

Socio-Economic Dynamics, Agronomic Constraints and Technological Interventions in Kashmir's Almond Sector: A Review

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Abstract

Almond (*Prunus dulcis*) is a vital temperate nut crop in Jammu and Kashmir historically accounts for over 90% of India's domestic almond production. However, local production satisfies less than 10% of India's total market demand, leading to national import costs exceeding ₹10,000 crore each year. Over the past twenty-five years the area under almond cultivation in Kashmir dropped significantly falling from more than 26,000 hectares in 2000 to roughly 5,400 hectares in recent years. This review analyzes the underlying causes of this decline and outlines practical, evidence-based strategies to modernize the sector. The decline stems from three major areas: (1) low farm-gate prices, high middleman margins (45-55%), and the conversion of traditional agricultural land into high-density dwarf apple orchards; (2) environmental challenges on the elevated Karewa (Wudar) plateaus, such as topsoil loss, summer droughts and early spring frosts that kill blossoms during the February–March flowering period; and (3) high genetic variation in traditional seedling rootstocks, irregular crop yields, and a lack of mechanized post-harvest processing facilities. Research from SKUAST-Kashmir and ICAR-CITH offers practical solutions to these issues. Late-blooming cultivars like Waris, Makhdoom, and Shalimar flower 15-20 days later than local varieties, allowing them to escape spring frosts. Additionally, introducing self-fertile scions reduces the risks associated with poor insect pollination during cold weather. Clonal hybrid rootstocks (such as GF-677 and Garnem) improve tree vigor, resist lime chlorosis, and tolerate drought conditions common in Karewa soils. Shifting to high-density planting configurations (1,250-1,900 trees/ha) combined with drip fertigation can increase average yields from 0.8-1.1 t/ha up to 2.8-3.8 t/ha, while reducing the vegetative juvenile period from 7 years down to 3. Revitalizing the sector requires aligning these field technologies with policy initiatives under the J&K Holistic Agriculture Development Programme (HADP). Key steps include enforcing legal bans on clay mining across the *Karewas*, deploying decentralized hulling machinery, and securing Geographical Indication (GI) certification. Restoring Kashmir's almond production is critical for reducing India's import reliance and protecting fragile Himalayan upland environments.

Key words: *Prunus dulcis*, Karewa tablelands, Late-blooming scions, Clonal rootstocks, High-density orcharding, Phenological mismatch, Value chain governance, HADP

Almond (*Prunus dulcis*) a member of the Rosaceae family is one of the oldest cultivated nut crops in the temperate zones of the Mediterranean, Central Asia and the Himalayas [1]. Almonds were introduced to the Kashmir Valley in the 16th century via trans-Himalayan trade routes adapting well to the temperate microclimates and elevated Karewa tablelands across Pulwama, Budgam, Srinagar and Baramulla districts [2-3]. Almond is an important temperate nut crop of Kashmir, contributing to farm income, rural livelihoods and the region's horticultural economy. Despite favourable agro-climatic conditions, the sector faces challenges associated with ageing and low-yielding seedling orchards, non-descript cultivars, inadequate pollination management, soil moisture deficiencies and suboptimal adoption of recommended cultivation practices

[4-5]. Socio-economic studies from Pampore highlight the influence of farmers resource endowments, information access, extension contact and technology adoption on almond production with many growers demonstrating only a medium level of adoption of recommended practices [6-7]. Research has also demonstrated the potential of improved cultivars, high-density planting, scientific nutrient management, moisture conservation and orchard rejuvenation to enhance productivity and profitability [8-9].

