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RESEARCH

Policy Framework to Buildup Seed Security and Sustainability of Nepal's Marigold Industry

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ABSTRACT

Purpose: *This policy paper discusses challenges and prospects arising from commercialization of hybrid marigold seeds in Nepal. The study aims to study about policy gaps, conservation challenges and scope of maintaining genetic diversity to support economic potential of marigold commercialization through development of locally suitable hybrids marigold seed with high yield and uniform crops and conserving local marigold landraces loss.*

Research Method: *The study adopts qualitative policy analysis approach including scoping review of relevant literature with primary insights from key informant interviews. The study also includes in-person interview with representatives from four institutional categories: a) public research authorities, b) government authorities, c) private research agencies and d) academicians. The research method also includes Geographic Information System (GIS) suitability mapping to categorize marigold cultivation potential into high, medium, and low zones based on agro-climatic and edaphic characteristics.*

Findings and Values: *The paper concludes that integration of conservation strategies and commercial hybrid marigold development can help to achieve self-sufficiency as well as sustainability in marigold flower production business landscape. The analysis of suitability for marigold cultivation in Nepal classifies high, medium, and low-potential areas based on agro-climatic and soil conditions and highlights region-specific strategies needed to promote sustainable floriculture growth. Five-folds policy recommendations include a) strengthening existing seed governance, b) promoting local hybrid breeding programs, c) promoting in-situ conservation of indigenous landraces, and d) building public-private partnerships to ensure long-term seed security and e) development of region-specific hybrid from landraces.*

Keywords: *Marigold seeds, Seed security, Suitability map, Sustainable floriculture*

INTRODUCTION

Across various civilizations, people cultivate flowers to fulfill aesthetic, cultural and religious needs and the economic use of marigold is increasing (Dadlani 2003). People usually use flowers in all their ceremonies, religious offerings and sometimes in social, political, and historical occasions. Marigold (*Tagetes spp.*) has special religious and cultural value in India, Nepal and Mayan culture in Mexico (List of materials used in Hinduism, Wikipedia). Marigold is widely used in traditional medicines across Asia, Europe, and the Americas for treating skin and digestive conditions (Ning *et al.* 2022). Furthermore, popularity of beverage (marigold tea) is also increasing. The commercial use of marigold has also

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expanded to include extracting color and raw material for incense sticks and perfume (Chauhan *et al.* 2022). This wider use of marigold increases demand for the volume of flowers, which has further scope of specific use. Although Nepal was once relied heavily on imported flowers during festive seasons, increasing commercial production has replaced imports and even promoted the export of flowers (The Rising Nepal 2023).

Currently, farmers have started to grow hybrid marigold varieties for commercial purposes, for which the seeds of hybrid marigold varieties of marigold are imported to Nepal. Since there is a lack of Nepal's own climate-adapted hybrid varieties, imported hybrids are high. This indicates strong demand for locally developed high-productive hybrids. Mehta *et al.* (2022) found that 55% of farmers use hybrid seeds, and 16.7% relied on a combination of hybrid seeds and hybrid cuttings. This reflects a significant shift towards the use of hybrid seeds, because of increased commercialization and market pull for high yields and uniformity of flowers. However, despite being popularity of hybrid marigold seeds, there is a dearth of reports on the import of marigold seeds to Nepal. This gap indicates that there are unofficial import channels, which is an issue regarding quality monitoring of seeds, genetic diversity, and long-term survival. There is even no documented data on the production of hybrid marigold varieties in Nepal, which further confirms that hybrid seeds consumed are mostly imported.

Furthermore, with the commercialization of floriculture, the reliance on hybrid varieties can increase, and even threaten the existence of marigold landraces (Rao & Hodgkin 2002). Replacing hybrids with local varieties may lead to a loss of beneficial genetic material, widely distributed in the form of different local landraces. These landraces are the foundations for the development of own hybrid of Nepal (Dahal *et al.* 2021). This situation alarms for the necessity to characterize and document the native landraces of marigold so that their conservation can be guaranteed. A systematic breeding program for conserving and developing genetic resources for hybrid improvement would enhance Nepal's floricultural independence and conserve the country's biodiversity (Dahal *et al.* 2021).

Nepal's floriculture sector has been expanding tremendously in recent years, and marigold farming has been at the forefront due to its huge demand for religious, cultural, and commercial purposes (The Kathmandu Post 2021). According to Singh (2006), hybrids commonly produce 12–18 t/ha, while traditional varieties yield considerably less under comparable management. These performance gaps, coupled with increasing domestic demand for marigolds during festivals and urban events, explain the rapid expansion of hybrid cultivation in Nepal. An increasing dependence on imported hybrid seeds also leads to a recurring foreign exchange outflow, which requires a look into the seed system of Nepal and its long-term self-sufficiency. Global floriculture research demonstrates that the hybrid African marigold varieties consistently outperform the local open-pollinated types both in yield and uniformity.

This policy paper has been developed in response to the urgent need for evidence on hybrid marigold seed use in Nepal. It provides a review of their current status, considers the challenges arising from reliance on imported hybrids and erosion of local germplasm, and then outlines some future possibilities for strengthening Nepal's own hybrid breeding and seed production capacity.

MATERIALS AND METHODS

Study design

We employed a mixed-methods design combining literature review, stakeholder consultations, and spatial analysis in this research to assess the viability of marigold (*Tagetes spp.*) cultivation in Nepal and inform seed system interventions with a conservation purpose.

Desk review for secondary information

In exploring the marigold conservation policy into practice in Nepal, we first conducted the

scoping review in April 2024. Broader seven folds overview of the available literature to map the emerging and evolving issues of the marigold industry in Nepal was presented: research gaps, official statistics, marigold varieties, local landrace threats, need for conservation, and feasibility scoping and global, and national strategies for marigold seeds conservation. A desk review was conducted to consolidate information on marigold production practices, genetic diversity, seed systems, and conservation practices from Nepalese and international literature. Peer-reviewed articles, grey literature, government reports, and policy documents on floriculture were analyzed systematically to provide the scientific and policy context for marigold production and biodiversity conservation.

