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RESEARCH ARTICLE

Breeding strategy for maize in Nepal based on the current market segments and target product profiles (TPPs): In depth analysis

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Abstracts

Nepal's maize sector has advanced significantly over the past three decades, driven by hybrid seed adoption and improved agronomic practices. Maize is vital for food security, livestock feed, fodder, and industrial raw materials, with regional contributions varying across provinces. Currently, open-pollinated varieties (OPVs) dominate (70%), while hybrids account for 30%. Cultivation occurs mainly in rainfed systems across high hills, mid-hills (60%), Terai/foot hills (20%), and high hills (10%). The cropping seasons are primarily summer (60%), followed by spring (25%) and winter (15%), aligning with climate conditions. Grain color preferences favor yellow (80%) for animal feed and adaptability, while white (20%) is preferred for food crops in favorable regions. The Target Product Profile emphasizes high yields, adaptability, disease and pest resistance, drought tolerance, and suitable grain quality. Hybrids are classified into early-maturity varieties for spring planting and full-season types for winter and summer, especially in Terai and hills. Market strategies consider environmental factors, production systems (rainfed and irrigated), end-uses (food, feed, silage), and grain traits, including specialty crops like sweet corn and bio-fortified varieties. Growth opportunities lie in leveraging Nepal's diverse climate, closing yield gaps through technology, and expanding maize's industrial and nutritional applications. Challenges include environmental constraints, limited adoption of best practices, socioeconomic barriers, and climate change impacts. Addressing these requires coordinated efforts among government, research institutions, the private sector, and farmers to promote hybrid technology, develop climate-resilient varieties, improve extension services, and ensure sustainable resource use. A strategic, collaborative approach is essential for boosting productivity, resilience, and market expansion, contributing to Nepal's food security and economy. A future breeding strategy in Nepal should focus on developing maize varieties aligned with market segmentation and TPPs, emphasizing traits like high yield, pest resistance, and adaptability to local agro-ecological conditions.

Keywords: Hybrid maize, market segment, target product profile, challenges, strategy

An overview of maize in Nepal for production, growth, and regional contributions

Maize (*Zea mays*) holds a vital position in Nepal's agricultural landscape, ranking as the second most important cereal crop after rice.

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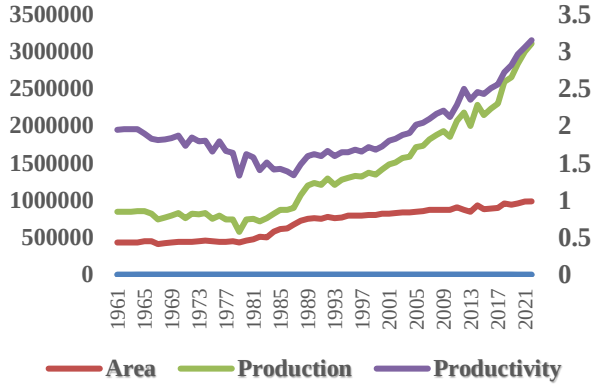
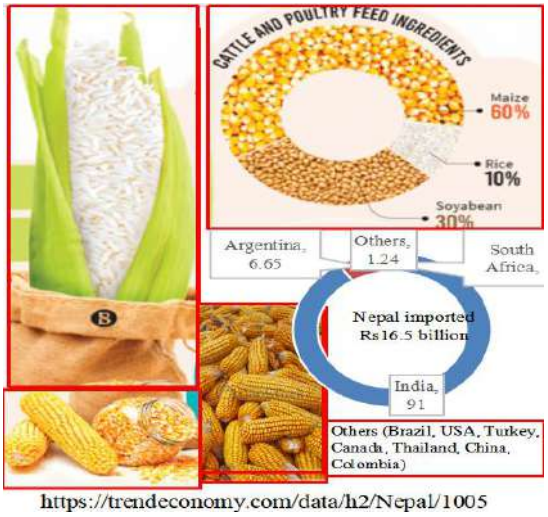
It accounts for approximately 43% of the total cereal area and contributes around 53% to the country's overall cereal production, underscoring its significance for food security and livelihoods. The total maize cultivated area in Nepal is approximately 0.98 million hectares. The crop's total production reaches about 3.10 million tons, with an average productivity of 3.15 tons per hectare (t/ha). Over the past three decades, maize productivity has experienced substantial growth. In 1990, the average yield was around 1.6 t/ha, but by 2022, this had more than doubled to 3.15 t/ha (MoALD, 2022). This remarkable increase is primarily attributed to advancements in hybrid seed technology, improved agronomic practices, and better access to inputs. The rate of maize productivity growth notably accelerated after 2010. This surge can be largely credited to the widespread adoption of hybrid maize varieties, which have significantly enhanced yields compared to traditional open-pollinated varieties (OPVs). The introduction and adoption of hybrids have transformed maize cultivation from subsistence-level farming to a more commercially oriented enterprise, contributing to improved food security and income generation.