Currently, the almond sector in India presents a significant economic imbalance. Jammu and Kashmir produces more than 90% of the country's domestic almonds, with minor contributions coming from Himachal Pradesh and Uttarakhand [10-11]. Yet, this domestic output covers less than 10% of what

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the country consumes. Driven by rising urban incomes, dietary health trends, and growing industrial food sectors, India's annual in-shell almond imports have surpassed 350,000 metric tons, costing over ₹ 10,000 crore (USD 1.2 billion) in foreign exchange [12-13]. Over 85% of these imports come from large-scale, mechanized orchards in California, alongside growing imports from Australia [14]. In contrast, Kashmir's almond production base has shrunk dramatically. The total cultivation

area dropped from a peak of 26,200 hectares in 2000-2001 to approximately 5,400 hectares in the year 2024-2025 a reduction of nearly 80% (Table 1). Total production fell from 18,300 metric tons to around 6,200 metric tons, while average productivity remains low at 0.80-1.15 tonnes / hectare. This is far below the international averages of 2.80-4.00 tonnes / hectare seen in highly developed producing regions like California and Spain [15-16].

Table 1 Trajectory of almond cultivation, production and yield in Jammu and Kashmir (1995-2025)

Cropping year	Area ('000 ha)	Production ('000 MT)	Productivity (t/ha)	National share (%)	Primary drivers / Sector shifts
1995-1996	20.8	10.4	0.50	98.2%	Traditional rainfed farming; unselected seedling germplasm; local trade.
2000-2001	26.2	18.3	0.70	98.5%	Peak cultivation area; clearing of Karewa plateaus; growth of interstate trade.
2005-2006	22.4	16.8	0.75	97.8%	Early topsoil extraction on Karewas; farmers begin shifting to Red Delicious apple.
2010-2011	18.1	13.9	0.77	96.5%	Expansion of brick kilns; imported Californian almonds dominate retail markets.
2015-2016	12.3	11.2	0.91	94.2%	Introduction of J&K High-Density Apple scheme; removal of old almond groves.
2020-2021	7.8	8.1	1.04	92.6%	Installation of tubewells for apple conversion; recurrent March frost damage.
2024-2025	5.4	6.2	1.15	91.0%	Stabilization of acreage; launch of HADP Nut Mission; field trials of clonal rootstocks.

Sources: Data compiled from Directorate of Horticulture J&K (2024); MoA&FW (2024); ICAR-CITH Annual Reports (2018–2023); SKUAST-K grower surveys

This steady decline has created serious challenges for smallholder farmers, damaged local soil structures, and reduced regional genetic diversity [17-18]. This review organizes the empirical evidence around four core areas: (i) the physical and environmental vulnerabilities of the Karewa tablelands; (ii) market and economic shifts affecting growers; (iii) the crop management and climate challenges limiting field yields; and (iv) modern technical interventions to support recovery.

The present study therefore examines the interrelationships among the socio-economic characteristics of almond growers, major agronomic constraints and emerging technological interventions, including improved cultivars, high-density orcharding, precision nutrient and water management, and rejuvenation of senile orchards. Strengthening farmer training, extension services, market linkages and access to quality planting material is essential for improving productivity, profitability and sustainability. An integrated, farmer-centred approach can help modernize Kashmir's almond sector while enhancing rural livelihoods and resilience to changing climatic conditions.

Environmental profile and Karewa (Wudar) vulnerability

Soil and land characteristics

Almond farming in Kashmir takes place almost exclusively on the Karewa formations, locally called Wudars. These elevated terraces were formed during the Plio-Pleistocene era by lake sediments left behind after tectonic movements altered the ancient Jhelum River basin [19]. Rising 100 to 300 meters above the valley floor floodplains, these plateaus cover large areas in Pulwama, Budgam, Srinagar, and Baramulla [20].

Karewa soils are generally classified as Typic Hapludalfs and Typic Eutrochrepts, featuring loess-paleosol horizons with high silt content (50-70%), moderate clay (15-25%), and low sand content. Soil pH ranges from neutral to moderately alkaline (7.2-8.3), driven by calcium carbonate

(CaCO₃) levels and marl deposits between 4% and 14%. While these soils drain well and protect roots from waterlogging during winter dormancy, they present notable nutritional challenges. Organic carbon in untreated topsoil is low (0.45-0.70%), and phosphorus is frequently locked up in insoluble calcium compounds. The high soil pH also restricts the availability of essential micronutrients like iron (Fe), zinc (Zn), and boron (B), causing frequent leaf chlorosis and poor fruit set [21-22].

