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Soybean Cultivation in Afghanistan: A Review of Varietal Adaptability, Agronomic Practices, and Food Security Opportunities

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ABSTRACT: Soybean (Glycine max L.) is a globally important legume and oilseed crop, valued for its high protein and oil content as well as its role in sustainable agriculture through biological nitrogen fixation [12,8]. Despite its global significance, soybean adoption in Afghanistan remains limited, with cereal-based systems dominating production and contributing to nutritional deficiencies and soil fertility decline [13]. Introducing soybean into Afghan farming systems offers opportunities to diversify production, enhance food security, and restore soil health [2,15].

This review synthesizes global advances in soybean research—including genomics, multi omics, and climate resilient breeding strategies [20,22,33]—alongside regional experiences from South Asia and localized trials in Afghanistan [25,26,30,34]. Evidence from Pakistan [25,31], India [26,32], Bangladesh [30,24], and Iran [34] demonstrates soybean's potential to improve soil fertility, strengthen climate resilience, and meet rising demand for protein rich food and feed [24,25,26,30,34]. Afghan specific trials in Kabul Province have identified promising varieties such as LD109168, LD0910911, Stine30E32, and which achieved yields above 2,500 kg ha^{-1} under semi-arid conditions [1,7,9]. However, adoption remains constrained by weak seed systems, limited farmer awareness, and underdeveloped processing infrastructure [30].

By integrating global lessons with Afghan realities, this review highlights soybean's potential as a strategic crop for food security and sustainable agriculture under semi-arid conditions, while underscoring the need for investment in seed systems, extension services, and processing industries [5].

KEYWORDS: Soybean adoption, varietal adaptability, food security, climate resilience and soil fertility

INTRODUCTION

Soybean (Glycine max L.) is globally recognized as one of the most important leguminous and oilseed crops, cultivated on more than 120 million hectares and producing over 350 million metric tons annually [3,4]. Its seeds contain approximately 35–42% protein and 18–22% oil, making soybean a cornerstone of both human nutrition and livestock feed systems [11]. Beyond its nutritional role, soybean contributes significantly to global trade, biofuel production, and sustainable agriculture through biological nitrogen fixation [12,8].

Yet in Afghanistan, soybean remains under researched and cultivation is still limited. The country's agricultural system is dominated by cereals such as wheat and maize, which provide caloric security but insufficient protein diversity [13]. This imbalance has contributed to nutritional deficiencies, soil fertility decline, and economic vulnerability. Introducing soybean into Afghan farming systems offers opportunities to diversify production, enhance dietary protein intake, and improve soil fertility through nitrogen fixation [2,15].

Kabul Province, located in the central highlands, exemplifies both the challenges and potential of soybean cultivation. Its semi-arid continental climate—marked by cold winters, hot summers, and annual rainfall of 300–400 mm—creates constraints for crop performance [10]. Early autumn frosts shorten the growing season, making late maturing varieties unsuitable, while highlighting the importance of early maturing and stress resilient genotypes such as and LD109168 that have shown adaptability under these conditions [1,9]. Nevertheless, Kabul's irrigated lands and rising demand for protein rich crops make soybean a promising candidate for diversification [7,9].

Recent varietal trials conducted at Kabul University and the Ministry of Agriculture, Irrigation and Livestock (MAIL) have identified suitable genotypes such as, LD109168, Stine30E32, and LD0910911 [1]. These localized studies provide critical evidence

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for varietal adaptability under semi-arid conditions, addressing a long-standing knowledge gap. However, adoption remains constrained by limited seed availability, weak extension services, and underdeveloped processing infrastructure [30,25].

Globally, advances in genomics, multi omics, and climate resilient breeding strategies are reshaping soybean research [20,22,33]. Integrating these innovations into Afghan agriculture could accelerate soybean adoption and strengthen food security. At the same time, global trade dynamics highlight the strategic importance of soybean in addressing sustainability challenges, from deforestation to inequality [36].

