka, Madhya Pradesh and Maharashtra emerge as the leading maize-growing states with cultivating area 1.70, 1.44 and 1.34 Mha, respectively. Bihar, Telangana, and Rajasthan fall in the middle range, each cultivating maize on 0.66, 0.51, and 0.96 Mha, respectively. Haryana, Uttarakhand, Assam, Odisha, Punjab, Chhattisgarh, Jharkhand, and Gujarat are relatively lower maize producing states in India.

In 2022-23, major maize-producing states in India experienced varied yields due to diverse agro-climatic conditions and farming practices. Karnataka tops in maize production with 5.18 Mt, followed by Madhya Pradesh and Maharashtra with 4.77 Mt and 3.92

Mt, respectively. Tamil Nadu, Bihar, Telangana, West Bengal, Andhra Pradesh and Rajasthan had moderate production ranging from 2.18 to 3.07Mt. However, Haryana, Uttarakhand, Assam, Odisha, Chhattisgarh, Punjab, Jharkhand, Himachal Pradesh, Gujarat and Uttar Pradesh had relatively lower production ranging from 0.02 to 1.62 Mt. Tamil Nadu leads in maize yield with 7.23 tha^{-1} followed by West Bengal at 7.11 tha^{-1}, whereas Andhra Pradesh, Telangana, Bihar, and Punjab also have good yields ranging from 4.36 to 6.41 tha^{-1}. Other remaining states, however, exhibited lower yields than the national average of 3.60 tha^{-1}.

2.1 Historical trends and projection of maize up to 2035-36

For assessing production over the next few years, the last 5-year (2018-19 to 2022-23) CAGR (compound Annual Growth Rate) of production growth was taken into consideration (Fig. 4). However, the share of poultry sector in maize consumption with CAGR ranges from 8.10 to 8.90% during 2024 to 2032, while livestock sector with 7.38% CAGR rate as per previous years.

2.1.1 Historical trends: From 1950-51, the area, production and yield under maize cultivation has been increasing steadily due to growing demand especially for food, feed and starch production (Fig. 3).

2.1.2 Projections: By 2035-36, it is expected that maize area, production and yield will continue to increase, albeit at a slower rate due to limitations in arable land and competition with other crops (Figs. 5&6). This growth will be driven by population growth, increased livestock production, and the expansion of the bioethanol industry.

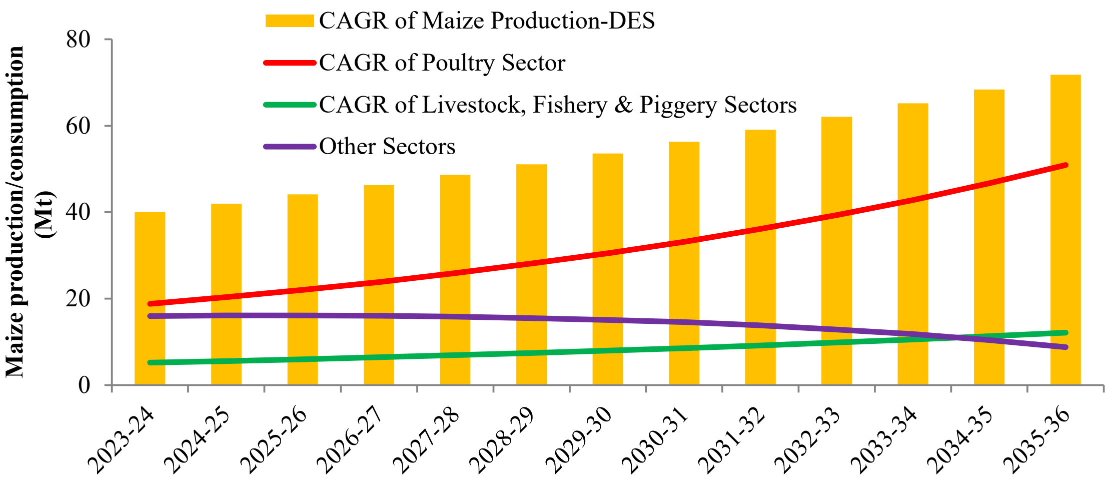

Fig. 4. Scenarios of production and share of poultry, livestock and other sectors for maize

