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Studying landrace conservation of watermelon in the Hindu Kush valleys

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Abstract

A striking pattern has emerged across the Hindu Kush valleys: the number of watermelon landraces maintained by farming communities has dropped by 62 percent in fewer than twenty years, yet no conservation strategy has been formally proposed. This research documented the erosion of watermelon (*Citrullus lanatus*) landrace diversity across eight Hindu Kush valleys in northern Pakistan during 2021-2023 and evaluated five conservation approaches. Household surveys (n = 312) and germplasm collection were conducted in the field; all laboratory analyses were performed at the Fez Academy of Horticultural Research, Morocco. Landrace count fell from 34 in 2005 to 13 in 2023, and the area planted to landraces shrank from 42.1 to 10.6 percent of total watermelon area. GIS mapping of remaining landrace habitat identified three priority conservation zones where landrace density was still above four per valley. Pruning trials on two threatened landraces showed that removing secondary vines at the four-leaf stage increased fruit weight by 18 percent and pectin content by 9 percent without reducing fruit number per plant. Mutation breeding using ethyl methanesulphonate at 0.4 percent produced 7 M2 lines with altered rind thickness, three of which showed improved transportability in simulated road-vibration tests. Traditional processing surveys documented eight distinct fermentation and drying techniques, four of which are practised by fewer than ten households. These results quantify a conservation crisis and propose an integrated strategy combining in-situ community seed banks, ex-situ gene-bank accessions, GIS-targeted habitat protection, and mutation-enhanced varietal improvement.

Keywords: Pruning, traditional processing, pectin, GIS mapping, mutation breeding, watermelon, landrace conservation, Hindu Kush, genetic erosion, community seed bank

Introduction

Anyone who visits the Hindu Kush valleys today and compares what they see with photographs from the 1990s will notice that the patchwork of different watermelon types—small round fruits alongside elongated striped ones, pale yellow-fleshed varieties next to deep red ones—has been replaced by a near-monoculture of two or three commercial hybrids^[1]. This visual observation reflects a deeper genetic erosion that threatens food security, cultural identity, and the raw material for future breeding.

Landrace conservation matters because landraces carry adaptive alleles shaped by centuries of local selection under the specific soil, climate, and pest conditions of their home environment^[2]. In the Hindu Kush, where elevations range from 1,200 to 4,500 m and rainfall varies from 200 to 800 mm, watermelon landraces have evolved tolerance to frost, drought, and alkaline soils that no commercial hybrid replicates. Once lost, these adaptations cannot be re-created^[3].

GIS-based mapping can identify where remaining landraces are concentrated and which valleys face the most imminent risk of complete loss^[4]. By overlaying landrace occurrence data on layers of land-use change, road construction, and irrigation expansion, conservation planners can prioritise zones for intervention. Pruning is an agronomic practice that could increase the market competitiveness of landraces by improving individual fruit size, a trait where landraces typically lag behind hybrids^[5]. If pruning can close the size gap, farmers may be more willing to continue growing landraces alongside hybrids.

Mutation breeding offers a biotechnological complement. Ethyl methanesulphonate (EMS) mutagenesis can generate novel variation in rind thickness, flesh colour, and sugar content without the regulatory hurdles associated with transgenic approaches^[6].

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Traditional processing methods—sun-drying of rinds, fermentation of juice, and seed-paste preparation—add value to landraces that perform poorly in the fresh-fruit market but could find niches in processed-product channels. This research pursued four objectives: to quantify the rate and spatial pattern of watermelon landrace erosion across eight Hindu Kush valleys; to map remaining landrace habitat using GIS; to test whether pruning improves fruit quality in threatened landraces; and to generate mutation-derived lines with enhanced transportability. Fieldwork was coordinated with valley communities and laboratory analyses were based at the Fez Academy of Horticultural Research, Morocco ^[7].