Key informant consultations

To complement the literature review and validate field-level practices, after review of the broader six areas of scope, we conducted ten semi-structured interviews from four categories of agencies semi-structured interviews with a representative key informant consisting a) public research authorities, b) government authorities, c) private research agencies and d) academicians were conducted. Although our interviews targeted institutional stakeholders, these actors work directly with all major value chain groups including hybrid seed suppliers, commercial growers, nurseries, and native landrace custodians enabling capture of perspectives from both hybrid and indigenous production systems. The interviews were centered on indigenous marigold varieties, hybrid seed usage patterns, conservation practices, and policy gaps. The interview allowed us to conceptualize and link the literatures facts and figures and set an agenda for policy recommendations.

GIS-Based suitability analysis

Spatial suitability analysis was performed in QGIS to map the biophysical potential of marigold cultivation in Nepal. The key environmental factors were selected based on their ecological significance for marigold growth: elevation, land cover, average annual temperature, precipitation, slope gradient, soil pH, and soil nutrient content (Nitrogen, Phosphorus, and Potassium). For standardizing each environmental factor, its raw values were reclassified as high, moderate, and low suitability. Their respective index scores are 3, 2, and 1 in accordance with the ecological requirements of the marigold. To generate CSI, all factors were combined by performing a weighted linear combination:

$$CSI = \sum (W_i \times S_i)$$

Where W_i is the weight from pairwise comparison and S_i is the index score (1 to 3). The final CSI values were grouped into high, moderate, and low suitability classes to generate the national marigold suitability map.

The relative weight for each factor was assigned through a pair-wise comparison from expert opinion. The calculated consistency ratio (CR = 0.029) was found within the acceptable reliability of the weighting system. Weighted overlay analysis provided a national suitability map classifying land into three classes: highly suitable, moderately suitable, and low/very low suitability for marigold cultivation.

Integration and recommendation development.

The results of the spatial analysis, literature review, and key informant feedback were integrated to recommend region-specific marigold seed conservation methods, hybrid development strategies, and policy recommendations to promote sustainable floriculture in Nepal.

RESULTS AND DISCUSSION

This study assessed the potential of marigold cultivation across Nepal by employing spatial suitability analysis, stakeholder consultation, and a review of existing conservation practices. The results provide an insight into where suitable cultivation areas are located, traditional marigold seed systems, and the implication on the distributional aspect of Nepal's conservation-based floriculture policy. Hybrid cultivation addresses immediate production and market needs and the native landrace conservation is

important for long-term genetic security; both are necessary, and neither substitute for the other.

The discussion brings together the outcomes of the Geographic Information System (GIS)-based suitability mapping and indigenous knowledge and highlights how such findings can feed into both conservation as well as sustainable hybrid development. The following sections analyze the current trends in hybrid marigold adoption, considering the research gap and hybrid dependency on marigold production. It continues to evaluate the government records on seed imports, broaching potential issues on unofficial trade and lack of regulation. The article continues with the analysis of the shortage of locally produced hybrid marigold, spotlighting the country's overdependence on foreign sources of seed and the threat this poses. The impact of hybrid dominance on native landraces and biodiversity is also addressed. The paper also provides a geographical scope of marigold cultivation over Nepal depending upon its climatic, geographic and edaphic suitability. Finally, the paper provides policy recommendations for overcoming these challenges such as seed import control, preservation of indigenous varieties, and support for local hybrid breeding programs to help ensure Nepal's floriculture sustainability.

Research gap and hybrid dependency on marigold production

While marigold (*Tagetes spp.*) is increasing in commercial importance, there is a tremendous gap regarding research on its overall performance, particularly in the Nepalese context. The majority of the limited studies have examined the growth and yield traits of hybrid marigold varieties such as Karma-1, Karma-2 (Adhikari & Pun 2011), Marvel Yellow, Marvel Orange, Marvel Garland and Inca Orange-1KS (Poudel *et al.* 2017). These studies tested various agronomic factors, including planting dates, growing conditions, spacing, pinching, and nutritional management, with increased productivity under optimized conditions. The research, however, is marked by a notable lack of investigations on marigold landraces, which may carry unique adaptability features and genetic diversity suited to local agroecological environments.

Furthermore, the increased utilization of hybrid varieties has significant implications. While hybrids offer higher yields, uniformity, and preferred floral characteristics, their widespread cultivation comes at the cost of genetic erosion of local landraces, reduced seed sovereignty for farmers, and increased dependence on external seed suppliers. While hybrids outperform local varieties in commercial yield, some native landraces show superior performance under stress or low-input conditions, making them important for future breeding. In Nepal, where the formal seed system for marigold is in its emerging stage, the dominance of hybrids raises questions about seed availability, affordability, and sustainability. Moreover, doubts regarding the registration status of these hybrid varieties in Nepal further contribute to seed security complexity since unregulated imports may affect local production and market stability (Gauchan & Shrestha 2017). Against these backgrounds, future research needs to focus on performance testing, genetic characterization, and conservation strategies of indigenous marigold landraces for their sustainable utilization and potential introduction in Nepalese floriculture. Policies should also strengthen research and extension systems to support these efforts.

Lack of official statistics on import of marigold seeds

Even as there is increasingly wider acceptance of hybrid marigold seeds, there is a significant dearth of official statistics on their import. There is no specific statistical information on the import of marigold seed to Nepal does not have provided by the Department of Customs of Nepal. The lack of documentation means that hybrid seeds may be entering the country through unofficial channels, and it is difficult to ensure seed quality, adaptability, and sustainability. The lack of import data also limits policymakers from controlling the seed trade and protecting local farmers from low quality or unsuitable varieties (Gauchan & Shrestha 2017). Further, dependence on foreign seed markets

without quality control can expose Nepali flower farmers to supply chain vulnerabilities, price fluctuations, and potential future trade bans (MoALD 2023). Additionally, the lack of legal registration and regulation of hybrid varieties in Nepal makes it difficult to authenticate and control the quality of imported seeds, which can affect local production and market stability.