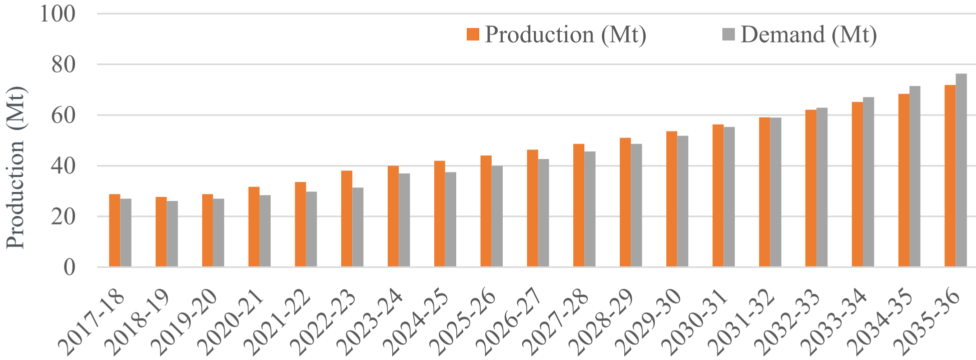

Fig. 5. Production and Demand of maize from 2017-18 to 2035-36

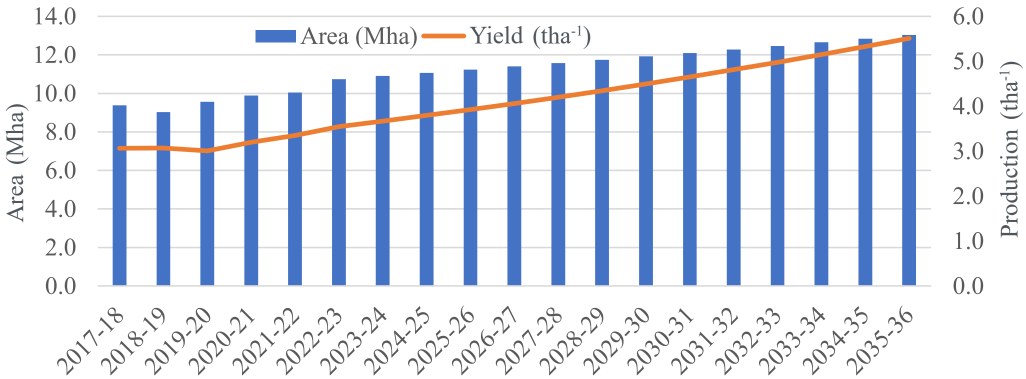

Fig. 6. Area, production and productivity of maize from 2017-18 to 2035-36 at current CAGR

2.2 Future requirements of maize in various sectors

2.2.1 Projected increase in demand: For the next ten years, the demand for maize specifically for ethanol production is projected to grow substantially. With the current usage trends and blending targets, the demand for maize for ethanol by 2035-36 could be between 71.5 to 76.3 Mt, excluding export demand (Fig. 7). This estimate is derived using the USDA-PSD database and considers multiple scenarios to account for various factors influencing demand.

2.2.2 Ethanol blending targets: GOI revised the target to E20 to be accomplished by 2025-26, and set a target of E30 by 2030. Currently, ethanol blending is around 10% which requires around 4000 - 5000 million liters of ethanol annually. To meet the 20% target, the requirement will have to increase to approximately 10000-12000 million liters annually by 2030. The estimation of domestic consumption requirements (Fig. 8a) and availability of maize and DDGS (Fig. 8b) for various alternative uses within India by 2030-35 are increasing with the same pace over the years.

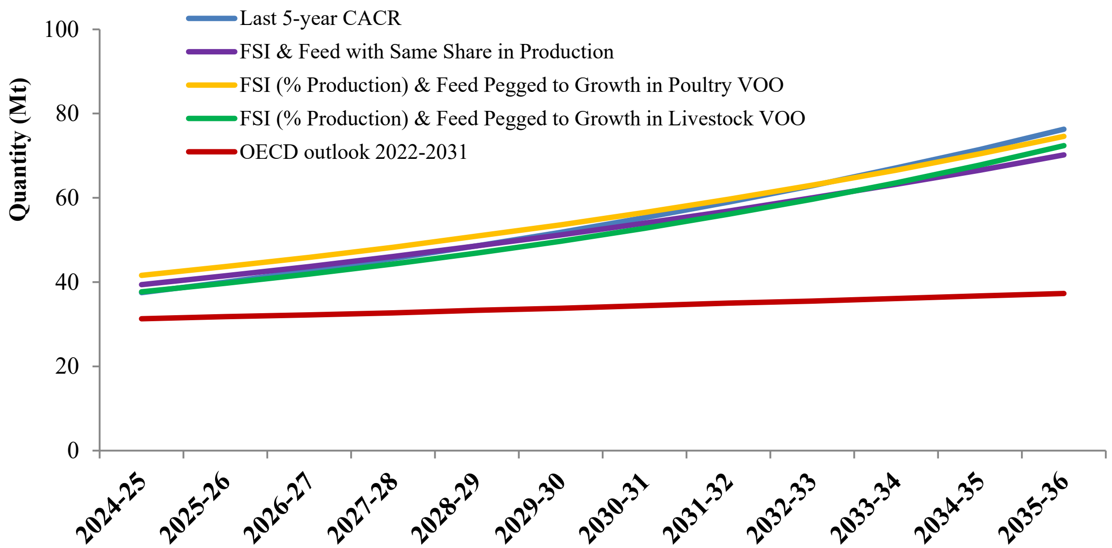

Fig. 7. Demand projections for maize in India (Jat *et al.*, 2024)

2.2.3 Maize-based ethanol and feed uses: If we consider that 1 ton of maize produces about 400 liters of ethanol, the maize requirement will increase proportionally with the ethanol demand. In the scenarios of the maize crunch, the maize for feed can be met from the effective utilization of the DDGS which can be mixed up to 10-12% of the feed (Fig. 9). Thus, the ethanol and feed industries need to work together for effective utilization of the by-product DDGS.