Irrigation deficits and rainfed risks

The most critical restriction on the Karewas is the lack of traditional, gravity-fed irrigation systems. Because these plateaus stand far above the regional river systems, over 95% of traditional almond orchards rely purely on rainfall [23]. While the Kashmir Valley receives 650–850 mm of precipitation yearly, the timing does not match the trees' growth stages. Most rain and snow fall between January and April. In contrast, the warmer months of May through July when trees require moisture for cell division, fruit growth, and kernel oil development are frequently dry and hot [24].

During June and July, soil moisture in the primary root zone (0-60 cm depth) often drops below the wilting point. This moisture deficit forces the tree to close its stomata, reducing photosynthesis, increasing premature fruit drop, and cutting final kernel weights by 25-40%. Dry conditions also make the trees more susceptible to wood-boring insects and vascular diseases, speeding up the decline of older orchards [25].

Soil mining and environmental pressures

Alongside natural constraints, human activities have degraded the Karewa landscape. Over the past few decades, large volumes of clay and soil have been excavated from the plateaus for use as fill material in infrastructure projects, such as the Udhampur-Srinagar-Baramulla Rail Link (USBRL) and highway developments [26]. This unregulated soil removal has stripped away the fertile topsoil layers across portions of

Budgam and Pulwama, exposing unproductive subsoils that cannot support deep root growth. Furthermore, more than 350 commercial brick kilns operate on or near these almond-growing plateaus. These kilns use agricultural topsoil for brick production and emit particulate matter, sulfur dioxide (SO₂), and fluorides. The settling of dust and gases on flowering orchards during early spring damages blossoms, reduces pollen germination, and causes leaf damage, further lowering yields in nearby farming clusters [22], [27].

BOX 1: *Agricultural challenges of the plateaus (Karewa)*

Topographical isolation: Elevated tablelands (1,600–1,950 m above sea level) sit far above river irrigation networks, leaving over 95% of orchards dependent on rainfall.

Soil issues: High-silt loess soils have an alkaline pH (7.2–8.3), high calcium carbonate levels (up to 14%), low organic carbon (<0.6%), and frequent zinc and iron deficiencies.

Summer water shortages: Lack of rain during June and July aligns with critical kernel development phases, reducing final fruit weights.

Land degradation: Soil excavation for construction projects and air emissions from over 350 brick kilns hurt spring blossom health.

Socio-economic pressures and market structure

Land conversion dynamics: Shifting to apple production

The main financial reason for the drop in almond acreage is the higher profit margins provided by modern commercial apple orchards. Over the last two decades, apple farming in Kashmir has transitioned toward using semi-dwarf and dwarf clonal rootstocks (such as M.9 and MM.106) paired with high-color spur cultivars (like Red Velox and King Roat) planted at high densities of 1,200 to 3,000 trees per hectare [17], [23].

High-density apple (HDA) systems produce harvestable crops by their second or third year, reaching full production of 30 to 45 t/ha by years five and six. At current market prices, a high-density apple orchard can generate gross annual revenues of ₹18.0 to ₹28.0 lakh/ha, yielding net profits between ₹12.0 and ₹18.0 lakh/ha. In comparison, traditional almond orchards grown from seed at low densities (150–200 trees/ha) take seven to nine years before producing commercial yields. Even at full maturity, these orchards produce only 0.8 to 1.2 t/ha of in-shell nuts, generating small gross returns of ₹1.8 to ₹3.0 lakh/ha and net profits that rarely go over ₹1.2 lakh/ha [28].

Consequently, where growers have installed tubewells or borewells on the plateaus to secure a water supply, they have systematically replaced almond trees with high-density apples. Investment analyses show that the Net Present Value (NPV) of a high-density apple setup on the *Karewas* exceeds ₹38.5 lakh/ha with an Internal Rate of Return (IRR) of 26.4%. Traditional seedling almond groves show a low NPV of ₹4.2 lakh/ha and an IRR of 11.2% [17]. For smallholders managing average plots of 0.45 hectares, shifting to apple production is a necessary economic choice to improve household income.

