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Superfruit in the Niche—Underutilized Sea Buckthorn in Gilgit-Baltistan, Pakistan

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Abstract: Sea buckthorn is a medicinal plant occurring throughout the temperate regions of the northern hemisphere. Considered as a "superfood" given the nutritional properties of its berries, the latter have a large international market potential, particularly in China and Europe. Although sea buckthorn grows widespread in northern Pakistan, it is a neglected species there. Fruit marketing is severely hampered by low raw product quality, varying prices, and low local demand. During 2017–2018 a total of 111 collectors and 17 commission agents were interviewed from Gilgit-Baltistan, Pakistan using semi-structured questionnaires. The results provide comprehensive information about the current situation from collection to post-harvest management of sea buckthorn fruits including the analysis of vitamin C under different sun and shade drying conditions. The findings are complemented by an analysis of the underlying supply chain. Fruit sale prices were low for the collectors (1.82 US$ kg^{-1}) since mostly poor households are involved in the harvest and sale. Traditional sun drying and storage conditions were inappropriate resulting in a decrease of chemical fruit quality and thus negatively affecting the sales price of produce. Supply chain analyses showed that the non-coordination among actors and lack of infrastructure affect the efficiency of the targeted sea buckthorn production at large. The study also shows the urgent need to set appropriate food quality standards, to increase communication among stakeholders, and to intensify training offers especially for collectors of sea buckthorn fruits.

Keywords: fruit collection and drying; *Hippophae rhamnoides*; non-regulated price; post-harvest handling; vitamin C

1. Introduction

Sea buckthorn (*Hippophae rhamnoides* L., Elagnaceae) is a shrub whose fruits are rich in vitamins and several other bioactive substances [1,2]. The species is a well-known medicinal plant containing carotenoids [3], tocopherols, ascorbic acid or vitamin C [4], vitamin K, the vitamin B complex [5], phytosterols [6], polyphenolic compounds [7], polyunsaturated fatty acids (PUFA), organic acids [8], coumarins, triterpenes [9], and zinc [10]. Yet the world market of sea buckthorn as a nutraceutical and medicinal plant is still largely unexplored. To our understanding, in Pakistan, it is traditionally known as a medicinal plant, although as field observations and deskwork suggest, knowledge on its use as a food crop is restrained due to limited awareness of producers and consumers.

In the local harvest calendars of farmers in the Karakoram Mountains, sea buckthorn is the last fruit crop ripening between September and November, whereby collection is still possible until January [11,12]. Despite its abundance and timely ripening during the slack season in farm labor demand, the species is hardly exploited and only marginally processed for value addition as juice, jam, squash, and oil [13,14]. Traditionally, some berries are harvested and dried for sale, while branches and bark are used as fuel (source of cooking and heating during the winters), and leaves are browsed by livestock as observed during our field survey.

The vitamin C concentration of sea buckthorn is 10 times higher than that of kiwi fruit (*Actinidia deliciosa* P.) which is commonly known as a rich source of ascorbic acid [15]. Vitamin C acts as a biological antioxidant for the formation and maintenance of connective tissue, it stimulates the immune system, increases iron uptake, and can help prevent scurvy disease and cancer. As humans are not able to synthesize ascorbic acid, the main source of ascorbic acid in the human diet is supplied by fruits and vegetables [16–19]. Ascorbic acid in *Hippophae* fresh berries ranges from 200 to 4000 mg 100 g^{-1} depending upon the species and variety [20–22]. It is well known that vitamin C is highly sensitive to post-harvest conservation processes such as drying and storage, thus it is also a freshness indicator [23].

At harvest, sea buckthorn berries have 70–80% moisture [24], which strongly limits their shelf-life. Preservation through drying is an effective solution to minimize quality losses by preventing biochemical and microbiological deterioration [25,26]. Drying of fruits and vegetables, however, causes changes in their physical (such as browning), chemical, and nutritional properties.

There are several methods of berry drying depending upon the type of fruit: from cheap and simple processes such as sun drying, to expensive non-conventional methods such as microwave and freeze-drying. Also, non-conventional drying methods with a modified atmosphere have been used to obtain dried products with high nutritional and sensory attributes [26,27].

Processing of sea buckthorn fruits varies according to the intended value addition; often the preliminary step is to extract juice or pulp, with a reasonable fraction of floating oil. The remaining press cake contains uncracked seeds that may be separated to extract other oil fractions [28,29]. End products of sea buckthorn are extracts used in herbal medicines for a variety of medicinal and therapeutic [30] as well as cosmetic purposes (creams, lotion, body and hair oil, shampoos, soaps), which have a growing market in Europe, Asia, and North America [31–34]. Edible products include juices, jams, jellies, and alcoholic drinks such as wine and beer.

In Asia, with 740,000 ha (wild collection) and 300,000 ha (cultivated), China is the leading producer and exporter; a total annual yield of about 8.5 million t has been reported to lead to revenues of 1.43 billion US$ [35]. Mongolia is the second leading producer with 13,500 ha (wild collection) and 6000 ha (cultivated) leading to an annual yield of between 1200–1600 t earning 5 million US$ [36,37]. In India, the species is only marginally utilized with 13,000 ha (wild collection) and a total annual yield of 600 t [38]. Pakistan in contrast harvests a comparatively low share on approximately 5700 ha harboring an estimated 12 million individuals. These populations are mainly concentrated in the northern region of Gilgit-Baltistan where most of this area consists of patches of sea buckthorn thickets away from residential areas, used and harvested to only a limited extent (about 285 ha; ~5%; [12]). The reasons for this low use are manifold: First, the utilization as a food crop seems to be rather recent as it is unknown to the traditional local cuisine. Second, the thorny nature of the plants makes easy harvest within the stand thickets difficult. Third, alternating bearing behavior prevents a reliable annual yield, this may be partly related to the effects of harsh environmental conditions. Fourth, there are areas with a high share of male plants that do not bear fruits at all, though they are important reservoirs of genetic diversity. Fifth, fruit sale revenues are generally low due to the oligopoly of a few middlemen and for value added products due to low customer demand. Sixth, knowledge on suitable stand management as well as harvesting and post-harvesting practices are lacking on a broad scale, though some training units are offered by non-government organizations (NGOs) and extension services.