3. PATHWAYS FOR INCREASING MAIZE PRODUCTION

The present and past policy framework for maize production were designed for the food and feed security which the country achieved. Now, for industrial security, reducing import bill on petroleum and environmental footprint (compared to rice and sugarcane), there is a need to increase maize productivity in India both in the *kharif* and *rabi* seasons to 4.0 and 6.5 tha^{-1}, respectively. The expansion of single cross hybrid coverage with adoption of mechanization and best crop management practices will be crucial in productivity enhancement. It is estimated that there is a scope of addition of 2.0 to 2.5 Mha under maize area in various ecologies by tapping options of rice fallows (up to 1.0 Mha), crop diversification and crop intensification.

Maize is no more a food crop and its diversion to ethanol production will not have larger food security implication in India. However, maize expansion by 1.0 Mha in upland of eastern India and by 0.4 Mha in western Indo-Gangetic plains is likely to have 5.0 Mt lesser rice production which can be compensated by enhancement of

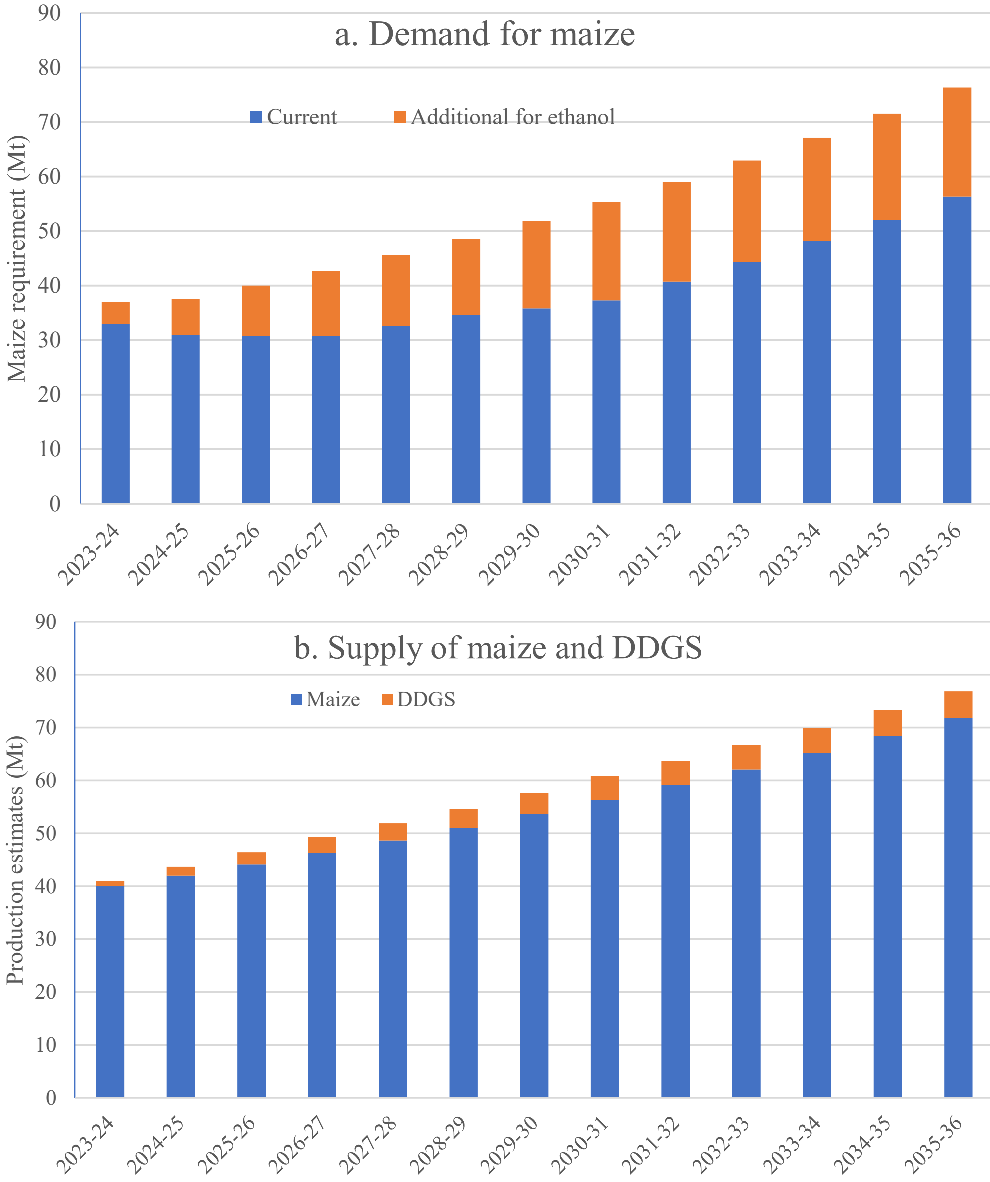

Fig. 8a&b. Estimation of domestic consumption requirements (a) and availability of maize and DDGS (b) for various alternative uses within India