Value chains and middleman control

Unlike the local apple trade which operates through large fruit markets (mandis) like Sopore and Shopian and is supported by over 300,000 metric tons of private Controlled Atmosphere (CA) cold storage facilities the almond market is highly fragmented and lacks formal regulation [29].

Broker networks: Almond sales rely heavily on village middlemen (Ladhaars) and pre-harvest commission agents. Because smallholders often need immediate cash for household expenses before harvest time, they agree to forward contracts that value their crops at low rates (₹180–₹240/kg in-shell or ₹500–₹650/kg for manually shelled kernels).

Imbalanced margins: Marketing studies in central Kashmir reveal that farmers receive only 38% to 48% of the final retail price. Brokers, aggregators, and wholesale dry-fruit traders in cities like Jammu, Delhi, and Mumbai capture 52% to 62% of the total profit margin without contributing to processing or quality control [18].

Lack of digital trade integration: While platforms like the Electronic National Agriculture Market (e-NAM) are available for primary fruits, almonds and walnuts are rarely traded through them. Without standardized quality metrics or open digital auctions, growers have little price transparency or bargaining power.

Import pressures and quality benchmarks

Kashmiri almonds face strict market competition from uniform foreign imports. Lowered import restrictions have allowed large volumes of Californian almonds (such as Nonpareil, Carmel, and Monterey) to capture major market shares in Indian cities [13]. Imported Californian almonds benefit from fully mechanized harvesting, automated hulling, and automated color sorting. This ensures consistent kernel size, no insect damage, low moisture content (<5.5%), and easy-to-crack shells. In contrast, Kashmiri almonds from traditional seedling orchards vary widely in size, shape, and shell thickness. Furthermore, because these older orchards rely on open-pollinated seedling trees, they occasionally produce bitter kernels containing amygdalin. The presence of even 1–2% bitter nuts in a batch lowers the value of the entire lot, disqualifying it from high-end retail and confectionery markets [3].

BOX 2: *The Kashmiri kernel tradeoff*

Nutritional advantages: Local Kashmiri kernels average significantly higher oil content (52.5% to 56.8%) than Californian Nonpareil varieties (44.0% to 48.5%). Their lipid profiles are high in oleic acid (68–74%), linoleic acid (18–24%), and vitamin E, giving them a richer taste and higher nutritional value.

Commercial drawbacks: Despite their better flavor, local crop lots receive lower wholesale prices due to mixed nut shapes, hard outer shells that require manual cracking, high kernel breakage rates (>15%) during shelling, and a lack of graded sorting. Overcoming this requires automated processing hubs and GI tracking.

Technical and crop management bottlenecks

Weather shifts, early blooming, and frost vulnerability

Almond has the lowest chilling requirement among temperate fruits grown in the western Himalayas, typically needing only 250–550 chilling hours below 7.2°C [1], [30]. Consequently, it is the first deciduous fruit tree to break dormancy at the end of winter. As average winter temperatures in the northwestern Himalayas have increased by 1.2°C to 1.6°C in recent decades, the almond flowering window has moved forward. Warm weather in mid-to-late February prompts early sap flow, leading to full blooms by late February

or early March [24]. This early blooming pattern exposes the crop to severe weather risks. March weather in Kashmir regularly brings Western Disturbances, causing sudden freezing snaps, cold rains, and wet snow. Almond blossoms and young fruitlets sustain tissue damage at temperatures between -1.5°C and -2.2°C. A single freezing night during full bloom can wipe out 80% to 100% of the potential harvest across whole farming districts [23]. Additionally, cold rain and temperatures below 12°C prevent local honeybees (*Apis mellifera* and *Apis cerana* Indica) from foraging. Because traditional cultivars are self-incompatible and require cross-pollination, poor weather during bloom prevents fertilization, leading to high fruit drop and crop failure [29].