Apart from the limited use of berries in Gilgit-Baltistan, harvesting and handling techniques also differ significantly among villages. Sophisticated harvesting and handling techniques have been rather recently introduced and promoted by local NGOs, foremost the Agha Khan Rural Support Program (AKRSP; [12]).

Collectors of sea buckthorn in Gilgit-Baltistan perform open-air sun drying rather than solar drying which involves protection by nets or transparent materials before selling to commission agents. Drying conditions are inappropriate due to lack of protection and grading facilities to keep fruits clean from dust, stones, leaves, and wood particles (Figure 1e–f). Fruit collectors are furthermore largely unaware about the decrease of physical quality of the sea buckthorn fruit under poorly defined drying conditions, such as browning, rancidness, and moisture content. These circumstances also affect the selling price of the final raw product.

Figure 1. Different harvesting and drying methods and their effects on sea buckthorn berry quality during 2017–2018 in Gilgit-Baltistan, Pakistan. (**a**) Simple, non-standardized harvesting tools including a wooden stick and a plastic bag; (**b**) threshing of sea buckthorn berries from semi-dried branches cut prior and transported home; (**c**) spread of berries on the roof of a house; cloth between clay surface and berries reduces contamination by foreign particles; (**d**) spread of berries on concrete floor in an experimental green house; (**e**) physical quality reduction through browning and dust particles; (**f**) rancidness of sea buckthorn berries (black spots) due to improper storage.

Fair distribution of value generated by the sea buckthorn supply chain among the various actors also remains a challenge. Small-scale collectors responsible for the collection and processing of sea buckthorn fruits remain on the losing edge. Managing the sea buckthorn supply chain on more sustainable lines can potentially impart a positive impact on the livelihoods of local communities. Our study intended to analyze various socio-economic and ecological constraints responsible for apparent inefficiencies in the sea buckthorn value chain. Taken together (socio-economic and ecological constraints in the sea buckthorn business), the present study aimed at following an approach known from large agricultural commodities [39], the sustainable supply chain management (SSCM). SSCM intends to analyze the main drawbacks in supply chains and identify measures to upgrade conditions in social, economic, and ecological terms. In view of the above, this study aimed to:

1. Assess the current situation and problems during collection, drying, and marketing of sea buckthorn fruits in the Gilgit-Baltistan area of Pakistan as an example of a highland plant value chain;
2. Recognize the preferences of collectors regarding fruit traits for the sake of future cultivation and introduction; and
3. Examine fruit vitamin C losses under traditional drying (sun drying) versus shade drying conditions.

The results will hopefully contribute to rising awareness among stakeholders and provide policy recommendations to tackle recurrent problems related to sea buckthorn harvesting, trade, and marketing to improve revenues for villagers in Gilgit-Baltistan.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Gilgit-Baltistan region of northern Pakistan (Figure 2). It stretches over an area of 72,496 km^2 with almost 1.8 million inhabitants and a multi-dimensional poverty of 35% [40]. More than 90% of Gilgit-Baltistan is covered by mountain ranges and glaciers, while the remaining area is arable land used by small-scale, subsistence-oriented farmers, which partly rely on local forest resources [41,42]. Among these, sea buckthorn is an underutilized plant resource which grows well under adverse agroecological conditions leading to highly scattered stands [43]. The climate of Gilgit-Baltistan varies widely from arid to semi-arid conditions along the elevation gradient with an annual precipitation of 200 mm (below 3000 m above sea level (m a.s.l.)) up to 2000 mm (above 6000 m a.s.l.). The temperature ranges from 40 °C during the summer to −10 °C during the winter [44].

Figure 2. Map of Pakistan showing the study area in Gilgit-Baltistan.

2.2. Survey on Sea Buckthorn Management, Harvest, and Post-Harvest Handling Practices

A survey on current management practices of sea buckthorn was conducted between August 2017 and January 2018 to assess its uses and harvesting techniques and to understand the collectors' and commissioners' perceptions, problems, and processing steps from collection of the plant parts until marketing. To this end a snowball sampling approach was used to select 111 sea buckthorn collectors and 17 commission agents (four out of which were also involved in collection) from eight different villages (Table 1). Per village, 15–20 collectors (currently collecting during the survey year) were interviewed considering the fact that mostly poor people were involved in the collection. In-person interviews with semi-structured questionnaires focused on the following aspects:

- status of collection and subsistence through sea buckthorn;
- current conditions and methods of harvest and post-harvest handling (collection of berries, storing, drying, value addition through product development);
- description of particular problems during collection, drying (number of days required for drying, price affected due to quality of drying), and marketing of sea buckthorn berries;
- perception of collectors about required/needed trainings and impact of already acquired trainings from government, NGOs, and private companies;
- identification of collectors' perception about preferred dendrological and fruit traits.

Table 1. Number of total and interviewed households involved in collection and commission during 2017–2018 in Gilgit-Baltistan, Pakistan.