Fig. 1: Area, production and productivity trends in Nepal



Nepal data for maize



https://trendeconomy.com/data/h2/Nepal/1005

Regionally, the provinces of Koshi, Bagmati, Lumbini and Gandaki collectively contribute roughly 70% of Nepal's total maize production. These regions benefit from favorable climatic and soil conditions that support maize cultivation, and they serve as the primary hubs for maize farming in the country. The Mid-hills predominantly cultivate OPVs, which are traditional open-pollinated varieties, while the Terai, inner Terai, and river basin areas have increasingly shifted towards hybrids, especially in recent years. This regional variation highlights differing adoption rates of improved seed technology and diverse agro-ecological conditions. Between 2010 and 2022, maize yields increased by approximately 33%, reflecting ongoing improvements in crop management, technology dissemination, and farmer awareness. This growth underscores the importance of continued research, extension services, and access to quality inputs to sustain and further accelerate maize productivity. Maize's strategic importance in Nepal's agriculture is evident through its extensive cultivation area, high contribution to cereal production, and rapid yield improvements driven by hybrid technology adoption. Continued efforts to promote hybrid varieties, improve input accessibility, and enhance farming practices are essential for sustaining growth (Shivani, and Prasad 2020) and ensuring food security for Nepal's population.

Over the past three decades, Nepal has witnessed steady progress in maize productivity, with an average annual increase of approximately 1%. This consistent growth has been driven by technological advancements, the adoption of hybrid varieties, and improved farming practices. Despite this progress, the demand for maize is projected to grow at a much faster rate estimated at 4-6% annually over the next 20 years necessitating further enhancements in production, input accessibility, and cropping strategies. Maize serves multiple purposes in Nepal's agricultural and food systems. The crop is primarily classified into yellow maize, used predominantly for feed, and white maize, mainly consumed as food. The versatile nature of maize allows it to be processed into various products, including roasted cobs, grits, sweet corn, and popcorn for direct human consumption, as well as for animal feed and forage. These include green maize, silage, and processed feed products, contributing significantly to livestock and poultry industries.

In the hill regions, approximately 86% of maize production is dedicated to household consumption, supporting local diets and food security (Gurung et al., 2011). Conversely, in the Terai and river basin areas, around 80% of maize production is utilized by feed industries, reflecting a shift toward commercial and industrial use, especially in poultry and livestock farming (http://www.iita.org/maize; FAO, 1992; Brown *et al.*, 1985, Gurung *et al.*, 2011). Maize plays a crucial role in Nepal's animal husbandry sector. Currently, the country consumes about 3,000 metric tons of poultry feed daily, highlighting the importance of maize in supporting poultry production. To meet the demand, Nepal imports a substantial volume of hybrid maize seed around 3,655 tons in the most recent year ensuring the availability of high-yielding varieties to farmers and feed manufacturers (MoALD, 2023). With the anticipated increase in maize demand, driven by population growth and expanding livestock industries, Nepal must focus on scaling up production through improved seed technology, better agronomic practices, and sustainable resource management. Enhancing local seed production, fostering private sector investments, and expanding extension services will be vital to bridge the gap between demand and supply, ensuring food security and supporting economic growth in the coming decades.