rice productivity. The targeted productivity and area expansion could be sufficient to meet the maize for ethanol blending target. However, a more rigorous assessment for input resources, alternative demands on maize, and feed/food security is required for sustainable ethanol production using maize.

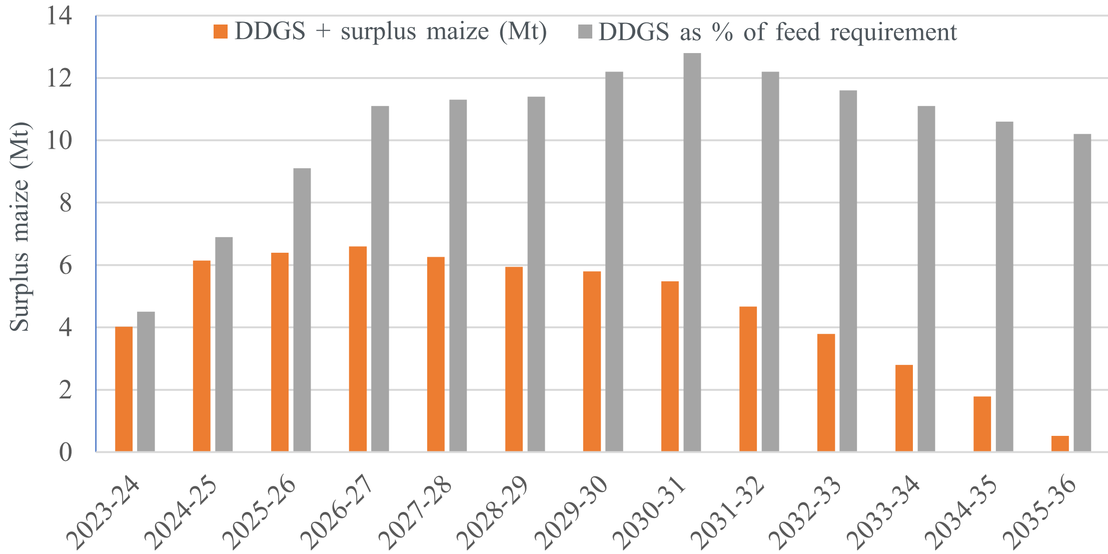

Fig. 9. The availability of maize and DDGS for poultry/livestock feed industries in the scenario of bioethanol production

3.1 Food/feed security and increased maize production

In India, the major driver of maize demand comes from poultry feed. Therefore, any shift in its use must consider feed/food security implications. Diverting maize to ethanol production can impact feed/food availability and prices. Studies have shown that significant allocation to biofuels can lead to higher food prices and affect food security (Bentivoglio and Rasetti, 2015). Policies must balance ethanol production with food/feed needs, while promoting sustainable agricultural practices to increase overall production. There is an opportunity to bring the rice fallows under maize cultivation in eastern IGP. The adoption of maize in place of 1.0 Mha upland rice with average productivity of<1.0 tha^{-1} in eastern India and 3 lakh ha in western IGP with <4.0 tha^{-1} yield are expected to offset the rice production to the extent of 2.2 Mt but add maize to the extent of 4.0-4.5 Mt.

3.2 Water and Land requirements

Maize requires substantial water, with an estimated 600-900 mm of water per growing season for one-kilogram maize. Efficient water management practices are essential to ensure sustainable maize production without depleting water resources (Hoekstra and Chapagain, 2007). Techniques such as drip irrigation, which can save up to 50% water compared to traditional methods, rainwater harvesting, and soil moisture conservation are critical. Additionally, drought-tolerant and heat-tolerant maize varieties are being developed in India by CIMMYT and partners to withstand climate-induce variability, and to improve water use efficiency (Zaidi *et al*., 2023). In case of land requirement, expanding maize cultivation for ethanol requires careful land management to avoid deforestation and habitat loss practices such as crop rotation, intercropping, and conservation tillage can maintain soil health and productivity. Using marginal lands, which are less suitable for food crops, for maize cultivation can also help meet ethanol feedstock requirements without compromising food production (Khanna *et al*., 2021).