Regions	District	Villages	No. of Household		
			Total	Interviewed	
				Collector	Commissioner
Gilgit	Hunza	Shimshal	240	20	4
		Passu	300	4	1
		Gulmit	220	15	2
Baltistan	Shigar	Arando	90	15	1
		Bisil	78	12	1
		Chutron	120	15	3
		Chandopi	140	15	3
		Thesil	160	15	2
	Total		1348	111	17

A sustainable supply chain management (SSCM) analysis was conducted at a dyadic level with 45 collectors (~suppliers, out of the 111 collectors) and 17 commission agents (~buyers). Respective data were collected using a structured five-point Likert scale questionnaire for seven supply chain constructs (Table 2) and their corresponding factors (Table A1) [45,46].

Table 2. Description of the sustainable supply chain constructs (based on [46]) used in the study.

Constructs	Description	References
Stakeholder engagement	To avoid any gray areas in the sustainable business operations, "transparency includes not only reporting to stakeholders, but actively engaging stakeholders and using their feedback and input to both secure buy-in and improve supply chain processes."	[47,48]
Long-term relationships	Strategically managed trustworthy long-term relationships with key suppliers in particular and other supply chain actors in general, impacting positively on firm performance.	[49,50]
Technology integration	Presence and mode of electronic transactions and communication for the efficient flow of information among supply chain actors.	[51,52]
Logistics integration	The backbone of the modern supply chain, providing the necessary infrastructure to successfully meet market demands through seamless logistics integration based on regular lines of communication for exchanging information about the three cornerstones of logistics: warehouses, inventory, and transportation between buyer and seller.	[47,53–55]
Strategic purchasing	Proactive and long-term focus in making purchasing decisions that will drive the firm's success.	[56,57]
Supplier integration	Communication and coordination with suppliers to seamlessly integrate them into focal firm activities for more efficient achievement of sustainability objectives.	[58,59]
Communication and coordination with suppliers	Enhanced communication and active coordination with suppliers as a prerequisite for supplier integration and sustainable supply chain management.	[60,61]

2.3. On-Farm Drying and Laboratory Experiment

A sub-selection of 30 out of the 111 collectors were randomly selected for close assessment of the traditional sun drying procedure of sea buckthorn fruits. For this purpose, five sea buckthorn shrubs were randomly selected from those villages that were inhabited by the identified collectors. The exact location of the sample trees and drying households was determined with a hand-held GPS (Garmin-eTrex 30, horizontal accuracy ±2 m, GARMIN® Ltd., Southampton, UK). Per tree, two portions of fresh berries (10−15 g each) were collected and stored in plastic gauze bags. Afterwards, the collectors were requested to traditionally sun-dry one portion while the other portion was kept for open shade drying (Figure 3). Collectors were asked to proceed with drying until weight constancy and to note the date when this was achieved; afterwards samples were taken again. To determine moisture content, final weight after drying was subtracted from the initial fresh weight.

Subsequently, all samples were analyzed in the laboratory to quantify the concentration of ascorbic acid (vitamin C). To this end seeds were separated from the dried pericarp (Figure 4) and each weighed separately (±0.5 g). The pericarp samples were homogenized and ground in 5% metaphosphoric acid dissolved in 5 mL of distilled water followed by extraction at room temperature for 15 min using a shaker at 40 rpm. Afterwards, samples were centrifuged at 4000 rpm for 10 min, supernatant was collected, and kept at −18 °C prior to analysis. After dilution, samples were analyzed using an HPLC (PerkinElmer, Series 200, Shelton, CT, USA) equipped with Shim-Pack CLC-ODS (C_{18}), 25 cm × 4.6 mm, 5 µm. For detection of ascorbic acid, an isocratic mobile phase of double distilled water or 70% methanol was used with a flow rate of 1 mL min^{-1}. The elution was analyzed with a UV–Vis detector set at 280 nm and the results were compared with that of an ascorbic acid standard solution.

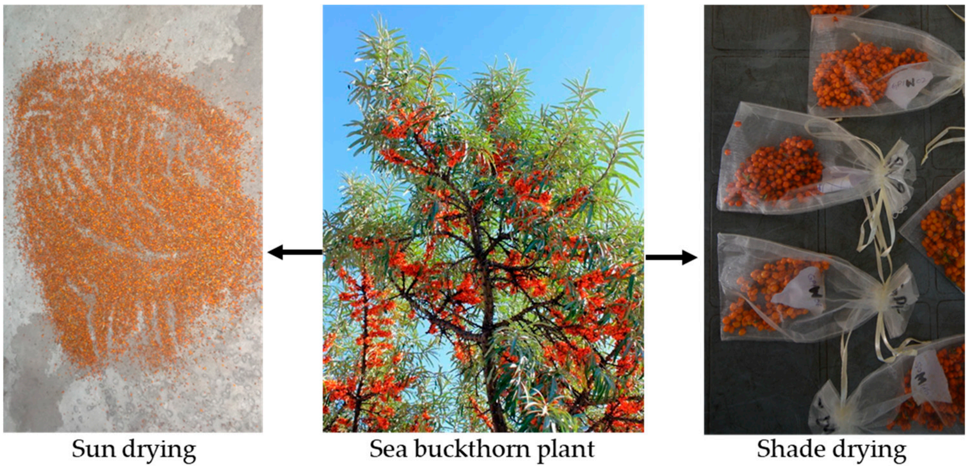

Figure 3. Experimental setup of sea buckthorn fruit drying modes: sun drying (farmers' practice, **left**) and shade drying (**right**), Gilgit-Baltistan, Pakistan.

Figure 4. Sample preparation for ascorbic acid (vitamin C) quantification by HPLC. (**a**) Seed separation from pericarp; (**b**) weight measurement; (**c**) grinding of pericarp; (**d**) grinded pericarp; (**e**) supernatant collected in an Eppendorf tube.