Limited locally developed hybrid marigold varieties

Despite the increasing importance of marigold production in Nepal's commercial floriculture sector and the availability of diverse native landraces, policies and legislative actions have failed to target the seed sector for marigolds. The National Seed Vision (2013-2025) emphasizes the production of hybrid seeds within the country but focuses primarily on major crops like rice, maize, and vegetables, without mentioning ornamental plants like marigolds. Hybrid marigold breeding varieties are not reported in Nepal (National Seed Vision 2013); hybrids are all imported (Mehta *et al.* 2022). This high reliance on external sources on one hand incurs export expenditure on one side and on the other hand, it does not assure the suitability/adoptability to the diverse agro-climatic conditions of Nepal and the hybrid varieties do not come true to type (Mehta *et al.* 2022). Such heavy reliance on external sources not only goes against the acclimatization of hybrids to Nepal's diverse agro-climatic environments but also becomes a financial strain on farmers, as they must purchase new seeds annually. Without investment in local hybrid breeding programs, Nepal's floriculture sector can risk not becoming self-sufficient in the long term and remaining exposed to fluctuations in the international seed market.

The import tax adds to the cost of, and imposes economic burden on, the farmers who have no choice but to purchase new seeds every season because hybrid varieties do not breed true to type (Singh 2006). Moreover, the absence of clear policy directives for ornamental plant seed production has hindered the growth of this sector. To promote sustainable development, it is imperative that national policies encompass the seed needs of ornamental plants, including marigolds, and support initiatives for local hybrid seed development.

Having national breeding programs and seed production units would allow for the creation of hybrids, suited to local climatic conditions, lessening reliance on foreign seeds (Government of Nepal 2013). Unless there is investment in domestic hybrid-breeding programs, Nepal's floriculture industry can fail to achieve long-term self-sufficiency and remain vulnerable to global seed market uncertainties (NARC 2024). National breeding programs and seed production would allow Nepal to develop hybrids, adapted to local climatic conditions and rely less on imported seeds (MoALD 2023).

Rising commercialization and local landraces threat

Commercial growers favor hybrid varieties due to their uniformity, yield, and enhanced floral traits, which increase their appeal for large-scale production, market pull, and export value. Thus, farmers are turning towards hybrid seeds of multinational corporations or large-scale seed firms, thereby replacing traditional, locally adapted landraces. With growing commercialization, the farming of hybrid marigold rise, which can lead to the displacement of traditional landraces (Adhikari & Pun 2011) and marigold is no exception. While the short-term gain is profitable, the process affects long-term genetic diversity, farmer autonomy, and seed sovereignty. The local varieties of marigold that have been cultivated in Nepal for centuries will face the threat of extinction as more farmers switch to high-yielding, market-preferred hybrid varieties. Landrace loss can reduce genetic diversity and eliminate desirable characteristics, such as resistance to indigenous pests, adaptation to Nepal's climate, and cultural significance in traditional applications (Azeez *et al.* 2018). These genetic resources, once lost, are not so readily recovered, so conservation actions are needed now (Chivenge *et al.* 2015).

One of the most significant threats from commercialization is genetic erosion as indigenous landraces are replaced by being

less market competitive compared to hybrids. Landraces, bred over the years under the conditions of local environments, possess unique genetic traits such as resistance to local pests, diseases, and climatic stresses. However, with farmers opting for commercially bred hybrids, locally adapted varieties are rapidly vanishing, and with them, the loss of valuable genetic resources that can otherwise contribute to climate resilience and sustainable agriculture. Experiments indicate that such a downfall of genes can result in reducing biodiversity and limiting breeding programs' ability to create improved, climate-resilient cultivars in the future (Jarvis *et al.* 2008).

In addition, dependence on hybrid varieties undermines seed sovereignty and subjects farmers to increased reliance on external seed suppliers. Unlike traditional landraces, which farmers can save, exchange, and replant, most hybrid seeds are non-reproducible or exhibit severe yield decline in later generations, forcing farmers to purchase new seeds every season. This dependency raises the cost of production, reduces the autonomy of small-scale farmers, and compromises seed security, particularly in countries like Nepal, where a well-established formal seed system is still in the process of development (Joshi 2017).

Need for conservation and sustainable hybrid development

Increased cultivation of marigold varieties has raised the fear of the disappearance of native landraces, causing genetic erosion. To prevent hazards because of over-reliance on foreign hybrid marigold seeds, Nepal should focus on identification, documentation, and conservation of native landraces of marigold (MoALD 2023). There is a need to adopt policies that address the upscaling of high-yielding hybrid varieties while conserving indigenous genetic material. Establishing a systematic breeding program with the objective of utilizing Nepal's genetic resources in hybrid development would be a long-term strategic measure for sustainability. Nepal's agricultural sector has several policies to promote both the cultivation of hybrid crops and the conservation of local varieties:

- National Seed Vision (NSV) 2013-2025: This policy envisioned for 2013 AD to 2025 AD is centered on the promotion of local seed production, including hybrids, to be self-reliant and to explore market opportunities. It is also centered on the utilization of local climatic conditions for seed production (Government of Nepal 2013).

- Agriculture Development Strategy (ADS): The ADS for 20 years duration from 2015 AD to 2035 AD requires the restructuring of agricultural research institutions and the development of breeding programs that are farmer needs oriented. It encourages real-time information systems on seed supply and demand, ensuring timely access to quality seeds (Government of Nepal 2015).

- In Situ Conservation Projects: The underutilization of local landraces has been realized by Nepal Government and the government encourages in situ conservation of local landraces through the involvement of people and communities. The approach will provide for the retention of evolutionary processes and adaptability of crops to environments (MFSC 2006).

Global strategies for marigold seed conservation: lessons for Nepal

Conservation of marigold seed diversity is a new global challenge due to increased use of hybrid varieties, which threatens the genetic integrity of native landraces. Genetic documentation and characterization of marigold varieties are critical for their conservation. Various global programs have successfully promoted marigold conservation through community seed banks, genetic characterization, participatory breeding, and policy measures. Projects such as the Millennium Seed Bank Project in the UK has preserved an enormous wealth of plant diversity including marigold (Royal Botanic Gardens Kew 2009), which can adapt to climate change and genetic erosion. Good models of open-pollinated flower seed conservation and distribution in other nations can be good guidelines for

Nepal's floriculture sector. A good example is High Mowing Organic Seed Company, a Vermont-based enterprise that deals with seed preservation.

Since 2015, the company has offered over 600 types of heirlooms, open-pollinated, and hybrid seeds, of which there is a range of flower seeds to both commercial floriculturists and home gardeners (High Mowing Organic Seeds 2015). Through its continued emphasis on organic and sustainable seed production, the company ensures that there are flower species for use, for example, the marigold, as well as servicing hybrid seed market needs.

Nepal may adopt the same business approach by promoting organic flower seed enterprises that aim at indigenous marigold landrace conservation in combination with the development of hybrids. Encouraging local seed companies to manufacture open-pollinated marigold seeds will preserve gene diversity while offering a secure, long-term supply of good-quality seeds for floriculture enterprises (Joshi 2017). Furthermore, encouraging public-private partnerships in the conservation of floriculture seeds can further boost Nepal's seed security by reducing reliance on foreign hybrid seeds imported from other countries. Nepal can learn from such initiatives by encouraging local seed companies to conserve and provide indigenous landraces as well as hybrids, thus preserving biodiversity while meeting market demands (Joshi & Gauchan 2017).

Nepal can adopt the same organic certification programs and seed cooperatives that ensure sustainable marigold seed production. By combining these approaches, Nepal can develop a sustainable hybrid seed policy supporting agricultural productivity and genetic diversity. The Chinese experiences demonstrate that an equilibrated policy approach whereby modern seed technology is coupled with biodiversity conservation is essential for long-term agricultural sustainability (Liu *et al.* 2013). Nepal should therefore actively adopt policy measures promoting the use of sustainable hybrid seeds while sustaining its genetic richness.

Suitability analysis of marigold cultivation in Nepal

Suitability analysis of marigold production in Nepal was conducted using ArcGIS, and a number of biophysical and environmental parameters are reported in Table 1.

The analysis adopted a weighted overlay method, where specific weights were assigned to the prime factors influencing the performance of marigold (Table 2).

Consequently, the highest weight (25%) was given to altitude, the areas above 1,800 m were not considered as intense temperatures and gradients were not suitable for marigold. Land use was provided 20% of the weight as cropland and exposed soil over forests and grasslands, holding land for commercial agriculture is an important factor affecting marigold cultivation. Temperature was provided with 15% weight as marigold thrives best in 15–29°C climate and thus is unsuitable for frost regions. Rainfall was provided with 12% weight and the regions receiving 600–1,200mm of rainfall per year is ranked as ideal and stating that irrigation can augment development in arid areas. Topographic factors such as slope considered 10% and a leaving slopes of $>$25% due to erosion potential. Soil parameter values were critical, including 8 % weight for pH which affecting the accessibility of nutrients (ideal value: 6.0–7.5). Nutrient values were considered with 5 % for phosphorus essential for flowering (10–25 kg/ha), 4 % for nitrogen, whose availability has to be supplied moderately (50–100 kg/ha) to avoid excessive vegetative growth, and 1 % for potassium being beneficial in resistance to stress but of lesser consideration due to Nepalese soil conditions. The accuracy of the model was checked using the consistency ration (CR) provided in equation 1.

$$\text{Consistency Ratio (CR)} = \frac{CI}{RI} \qquad (1)$$

In this study, the consistency of the pairwise comparison matrix was evaluated using the *Consistency Ratio (CR)*. The *Consistency Ratio*

Table 1. List of biophysical and environmental parameters affecting marigold performance.

Factors	High	Moderate	Low	Reference
Elevation	60–1800 m	1800–2200 m	>2200 m	Shrestha *et al.* 1999
Slope	0–15 %	15–25 %	>25 %	Karki *et al.* 2017
Land Cover	Cropland, Bare soil	Grassland, wooden land	Waterbody, glacier, snow, forest, riverbed, builtup, bare rock	Uddin *et al.* 2015
Temperature	15–29°C	10–15, 29–32°C	<10, >32°C	FAO 2018
Precipitation	600–1200 mm/year	400–600 or 1200–1500 mm/year	<400 or >1500 mm/year	Dahal *et al.* 2016
Nitrogen	0.1–0.2%	0.05–0.1, 0.2–0.3 %	<0.05, >0.3 %	Fageria *et al.* 2010
Soil pH	6–7.5	5.5–6.0, 7.5–8.0	<5.5 or >8.0	Brady & Weil 2016
Potassium	100–150 kg/ha	50–100 or 150–200 kg/ha	<50 or >200 kg/ha	Romheld & Kirkby 2010
Phosphorous	10–25 kg/ha	5–10, 25–40	<5 or >40	Marschner 1995
Organic Matter	1.5–3 %	1–1.5 or 3–4 %	<1 or >4 %	Lal 2015

Table 2. Prime factors influencing performance (t ha^{-1}) of marigold with their specific weight.

Factor	Weight	Rationale
Elevation	25%	Excludes snow/glaciers and steep slopes (>1,800m).
Land Cover	20%	Prioritizes cropland/bare soil over forests/grasslands.
Temperature	15%	Critical for growth (15–29°C; excludes frost-prone zones).
Precipitation	12%	600–1,200mm optimal; irrigation possible in dry zones.
Slope	10%	Steep slopes (>25%) are non-arable (erosion risk).
Soil pH	8%	Affects nutrient availability (optimal pH 6.0–7.5).
Phosphorus (P)	5%	Vital for flowering (10–25 kg/ha).
Nitrogen (N)	4%	Moderate requirement (50–100 kg/ha; excess harms flowering).
Potassium (K)	1%	Supports stress tolerance; less critical in Nepal's climate.
Total	100%	

(CR) was computed as the ratio of CI to RI, yielding a CR value of 0.029. Since the CR value is less than 1, it indicates that the pairwise comparison matrix is consistent, meeting the threshold required for reliable decision-making in the analysis. This ensures that the judgments made during the comparison process are coherent and satisfy the consistency criteria, supporting the robustness of the results derived from the matrix. The accuracy check confirmed the model's reliability, with *Consistency Ratio (CR)* equal to 0.029 (<1) indicating an orderly decision matrix.

This *applicability map* is crucial in providing policymakers, scientists, and farmers with information to guide the expansion of marigold farms in the most appropriate locations while minimizing risks against disproportionate terrain and climate conditions. A marigold suitability status was identified from various sources as shown in Table 3.

Marigold *Suitability Analysis Map of Nepal* as shown in Fig. 1 illustrates the geographical distribution of locations, favorable for growing marigold based on a range of environmental and agronomic factors. The color-coded categorization indicates:

- High Suitability (Green): The best areas with the highest suitability for growing marigolds, which largely coincide in Terai and low hill regions where temperature, rainfall, productivity of the soil, and slope are ideal. The analysis shows 3,217,925 ha land to be under this category.

Medium Suitability (Yellow): Places where marigold can be cultivated but may require additional inputs such as irrigation, fertilizing the soil, or anti-erosion methods. The analysis shows 9,091,300 ha of land to be under this category.

- Very Low Suitability (Red): Steeply sloped and high elevation areas with environmental limitations restricting marigold growth due to cold, soil, or excessively steep slope conditions. The analysis shows 2055244 ha of land to be under this category.

Fig. 2 shows the suitability of marigold cultivation in Nepal based on individual climatic and edaphic parameters. The maps presented here are the most significant *agro-climatic* and *soil factors* influencing marigold cultivation suitability in Nepal. By taking into account elevation, land cover, temperature, rainfall, soil type, and nutrient status, these maps categorize the region into *high*, *medium*, and *low suitability zones*. This analysis helps to identify the most suitable places for commercial farming, guide seed conservation, and guide policy interventions for sustainable floriculture development.

This suitability mapping is a *scientific basis for decision-making* and policy planning in favor of interventions to develop floriculture. The findings can be applied to agriculture zoning policy, investment policy, and regional floriculture expansion programs to encourage the commercial production of marigold in Nepal for which the conservation of landraces is justifiable to develop Nepal's own hybrid varieties suitable for the respective regions.

Policy recommendations

Based on the discussions above regarding increasing usage of hybrid seeds, conservation of native landraces, and experiences from other nations, Nepal must formulate a well-balanced policy that promotes agricultural modernization without compromising biodiversity. The policy recommendations below have some of the principal strategies to achieve this:

Strengthening Seed Regulation and Governance: To ensure the sustainability of marigold cultivation in Nepal, it is necessary to strengthen seed regulation and governance. Greater reliance on imported hybrid marigold seeds has highlighted the lack of rigorous regulation and supervision in this sector. A proper seed governance system needs to be established for regulating and monitoring the import, distribution, and use of hybrid marigold seeds. This would include establishing a national database of all seed imports, whereby the origin, quality, and adaptability of seeds entering Nepal can be traced. Additionally, the presence

Table 3. Factors and suitability description of marigold.

SN	Factors	Resolutions	Source
1	Digital Elevation Model (DEM)	250 m	NASA Jet Propulsion Laboratory, 2013
2	Slope	250 m	NASA Jet Propulsion Laboratory, 2013
3	Temperature	250 m reclassified from 1000 m	NASA LP DAAC, 2024
4	Precipitation	1000 m (Downscale to 250 m)	CHIRPS (*Funk et al.*, 2015)
5	Land Cover Classification	30 m reclassified to 250 m	FRTC, 2022
6	Soil pH	250 m	NARC, 2024
7	Total Nitrogen	250 m	NARC, 2024
8	Phosphorous	250 m	NARC, 2024
9	Potassium	250 m	NARC, 2024

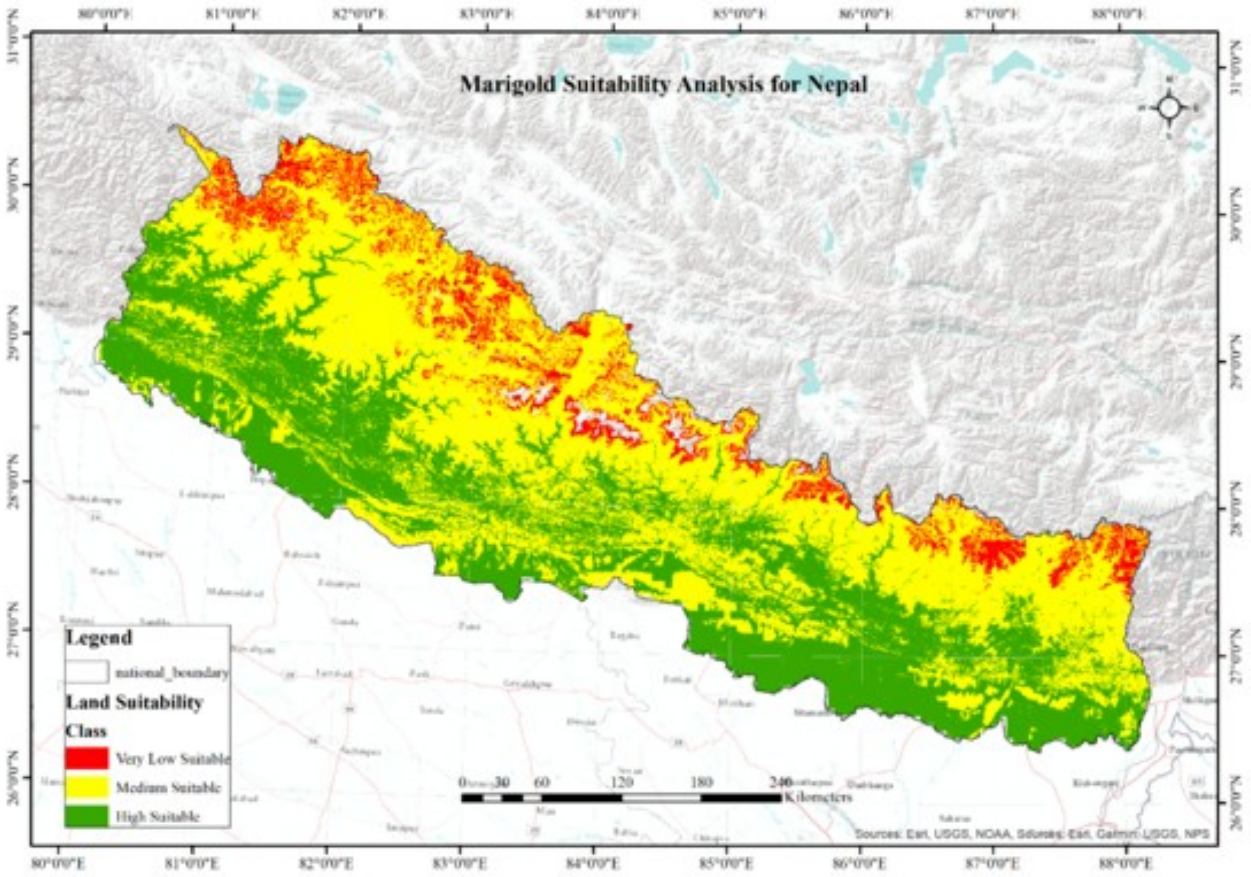

Figure 1. Geographical distribution of locations favorable for growing marigold based on a range of environmental and agronomic factors.

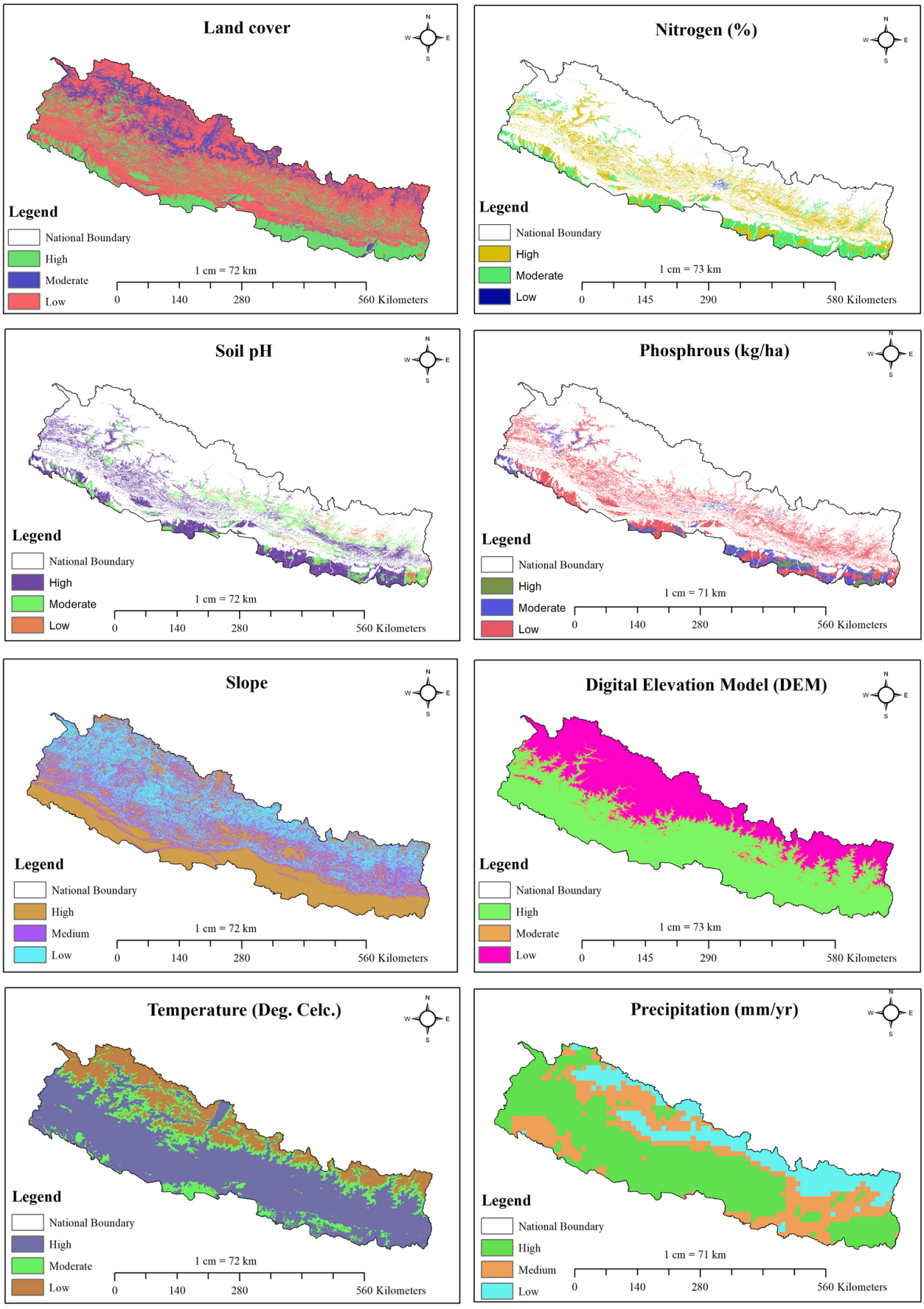

Figure 2a. Suitability map of marigold cultivation in Nepal based on individual climatic and edaphic parameters.

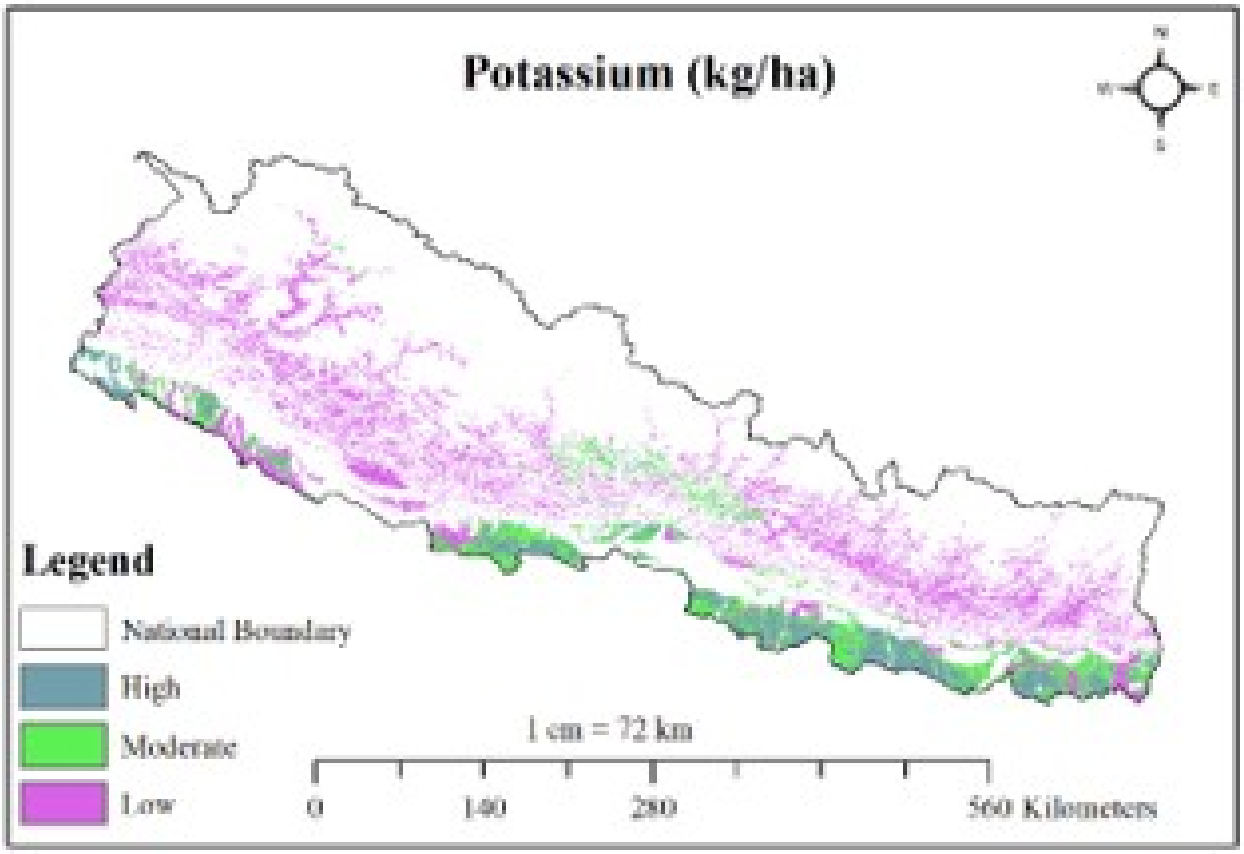

Figure 2b. Suitability map of marigold cultivation in Nepal based on edaphic parameters.

of a regulatory body for ornamental plants alone would ensure that all seeds entering the country are of quality, and seeds entering through non-official channels are effectively controlled. By seed traceability being improved, the government will be in a position to safeguard Nepali farmers' interests and prevent the spread of low quality or unsuitable seeds.

Investment in local and hybrid breeding programs: Given the current overdependence on foreign hybrid marigold seeds, investment is required in local hybrid breeding programs that will tackle Nepal's unique agro-climatic conditions. Such programs would curtail the reliance on imported seed markets and allow Nepal to create marigold varieties specifically suited to its climatic conditions. Domestic breeding programs would also ensure that marigolds would be bred in ways that align with the country's agricultural methodology and climatic factors, reducing both the import cost and environmental impact of foreign seeds. By establishing breeding programs sponsored by the government, Nepal can develop hybrids that are not only stronger but also that provide long-term self-sufficiency. Additionally, providing incentives to local enterprises and agricultural universities to become involved in hybrid development would be a step toward a more sustainable and independent floriculture sector.

Encouraging in situ conservation of native landraces: The heightened commercial interest in hybrid marigolds has raised concern for the conservation of local landraces that are important for the preservation of *genetic diversity* and resilience. Policy, as such, must prioritize *in situ conservation*, where local varieties of marigolds are preserved and protected within their natural habitat. In situ conservation will enable the landraces to continue evolving and adapting to local conditions. The government, together with the local communities, needs to identify, document, and conserve local varieties of marigold and encourage farmers to persist with traditional forms of farming. Through incentives such as subsidies or inclusion in conservation programs, farmers will be encouraged to preserve these

varieties, which contain not only genetic but also cultural and ecological values. This policy action would render conservation of marigold landraces a sustainable component of Nepal's agriculture.

Public-Private Partnerships (PPP) in seed conservation: To achieve seed security and sustainability, PPPs should be encouraged in the conservation of indigenous marigold varieties. These partnerships can merge the technical and financial resources of the government, local seed companies, and non-governmental organizations in support of both seed conservation and hybrid development. Public-private partnerships can establish seed banks, breeding programs, and conservation initiatives that balance the demand for high-yielding hybrid varieties with the desire to preserve local genetic materials. Hybrid African marigold cultivars have a yield capacity of 12–18 t ha^{-1} of flowers, whereas traditional open-pollinated or local material has a yield capacity of 6–10 t ha^{-1} under similar management practices (Singh 2006). This yield advantage has contributed to the widespread adoption of hybrid seeds in Nepal's commercial floriculture industry. In addition, promotion of the development of local seed companies dedicated to producing indigenous and hybrid marigold seeds would maintain Nepal's floriculture sector diverse and robust. By fostering a partnership between the private sector and the government, Nepal can enjoy a steady supply of quality seeds and, simultaneously, maintain biodiversity for future generations.

Raising awareness on the importance of seed sovereignty: One of the most important issues for Nepal's marigold industry is the erosion of *seed sovereignty*, as farmers become more reliant on external suppliers of hybrid seeds. To mitigate this, there must be a combined effort to raise awareness of the value of seed sovereignty and the dangers of over-reliance on imported hybrids. Special campaigns targeting farmers must highlight the risks inherent in hybrid dependence, such as higher seed costs, loss of genetic diversity, and the inability to save seeds and replant them. Public awareness exercises, workshops, and training sessions can inform farmers about the importance of conserving indigenous landraces and using hybrid seeds responsibly. In addition, the local agricultural extension services need to be strengthened in order to provide farmers with the skills and inputs required for them to manage sustainably both hybrid and indigenous varieties so that seed sovereignty can be ensured in the long term.

Integration of indigenous conservation into national agricultural policies: Nepal's existing agricultural policies, including the *National Seed Vision (2013–2025)* and the *Agriculture Development Strategy (2015–2035)*, focus on staple crops and ignore ornamental crops like marigolds. In order to secure a sustainable future for Nepal's floriculture sector, these policies must be revised to include the conservation of native marigold strains and the development of local hybrid breeding programs. By integrating ornamental crops into national agricultural systems, Nepal can ensure marigold farming is both economically and environmentally sustainable. The government needs to allot special budget and resources to ornamental crops like marigolds for research, seed development, and conservation. The incorporation of these things into national agricultural policy will render the policy broader and more inclusive, addressing the issues of commercial farmers and biodiversity conservation.

Global collaboration for marigold seed conservation: As the world demand for marigold seeds is growing, Nepal can benefit from global best practices in seed conservation. In collaboration with international projects such as the Millennium Seed Bank Project or High Mowing Organic Seed Company, Nepal can avail itself of superior research and conservation techniques. These international models hold valuable lessons in sustainable seed bank management, participatory breeding (*Gunasekare, 2006*), and the integration of biodiversity conservation with commercial seed production. Nepal may emulate the same principles by promoting the development of local seed enterprises that conserve indigenous marigold varieties while meeting market demands for hybrids. Besides, international cooperation can provide Nepal with the necessary resources and technical know-how to preserve its marigold genetic heritage, rendering

it less reliant on imported hybrid seeds from abroad and attaining long-term sustainability in the floriculture sector.

Region specific conservation and production activities: A strategic plan for marigold seed conservation is needed for maintaining *genetic diversity* and sustainable production in Nepal. Policies must target conserving indigenous landraces, encouraging participatory breeding, and ensuring certified seed production following regional suitability. *Ex-situ* and *in-situ conservation* approaches must be followed to save indigenous varieties and create climate-resistant hybrids. A region-specific seed conservation policy will make Nepal's floriculture industry more robust while minimizing reliance on imported hybrids.

CONCLUSION

This policy study demonstrates that Nepal's marigold sector has a mix of opportunity and risk: while the availability of hybrid seeds has facilitated commercial expansion, growing dependence on imported hybrids, an absence of official import data on seeds, and weak regulatory frameworks pose threats to *seed sovereignty*, *genetic diversity*, and *sectoral resilience* in the long term. GIS suitability mapping has confirmed that there is considerable ecological potential in Nepal for marigold cultivation; however, this potential cannot be tapped without a clear national strategy balancing commercialization with conservation.

These findings indicate that policymakers need to take conscious efforts toward the formal inclusion of marigold and other ornamental crops within Nepal's existing *seed*, *biodiversity*, and *agricultural development policies*. Enhancement in monitoring seed imports, regulating the registration of hybrids, and undertaking region-specific production and conservation programs are immediate priorities. This necessitates support for local breeding initiatives and the institution of structured conservation mechanisms *in situ* and *ex situ* to preserve genetic resources in Nepal.

To practitioners, farmers, seed companies, and extension services, the study underlines the need for balancing the rate of hybrid adoption for market advantage with measures that protect indigenous landraces. On-farm conservation, community seed banks, participatory breeding, and diversified sources of seed can reduce risks in production and offer long-term security in seed.

The study highlights some clear evidence gaps for the scientific community: performance comparison of hybrids and landraces across agro-ecologies, genetic characterization of native germplasm, understanding farmers' varietal preferences, and impacts of regulatory reforms. Addressing these gaps, therefore, will enable *evidence-based policy decisions* that would eventually strengthen Nepal's floriculture seed systems.

In sum, a commercially competitive yet biodiversity-conscious floriculture sector in Nepal can be achieved by pursuing an integrated approach that brings together stronger regulation, local hybrid development, conservation of native genetic resources, and region-specific production planning. This pathway supports sustainable marigold cultivation and provides a model for ornamental crop development more generally.

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