Technical challenges for maize production

One of the primary technical challenges in maize production in Nepal is that summer maize is predominantly cultivated under rain-fed conditions, which makes it highly vulnerable to erratic weather patterns and moisture stress. These rain-fed systems often involve low-input farming practices, limiting the use of fertilizers, pesticides, and other inputs that could enhance yields. Additionally, much of the maize is grown on marginal lands with poor soil fertility, which hampers crop growth and productivity. (Chapai et al., 2024) Another significant challenge is the heavy reliance on open-pollinated varieties (OPVs), which constitute about 70% of the maize cultivated, compared to only around 30% hybrid varieties. OPVs are generally less productive, have lower yield potential, and are more susceptible to pests and diseases compared to hybrid maize. The limited adoption of hybrid seeds stems from factors such as high seed costs, lack of awareness, and inadequate seed production and distribution systems. Furthermore, farmers often face difficulties in accessing improved seed varieties, which hampers the widespread adoption of modern, high-yielding, and disease-resistant hybrids. The lack of availability of quality seeds, along with limited knowledge and technical know-how on optimal planting practices, fertilizer application, and pest management, further constrains productivity. In addition to seed technology limitations, insufficient access to modern agricultural inputs, machinery, and

extension services restricts the implementation of best practices. Overall, these technical and technological constraints significantly hinder efforts to improve maize yields and sustainability in Nepal's challenging agro-ecological environments. (NMRP, 2024).

Limited adoption of good practices, environmental and socioeconomic challenges

One of the major challenges facing maize production is the limited adoption of good agricultural practices (GAP) among farmers. Despite advancements in technology and knowledge, many farmers continue to follow traditional cultivation methods that often result in suboptimal yields and inefficient resource use. This slow adoption is influenced by factors such as lack of awareness, inadequate extension services, and limited access to training programs. Compounding this issue is the decreasing availability of agricultural land due to urbanization, land fragmentation, and environmental degradation, which reduces the area available for maize cultivation and forces farmers to maximize productivity on limited plots. Consequently, increased production costs stemming from the need for inputs like improved seeds, fertilizers, and pest control measures further burden farmers, especially given their often-limited financial capacity (Kharel *et al.,* 2024). Poor access to essential agricultural inputs, such as quality seeds, fertilizers, and pesticides, hampers the implementation of best practices and reduces overall productivity. Additionally, farmers face challenges in accessing reliable markets and extension services that could provide technical support and facilitate better crop management. These limitations hinder efforts to improve crop yields, ensure sustainable farming, and enhance farmers' livelihoods. Overall, addressing these challenges requires concerted efforts to promote awareness, improve infrastructure, and strengthen extension services to enable farmers to adopt modern, sustainable, and efficient maize production practices (NMRP, 2020) Maize cultivation faces significant environmental challenges that threaten its productivity and sustainability. One of the primary concerns is the degradation of natural resources, including soil erosion, declining soil fertility, and water scarcity. Unsustainable farming practices, deforestation, and overuse of chemical inputs accelerate soil degradation, reducing the land's productivity over time and compromising long-term food security reported by Adhikari and Pandit, (2020). Global climate change presents a profound threat to maize production through increased variability in weather patterns, unpredictable rainfall, rising temperatures, and extreme weather events such as droughts and floods. These changes adversely affect crop growth stages, reduce yields, and increase the vulnerability of maize crops to stress conditions. (Lobell *et al.,* 2011). Additionally, environmental changes have led to the emergence and proliferation of new pests and diseases. Notably, the outbreaks of pests like Fall Armyworm (FAW) and the resurgence of diseases such as Gray Leaf Spot (GLS) and stalk rot pose serious risks to maize health. These biotic stresses are often exacerbated by changing climatic conditions, which create favorable environments for pests and pathogens, further undermining crop resilience and productivity. Addressing these environmental challenges requires integrated approaches focusing on sustainable resource management, climate-resilient crop varieties, and effective pest and disease management strategies to ensure the long-term viability of maize cultivation. Maize production faces several socioeconomic barriers that hinder its productivity and growth. A significant challenge is the prevalence of subsistence farming, characterized by small landholdings and limited capital investment, which restricts farmers' ability to adopt improved practices and technologies. Furthermore, existing national policies often lack sufficient support for the development and dissemination

of hybrid maize seeds, limiting access to high-yielding varieties that could enhance productivity. Labor shortages pose another critical issue, driven by rural out-migration, seasonal in/out-migration, and the feminization of agriculture, which collectively reduce the availability of skilled labor for planting, maintenance, and harvesting activities. These labor constraints impact timely farm operations and productivity. Changes in cropping systems, such as the shift from traditional rice-based systems to rice-toria-maize or rice-potato-maize rotations, add complexity to farm management and require farmers to adapt to new agronomic practices and market dynamics. Market volatility and increasing trade deficits further complicate maize production, as fluctuating prices and unpredictable market access discourage farmers from investing in improved inputs and practices. This economic uncertainty diminishes incentives for adopting modern technologies and hampers the overall development of the maize sector. Addressing these socioeconomic challenges necessitates policy reforms, targeted support programs, capacity-building initiatives, and market stabilization measures to empower farmers and promote sustainable maize production (Thirwall and Agbola , 2014).