2.4. Statistical Analysis

The obtained data were analyzed with the help of R-software (version 3.3.3, R core team, 2017, Vienna, Austria). Differences in mean annual income between interviewed household groups (collectors, commission agents, and collectors involved in value addition) were explored employing Kruskal–Wallis tests at $p < 0.05$. The value of the sea buckthorn firewood was estimated according to the household's monthly consumption and approximate market price. The numbers of days required for drying (DRD) was analyzed with an analysis of variance (ANOVA) using a generalized linear model followed by a Chi-squared test following a Poisson distribution. An ANOVA using a simple linear model was performed for vitamin C concentrations and moisture contents as residuals of the data were normally distributed. Afterwards, if applicable, a Tukey test ($p < 0.05$) was performed for both data sets to separate means using the MULTCOMP package [62]. Data were graphically displayed as alluvial diagrams using RAWGraphs (Licensed under CC BY-NC-SA 4.0. [63]). Partial least square structural equation modeling (PLS-SEM) was used for model prediction of the SSCM constructs by employing smart-PLS version 3.2.8 [64]. Simulation was performed with 300 iterations and a 10^{-7} stop criterion; furthermore, the model was evaluated using a bootstrapping method with 5000 subsamples at a 0.05 significance level. Normed fit index (NFI) and standardized root mean square residual (SRMR) including confidence intervals (d_UL: unweighted least square discrepancy; d_G: geodesic discrepancy) [64], Cronbach alpha [65], and composite reliability (CR) [66] were used to evaluate model fit. The acceptable α and CR value for the factors used in the study was ≥ 0.7; factors lower than this value were excluded [67]. In addition, average variance extracted (AVE) was used including the acceptable threshold value of 0.4 [68].

3. Results

3.1. Survey on Sea Buckthorn Management, Harvest, and Post-Harvest Handling Practices

3.1.1. Status and Subsistence through Collection

Collectors and commission agents had on average four to six years of experience with sea buckthorn management and trade. Collectors' average income from fruits in the study area was 1.8 US$ kg^{-1}. For commission agents, mean annual income from sea buckthorn berry sale was about 4.5 times higher than for collectors. The income of collectors from the sale of sea buckthorn byproducts was almost twice as high as for berry sales alone (Table 3).

Table 3. Mean and median (values in brackets) ± SD annual income (US$) of sea buckthorn berry and byproduct sale of interviewed households during 2017–2018 in Gilgit-Baltistan, Pakistan.

	Groups	Berry Sale (US$)	Byproduct Sale (US$)
Collector	Berries only (n = 93)	181 (125) ^{a} ± 196	-
	Berries and byproducts (n = 18)	213 (101) ^{a} ± 247	378 (75) ^{a} ± 831
Commission agent	Berries and byproduct (n = 17)	838 (385) ^{b} ± 924	307 (0) ^{b} ± 878

^{ab} Medians with different superscripts differ significantly at $p \leq 0.05$ (Kruskal–Wallis test).

Men, women, and children (under 15 years) in a family (22:53:25) were involved in collection of sea buckthorn berries, whereas only a few women directly earned cash, as men dominated sea buckthorn sales (Table 4). The collection of berries took place mostly on a family's own land, whereas about half of the landowners allowed other collectors to harvest free of charge (Table 4).

Table 4. Descriptive statistics of interviewed households (collectors, n = 111; commission agents, n = 17) and status of collection of sea buckthorn berries during 2017–2018 in Gilgit-Baltistan, Pakistan.

Variable	Unit	Group	Mean	Min.	Max.
Experience	Year	Collector	4 ± 3	1	19
	Year	Commission agent	6 ± 4	1	18
Amount collected/purchased	kg	Collector	110 ± 136	15	1250
	kg	Commission agent	3356 ± 3201	500	10,000
Selling price for collectors	US$ kg^{-1}	Current	1.82 ± 0.38	0.96	2.4
	US$ kg^{-1}	Demand increase	2.84 ± 0.73	1.44	4.81
Firewood for household use	US$ $year^{-1}$	Estimated price	511 ± 142	240	923
			Total		
Family labor involved in collection of berries	%	Men	22		
	%	Women	53		
	%	Children under 15 years	25		
Picking area	%	Owned	62		
	%	Community land	10		
	%	Both	28		
Picking from other land than picking area	%	Allowed	46		
	%	Not allowed	54		

3.1.2. Conditions and Methods of Harvest to Post-Harvest Handling

Harvesting and drying of sea buckthorn fruits varied depending upon the region/village studied. Nineteen collectors (17%) harvested the fresh berries from October until November and dried them afterwards. This was mainly practiced in the Passu and Gulmit region near the Karakorum Highway and called "*in vivo* fresh berry threshing" (Figure 5a). Twenty collectors (18%) harvested the already dried up berries at the end of December until February and post-dried them afterwards. This was mainly practised in the Shimshal Valley and called "*in vivo* dry berry threshing" (Figure 5a). Seventy-two collectors (65%) chopped the fruit bearing branches from August until November, transported them home, semi-dried these branches, and threshed them afterwards. This practice took place only in Baltistan and was referred to as "*ex situ* berry branch harvesting" (Figure 5a).