This review synthesizes global and regional literature on soybean cultivation, highlights Afghanistan's unique challenges, and discusses opportunities for varietal adaptability under semi-arid conditions. By bridging localized trials with global advances, the article provides evidence-based recommendations for farmers, policymakers, and researchers to promote soybean as a strategic crop for Afghanistan's agricultural sustainability.

LITERATURE REVIEW

Global Importance of Soybean: Soybean is cultivated worldwide as a dual-purpose crop, providing both protein and oil. Recent reviews emphasize its role in food security, livestock feed, and industrial applications [3,4]. Advances in genomics and physiology have highlighted soybean's yield potential and adaptability under diverse agroecological conditions [12]. Multi omics approaches, including genomics, metabolomics, and bioinformatics, are increasingly applied to improve resilience against drought, heat, and pests [20,22].

Agronomic Practices and Soil Fertility: Soybean enhances sustainability via biological nitrogen fixation [2,15]. Integrated nutrient management strategies have been shown to optimize yield and soil health [18]. Crop rotations with cereals further improve soil organic matter and resilience to climate stress [19,13].

Climatic Challenges and Adaptability: Semi-arid regions face constraints such as water scarcity, heat stress, and frost risk. Global studies confirm that drought and heat during flowering and grain filling reduce pod set and seed weight [10,23]. Breeding programs are increasingly focused on developing drought tolerant and early maturing varieties suitable for short growing seasons [21,26]. Genotype × environment interactions remain critical for yield stability, particularly in regions with variable rainfall and temperature extremes [23].

Regional Studies in South Asia: South Asia has emerged as a key region for soybean expansion. In Pakistan, varietal trials under semi-arid conditions have demonstrated yield improvements through optimized rotations and irrigation practices [25,31]. In India, soybean-based cropping systems have been promoted for climate resilience and soil fertility enhancement [26,32]. Bangladesh has explored soybean adoption for poultry feed and food security, though constraints in seed systems and farmer awareness remain [30,24].

Global Trade and Policy Dimensions: Soybean is also central to global trade, with demand driven by livestock feed and edible oil industries. Recent analyses highlight sustainability challenges, including deforestation, inequality, and food security concerns linked to expanding soybean trade [36]. Policy frameworks and corporate sustainability initiatives are increasingly shaping soybean's role in global markets, underscoring the need for balanced strategies that integrate productivity with environmental stewardship.

Knowledge Gaps: While global advances in genomics, agronomy, and trade provide valuable insights, Afghanistan specific research remains limited. Localized varietal trials [1,7,9] are beginning to fill this gap, but multi season and multi-location studies are needed to validate adaptability across diverse agroecological zones. Integration of global innovations into Afghan agriculture could accelerate adoption, but requires investment in seed systems, extension services, and processing infrastructure.

MATERIALS AND METHODS

This review article was developed through a structured synthesis of recent literature on soybean cultivation, varietal adaptability, and agronomic practices under semi-arid conditions. The methodology followed three key stages: source identification, selection criteria, and thematic analysis.

Source Identification: Relevant publications were identified through searches in international databases including Scopus, Web of Science, PubMed, and Google Scholar, as well as institutional repositories such as FAO, UNDP, ICRISAT, and MAIL. Keywords included *soybean, semi-arid cultivation, Afghanistan, South Asia, varietal adaptability, nitrogen fixation,* and *food security*.

Additional references included Afghan university theses and institutional reports, specifically to capture localized evidence on varietal performance and farmer practices that are often absent from international databases.

Selection Criteria: To ensure relevance and currency, only publications from 2020 to 2025 were included, except for foundational works that remain widely cited in agronomy. Studies were selected if they met one or more of the following criteria:

1. Soybean yield and physiology under stress conditions.
2. Varietal trials or genotype × environment (G×E) interactions.
3. Soybean's role in food security, soil fertility, or agro-industrial development.
4. Regional insights from South Asia (India, Pakistan, Iran, Bangladesh) or localized Afghan studies.

Thematic Analysis: Selected sources were categorized into thematic areas:

- Global importance and physiology (yield potential, protein/oil content, nitrogen fixation).
- Agronomic practices and soil fertility (rotations, nutrient management, integrated systems).
- Climatic challenges and varietal adaptability (drought, heat, frost, photoperiod sensitivity).
- Regional studies in South Asia.
- Afghan-specific trials and policy context.
- Global trade and sustainability dimensions (market drivers, deforestation, inequality).

This thematic framework allowed for systematic comparison between global advances and Afghanistan's local realities. The synthesis emphasized evidence-based recommendations for varietal selection, agronomic management, and policy integration.

Limitations: As a literature-based review, this study is limited by the availability of published data. Afghan-specific research remains scarce, with most evidence derived from single-season trials. Future work should incorporate multi-location, multi-season studies and integrate genomic and climate-resilient breeding approaches to strengthen soybean adoption strategies in Afghanistan.

RESULTS AND ANALYSIS

Global Findings: Recent global reviews confirm soybean's dual role as a source of protein and oil, while also contributing to sustainable agriculture through nitrogen fixation [15,16]. Advances in genomics, multi-omics, and bioinformatics have accelerated breeding for drought and heat tolerance [20,22]. Yield potential is strongly influenced by genotype × environment (G×E) interactions, with photoperiod sensitivity and climatic stress being critical determinants of adaptability [12,23].

Agronomic Practices: Integrated nutrient management and crop rotations consistently improve soybean productivity and soil fertility. Evidence from multiple regions shows that rotations with cereals such as wheat and maize enhance organic matter and microbial activity, strengthening resilience against climatic stress [2,15,18]. Sustainable cropping systems, including organic and integrated management, are increasingly promoted as climate-smart strategies [21].

Climatic Constraints: Semi-arid regions face significant yield limitations due to water scarcity, heat stress during flowering, and frost risk during maturity. Global studies demonstrate that drought reduces pod set and seed weight, while heat stress lowers grain filling efficiency [10,26]. Breeding programs have responded by developing early-maturing and stress-tolerant varieties, though trade-offs between yield potential and resilience remain [32].

Regional Insights (South Asia):

- **Pakistan**: Varietal trials under semi-arid conditions show yield improvements when soybean is integrated into rotations and supported with irrigation [14,31].
- **India**: Soybean-based cropping systems have been promoted for climate resilience, with varietal adaptability studies highlighting the importance of photoperiod sensitivity [26,32].
- **Bangladesh**: Adoption is driven by demand for poultry feed, but constraints include limited seed systems and farmer awareness [30,24].
- **Iran**: Soybean cultivation faces challenges of water scarcity and limited infrastructure, though varietal adaptability studies show promise [34].

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Table 1. Regional soybean yields in South Asia

Country	Average yield (kg ha^{-1})	Adoption level	Key constraints	Opportunities
Afghanistan	2,568–2,850	Low (pilot trials)	Weak seed systems, limited farmer awareness	Diversification, food security, soil fertility improvement
Pakistan	2,500–3,000	Moderate	Water scarcity, limited extension services	Integration into rotations, yield stability
India	2,200–2,800	High	Climate stress, photoperiod sensitivity	Climate-resilient cropping systems
Bangladesh	2,000–2,400	Emerging	Seed availability, farmer awareness	Poultry feed demand, food security potential
Iran	2,100–2,600	Low	Water scarcity, infrastructure gaps	Varietal adaptability, irrigated expansion

This comparison underscores that Afghanistan's yield potential is equal to or better than its neighbors, but adoption lags due to institutional and infrastructural weaknesses.
Localized trials at Kabul University and MAIL research farms identified promising varieties such as LD109168, LD0910911, Stine30E32, and, which demonstrated grain yields between 2,568–2,850 kg ha^{-1} under Kabul's semi-arid conditions [1,10,9].

Table 2. Soybean varietal performance under semi-arid conditions in Afghanistan

Variety	Yield (kg ha^{-1})	Maturity group	Adaptability traits
	2,568	Medium (96–105 days)	Early maturity, frost tolerance
LD109168	2,850	Medium	High yield stability, semi-arid adaptability
STINE30E32	2,720	Medium	Good pod set under heat stress
LD0910911	2,640	Medium	Balanced protein content, drought resilience

Table 3. Soybean varieties characterized in Afghanistan (FAO Catalogue, 2023)

VARIETY	ORIGIN	YIELD POTENTIAL (KG HA^{-1})	PROTEIN %	OIL %	DISTINCT TRAITS
GETWAY 8711	USA	2,300	26.3	27.0	Violet flowers, purple hypocotyl, dull luster
STINE 3400	USA	2,500	27.0	25.0	Brown-black pods, grey hairs, intermediate gloss
HWANGKEUM	Korea	2,600	38.0	20.0	Yellow testa, shiny luster, large spherical seeds
DEWAN	Korea	2,450	34.0	21.0	Medium seed size, drought tolerance
LD04-11056	USA	2,550	33.5	22.0	Medium brown testa, semi-erect growth
LD02-4485	USA	2,480	32.0	21.5	Grey pubescence, balanced protein content
LD04-13265	USA	2,600	34.2	20.5	Yellow hilum, bright seed gloss
LD05-1540	USA	2,520	33.0	21.0	Medium seed size, frost resilience
LD09-30224	USA	2,650	34.5	21.5	Medium brown testa, drought resilience
LD10-9168	USA	2,700	35.0	22.0	Strong pod set, semi-arid adaptability
STINE 30E32	USA	2,720	35.0	22.0	Good pod set under heat stress
STINE 29E22	USA	2,680	34.0	21.5	Large seed size, high yield stability

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The FAO catalogue confirms Afghanistan's access to diverse soybean germplasm imported mainly from the USA and Korea. Varieties such as Hwangkeum stand out for their high protein content (38%), while Getway 8711 offers the highest oil content (27%). Stine 30E32 and LD109168 demonstrate strong yield potential above 2,700 kg ha^{-1}, coupled with resilience under heat and semi-arid stress. LD09-30224 and Dewan provide drought tolerance, while LD04-13265 and LD05-1540 offer frost resilience and stable seed traits.

This characterization strengthens the case for soybean's role in food security, dietary diversification, and climate resilience in Afghanistan. By strategically selecting varieties based on nutritional priorities—protein enrichment for human diets or oil extraction for agro-industrial use—Afghanistan can leverage this genetic diversity to address malnutrition, improve soil fertility, and reduce dependence on imports.

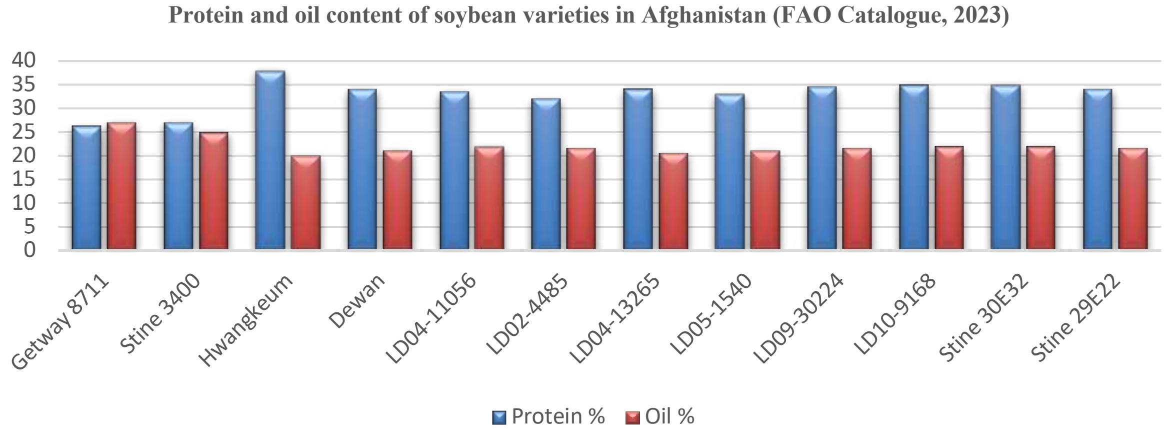

Figure 1. Protein and oil content of soybean varieties in Afghanistan (FAO Catalogue, 2023).

The figure highlights the nutritional trade-off among varieties: Hwangkeum for protein enrichment (38%) and Getway 8711 for oil extraction (27%), with balanced options such as LD109168 and Stine 30E32 (≈35% protein, 22% oil). This diversity underscores Afghanistan's opportunity to select varieties strategically for either dietary protein or edible oil production.

- **High-protein varieties**: Hwangkeum (38%), LD10-9168*,* Stine 30E32, and LD09-30224 (34–35%), valuable for food security and dietary diversification.
- **High-oil varieties**: Getway 8711 (27%) and Stine 3400 (25%), suitable for edible oil production.
- **Balanced varieties**: Several lines, including LD04-13265 and LD05-1540, combine moderate protein (33–34%) with oil content around 21%, offering dual benefits for both food and feed.

This diversity underscores Afghanistan's opportunity to strategically select varieties depending on nutritional priorities — protein enrichment for human diets or oil extraction for agro-industrial use. By leveraging this genetic diversity, soybean can contribute to climate resilience, soil fertility improvement, and reduced dependence on imports.

Afghan Varietal Trials: Trials conducted in 2023 demonstrated yields above 2,500 kg ha^{-1} across all tested varieties, confirming soybean's adaptability under Kabul's semi-arid conditions [1]. LD109168 was the highest-yielding variety (2,850 kg ha^{-1}), showing strong yield stability and semi-arid adaptability. (2,568 kg ha^{-1}) matured early (96–105 days) and exhibited frost tolerance, making it suitable for highland regions. Stine30E32 (2,720 kg ha^{-1}) maintained pod set under heat stress, while LD0910911 (2,640 kg ha^{-1}) combined balanced protein content with drought resilience.

These findings highlight clear trade-offs between yield and stress tolerance:

- LD109168 → highest productivity, stable under semi-arid conditions.
- → early maturity, frost resilience for highland zones.
- Stine30E32 → strong pod set under heat stress.
- LD0910911 → balanced protein, drought resilience.

Together, these results provide empirical evidence of varietal adaptability in Afghanistan and support soybean's potential expansion across diverse agro-ecological zones.

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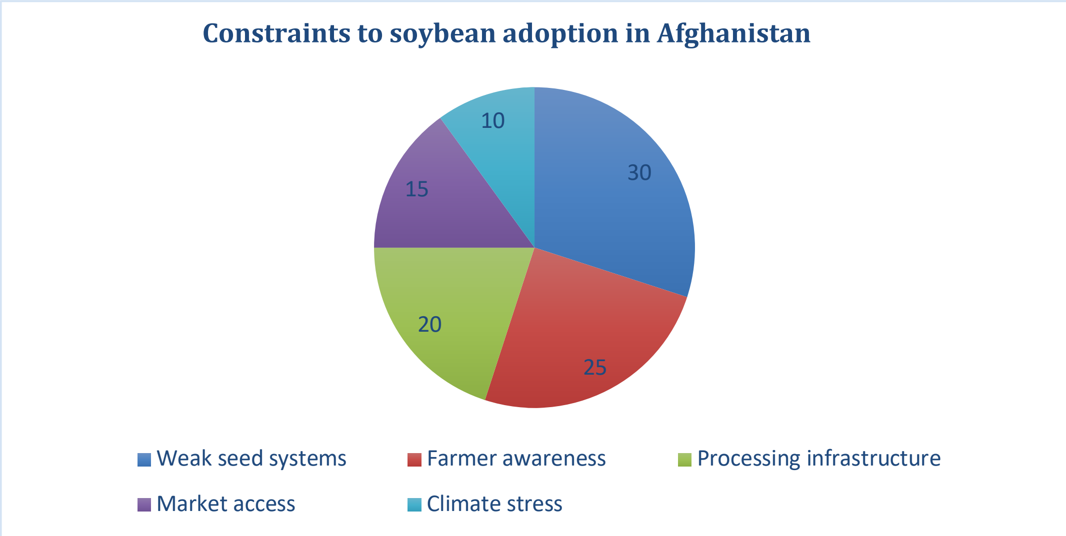

Figure 2. Constraints to soybean adoption in Afghanistan:

Weak seed systems (30%) and limited farmer awareness (25%) are the most significant barriers. Processing infrastructure (20%) and market access (15%) also limit adoption, while climate stress (10%) plays a smaller role compared to systemic issues. These findings emphasize that institutional and infrastructural weaknesses outweigh environmental constraints, underscoring the need for investment in seed systems, extension services, and value-chain development.

Trade and Policy Dimensions: Global trade analyses highlight soybean's strategic role in food security and sustainability, but expansion has been linked to deforestation and inequality [36]. For Afghanistan, integrating soybean into national food security strategies could reduce dependence on imports of edible oil and protein products, while supporting agro-industrial development. Policy frameworks must ensure that expansion is environmentally sustainable and socially inclusive, aligning productivity goals with climate resilience and equity.

Table 4. Comparative soybean performance in Afghanistan, South Asia, and global averages

Region	Yield (kg ha^{-1})	Protein %	Oil %	Adoption level
Afghanistan	2,568–2,850	26–38	20–27	Low (pilot trials)
Pakistan	2,500–3,000	30–35	18–22	Moderate
India	2,200–2,800	32–36	18–22	High
Bangladesh	2,000–2,400	30–34	18–21	Emerging
Iran	2,100–2,600	31–35	19–22	Low
Global average	2,800–3,200	35–42	18–22	High

Afghanistan's soybean yields (2,568–2,850 kg ha^{-1}) are comparable to those of Pakistan and slightly higher than India and Bangladesh, despite its low adoption level. Protein content (26–38%) overlaps with global averages, while oil content (20–27%) remains consistent with international standards. Globally, soybean averages 2,800–3,200 kg ha^{-1} with high adoption, underscoring Afghanistan's potential to catch up if systemic constraints—particularly weak seed systems, limited farmer awareness, and underdeveloped processing infrastructure—are addressed.

This comparison highlights that Afghanistan's biological potential is not the limiting factor; rather, institutional and infrastructural weaknesses are the primary barriers. Addressing these systemic issues could enable Afghanistan to align with regional and global performance benchmarks, while simultaneously advancing food security, dietary diversification, and climate resilience.

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DISCUSSION

The synthesis of global, regional, and Afghan-specific studies highlights both the promise and constraints of soybean cultivation under semi-arid conditions. Globally, soybean has demonstrated remarkable adaptability through advances in genomics, multi-omics, and agronomic innovations [20,22]. These approaches have produced varieties with improved drought and heat tolerance, offering lessons for Afghanistan's climate-challenged agriculture. However, translating these advances into local practice requires robust seed systems, farmer training, and institutional support.

Global Lessons for Afghanistan: International evidence confirm that soybean can thrive in semi-arid regions when supported by appropriate rotations, irrigation, and nutrient management [2,18]. Early-maturing varieties are particularly suited to environments with short growing seasons and frost risk [21,26]. These findings suggest that Afghanistan should prioritize varietal selection based on photoperiod sensitivity and stress resilience, while simultaneously investing in extension services to disseminate best practices.

Regional Relevance: South Asian experiences provide practical parallels. In Pakistan, soybean rotations have improved soil fertility and yield stability under semi-arid conditions [31]. India has emphasized climate-resilient cropping systems, demonstrating how soybean can be integrated into traditional cereal-based systems [26,32]. In Bangladesh, adoption for poultry feed highlights the importance of market demand in driving cultivation [30]. These regional insights underscore that Afghanistan's soybean strategy must align agronomic adaptability with market development and farmer incentives.

Afghan Context: Afghan trials have identified promising varieties such as LD109168, LD0910911, Stine30E32, and Hwangkeum, which achieved yields above 2,500 kg ha^{-1} under Kabul's semi-arid conditions [1,9,10]. While these results are encouraging, they remain limited to single-season trials. Scaling up requires multilocation, multi-season testing to validate performance across diverse agro-ecological zones. Like Pakistan [25,31], Afghanistan's semi-arid trials confirm the importance of rotations and irrigation for yield stability, underscoring that varietal adaptability must be paired with sound agronomic practices to achieve consistent results.

Policy and Trade Implications: Global trade analyses highlight soybean's strategic role in food security and sustainability, but expansion has been linked to deforestation and inequality [36]. For Afghanistan, integrating soybean into national food security strategies could reduce dependence on imports of edible oil and protein products, while supporting agro-industrial development. Policy frameworks must ensure that expansion is environmentally sustainable and socially inclusive, aligning productivity goals with climate resilience and equity. Moreover, Afghanistan could strengthen its agricultural economy by linking soybean production to South Asian feed markets, where demand for protein-rich feed is rising in Pakistan, India, and Bangladesh [25,26,30]. Regional trade integration would not only create market incentives for Afghan farmers but also embed soybean adoption within broader food security and economic cooperation frameworks.

Knowledge Gaps and Future Directions: Despite promising findings, significant gaps remain. Afghanistan lacks comprehensive multi-season varietal trials, climate-resilient breeding programs, and market infrastructure for soybean processing. Future research should focus on:

- Breeding for drought, heat, and frost tolerance.
- Expanding multi-location trials across provinces.
- Strengthening seed systems and extension services.
- Developing processing industries for oil, flour, and feed.
- Aligning soybean adoption with national food security and climate resilience policies.

CONCLUSION

Soybean cultivation represents both a challenge and an opportunity for Afghanistan's agricultural future. Globally, soybean has proven to be a versatile crop, contributing to food security, livestock feed, and sustainable farming systems through nitrogen fixation and climate-resilient breeding [12,20]. Regional experiences in South Asia demonstrate that soybean can thrive under semi-arid conditions when supported by appropriate rotations, irrigation, and varietal selection [26,31].

Afghan-specific trials have identified promising varieties such as LD109168, LD0910911, Stine30E32, and Hwangkeum, which achieved yields above 2,500 kg ha^{-1} under Kabul's semi-arid climate [1,9,10]. These findings provide critical evidence of adaptability, but adoption remains constrained by weak seed systems, limited farmer awareness, and underdeveloped processing infrastructure.

To unlock soybean's potential, Afghanistan must prioritize:

- Multi-location, multi-season varietal trials to validate adaptability across diverse agro-ecological zones.
- Investment in seed systems and extension services to ensure farmer access and knowledge.
- Integration of global genomic and agronomic innovations into local breeding programs.
- Development of processing industries for oil, flour, and feed to create market demand.
- Policy alignment with national food security and climate resilience strategies.

By bridging global advances with local realities, soybean can become a strategic crop for Afghanistan, addressing nutritional deficiencies, improving soil fertility, and reducing dependence on imports. Coordinated research, supportive policy, and farmer engagement can make soybean cultivation a cornerstone of Afghanistan's agricultural sustainability and climate resilience.

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