Variations in seedling rootstocks

A central weakness of traditional Kashmiri almond groves is the historical reliance on unselected, open-pollinated seedling rootstocks. Orchards were frequently set up by planting sprouted seeds gathered from mixed commercial nut lots. Because almond is a highly heterozygous, cross-pollinated crop, growing it from seed causes significant genetic variation in the resulting trees [31]. This genetic variation means that trees within the same orchard show wide differences in growth vigor, flowering dates, final yield, shell hardness, and nut size. This makes standard management and synchronized harvesting very difficult. Furthermore, seedling taproots produce very few shallow lateral feeder roots, reducing the tree's ability to take up nutrients and moisture from dry surface soils. These seedling trees are also highly susceptible to common soil diseases like crown gall (*Agrobacterium tumefaciens*), collar rot (*Phytophthora cactorum*), and root rot in heavy clay soils [28], [32].

Pests and chronic diseases

Older orchards face ongoing pressure from several key pests and diseases:

Fungal field diseases: Leaf curl (*Taphrina deformans*) causes twisted leaves and early leaf drop during damp springs. Shot hole (*Wilsonomyces carpophilus*) leaves spots on leaves and young nuts, causing sap bleeding and weakening fruit spurs. Brown rot (*Monilinia laxa*) attacks open blossoms during rainy weeks, leading to twig blight.

Bacterial canker (*Pseudomonas syringae*): This bacterium enters the tree through bark injured by winter freezes, causing severe gumming, branch dieback, and canopy loss.

Insect pressures: San Jose scale (*Quadraspidiotus perniciosus*) weakens limbs and mars fruit appearance; peach curl aphids (*Brachycaudus helichrysi*) stunt new spring shoots; and flat-headed borers (*Sphenoptera laferiei*) tunnel into the trunks of drought-stressed trees, destroying vascular tissue and killing mature trees.

Technical interventions and modernization

Late-blooming cultivars to avoid frost

To protect the crop from late spring freezes, orchards should use scion cultivars that stay dormant through February and early March. Selective breeding efforts by SKUAST-Kashmir and ICAR-Central Institute of Temperate Horticulture have identified several excellent selections that flower 15 to 22 days later than local varieties. This shifts the main bloom period into late March or early April, when the risk of freezing temperatures drops below 5% [3], [30].

Table 2 Characteristics of recommended almond cultivars for Kashmir

Cultivar / Selection	Flowering window	Shell type	Shelling recovery (%)	Expected yield (t/ha)	Key agricultural traits
Waris	Late March	Intermediate / Soft	46-49%	2.2-2.8	Upright growth habit; fits high-density grids; strong spur replacement.
Makhdoom	Mid-to-late March	Soft shell	40-44%	2.1-2.6	Spreading canopy; good cold tolerance; reliable annual production.
Shalimar	Mid-to-late March	Paper shell	50-54%	2.0-2.5	Excellent kernel recovery; clean, light shell; high commercial grade.
Parbat	Late March	Medium soft	42-45%	1.9-2.3	Cold tolerant; functions well as a synchronized pollinizer for Waris.
Pranyaj	Late March	Soft shell	44-47%	2.0-2.4	Selection from ICAR-CITH; resists shot hole; uniform, full kernels.
Tuono / Guara	Late to very late	Semi-hard to Hard	32-38%	2.8-3.5	Self-fertile variety; sets good crops without needing bee pollination.

Sources: Data compiled from SKUAST-K Division of Fruit Science and ICAR-CITH Variety Evaluation Bulletins (2020-2024)

Cultivars that carry self-fertility genes (such as Tuono and Guara) work independently of insect pollinators. This ensures reliable fruit set even when cold spring rains limit bee flight [1].

Clonal rootstocks and modern trellising

Replacing unpredictable seedling rootstocks with uniform, tested clonal hybrid rootstocks brings clear improvements in tree growth, orchard uniformity, and stress resistance:

GF-677 (*Prunus persica* × *Prunus amygdalus*): A vigorous, deep-rooted rootstock that performs exceptionally well in alkaline and calcareous soils (handling up to 12% active lime). GF-677 improves iron and zinc uptake, preventing lime-induced yellowing on Karewa soils [3], [33].

Garnem (*P. dulcis* × [*P. persica* × *P. davidiana*]): Red-leaved hybrid rootstocks that resists root-knot nematodes (*Meloidogyne spp.*), provides strong tree vigor, and helps trees begin bearing fruit early when paired with drip irrigation.

High-density planting (HDP): Pairing these clonal rootstocks with central-leader or 2D planar canopy training systems at tight spacings such as 4.0 × 2.0 m (1,250 trees/ha) or 3.5 × 1.5 m (1,900 trees/ha) allows growers to secure commercial harvests by the third year. Full production can reach 3.0 to 3.8 t/ha by years five and six.

Micro-irrigation and proportional fertigation

Although almond trees can withstand mild drought, securing profitable yields requires adequate soil moisture during early fruit expansion (April-May) and kernel

development (June-July). Solar-powered lift-drip irrigation systems pumping water up to the Karewa plateaus can cut water consumption by 55% compared to traditional flood methods, while supplying liquid nutrients straight to the active root zones [21]. Applying water-soluble nitrogen, potassium, and targeted micronutrients (such as foliar zinc and boron before bloom) improves kernel weights and reduces double-kernel defects.

Pollination adjustments and active frost defense

Placing 4 to 6 strong colonies of *Apis mellifera* bees per hectare when orchards reach 10% bloom ensures thorough cross-pollination in self-incompatible varieties [18]. For frost

protection, micro-sprinklers running over the canopy or at ground level during freezing nights release latent heat as the water freezes, protecting delicate flower parts down to -3.0°C. Additionally, applying foliar sprays of potassium silicate, zinc, or brassinosteroids before forecasted cold spells helps protect plant cell membranes from ice damage [30].

Structural comparison: Traditional vs. high-density systems

To show the practical differences between old orchard management styles and modernized systems, (Table 3) compares key technical and production parameters and modernized high-density almond production systems

Table 3 Comparison of traditional seedling and high-density clonal almond systems

System parameter	Traditional rainfed seedling system	Modern intensive high-density system
Tree density	Low: 150–200 trees/ha (7.0 × 7.0 m spacing)	High: 1,250–1,900 trees/ha (4.0 × 2.0 m or 3.5 × 1.5 m)
Rootstock material	Variable, open-pollinated seedling pits	Uniform, clonal hybrid rootstocks (GF-677, Garnem)
Scion phenology	Early blooming (late Feb–early March; high frost risk)	Late blooming (late March; escapes frost) or self-fertile
Canopy architecture	Unpruned open vase; thick interior; poor light penetration	2D planar cordon or central leader grown on trellis wires
Water management	100% rainfed; severe moisture deficits in June and July	Automated drip irrigation and targeted fertigation
Time to first yield	6 to 8 years after planting	2 to 3 years after planting
Age at full production	10 to 12 years	5 to 6 years
Nut yield (In-shell)	Low: 0.8 to 1.1 t/ha	High: 2.8 to 3.8 t/ha
Kernel uniformity	Uneven; mixed shell thickness; occasional bitter nuts	High uniformity; soft/paper shells; no bitter nuts
Net financial return	Low and Volatile: ₹0.8 to ₹1.4 lakh/ha/year	Stable: ₹6.5 to ₹9.5 lakh/ha/year

Policy frameworks and strategic roadmap

Integrating government support: HADP and MIDH

Rebuilding Kashmir's almond sector requires backing new field technologies with coordinated financial and policy programs. Under the J&K Holistic Agriculture Development Programme (HADP, 2023-2028), specific funds are set aside for nut crop development [34]. Combining HADP resources with the Mission for Integrated Development of Horticulture (MIDH) and PMKSY micro-irrigation grants can provide smallholders with 50% to 70% subsidies to cover the costs of certified clonal rootstocks, drip irrigation kits, and trellis materials.