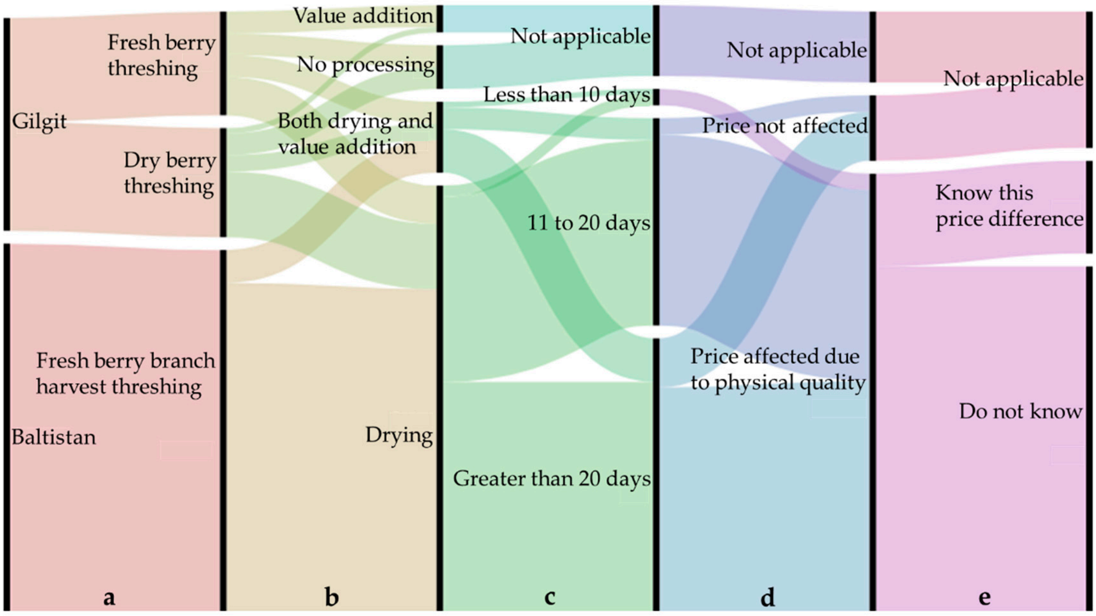

Figure 5. Alluvial graph showing the collection, processing, and days required for drying of sea buckthorn berries according to collectors (n = 111) in the study area of Gilgit-Baltistan, Pakistan (during 2017–2018). Share of (**a**) harvesting/drying methods practiced per region; (**b**) post-harvest processing conducted; (**c**) number of days required to dry berries; (**d**) price affected due to deteriorated physical quality (Figure 1e); and (**e**) knowledge of price difference when quality is reduced.

There were different homemade harvesting tools used such as fertilizer bags folded around a mulberry wood stick, beating sticks, and on-spot collection storage bins. For drying, mostly sun drying on clay roofs or concrete floors was performed at collectors' as well as agents' homesteads, whereas 11% of agents tried to apply solar drying when fresh bulks were purchased (Figure 1a–d).

Most of the sea buckthorn collectors (76.5%) were involved in drying, while only a few (4.5%) added value by processing the fruits into jams, juices, and pulp concentrates. Both activities (drying and processing) were conducted by 11.7%, whereas 7.2% of collectors were neither involved in drying nor value addition (Figure 5b). The sales price of berries was strongly affected by drying conditions (Figure 1c–e), whereby 80% claimed that quality affected price (Figure 5d,e). Storage containers used for dried sea buckthorn fruits were either plastic fertilizer or rice bags (90.1%); the remainder was stored in jute fiber bags.

3.1.3. Collectors' Problems

Collectors reported major problems during fruit collection and marketing (Table 5). The most common problems were lack of collection material, unmanaged and dense thickets of sea buckthorn, as well as lack of direct market access. Though ranked lower, further constraints were lack of storage facilities, lack of harvesting knowledge, poor road infrastructure, and variable price margins of sea buckthorn berry sale.

Table 5. Identified problems during collection, drying, and marketing of sea buckthorn berries and their proposed solutions by collectors (n = 111) interviewed during 2017–2018 in Gilgit-Baltistan, Pakistan.

Problems During Collection	Response Frequency (%)
Lack of collection equipment	74
Unmanaged/dense stands	71
Lack of storage facility	41
Difficult collection due to lack of harvesting knowledge	37
Problems During Drying	
Harsh weather (strong winds and rainfall)	95
Dust	93
Grading issues	48
Drying equipment unavailability	34
More days needed for drying	15
Bird damage	14
Quality deterioration	12
Problems During Marketing	
Lack of market access	57
Transportation due to poor road infrastructure	34
No regulated fix price	33
Potential Solutions	
Availability of drying units	76
Availability of grading units	43
Provisions of latest harvesting tools	55

The major problem of sun drying was reportedly harsh weather conditions (strong winds, precipitation), including depositions of dust particles. Other respondents noticed grading issues, unavailability of drying equipment, a higher number of days required for sun drying due to changing weather conditions, bird damage, and quality deterioration (Table 5). Most of the collectors (97%) mentioned that it took more than 10 days for proper sun drying of sea buckthorn berries, whereas only 3% of the collectors needed <10 days for drying (Figure 5c). The potential solutions proposed by the collectors to solve these problems were provision of drying and grading units nearby and supply of better harvesting tools (Table 5).

3.1.4. Collectors' Perception about Trainings

Collectors mentioned the need of trainings about improved practices of sea buckthorn management. The most important trainings concerned collection, value addition, and drying practices (Table 6). About one-quarter of collectors already received trainings from government, NGOs, and private enterprises. During these trainings, they learned about safety measures during collection, product development strategies, maintenance of sea buckthorn plants, and marketing strategies (in decedent order; Table 6).

3.1.5. Preferred Plant and Fruit Traits by Collectors

Preferred plant traits were increased numbers of fruits per plant (81%), less or no thorns (65%), easy shattering (51%), and large fruits (32%). Collectors from the Gilgit region preferred large and greater number of fruits per plant as well as a large crown area, whereas respondents from Baltistan favored a combination of less or no thorns and easy shattering (Figure 6).