Maize hybrid development and releases in Nepal

The first single-cross maize hybrid, Gaurav Hybrid, was released in 2003; however, it was not successful in commercial seed production. Since then, several hybrids have been developed and released. Other single cross yellow hybrids i.e., Rampur Hybrid-2 (2012), Khumal Hybrid-2 (2014), Rampur Hybrid-4 (2016) and Rampur Hybrid-6 (2016) are released for normal season likewise Rampur Hybrid-8 (2017), Rampur Hybrid-10 (2017) are registered for heat-resilient maize hybrids. Rampur Hybrid-12, Rampur Hybrid-14, and Rampur Hybrid-16 (2022) are the recently released single cross hybrids for both hills and terai. Among the hybrids, Rampur Hybrid 10 and Rampur Hybrid 12 are popular and being commercial seed production done by diverse seed company. The pipeline Hybrids are CAH1511, CAH1519 (Lumbini), and CAH196 (SEAN) which has high yield potential and tolerant to waterlogged condition. Besides the promising Hybrids are CAH1817 and CAH193 having high yield potential > 12 ton per hectare which is comparable to the multi-national company hybrids and scope to import substitution. It is grace to share the progress of Nepalese hybrid seed production is the result of collaborative efforts among the National Maize Research Program (NMRP/NARC), the Hybrid Maize Technology Mission (HTMA), CIMMYT, and private partners (Gorkha, Lumbini, Panchashakti , Unique seed company etc.), which successfully produced approximately 200 metric tons of Nepalese maize hybrid F_1 seeds.

Fig 2: Hybrid maize seed production(tons) in Nepal

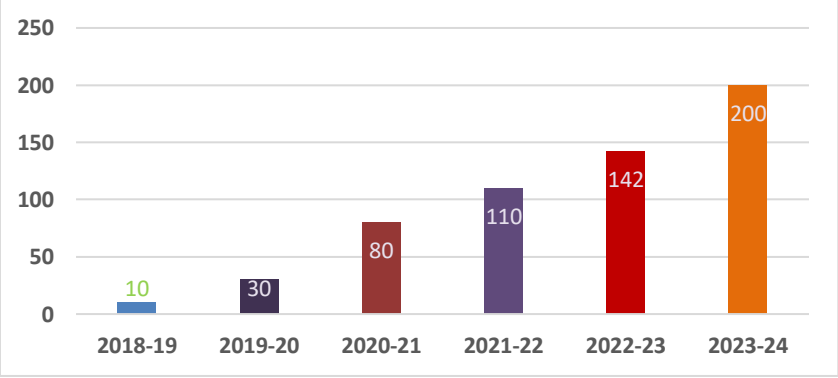
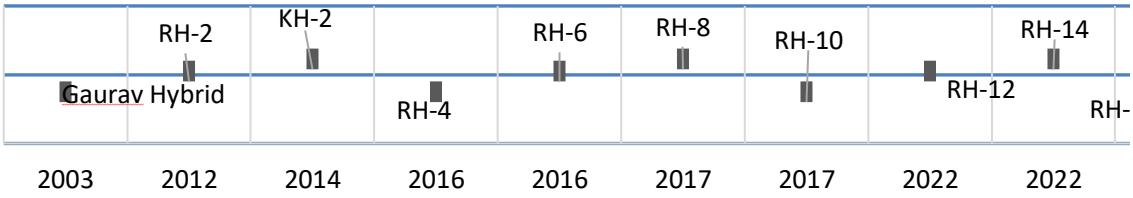


Fig 3: Timeline for hybrid maize (NMRP, 2024)



Current Nepalese maize market segments

The maize value chain is broad, and the synergy between the developer of the product (breeder), the producer (farmer), and the consumer needs to be effective. Hence, streamlining of the market segments and eventually the target product profiles is key in ensuring that the breeders develop improved products/varieties with relevant traits that address the needs of farmers, consumers, and the seed industry (Sinyinda, 2024). Market intelligence in breeding programs is critical to understand the evolving needs of key stakeholders, including farmers, consumers, and the seed industry. It helps continuously improve the breeding pipelines to develop and deliver impactful products in targeted market segments (Prasanna, 2024). This approach aims to better serve smallholder maize farmers in Nepal.