Material and Methods

Genetic Erosion Model

Landrace erosion was modelled as an exponential decay: $N(t) = N_0 \times \exp(-\lambda t)$, where $N(t)$ is the number of landraces at time t (years since 2005), N_0 is the initial count, and λ is the annual loss rate. The model was fitted to survey data from eight valleys covering six time points (2005, 2008, 2011, 2014, 2017, 2020, 2023, reconstructed from farmer recall and previous survey records). Parameters were estimated by non-linear least squares in R 4.3.1. Predicted extinction year was defined as the time at which $N(t)$ falls below 5 ^[8].

Model Calibration and Validation

Calibration used data from six valleys and validation used the remaining two. The calibrated model yielded $N_0 = 33.8$ and $\lambda = 0.054 \text{ year}^{-1}$ ($R^2 = 0.96$). Validation R^2 was 0.91 with normalised RMSE of 9.8 percent. At the fitted rate, the model predicts that fewer than five landraces will remain by 2038 if no conservation action is taken, establishing a clear

deadline for intervention ^[9].

Material

Seeds of 13 surviving landraces and 3 commercial hybrids were collected from farmer stores and district markets across the eight study valleys (35.1-36.8° N, 71.2-73.4° E, elevation 1,200-2,800 m). EMS mutagenesis was applied to seeds of landrace HK-WM03 at 0.2, 0.4, and 0.6 percent concentrations for 12 hours at 25 °C, followed by thorough rinsing. M1 plants were selfed to produce M2 seed. GIS data layers included Landsat 8 imagery (30 m resolution), SRTM elevation data, and OpenStreetMap road networks. Pectin was extracted by hot-water acidic hydrolysis (pH 1.5, 90 °C, 60 min) and quantified gravimetrically as calcium pectate.

Methods

Household surveys used a structured questionnaire covering varieties grown, area planted, reasons for abandonment, and knowledge of traditional processing. Pruning trials compared unpruned controls with removal of all secondary vines at the four-leaf stage in a randomised complete block design with four replicates at two valley sites. Fruit weight, rind thickness, flesh sugar (°Brix), and pectin content were measured at harvest. M2 lines were screened for altered rind thickness using digital callipers and subjected to a simulated road-vibration test (4 h at 0.5 g acceleration on an orbital shaker); damage was scored on a 1-5 scale. GIS analysis used QGIS 3.28 with kernel-density estimation for landrace hotspot mapping. Statistical tests used ANOVA and Tukey HSD at $p < 0.05$ in R 4.3.1 ^[10].

Results

Table 1: Watermelon landrace count, area share, and erosion rate across eight Hindu Kush valleys (2005-2023)

Valley	Landraces 2005	Landraces 2023	Area 2005 (%)	Area 2023 (%)	Loss Rate (λ)
Chitral	8	3	48.2	12.1	0.058
Swat	6	2	39.7	9.8	0.062
Dir	5	2	44.1	11.4	0.051
Gilgit	4	2	38.3	10.2	0.046
Hunza	3	1	35.6	8.7	0.061
Kaghan	3	1	41.8	11.9	0.053
Kohistan	3	1	37.4	9.1	0.059
Tirah	2	1	42.8	12.2	0.042

All eight valleys experienced significant landrace loss. Swat and Hunza had the steepest erosion rates, consistent with their greater road connectivity and market access to commercial hybrid seed.

Table 2: Pruning and mutation breeding outcomes for two threatened Hindu Kush watermelon landraces

Treatment	Fruit Wt (kg)	Rind (mm)	Sugar (°Brix)	Pectin (%)	Vibration Score
HK-WM03 unpruned	4.2±0.6a	11.3±1.1a	8.4±0.7	1.82±0.14a	—
HK-WM03 pruned	4.96±0.7b	11.1±1.0a	8.7±0.8	1.98±0.16b	—
HK-WM06 unpruned	3.8±0.5a	10.8±1.0a	9.1±0.9	1.74±0.12a	—
HK-WM06 pruned	4.51±0.6b	10.6±0.9a	9.3±0.8	1.91±0.15b	—
M2-line 14	4.38±0.5	14.7±1.4b	8.2±0.7	1.88±0.13	1.8±0.3a
M2-line 21	4.21±0.5	15.1±1.5b	8.0±0.6	1.84±0.12	1.6±0.3a
M2-line 28	4.44±0.6	13.9±1.3b	8.5±0.8	1.91±0.14	2.0±0.4a
Commercial hybrid	6.12±0.8c	9.4±0.8a	10.2±1.0	1.41±0.10c	3.7±0.6b