Table 6. Required trainings for collectors (n = 111) of sea buckthorn interviewed during 2017–2018 in Gilgit-Baltistan, Pakistan.

Training Demand	Response Frequency (%)	
Latest collection methods	76	
Value addition	60	
Latest drying methods	38	
Grading techniques	17	
Marketing techniques	16	
Cultivation practices	6	
	Yes	No
Have you taken any type of training?	28	72
Theme of received training		
Safety measures during collection	81	
Product development	74	
Maintenance of plants	35	
Marketing	23	

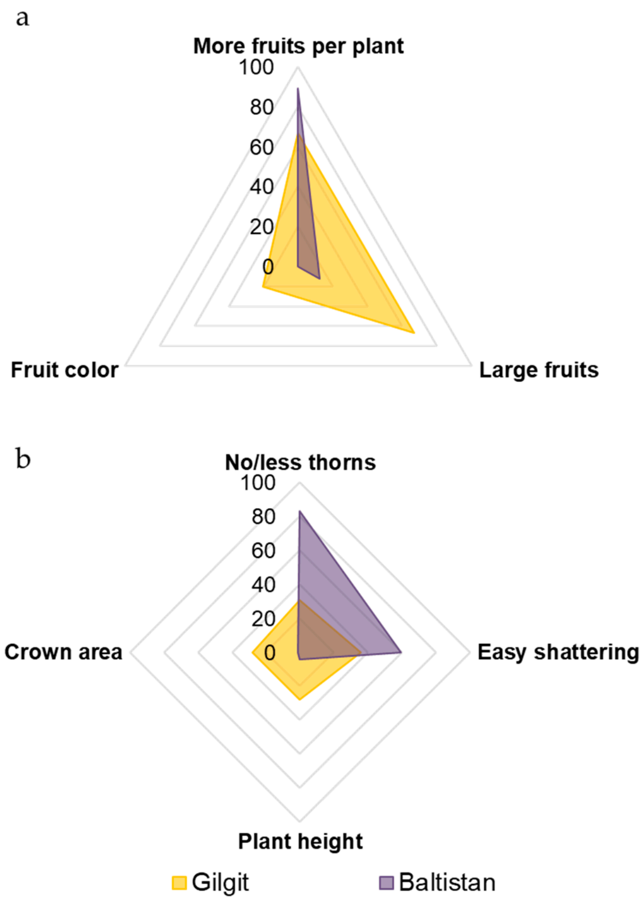

Figure 6. Radar plots showing plant trait preferences (%) of sea buckthorn collectors (n = 111) interviewed during 2017–2018 in Gilgit-Baltistan, Pakistan; (**a**) dendrological and (**b**) fruit traits.

3.1.6. Sustainable Supply Chain Constructs

One out of seven SSCM constructs showed a Cronbach alpha less than 0.7, namely "Long-Term Relationship", and was therefore excluded for further analysis, whereas other constructs including their item loadings indicated a reliable and valid outer model (Table A1). SRMR did not fit the actual threshold, but was close to the actual value (Table 7). In addition, the path coefficients (β) showed the significance of the relationships (paths) of the predicted model (Table A2). There was a strong correlation between the latent endogenous construct and latent exogenous construct (Table A3). The model with communication and coordination with suppliers as antecedents and stakeholder engagement as an outcome is displayed in Figure 7 and further discussed in Section 4.

Table 7. Model fit summary of the predicted model.

	Estimated Model
SRMR	0.092
d_ULS	2.734
d_G	1.716
Chi-square	452.915
NFI	0.735

SRMR: standardized root mean square residual, d_ULS: unweighted least square discrepancy, d_G: geodesic discrepancy, NFI: normed fit index.

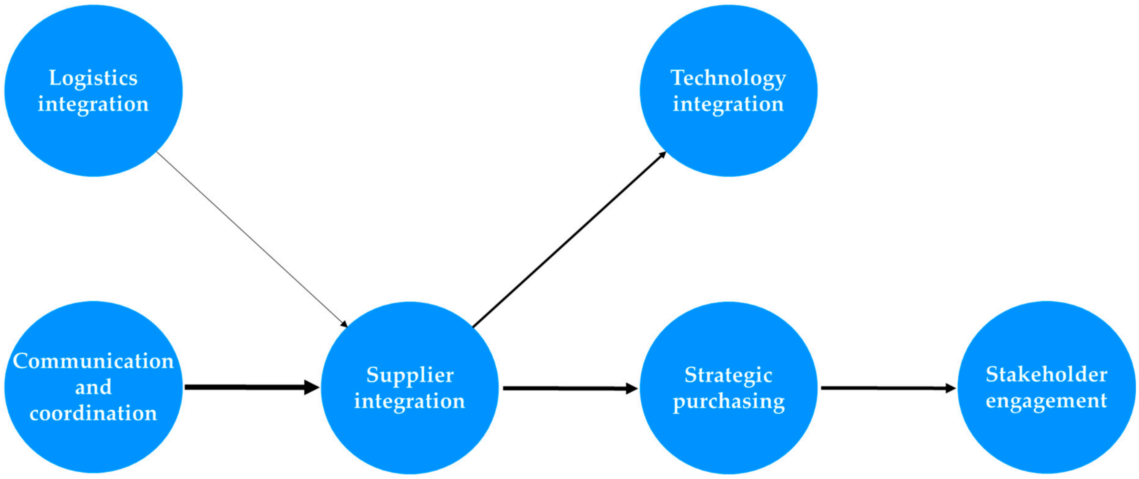

Figure 7. Model of communication and coordination with suppliers for sea buckthorn fruits as predicted by partial least square structural equation modeling (increasing thickness of arrows marks increasing correlation coefficients, cf. Table A3).