4. SWOT ANALYSIS OF MAIZE FOR BIOETHANOL PRODUCTION

Maize could potentially enrich India's biofuel landscape due to its cost-effectiveness, water efficiency, and eco-friendliness. The strengths, weaknesses, opportunities and threats for maize feedstock towards ethanol production are highlighted in Fig. 10.

4.1 Strengths

Maize offers several compelling strengths as a crop for ethanol production. It boasts the highest yield potential among cereals, ensuring a robust supply of raw material for ethanol. Its lower water requirement compared to other crops makes it suitable for regions with limited water resources, contributing to sustainable agriculture. Maize's

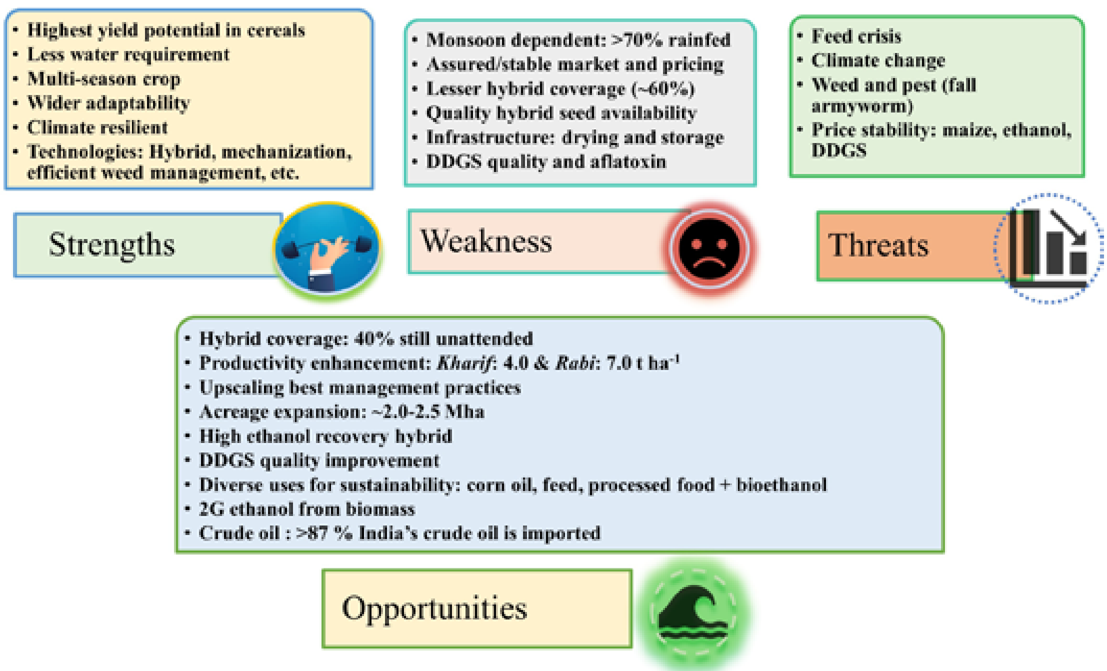

Fig. 10. The strengths, weaknesses, opportunities and threats for maize feedstock towards ethanol production in India

adaptability to various agro-climatic conditions and its resilience to climate stresses further enhance its viability. Additionally, the adoption of advanced technologies such as hybrid varieties, mechanization, and efficient weed management can significantly boost productivity and profitability, making maize an ideal candidate for ethanol production.

4.2 Weaknesses

A significant portion of maize farming is rainfed making it a highly dependent on monsoon rains, which can be unpredictable. There is a need for a stable market and pricing to ensure farmers' confidence in growing maize for ethanol. Currently, only about 60% of maize cultivation uses hybrid seeds, limiting yield potential. The infrastructure for drying and storing maize is inadequate, leading to post-harvest losses. Additionally, the quality of DDGS as by-product of ethanol production needs improvement to ensure its effective utilization as animal feed.

4.3 Opportunities

Expanding hybrid seed coverage which is currently at 40%, can significantly boost yields. There is substantial potential for productivity enhancement with achievable yields of 4.0 tha^{-1} in *kharif* and 7.0 tha^{-1} in *rabi* seasons. Upscaling best management practices and expanding maize cultivation by 2.0 to 2.5 Mha can further increase the raw material supply. Developing high ethanol recovery hybrids and improving DDGS quality can make ethanol production more efficient and profitable. Maize's diverse uses including for corn oil, feed, and processed food, alongside ethanol provide multiple income streams for farmers. Additionally, advancing second-generation (2G) ethanol technologies using maize residue can further enhance ethanol output.

4.4 Threats

A potential feed crisis must be addressed to balance the demand for food, feed, and fuel. Climate change poses risks to maize cultivation although adopting climate-smart agriculture (CSA) practices can mitigate these effects. Weed and pest issues such as Fall armyworm (FAW) needs a effective management to protect maize yields. However, Price stability for maize, ethanol, and DDGS is crucial to ensure the economic viability of ethanol projects. Moreover, Government policies and market interventions will play a key role in maintaining stable prices and supporting the maize-to-ethanol industry.