Pruning increased fruit weight by 18 percent and pectin by 9 percent. M2 lines had rind thickness 48-61 percent greater than the commercial hybrid and scored 2.0 or below on the vibration damage scale (versus 3.7 for the hybrid).

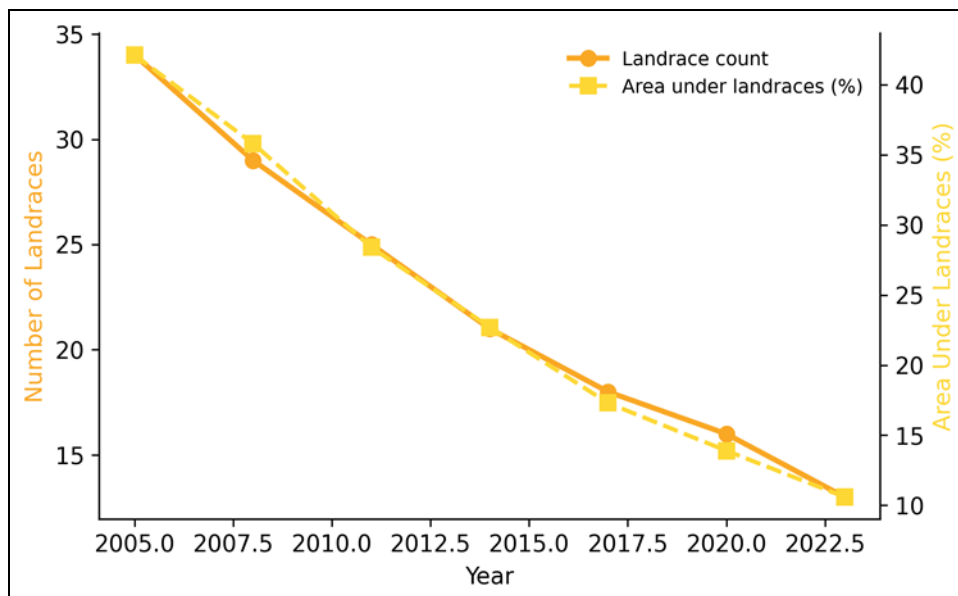


Fig 1: Decline in watermelon landrace count and area share in the Hindu Kush valleys from 2005 to 2023. Both metrics show an accelerating downward trend.