3.2. On-Farm Drying and Laboratory Experiment

3.2.1. Days Required for Drying and Moisture Content

The moisture content of sun- and shade-dried samples ranged from 26% to 35% with no significant treatment effects (Table 8). Days required to dry (DRD) for sun-dried samples were consistently and significantly lower than in shade-dried samples (Table 8) ranging from 8–19 and 15–30 days, respectively. The village-specific DRD was highest for Arando and Chutran and lowest for Chandopi, Passu, and Thesal.

3.2.2. Concentration of Ascorbic Acid

Mean vitamin C concentrations among villages ranged between 6 and 275 mg 100 g^{-1}, whereby sun-dried fruits showed significantly lower values than shade-dried ones (Figure 8). Also, values were lowest for Chandopi (12 and 20 mg 100 g^{-1}, respectively), followed by those for Arando, Bisil, Thesal, Chutran, and highest for Passu (120 and 275 mg 100 g^{-1}, respectively).

Table 8. Average drying traits of sea buckthorn under sun-dried and shade-dried conditions in Gilgit-Baltistan, Pakistan.

Villages	Drying Method	*n*	Moisture %	DRD	Sig
Passu	Shade	5	31	15	ac
	Sun	5	28	9	ab
Thesal	Shade	5	33	16	bc
	Sun	5	34	8	a
Chandopi	Shade	5	35	15	ac
	Sun	5	33	9	ab
Chutran	Shade	5	35	30	d
	Sun	5	34	15	ac
Bisil	Shade	5	31	20	cd
	Sun	5	30	12	ac
Arando	Shade	5	26	30	d
	Sun	5	26	19	c
Total		60			

n = number of samples; small letters indicate significant differences of DRD (days required for drying) at $p < 0.05$ among villages and between drying conditions (sharing the same letters indicates non-significant differences).

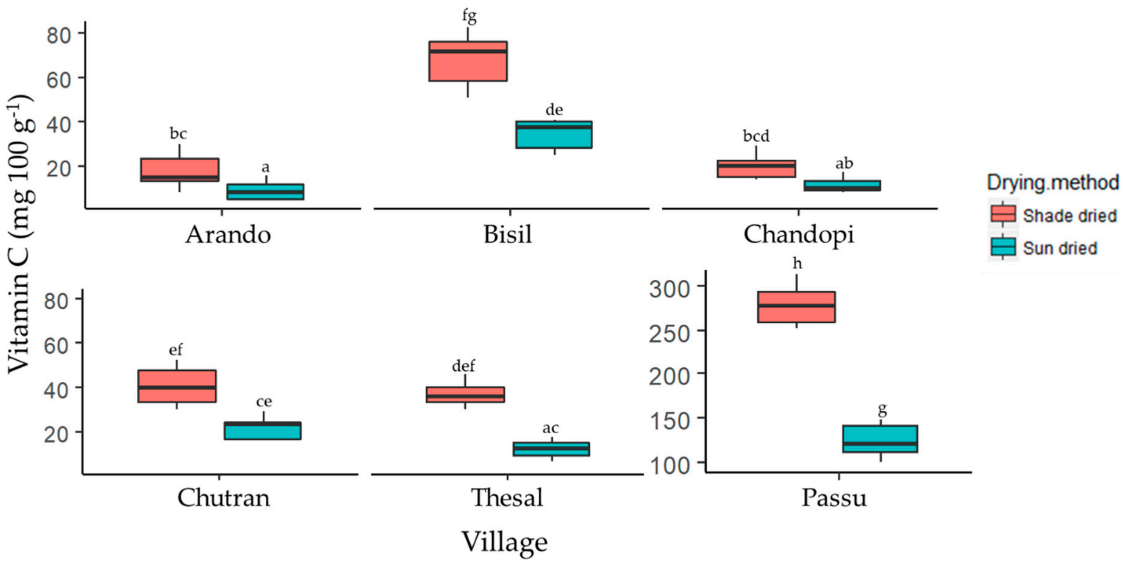

Figure 8. Boxplot diagram of vitamin C concentrations in sun-dried and shade-dried sea buckthorn fruits among the villages surveyed in Gilgit-Baltistan, Pakistan. Small letters indicate significant differences of vitamin C concentration in berries at $p < 0.05$ among villages and between drying conditions (means sharing the same letters are similar).

4. Discussion

4.1. Status of Collection, Post-Harvest Handling, and Management

China and Mongolia provide subsidies to farmers to promote cultivation and collection of sea buckthorn berries; in Mongolia sea buckthorn is one of the major fruit crops and average annual income of a sea buckthorn collection household was reported to be 3413 US$ [37,69]. Collectors involved in value addition had a significantly higher income through byproduct sales than from sales of berries alone. In Pakistan, the price of sea buckthorn is not state-regulated and the current sale price of 1.8 US$ kg^{-1} is not satisfactory; collectors have demanded an increase to at least 2.8 US$ kg^{-1} (56%). In comparison, the current price for dried apricot, mulberry, and apples in Gilgit-Baltistan was approximately 3.0, 1.2, and 1.0 US$ kg^{-1}, respectively. There were other benefits for households involved in sea buckthorn collection of which use as firewood for heating during winters and cooking contributed an equivalent of 511 US$ in annual savings.

At the time of our survey most collectors of sea buckthorn berries had just started their activity due to ongoing awareness raising campaigns by NGOs coupled with an increasing consumer demand. As sea buckthorn is not commercially cultivated in the study area, harvesting takes place on private and common land. Despite the fact that mostly women are involved in the collection of berries, men dominate sales.