Overall, SWOT analysis for maize-to-ethanol is a viable solution for India's energy needs reducing dependency on imported crude oil and enhancing energy security while lowering the trade deficit. Investing in maize-to-ethanol is both economically imperative and strategically vital for long-term sustainability in agriculture. By addressing weaknesses and leveraging opportunities, maize-to-ethanol can significantly enhance India's energy security and agricultural productivity, ultimately benefiting farmers' income.

5. RECOMMENDATIONS ON STRATEGIC CHANGES FOR BIOETHANOL FROM MAIZE WITHIN THE EXISTING LEGISLATIVE FRAMEWORK IN INDIA

5.1 Crops diversification

In north western India, production of rice raised environmental and water security concerns and hence, crop diversification is essential. Similarly, the upland paddy in Eastern India having low productivity also need suitable crop replacement for enhancing farm income. Replacing rice, a water-intensive crop, with maize which offers higher productivity and reduced groundwater usage can help farmers become more resilient to climate variability and resource scarcity. Additionally, maize serves as both a food source and a feedstock for ethanol, providing farmers with new income opportunities. Thus, integrating maize into cropping systems is crucial for ensuring energy security, enhancing farm profitability and environmental stewardship in north western and eastern India.

5.2 Government incentives

To encourage the maize ethanol value chain, Government of India may go for suitable incentives in the form of subsidies, tax credits, or price support programmes.

5.3 Sustainability standards

In order to have the bioethanol production in socially and ecologically responsible manner, GoI may enforce certain sustainability standards for the industries. These requirements may include natural ecosystems protection, reduction in the emission of greenhouse gases, and establishing rules and regulations for sustainable agricultural methods.

5.4 Food support & safety nets

In order to address potential problems, if any, of food security caused by production of bioethanol, Government may need to strengthen the food aid programs and safety nets. This will ensure that poor communities have access to reasonably priced and nutrient-dense food.

5.5 Linking of price

Proper monitoring of the linking of the ethanol prices *vis-à-vis* maize prices is required for sustainable bioethanol production. Similarly, the pricing of the by-product such as DDGS and its utilization is very important for sustenance of the bioethanol industries. Considering the current productivity of rice in North Western Plain Zone and its assured procurement at MSP for PDS, a suitable assured and ruminative market mechanism should be developed for maize as well by the Government. A system should be established to procure maize at pricing linked with productivity so that shift from rice to maize is smooth by equalling the farm profitability.

5.6 Standards for bioethanol and their by-products

Standards for bioethanol and their by-products needs to be established and regulated.

5.7 Research and Innovation

To enhance the efficiency of bioethanol production in a sustainable manner, it is imperative to make technological advancements, including breeding, seed systems, processing, and value chains. This is critical to make best possible use of land and water resources, while still achieving energy and environmental goals. Yet another dimension of this is to launch a project on 'Breeding for Waxy Corn' as it has more efficient conversion efficiency due to presence of mostly amylopectin component of starch than normal dent or Flint corn.

5.8 Water usage

The production of bioethanol, especially from crops like maize, may require irrigation water inputs for better productivity. However, the total water requirements would be less than the rice. Besides using water-use efficient and climate-resilient maize varieties, policies for water management are necessary to prevent the over use of water. To balance agricultural and environmental needs, there is a need to intensively promote water use-efficient crop varieties and irrigation methods.

5.9 Greenhouse gas emissions and policy implications

Compared to fossil fuels, bioethanol can significantly decrease greenhouse gas emissions. To lower emissions, bioethanol-promoting policies must be synchronized with climate goals. This involves establishing criteria for renewable fuels, offering financial incentives to produce bioethanol with minimal emissions, and assisting in creation of advanced biofuels with even smaller carbon footprints.

5.10 Biodiversity impacts

Biodiversity conservation policies should be integrated into bioethanol production frameworks. This may include encouraging sustainable intensification, agroforestry systems, protecting critical habitats, and promoting stocks that have minimal impact on biodiversity.

6. INTERVENTIONS NEEDED

Systematic and mission-mode efforts are needed to enhance coverage under climate-resilient single-cross maize hybrids, improve availability of quality seed to farming communities in stress-prone environments, creation of regional seed hubs, implementing better crop management practices (specially for managing nutrients, diseases, insect-pests, and weeds), establishing facilities for maize drying and storage, particularly for aflatoxin management, etc. The tapping of rice fallows, expansion of maize in the upland areas in Eastern India, western Indo-Gangetic plains and intercropping with wide-spaced crops will be key for increasing maize production. There could be a significant role of the improved ethanol process optimization (enzymes and process cardinals) for sustainable and higher recovery of ethanol production from maize in India. Apart from ethanol, 25-30% DDGS is produced which has 25-30% protein & 10-15% fat. At present, DDGS is being utilized @ 2-4% in feed sector which has scope to go up to 10%. The improvement in DGDS quality with lesser aflatoxin contamination and proper drying will be key for remunerative prices and its utilization in feed/food industries.

6.1 Required planning

To achieve the targets of EBP (E20 & E30) set by the Government of India, there is a need for proper planning under different phases. In the short-term planning (<3 years), major focus should be on : (i) development of catchment area for the distilleries; (ii) on farm demonstration of high yielding climate-resilient and water use-efficient single cross hybrids from both public and private sectors; (iii) adoption of best package of practices and mechanization for maize cultivation; (iv) research on high yielding maize hybrids like waxy corn with better ethanol recovery; (v) exploration for alternate seed production sites; (vi) capacity building of distilleries and stakeholders on scientific maize cultivation; (vii) creation of drying facilities at aggregators level and (viii) suitability mapping of maize under new areas.

In mid-term planning (3-5 years), the focus should be on : (i) creation of proper storage facilities; (ii) creation of regional seed production hubs and increasing acreage under climate-resilient single cross maize hybrids; (iii) improving DDGS quality and its diversified uses; (iv) process optimization for better ethanol recovery under Indian conditions; (v) expansion of maize area by utilizing rice fallows and upland paddy area in eastern India and crop diversification in western IGP; and (vi) gene editing for higher ethanol recovery from maize. In long-term planning (>5 years), the focus should be on : (i) effectively linking maize prices *vis-à-vis* bioethanol prices; (ii) establishment of stable management system from harvesting to ethanol production; and (iii) self-sustaining ethanol distilleries through research and policies linkages.

6.2 Policy support-can maize support EBP in India?

The advancement of the technology needs support of the policies for creation of greater impact. In this direction, there is need for suitable sustainable policies for proper storage facilities, drying at aggregator’s level, technology targeting with maize suitability mapping, incentivization for upscaling hybrid seed production and best crop management practices, and maize mechanization hub, etc. The utilization of the CSR fund specially from big contributors like information technology and services sectors for creation of maize hubs and research on sustainable ethanol production can also contribute significantly in this direction. The linking of the ethanol prices with maize prices on regular basis is required for sustainable bioethanol production. Similarly, the pricing of the by-product DDGS and its utilization is very important for sustenance of ethanol industries. The government of India have taken initiatives in this direction by announcing remunerative prices for procurement of maize for ethanol at minimum support price by NAFED and NCCF, incentivization of maize cultivation under NFSM/ crop diversification/catchment area development/ PPPAVCD schemes, supporting the research project to ICAR for ethanol, etc. The ICAR-IIMR with different partners is implementing the research projects funded by the MoA&FW, GoI for developing catchments areas around the distilleries, developing high yielding maize hybrids and optimizing process for better ethanol recovery.

7. WAY FORWARD

The GOI has identified maize as one of the most important candidate feedstocks to meet the target of E20 by 2025-26 and E30 by 2030. The amount of maize required for ethanol production alone will increase to 18-20 Mt by 2030. Simultaneously, the country needs to significantly increase maize production and productivity by adopting scientific and technological interventions for sustainable growth and utilization by the poultry, livestock and grains-based distilleries. Nearly 77% of maize in India is grown as *kharif* maize, which is mostly rainfed. *Kharif* maize yield needs to be increased from the present 3.0 tha^{-1} to more than 4.0 tha^{-1}. This warrants accelerated breeding and deployment of climate-resilient maize hybrids with early to medium duration. Also, the *rabi* maize productivity needs to improve to ≥6.5 tha^{-1}. In rabi season, besides high-yielding maize hybrids with medium maturity, long duration maize hybrids with a yield potential of 12-13 tha^{-1} can also be potentially deployed. Using single-cross maize hybrids suitable for higher plant density, adopting improved weed, insect-pest, and disease management practices, maize production and productivity can be significantly increased. Besides increasing single-cross hybrid maize area coverage, integrated pest management modules have to be implemented more effectively across the maize-growing areas in the country. A major issue in the present-day agriculture is availability of water. Water management systems such as sprinkler irrigation and residue management can play a major role in reducing water usage and improving water use efficiency. Mechanized maize cultivation must be strengthened, alternative seed hubs (beyond peninsular India) should be created, aflatoxin management must be geared up, and modern genetic innovations, such as genomic selection and genome editing should be used to develop climate-resilient maize hybrids with suitable plant type of ethanol production. Both the quality and quantity of DDGS need to be improved. By breeding cultivars with high starch content, high yields, and better ethanol recovery, it is possible to enhance bioethanol production and efficiency. Apart from this, the current maize breeding program with emphasis on bio fortification should be continued for use of maize for feed and food. It is also necessary to improve microbial and mechanical engineering to extract more ethanol from less maize. Standardizing biofuels and promoting their high-volume trading on global platforms must be prioritized. Efforts should be directed toward achieving cost parity for second-generation (2G) technology and accelerating third-generation (3G) biofuel commercialization. The 2G biofuels are produced from non-food biomass like agricultural residues (Maize stover, Wheat straw), forestry residues and dedicated energy crops (Corn, Sugarcane, Sweet sorghum, Switchgrass, Miscanthus, Poplar, Willow, Cassava), whereas 3G are derived from algae (Chlorella, Spirulina) and other microorganisms (Agave). A substantial amount of funding will be required for implementing these initiatives. The new techniques such as genome editing for gene (s) likes *COMT* and marker assisted selection for waxy corn needs to be integrated in ongoing breeding programmes for more bio-ethanol recovery.