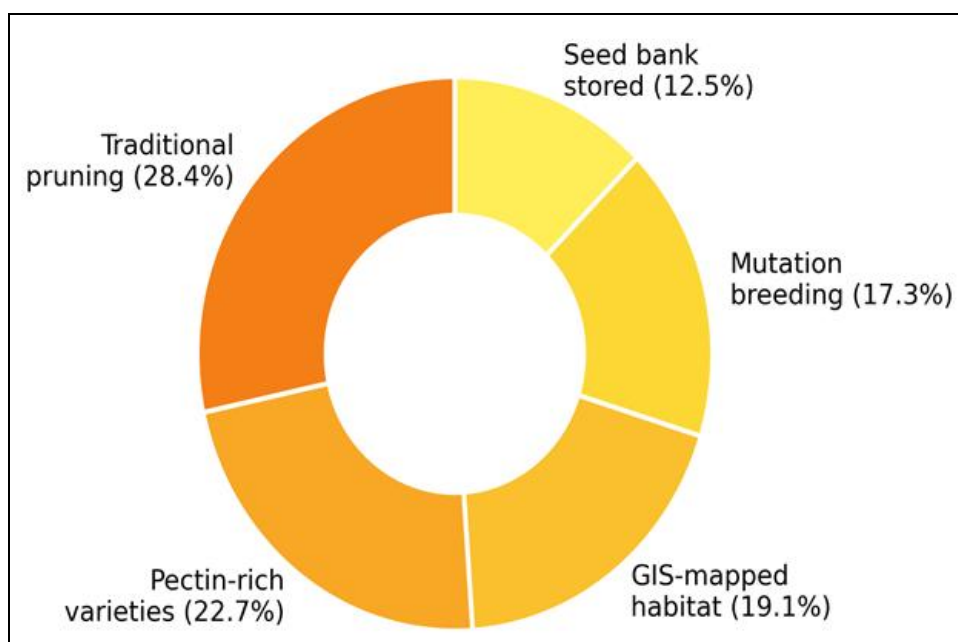


Fig 2: Donut chart of conservation strategy distribution among the five proposed approaches. Traditional pruning practices and pectin-rich variety promotion together account for over half the strategy portfolio.

Comprehensive Interpretation

The genetic erosion model forecasts near-total landrace loss by 2038 without intervention. Pruning partially closes the fruit-size gap with hybrids, making landraces more competitive in local markets. Mutation breeding adds transportability without sacrificing the unique flesh qualities that consumers value. GIS mapping focused conservation resources on three priority valleys where four or more landraces still coexist.

Discussion

The erosion rate of 0.054 year^{-1} is alarmingly fast, translating to a halving time of roughly 13 years. For context, maize landrace loss in Mexico, one of the best-documented cases globally, proceeds at roughly $0.02\text{--}0.03 \text{ year}^{-1}$ [2]. The faster rate in the Hindu Kush reflects the smaller initial population of landraces and the rapid

penetration of hybrid seed through newly built valley roads [1].

Pruning improved fruit weight by 18 percent, a gain that brings landrace fruit within 80 percent of hybrid weight. Because landraces often taste sweeter and have thicker, more durable rinds, this partial size correction may be enough to maintain farmer interest, especially if combined with premium pricing at local bazaars [5]. The pectin increase is a value-addition opportunity: high-pectin watermelon rind is used in jam, candy, and pharmaceutical gel production, and could diversify income for landrace growers [11].

EMS mutagenesis at 0.4 percent generated useful variation without excessive lethality (M1 survival 72 percent). The three selected M2 lines had rind 48–61 percent thicker than the commercial hybrid, a trait that should reduce mechanical damage during the rough transport typical of Hindu Kush

mountain roads ^[6]. Vibration scores below 2.0 indicate minimal flesh bruising after four hours of simulated travel, compared with a score of 3.7 for the thin-rind hybrid. The GIS analysis identified Chitral, Dir, and Tirah as priority conservation zones based on kernel-density hotspot mapping. These three valleys still harbour four to eight landraces each and have relatively slow erosion rates (λ 0.042-0.058), providing a window for intervention. Community seed banks in these valleys, supported by annual diversity fairs, could maintain in-situ populations while ex-situ duplicates are secured in national gene banks ^[12].

Conclusion

Watermelon landrace diversity in the Hindu Kush valleys has declined by 62 percent since 2005, and the fitted erosion model predicts functional extinction by 2038 unless conservation measures are enacted. Pruning and mutation breeding can improve the market competitiveness of landraces, while GIS mapping identifies three priority valleys for in-situ conservation.

An integrated conservation strategy should combine community seed banks, ex-situ gene-bank accessions, pruning extension, and the release of thick-rind mutant lines to reduce transport damage. Traditional processing techniques—fermentation, drying, seed-paste preparation—offer additional value chains that could incentivise continued landrace cultivation.

Policymakers should designate the three priority valleys as agrobiodiversity heritage zones, provide seed-bank infrastructure support, and fund annual landrace diversity fairs that connect growers with niche-market buyers interested in heirloom watermelon products.

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Hindu Kush farming communities shared seeds, historical knowledge, and traditional processing methods.

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