Legal protection for Karewa soils

Technical changes will have little impact if the underlying soil base continues to erode. The local administration must strictly enforce land-use zoning rules to prevent the excavation of Karewa top soils for infrastructure projects. Environmental policies should also require local brick kilns to move away from primary fruit-growing zones or adopt cleaner zigzag firing setups with emission filters to safeguard spring blossom health [35].

Processing centers and GI branding

To handle the challenges of manual cracking and reduce kernel breakage rates, government bodies and local businesses should establish regional post-harvest processing hubs in major almond production zones like Pulwama, Chadoora, and Tral. Equipping these hubs with mechanical hullers, controlled drying bins, and optical sorting machines will help keep kernel breakage below 3% while enabling standard size grading. Importantly, securing Geographical Indication (GI) certification for Kashmiri almonds focusing on their high oil content (52-56%), elevated vitamin E levels, and sweet taste

will help distinguish local harvests from generic imported nuts, allowing growers to earn a 25% to 40% price premium in premium markets.

Farmer collectives and digital sales

Organizing smallholders into almond-focused Farmer Producer Organizations (FPOs) will help aggregate crop volumes, bypass local middleman networks, and allow direct sales to large confectionery brands, healthy food companies, and online marketplaces. Connecting these FPOs with the electronic National Agriculture Market (e-NAM) using certified quality testing will create more transparent, competitive pricing for growers.

Research priorities and future needs

To ensure the long-term success of modern almond farming in Kashmir, agricultural research should focus on several clear practical gaps:

Rootstock compatibility trials: Long-term field studies to check the graft compatibility, structural stability, and nutrient uptake of local scions (like Waris and Makhdoom) on hybrid clonal rootstocks (GF-677, Garnem) across various Karewa soil types.

Breeding for frost tolerance: Using marker-assisted selection to target late-blooming traits (Lb) and self-fertility genes (Sf) to breed resilient cultivars suited to changing Himalayan Spring weather.

High-density pruning guidelines: Creating clear summer and winter pruning schedules for 2D trained trees to optimize sunlight capture and allow for easier harvesting in hillside orchards [36].

Economic analysis models: Detailed lifecycle cost modeling to help smallholder farmers manage the financial shift from traditional setups to high-density almond or apple systems under local climate conditions.

CONCLUSION

Kashmir's almond sector is at a critical juncture, characterized by a substantial decline in cultivation area and production, low productivity, increasing climatic risks, and growing competition from imported almonds and alternative horticultural crops. The review highlights that the sector's challenges extend beyond conventional agronomic limitations to include the degradation of Karewa soils, inadequate irrigation facilities, frost-induced crop losses, ageing and genetically heterogeneous orchards, inefficient marketing channels, and limited adoption of improved cultivation technologies. Although Kashmiri almonds possess distinctive nutritional and quality attributes, their commercial potential remains underutilized because of inconsistent nut characteristics, inadequate post-harvest processing, limited value addition, and weak market integration. Revitalizing the sector requires an integrated strategy involving the adoption of

late-blooming and self-fertile cultivars, suitable clonal rootstocks, high-density planting systems, precision irrigation and fertigation, scientific pollination management, and systematic orchard rejuvenation. Equally important are the conservation of Karewa landscapes, strengthening of farmer training and extension services, establishment of modern processing and grading facilities, promotion of Farmer Producer Organizations (FPOs), and improved access to transparent digital markets and premium branding opportunities. Government initiatives such as the Holistic Agriculture Development Programme (HADP) and the Mission for Integrated Development of Horticulture (MIDH), supported by region-specific research and effective policy implementation, can facilitate this transition. Future research should prioritize the long-term evaluation of rootstock–scion combinations, climate-resilient cultivars, high-density orchard management, and the economic feasibility of modern production systems for smallholders. Ultimately, a coordinated, farmer-centred, and environmentally sustainable approach is essential to restore almond cultivation in Kashmir, improve farm profitability, conserve the ecological and genetic resources of the Karewa tablelands, and strengthen the region's competitiveness in the domestic almond market.

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