8. REFERENCES

Azad, V.K., De, K, Majumder, S. (2024). Ethanol blending and its environmental impacts: A case study of India. *Energy Sustain Develop* 79: 101385. https://doi.org/10.1016/j.esd.2024.101385.

Bentivoglio, D., Rasetti, M. (2015). Biofuel sustainability: review of implications for land use and food price. *Rivista di Economia Agraria,* Anno LXX, n. 1: 7-31.

CIMMYT (2024). Heat tolerant maize hybrids: a pursuit to strengthen food security in South Asia. Available https://www.cimmyt.org/blogs/heat-tolerant-maize-hybrids-a-pursuit-to-strengthen-food-security-in-south-asia/.

Gebbers, R., Adamchuk, V.I. (2010). Precision agriculture and food security. *Science* 327 (5967): 828–831.

Hoekstra, A.Y., Chapagain, A.K. (2007). Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resour Manage* 21: 35–48. doi: https://doi.org/10.1007/s11269-006-9039-x.

IEA Bioenergy (2019). IEA Bioenergy Annual Report 2018. Available https://www.ieabioenergy.com/wp-content/uploads/2019/04/IEA-Bioenergy-Annual-Report.

Jacob, Lopes, E., Zepka, L.Q. (2017). Frontiers in Bioenergy and Biofuels. InTechOpeneBooks. doi: https://doi.org/10.5772/63185.

Jat, H.S., Jat, S.L., Kumar, B. and Saini, S. (2024). E20 Ethanol from Maize: Impact on Food Security. ICAR-Indian Institute of Maize Research (IIMR), Ludhiana, Punjab. Page: 58.

Khanna, M., Chen, L., Basso, B. et al. (2021). Redefining marginal land for bioenergy crop production. *GCB Bioenergy* 13(10): 1590-1609. https://doi.org/10.1111/gcbb.12877.

Maga, D., Thonemann, N., Hiebel, M. et al. (2019). Comparative life cycle assessment of first-and second-generation ethanol from sugarcane in Brazil. *International Journal of Life Cycle Assessment*, 24: 266-280. doi: 10.1007/s11367-018-1505-1.

National Policy on Biofuels (2018). The Gazzette of India, Ministry of Petroleum and Natural Gas Notification, New Delhi, the 4th June, 2018. Available https://mopng.gov.in/en/page/1.1

NITI Aayog (2021). Roadmap for ethanol blending in India 2020-25. Available https://www.niti.gov.in/sites/default/files/2021-06/EthanolBlendingInIndia_comp-ressed.pdf.

Organisation for Economic Co-operation and Development, and Food and Agriculture Organization of the United Nations-OECD and FAO-UN (2021). OECD-FAO Agricultural Outlook. OECD Publishing. Available https://www.oecd.org/agriculture/oecd-fao-agricultural-outlook-20745819.

Prasanna, B.M., Cairns, J.E., Zaidi, P.H. et al. (2021). Beat the stress: Breeding for climate resilience in maize for the tropical rainfed environments. *Theor Appl Genet* 134: 1729-1752. https://doi.org/10.1007/s00122-021-03773-7.

Renewable Fuels Association-RFA (2021). Round the year industry functioning, Renewable Energy. Available at https://ethanolrfa.org/.

Tilman, D., Hill, J., Lehman, C. (2006). Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* 314(5805): 1598-1600. https://doi.org/10.1126/science.1133306.

UNICA (2020). Impact of Sugar Availability on Domestic and Export Markets. Available at https://www.oecd-ilibrary.org.

Yangcheng, H., Jiang, H., Blanco, M. et al. (2013). Characterization of normal and waxy corn starch for bioethanol production. *J Agric Food Chem.* 16: 61(2): 379-386. doi: 10.1021/jf305100n.

Zaidi, P.H., Vinayan, M.T., Nair, S.K. et al. (2023). Heat tolerant maize for rainfed hot-dry environments in the lowland tropics: From breeding to improved seed delivery. *Crop J* 11: 986-1000. https://doi.org/10.1016/j.cj.2023.06.008.

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