A range of harvesting methods were observed, which all caused some damage to individual plants. If correctly applied, targeted pruning can lead to better yield without risking stand destruction. Alternative harvesting methods such as milking by using chain gloves [70] and shock freezing technologies through freeze chambers or liquid nitrogen applications (as known from Ludwigslust, Germany) are difficult to establish because either materials are not available (chain gloves) or infrastructure (road, power grid) is poor, preventing the installation and maintenance of low and constant temperature units.

Another constraint related to harvesting observed in the study area is over-exploitation and premature harvesting of berries (most common practice for fruits and vegetables in Pakistan). This threatens plant survival as observed for other medicinal plants of the Northern Kashmir Himalayas in Pakistan [71]. Poor harvesting of sea buckthorn fruit may result in the depletion of stand vitality; hence, it may cause the loss of genetic diversity as observed in species such as *Hallea rubrostipulata* (K. Schum) J-F Leroy (Rubiaceae) and *Warburgia ugandensis* Sprague (Canellaceae) in Uganda [72].

Most sea buckthorn collectors sun-dried the berries before selling them to agents (Figure 5b). Strong winds and precipitation during the collection period often required more than 10 days of sun drying; this was reported as problematic since it resulted in part or complete deterioration of quality characteristics, as also observed in other fruits and medicinal crops [73,74].

After drying, proper packaging is important to maintain berry quality [75]. The collectors used plastic fiber bags, which are sturdy, but do not allow aeration for the semi-dried organic material. This may lead to a rancid and/or moldy raw product [76,77] which has been observed in the field several times (Figure 1f). Commission agents therefore often restart drying and cleaning berries once they have collected and/or purchased and transported the bags to their storage facilities. If bags of unidentified origin are reused, unknown contaminants may affect berry quality. In our study, most agents transferred berries into jute fiber bags and stored them under dry conditions between 40% and 50% relative humidity and 8–12 °C for two to three months (own data).

Possible solutions to these problems may be advice on the use of more appropriate collection material or the establishment of cooperative collection and storage mechanisms. This could be regulated by government agencies or NGOs as dealers are rarely interested in collectors' problems [78].

Collectors often lack direct market access, transportation due to poor road infrastructure, and suffer from large price fluctuations. There is a range of studies for other medicinal plants confirming such constraints and showing the effects of dominance of a few middlemen and a basically unregulated supply chain [79–83].

Price negotiations between collectors and commission agents about quality characteristics of sea buckthorn berries are very unbalanced as middlemen have much more knowledge about the quality produced in the region and thus an advantage over collectors, resulting in price dictation. This has been observed in several other medicinal plants from studies in India [84–86]. As price is largely influenced by the physical quality of berries (Figure 1c–e), effective drying facilities are key for reducing post-harvest losses of quickly perishable crops [87,88].

In our study, collectors were interested in a greater number of fruits per plant, no thorns, and easy shattering. There are several known varieties of sea buckthorn exhibiting larger fruits and less/no thorns especially in China ('Hongguo' and 'Liaohuyihao'), Mongolia ('Wulangemu'; [89]), Germany ('Frugana', 'Hergo', 'Leikora', and 'Dorana'; [90]), Finland ('Tytti', 'Terhi', and 'Tarmo'), and Russia ('Botanicheskaya Ljubitelskaya', 'Prozrachnaya', and 'Podarok Sadu'; [91]). These varieties could be used for breeding purposes after a critical screening and evaluation of promising local plant genetic material (large fruits) such as found in the Shimshal valley and Skardu region [43]. Using local materials for breeding would also help to preserve regional diversity.

4.2. Quality Loss Due to Sun Drying of Sea Buckthorn Berries

In Gilgit-Baltistan, most collectors were involved in sun drying of sea buckthorn, a time-consuming process that needs constant physical attention and special infrastructure. Freeze-drying of fresh fruits would be hygienically and nutritionally best to produce a product with a long shelf-life and high biochemical quality. So far, lack of this technology in the study area prevents the production of a high quality and economically beneficial raw product suitable for national and international markets. Very recently small initiatives started as they received funding from UNDP (United Nations Development Programme), WWF (World Wide Fund for Nature), and the Coca Cola Company to promote the interest of collectors for making value-added products (jams, juices, pulp, and squashes) for local markets.

Although our study confirms that the quality of sea buckthorn berries is significantly affected by sun drying, we found no previous studies on such effects for this species. As for other crops, sun-dried plant products have an inadequate quality due to remaining moisture, dust, insect infestations, and microbial contamination [74,92–94]. The moisture content of sea buckthorn berries was similar in sun-dried and shade-dried samples showing that both drying methods are appropriate, though the period of DRD was pronouncedly extended under shade drying. Since ascorbic acid concentration was only measured after drying and not after harvest of fruits, the total vitamin C loss could not be determined. Our experiment demonstrated that current sun drying of sea buckthorn berries is inadequate in terms of biochemical quality and that there is an urgent need of alternative drying techniques or improved handling modes. Our study showed that the vitamin C concentration of sea buckthorn berries is almost twice as high in shade-dried than in sun-dried berries. These values are similar to those of kiwis (*Actinidia deliciosa* P.; [95,96]), grapes and sultanas (*Vitis vinifera* L. cv. *Sultanina*; [97]), mango (*Mangifera indica* L.; [98]), amla (*Emblica officinalis* L.; [99]), jack fruit (*Artocarpus integer* Spreng.; [100,101]), and chiko/sapota (*Manilkara zapota* L.; [102]), among others [74]. Hence, there is a trade-off between sun exposure (fast drying) and shade applications (reduced deterioration of active substances), while certainly a mix of both strategies might be interesting for sea buckthorn, particularly under tough weather conditions and limited infrastructure such as in Gilgit-Baltistan.

4.3. