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Hippophae spp. (sea buckthorn) value addition for sustainable livelihood generation in the Uttarakhand Himalayan region

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SUPPLEMENTARY MATERIAL

Appendix

Detailed methodology of the review article is given below.

A.1. Research Approach

This review used a qualitative research approach to assess the potential of SBT (*Hippophae spp.*) in fostering sustainable livelihood in the Uttarakhand Himalayan region. By analysing existing literature, case studies, and government initiatives, this review attempted to comprehensively understand SBT's ecological, economic, and commercial significance and how value chain of SBT could be formed in Uttarakhand.

A.2. Data Collection Methods

To ensure a holistic review, data were collected from primary and secondary sources:

A.2.1. Primary sources

Scientific Journals & Articles: Peer-reviewed research papers from databases like Scopus, Google Scholar, Web of Science, and PubMed were analysed. These sources provided insights into SBT's nutritional properties, environmental impact, and its role in soil erosion prevention and nitrogen fixation.

Government Reports & Policy Documents: Policy frameworks, agricultural development schemes, and official reports from ministries and organizations focusing on Himalayan

biodiversity were examined. These documents helped us understand government initiatives like the PM-FME scheme and other financial aids supporting SBT farming.

Case Studies: Successful SBT farming models in Ladakh and Himachal Pradesh were reviewed to draw comparisons with Uttarakhand. Valuable insights from international case studies were also considered. Case studies with indicated employment opportunities, particularly for women, and the impact of value-added SBT products on local economies were selected for the review.

A.2.2. Secondary sources

Books & Conference Proceedings: Scholarly and conference proceedings on medicinal plants, agroforestry, and Himalayan biodiversity were studied to understand the traditional and commercial uses of SBT.

Market & Industry Reports: Data from industry reports on nutraceutical markets, herbal product trends, and agricultural trade were examined to gauge SBT's market potential.

News Articles & Media Reports: Recent developments, government interventions, and private sector involvement in SBT commercialization were gathered from news sources.

A.3. Search strategy and literature scope

This study is a structured narrative review with semi-quantitative prioritization using Relative Weighting Approach, synthesizing varied evidence regarding the potential of SBT for sustainable livelihood generation in Uttarakhand. The literature search was conducted using academic databases: Scopus, Google Scholar, PubMed. To get relevant documents describing botanical science (taxonomy and biochemistry), socio-economics (medicinal-, ecological-, food-, trade-value), and policy analysis (control and permission in resources) of SBT in the Himalayan region (especially in Uttarakhand, Himachal Pradesh, and Ladakh), Boolean logic was used in these databases. For retrieval of documents related to the botanical science of SBT, the following search string was used: ("Hippophae" OR "Sea buckthorn" OR "Seabuckthorn") AND ("Uttarakhand" OR "Himalaya" OR "India") AND ("Livelihood" OR "Economy" OR "Value Chain"). For retrieval of documents explaning socio-economics of SBT, the following search string was used: ("Hippophae" OR "Sea buckthorn") AND ("Soil conservation" OR "Nitrogen fixation" OR "Land restoration") AND ("Himalayan region").

For retrieval of documents performing policy analysis related to SBT, the following search string was used: ("Hippophae" OR "Sea buckthorn") AND ("Market" OR "Nutraceutical" OR "Processing" OR "Industry") AND ("Barriers" OR "Challenges").

Adding to this, the targeted search of government portals like Ministry of Food Processing Industries, Government of India and Institutional websites like, Defence Research and Development Organisation (DRDO) was also performed to get official documents of the government of India, related to SBT agriculture and commercialisation.

The search for documents lasted till 26 July, 2025. This review article includes data from the year 1992 to 2025. This wide time frame was chosen to provide historical context, while placing contemporary research as the primary focus.

A.4. Inclusion and exclusion criteria

As this review article relied on multiple types of sources, a clear set of criteria was applied for the selection of relevant literature.

A.4.1. Inclusion criteria; Sources were included only if they met the following conditions:

- Alignment to the theme; sources discussing biology, cultivation, ethnobotany, commercialisation, ecological role, or policy related frameworks related to SBT.
- Geographical relevance; Sources focusing on Indian Himalayan region, particularly Uttarakhand, Ladakh and Himachal Pradesh. International case studies from countries like China and Russia were also included.
- Source; Only peer reviewed scientific articles, government or institutional reports, scholarly books or chapters, reputable media and market analysis reports were included.
- Language; Only publications in English language were preferred, though some official government reports (being in Hindi Language) with highly relevant data were also included. Unbiased translation of such reports was ensured by comparing translations by all the authors of this review article. Statements from such reports were only used after consensus of all the authors.

A.4.2. Exclusion criteria; Sources excluded if they were:

- Thematically or geographically irrelevant.

- Non-reputed sources, like predatory journals, unverified websites, or personal blogs.
- Inaccessible full text.

A.5. Data Synthesis & Categorization

To effectively analyse SBT's impact, the collected documents were categorized under the following themes:

- Ecological Importance: Data explaining the plant's role in biodiversity conservation, soil stabilization, and nitrogen fixation (12 documents).
- Economic Potential: Data emphasizing on the income generation from SBT-based products, employment opportunities, and its relevance in the nutraceutical and pharmaceutical industries (13 documents).
- Challenges in Cultivation: Data describing the barriers to SBT cultivation, which includes, lack of infrastructure, financial constraints, policy gaps, and limited market accessibility, etc (7 documents).
- Government & Private Sector Initiatives: Data providing analysis of ongoing schemes, investments, and potential policy recommendations for promoting SBT farming in Uttarakhand (12 documents).
- Comparative Analysis: Data drawing comparison between SBT industry of Ladakh and Himachal Pradesh with Uttarakhand's potential for development in SBT industry (11 documents).

It is important to note that, several documents were kept under more than one themes, because of their inter-theme relevance. Other documents were cited to give background, context and supporting evidence in the study. Detailed account of categorisation of collected documents in the above-mentioned themes is given in the Supplementary Table S1.

Supplementary Table S1. Thematic categorisation of literature reviewed for the study

Ref No.	**Reference (Author/ Source, Year)**	**Study region**	**Study type**
Ecological Importance (12 documents)			
4	Lu R, 1992	Himalayas	Report
33	Acharya SO et al., 2010	Trans-Himalayas	Review
8	Kanayama Y et al., 2009	Global	Conference paper

75	Yang FS et al., 2014	North-West China	Research Article
9	Kumar A et al., 2021	Global	Review
10	Bartish IV & Thakur R., 2022	Global	Book Chapter
74	Kolyada N et al., 2021	Russia	Conference paper
25	Dhyani D et al., 2013	Uttarakhand	Research article
34	Negi S & Anand N, 2015	India	Review article
69	Chakraborty A et al., 2017	Uttarakhand	Research article
32	Sharma et al., 2019	Himalayas	Review
60	Singh et al., 2020	Uttarakhand	Research article
Economic Potential (13 documents)			
59	Tomar et al., 2011	Uttarakhand	Bulletin
41	Dhyani et al., 2011	Uttarakhand	Review
5	Zakynthinos G et al., 2015	Global	Review
17	Criste A et al., 2020	Romania	Research article
18	El-Sohaimy SA et al., 2022	India	Research article
19	Kania-Dobrowolska M et al., 2023	Europe	Review
22	Chen Y et al., 2023	Global	Review
23	Wani TA et al., 2016	Global	Review
24	Negi M & Rajani, 2018	Uttarakhand	Research article
62	Dolkar P et al., 2017	Trans-Himalayas	Research article
37	Nawaz MA et al., 2019	Pakistan	Research article
38	Yadav A et al., 2019	Himalayas	Book chapter
36	Fortune Business Insights™, 2025	Global	Market report
Cultivation challenges (7 documents)			
39	Tamchos S & Kaul V., 2019	Ladakh	Review
27	Lamo K & Solanki SPS., 2019	Trans-Himalayas	Review
29	Li G et al., 2015	China	Research article
28	Kumar S & Hole RM, 2021	Uttarakhand	Research article
30	Pareek N et al., 2019	Uttarakhand	Bulletin
61	Sharma N., 2023	Uttarakhand	Research article

67	Husain M et al., 2018	Ladakh	Review
Government and private sector initiatives (12 documents)			
14	Herbal Research & Development Institute, 2016	Uttarakhand	Government report
15	Giri L & Chorol S., 2016	Uttarakhand	Institutional report
42	Ministry of Food Processing Industries-Annual Report, 2023	India	Government report
49	Prime Minister's Formalisation of Micro Food Processing Enterprises Scheme, 2020	India	Policy document
35	Stobdan T & Phunchok T., 2017	Ladakh	Government report
50	Stobdan T et al., 2017	Ladakh	Research article
56	Singh V., 2018	India	Policy roadmap
55	International Centre for Integrated Mountain Development, 2018	Hindu Kush Himalayan Region	Institutional report
53	The Tribune, 2021	India	News article
87	Jagran News, 2023	Ladakh	News article
88	Eenadu Television Bharat, 2023	Uttarakhand	News article
63	Indian Institute of Food Processing Technology, 2020	India	Project report
Comparative analysis (11 documents)			
52	Stobdan T et al., 2011	Ladakh	Book
51	Stobdan T et al., 2012	Ladakh	Book chapter
50	Stobdan T et al., 2017	Ladakh	Review
37	Nawaz MA et al., 2019	Pakistan	Research article
47	Rana RK & Dhailiwal YS, 2022	Himachal Pradesh	Research article
31	Singh R., 2004	Ladakh	Dissertation
27	Lamo K & Solanki SPS., 2019	Ladakh	Review
83	Uttarakhand Agriculture Statistics, 2021	Uttarakhand	Government Report
71	Stevens M & Satterfield T., 2024	Uttarakhand	Research article

39	Tamchos S & Kaul V., 2019	Ladakh	Short communication
84	Yadav VK et al., 2009	Uttarakhand	Book chapter

Abbreviations: ICIMOD, International Centre for Integrated Mountain Development; PM-FME, Pradhan Mantri Formalisation of Micro Food Processing Enterprises; HRDI, Herbal Research and Development Institute; IIFPT, Indian Institute of Food Processing Technology.

A.6. Data validation

The findings were cross verified across different types of sources. For example, findings from peer reviewed articles were cross validated from government or institute reports and vice-versa and it was checked whether both the types of sources come into agreement or not, which enhanced the robustness of the conclusion of this article.

A.7. Impact Level of barriers to SBT commercialisation

Impact level (%) of the key barriers to SBT commercialisation was performed as the primary finding(s) of the quantitative analysis of this review article, by using the 'Relative Weighting Approach'. These finding(s) were integrated in latter sections of this article as qualitative evidence. This method obeyed the following methodology:

A.7.1. Data collection

From the Supplementary Table S1, the key documents which were selected on the basis of the following eligibility criteria:

- Topical relevance: The documents discussing *Hippophae* (SBT) cultivation, value chains, or livelihood generation.
- Geographic Focus: The documents focusing on the socio-economic scenario of Indian Himalayan Region (Ladakh, Himachal Pradesh, Uttarakhand) for comparison.
- Data content: The documents giving explicit statements on challenges faced by farmers or stakeholders.

Documents which did not follow the above-mentioned criteria were excluded, like, documents which were focused on the mountain ranges other than the Himalayan region and the documents with results similar to already selected documents, etc. Any

discrepancy or selection bias was reduced by critical discussion and consensus of the authors.

A.7.2. Barrier identification

Detailed account of study region, study type, barriers reported and rationale behind selection of each document is provided in Supplementary Table S2. Only studies utilised for understanding the ecological and economic impact, cultivation-related challenges, policy issues, governmental initiatives, comparative analysis of Himalayan states (Uttarakhand, Ladakh and Himachal Pradesh) were categorised. It is important to note that, several documents were kept under more than one themes, because of their inter-theme relevance. Studies other than the above were cited to support background and contextual information. From the categorised studies in Supplementary Table S1, 11 key documents were selected for identification and impact assessment of key barriers in SBT commercialisation.

Supplementary Table S2. Screened key documents for key barriers identification in Sea buckthorn (SBT) commercialisation and rationale for inclusion

Ref No.	**Reference (Author/ Source, Year)**	**Study region**	**Study type**	**Rationale**	**Barriers reported**
32	Sharma et al., 2019	Himalayas	Review (Applied ecological-development study of SBT)	Links SBT utilization to ecological restoration and livelihood. Identifies institutional gaps as structural constraints affecting cultivation and commercialisation	Infrastructure shortages; Supply Chain Issues; Market-Awareness Gaps; Propagation hurdles
34	Negi S & Anand N, 2015	India	Review article (Supply chain issues)	Highlights supply chain structure and issues of fruits in	Supply-chain issues

				India	
35	Stobdan T & Phunchok T., 2017	Ladakh	Government report (Value chain development and commercialisation of SBT)	Explains value chain of SBT production. Highlights infrastructure gaps, post-harvest losses and barriers in market development	Infrastructure shortages; supply-chain issues; Market-awareness; Post harvest losses.
39	Tamchos S & Kaul V., 2019	Ladakh	Short Communication (Perspective)	Explains institutional initiatives, and policy issues in SBT commercialisation. Highlights limitations of regulatory support, and implementation of programmes and policies	Policy and regulatory barriers
41	Dhyani et al., 2011	Uttarakhand	Review (SBT related livelihood and development study)	Explains role of SBT in food security and livelihood. Highlights limited market awareness, training and farmers' participation in SBT farming	Market awareness gaps
51	Stobdan T et al., 2012	Ladakh	Book chapter (Ecology and economics of SBT cultivation)	Explains farming potential and ecological constraints in SBT cultivation. Highlights the need	Infrastructure shortages

				of technical and infrastructural support for SBT farming	
52	Stobdan T et al., 2011	Ladakh	Book (Technical report)	Pinpoints national level SBT research and programme implementation. Highlights biotic stress, certification and regulatory hurdles in scaling production and trade	Certification burdens; Policy and regulatory barriers
59	Tomar et al., 2011	Uttarakhand	Bulletin (Policy-resource)	Explains relevance of non-timber forest product (NTFP) based livelihood in Uttarakhand. Highlights limited market awareness of SBT	Market awareness gaps
60	Singh et al., 2020	Uttarakhand	Research article (Field biodiversity study)	Explains SBT distribution and utilisation constraints. Highlights poor market awareness within natives despite natural availability.	Market awareness gaps
61	Sharma N., 2023	Uttarakhand	Research article (SBT-plant pathology, field	Explains disease-related production risks, which affects	Biotic stress; Supply-chain issues; Market

			study)	fruit availability and quality, ultimately limiting supply-chain development	awareness gaps
62	Dolkar P et al., 2017	Trans-Himalayas	Research article (Field research-seed quality/variation in SBT)	Explains variation and stress-related effects on seed physiology and quality in natural SBT populations. Highlights effect of biotic stress on commercialisation of SBT.	Biotic stress

Abbreviations: SBT, Sea buckthorn; MoEF, Ministry of Environment, Forest and Climate Change; DRDO, Defence Research and Development Organisation; MIDH, Mission for Integrated Development of Horticulture; PM-FME, Pradhan Mantri Formalization of Micro Food Processing Enterprises; DIHAR, Defence Institute of High-Altitude Research; NMSHE, National Mission on Sustainable Himalayan Ecosystem; MHWDP, Mid-Himalayan Watershed Development Project; NTFP, Non-Timber Forest Product; ha, hectare.

A.7.3. Scoring of barriers

A.7.3.1. Occurrence (O_i); The occurrence scores were based on the frequency with which a specific barrier was cited across the selected documents, which was calculated by the following formula;

$O_i = N_i/T$

Where N_i is the number of documents (count) that explicitly cite barrier 'i', and T is the total number of documents included (which is 11 in this case). Detailed account is given in Supplementary Table S3.

Supplementary Table S3. Number of studies reporting each barrier (N_i) and Occurrence scores (O_i) of each barrier in SBT commercialisation

Barrier	**References**	**N_i**	**O_i**	**Interpretation**

Infrastructure shortages	32, 35, 51	3	0.27	Reported in several studies
Supply-chain issues	32, 34, 35, 61	4	0.36	Reported frequently
Market awareness gaps	32, 35, 41, 59-61	6	0.55	Reported most consistently
Certification burdens	35, 52	2	0.18	Occasionally reported
Biotic stress	61, 62	2	0.18	Occasionally reported
Propagation hurdles	32	1	0.09	Rarely reported
Post-harvest losses	35	1	0.09	Rarely reported
Policy/regulatory issues	39, 52	2	0.18	Occasionally reported

Abbreviations: SBT, Sea buckthorn; Ni, number of studies reporting each barrier; Oi, occurrence score

A.7.3.2. Severity (S_i); To capture real-world impact, we convened a panel of three experts, which were; Three authors of this study, which were, Yashaswi Singh, Abhishek Kumar, and Swati Singh, as experts, independently scored each barrier as S_{i1}, S_{i2} and S_{i3}, respectively, without prior consultation to minimize bias. The final Severity score (S_i) is the arithmetic mean of individual severity scores by the experts (Supplementary Table S4).

The severity score (S_i) was calculated by the following formula:

$$S_i = \frac{(S_{i1} + S_{i2} + S_{i3})}{3}$$

Inter-expert agreement was reported by Standard deviation (SD) using the following formula:

$$SD_i = \sqrt{\frac{(S_{i1} - S_i)^2 + (S_{i2} - S_i)^2 + (S_{i3} - S_i)^2}{2}}$$

The SD values of severity scores (S_{i1}, S_{i2}, and S_{i3}) of all the experts were generally low (0.03-0.09), indicating good agreement among the experts.

Supplementary Table S4. Individual Severity Scores (S_{i1-3}), Mean Severity Score, Standard deviations (SD) and Rationale for scoring of each barrier

Barrier	**S_{i1}**	**S_{i2}**	**S_{i3}**	**S_i**	**SD**	**Rationale (Expert)**
Infrastructure shortages	0.88	0.90	0.77	0.85	0.07	Absence of cold chain logistics (Yashaswi Singh); Lack of mechanical harvesting tools (Abhishek Kumar); Shortage of irrigation networks (Swati

						Singh)
Supply-chain issues	0.70	0.75	0.70	0.72	0.03	Lack of high yielding SBT varieties (Yashaswi Singh); High biochemical instability of SBT (Abhishek Kumar); Inaccessibility of locals to natural SBT populations (Swati Singh).
Market awareness gaps	0.70	0.75	0.70	0.72	0.03	Poor market linkages for small SBT farmers and traders (Yashaswi Singh); SBT as lesser-known fruit, despite superior nutritional profile (Abhishek Kumar); Weak market pull, indicated by low wild harvest of SBT (Swati Singh)
Certification burdens	0.60	0.60	0.75	0.65	0.09	Lack of certified SBT varieties (Yashaswi Singh); Chemical preservation of SBT removes organic status (Abhishek Kumar); Forest permit system creates hurdles in the SBT supply chain (Swati Singh).
Biotic stress	0.75	0.80	0.85	0.80	0.05	High tree mortality by vascular wilts, threat to commercial forestry (Yashaswi Singh); Lack of control of vascular wilts in SBT (Abhishek Kumar); Soil-borne pathogens like *Fusarium sporotrichoides* causes "Dried-Shrink" disease (Swati Singh).
Propagation hurdles	0.75	0.80	0.70	0.75	0.05	Specific altitude requirement (Yashaswi Singh); Commercial success dependent on the presence of symbiotic *Frankia* and mycorrhizae for nitrogen fixation (Abhishek Kumar); Fragile mountain-soil ecosystem (Swati Singh).
Post-harvest losses	0.8	0.75	0.85	0.8	0.06	Inefficient harvesting methods (Yashaswi Singh); Nutrient loss of SBT

						(Abhishek Kumar); Inefficient wild resource utilization (Swati Singh).
Policy/regulatory issues	0.7	0.6	0.7	0.67	0.06	Fragmented land tenure between Forest department and natives (Yashaswi Singh); Ambiguities in the access and benefit sharing (ABS) framework (Abhishek Kumar); Lack of sustainable SBT harvesting protocols (Swati Singh).

Abbreviations: SBT, Sea buckthorn; Si1–Si3, Individual severity scores assigned by three experts; Si, Mean severity score; SD, Standard deviation.

A.7.4. Weight assignment

A.7.4.1. Raw weight (R_i); By the Occurrence Score (Oi) and Severity Score (Si), the Raw Weight (R_i) was calculated by the following formula:

$$R_i = O_i \times S_i$$

The raw weight was normalised against sum of all the raw weights, to get the relative weight to draw comparison.

The calculation of Relative Weight (W_i) of the Raw Weight (R_i) of all the barriers, the following formula was used:

$$W_i = R_i/(\sum R_i)$$

A.7.4.2. Relative weights (W_i%); The raw weights were normalised across all the barriers using and expressed into percentage using the following formula;

$W_i\% = [R_i / \sum_i R] \times 100$

Where, $\sum R_i$ is the sum of Raw Weights of all the barriers, which is 1.407.

The W_i was converted into Relative Impact (W_i%) by the following formula:

$$W_i\% = 100 \times W_i$$

As per the W_i% values, the key barriers were ranked.

These values are mentioned in Supplementary Table S5.

Supplementary Table S5. Occurence Score (O_i), Severity Score (S_i), Raw weight (R_i), Relative weight (W_i), Relative Impact (W_i%) and Rank of Key Barriers

Barrier	**O_i**	**S_i**	**R_i**	**W_i**	**W_i%**	**Rank**
Market-awareness gaps	0.55	0.72	0.396	0.282	28.2%	1
Supply-chain issues	0.36	0.72	0.259	0.184	18.4%	2
Infrastructure shortages	0.27	0.85	0.230	0.164	16.4%	3
Biotic stresses	0.18	0.80	0.144	0.102	10.2%	4
Policy / regulatory issues	0.18	0.67	0.121	0.086	8.6%	5
Certification burdens	0.18	0.65	0.117	0.083	8.3%	6
Post-harvest losses	0.09	0.80	0.072	0.051	5.1%	7
Propagation hurdles	0.09	0.75	0.068	0.048	4.8%	8

Abbreviations: SBT, Sea buckthorn; Oi, occurrence score of each barrier; Si, mean severity score; Ri, raw weight; Wi, relative weight of each barrier; Wi%, relative impact expressed as percentage.

Worked numerical example:

Barrier: Infrastructure shortages

Number of studies reporting the barrier, N_i= 3

Total studies, T=11

Therefore, $O_i = \frac{3}{11} = 0.27$

Expert severity scores: 0.88, 0.90, 0.77

Therefore, mean severity score, $S_i = \frac{0.88+0.90+0.77}{3} = 0.85$

Standard deviation, $SD = \sqrt{\frac{(0.88-0.85)^2 + (0.90-0.85)^2+(0.77-0.85)^2}{2}}$ = 0.07

This indicates good expert agreement.

Raw weight, $R_i = 0.27 \times 0.85 = 0.2295 \sim 0.230$

Sum of Raw weights of all barriers, $\sum R_i = 0.396 + 0.259 + 0.230 + 0.144 + 0.121 + 0.117 + 0.072 + 0.068 = 1.407$

So, Relative weight, $W_i = \frac{0.230}{1.407} = 0.1635 \sim 0.164$

Hence, Relative impact, $W_i\% = 0.164 \times 100 = 16.4\%$

Calculated values were rounded to appropriate decimal places, without affecting normalisation or ranking of barriers.

Similarly, relative impact of other key barriers was calculated.

In a nutshell, Supplementary Tables S1-S5 collectively describe the identification, classification and ranking of the barriers to SBT commercialisation. Supplementary Table S1 gives the list of reviewed studies according to the relevant themes of the review. Supplementary Table enlists the key documents used for barrier identification. Supplementary Table S3 reports the Occurrence Scores (O_i) for each barrier in the selected documents. Supplementary Table S4 reports the Severity scores (S_i) as mean of severity values given by experts on a 0-1 scale, with standard deviation (SD) values, reflecting agreement among experts. Supplementary Table S5 gives Raw Weight (R_i), Relative Weight (W_i) and the Relative Impact (W_i%) of all the key barriers in comparison to each other.