The following maize market segments are identified below-

Varietal type: Hybrids (30%), OPVs (70%)
Cultivated region: High hills (10%), mid hills (60%), Terai/foot hills (20%)
Growing season: Winter (15%), spring (25%), summer (60%)
Scale of production: Commercial farmers (15%) and small holders (85%)
End use/application: Animal feed and fodder (silage, green) (55%); food and beverage (45%)-direct consumption and processed consumption (Grit, green cob, baby corn)
Grain color: White (20%)-food crop and requires favorable geographical condition, yellow (80%)-animal feed and high geographical adaptability
Key market players: Hybrids 30% (MNC hybrids-97%, National hybrids-3%), OPVs (70%)

Product concept for hybrid maize in Nepal

Target product profile (TPP): The TPP serves as the blueprint for the 'ideal' hybrid maize product, focusing on traits that meet the specific needs of Nepalese farmers.
Target population environment (TPE): The TPE defines the specific environments where the hybrids will perform optimally
Early maturity hybrids: Designed for spring season planting, suitable for Terai regions, inner Terai, foot hills and dry weather conditions.
Full-season hybrids: Optimized for winter and summer planting
Adapted for the hills and summer: Suitable for the Terai regions. This targeted approach aims to develop maize hybrids that maximize productivity and resilience across Nepal's diverse agro-ecological zones, aligning with farmers' seasonal and environmental needs (Prasanna, 2024).

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Table 1: Product concept for hybrid maize in Nepal

Criteria	Market segment					
	1	**2**	**3**	**4**	**5**	**6**
Agro-ecological zone	Hills	Hills	Hills	Terai	Terai	Terai
Production system	Rainfed	Rainfed	Rainfed	Irrigated/ Rainfed	Irrigated	Irrigated
End use	Grains-Feed	Grains-Food	Grains-Food	Grains-Feed and Food	Grains-Feed	Fodder and silage
Maturity	Full season	Full season	Full season	Early	Full season	Full season
Specialized traits	Resilient	High value	Resilient	Resilient, High value	Resilient	Resilient
Color	Yellow	Yellow	White	Yellow	Yellow	Yellow

Key elements of market segment for hybrid maize

Agro-ecological Zone: Terai (T): Terai, inner Terai and River basins (<900 masl), Hills (H): Mid and high (>900 masl)

Production system: Rainfed (R), Irrigated (I)

End use: Grains (G)-Food, Feed, Fodder and Silage (Fs),

Maturity: Early (E), Full season (F)

Specialty corn: High value (Hv): Sweet corn, Pop corn, Green cob, QPM, Biofortified (PVA, Zn)

Grain color: White (W), Yellow (Y)

For Terai TIGFABY-Terai, Irrigated, Grain-Fe, Full season, Resilient-C and D, Yellow (15%) TIGEABY-Terai, Irrigated, Grain, Early, Resilient-D and H, Yellow (25%) TIFsFABY-Terai, Irrigated, Fodder and silage, Full season, Resilient-Dis and In, Yellow (5%) For hills HRGFABY-Hills, Rainfed, Grain-Fo and Fe, Full season, Resilient-D andW, Yellow (40%) HRGFABW-Hills, Rainfed, Grain, Full season, Resilient-D&W, White (10%) HRHvFBY-Hills, Rainfed, Grain, Full season, High value, Yellow (5%).

Table 2: Target product profiles (TPPs) for hybrid maize in Nepal

Concept	Main grower or end use requirement	Market segment change
1. Feed and fodder	Reliable feed and fodder/silage	Yellow and high biomass
2. Food	Food consumption	White
3. Green cob	Fresh green-cob market met (including sweet taste and large cobs)	End use
4. Nutritious	Biofortified (PVA, QPM, Zn, Fe)	End use
5. Resilient	Resistance to major stresses including abiotic (H eat, drought, water logged and cold) and biotic st resses (TLB, FAW, Stalk rot, GLS)	Benchmark

The key aspects of total product profiles (TPPs) for hybrid maize in Nepal

High yield potential: Hybrid maize varieties offering 20-25% higher yields compared to conventional varieties, significantly enhancing productivity.

Adaptability to diverse Agro-Ecological Zones: Development and promotion of hybrids suitable for the varied climates and terrains across Nepal, including Terai, Hills, and Mountain regions.

Industrial and commercial use: Promotion of hybrid maize varieties tailored for industrial applications such as starch, feed, and processed food industries.

Resistance to diseases and pests: Incorporation of genetic traits for resilience against prevalent pests and diseases, reducing crop losses and input costs.

Tolerance to abiotic stresses: Development of hybrids capable of withstanding heat, drought, cold, and waterlogging conditions, ensuring stability in productivity amid climate variability.

Grain quality suitability: Production of hybrids with desired grain qualities white or yellow aligned with end-use preferences, including food, feed, and processing industries.

Early maturity hybrids: Availability of early-maturing hybrids suitable for spring season cultivation, enabling quick harvests and multiple cropping cycles.

Full-season hybrids: Development of hybrids with longer growing periods for winter and summer cultivation in Terai and Hills regions, optimizing land use.

Quality protein maize (QPM) hybrids: Promotion of QPM hybrids that offer enhanced nutritional value, particularly in protein content, benefiting health and nutrition.

Opportunities and future direction

The varied climatic zones and agro-ecological conditions across regions provide a broad scope for maize cultivation, enabling adaptation to different environments and expanding production potential.

The flexibility in cropping systems allows integration of maize with other crops, optimizing land use, improving farm productivity, and diversifying income sources for farmers. There is significant potential to increase maize yields through the adoption of improved technologies, better management practices, and access to quality seeds, thereby

In conclusion, Nepal’s maize sector has experienced significant progress over the past three decades, driven by technological advancements, particularly the adoption of hybrid seed varieties, and improved agronomic practices. Maize plays a crucial role in the country’s food security and livelihoods, closing the existing productivity gap. Maize is essential food source for mid-hill communities and raw material for industries. Maize serves as a vital staple food for mid-hill populations and offers raw material for various agro-industries, supporting local economies and food security. Maize's versatility allows its utilization across multiple sectors—food, feed, fodder, fuel, and other industrial applications creating opportunities for value addition and market. To harness the full potential of maize production, it is essential to foster intensive and coordinated collaboration among all stakeholders. This includes research institutions, the government’s crop development system, extension services (comprising the three tiers: government agencies, universities, and private sector entities such as seed companies and agrovets), non-governmental organizations (NGOs), international organizations, and farming communities. Key strategies for the future should to be included as Focused dissemination and adoption of hybrid maize varieties in identified potential areas to boost yields and farm incomes.Invest in research to develop and disseminate stress-tolerant maize varieties capable of withstanding climate challenges such as heat, drought, cold, water logging, pests, and diseases.Establish platforms for effective information exchange and technology transfer among stakeholders to ensure widespread adoption of proven innovations. A concerted effort in these areas will be crucial for sustainable maize production, resilience to climate change, and enhanced food security. The role of genomics, haploid breeding, and genome editing technologies in the development and improvement of hybrid maize is crucial for the improvement of the hybrid maize research in Nepal and must be targeted in near future.

accounting for a substantial share of cereal production and serving diverse uses such as food, feed, fodder, and industrial raw materials. The strategic regional contributions, especially from Koshi, Bagmati, Lumbini, and Gandaki provinces, highlight the importance of favorable agro-ecological conditions for maize cultivation. Despite notable advancements, the sector faces multiple challenges, including technical constraints related to rain-fed cultivation, limited adoption of good agricultural practices, environmental issues like soil degradation and climate change, and socio-economic barriers such as land fragmentation and market access issues. These obstacles hinder the full realization of maize's potential in Nepal. Opportunities for growth remain substantial, given the country's diverse climate zones, cropping systems, and the versatility of maize utilization. To fully harness these prospects, a coordinated effort among stakeholders' research institutions, government agencies, private sector, and farmers is essential. Priorities should include promoting hybrid technology, developing climate-resilient varieties, improving input accessibility, and strengthening extension services. Emphasizing sustainable resource management and innovative breeding strategies will be vital for increasing productivity, ensuring resilience against climate stresses, and meeting the rising demand driven by population and livestock industry growth. Together, genomics, haploid breeding, and genome editing revolutionize hybrid maize development by increasing precision, speed, and efficiency. These technologies enable breeders to develop high-performing, resilient, and nutritionally superior hybrids tailored to Nepal's diverse agro-ecological conditions, ultimately contributing to food security and economic growth. Overall, a focused, collaborative approach can sustain the sector's development, enhance food security, and contribute significantly to Nepal's agricultural economy in the years ahead.

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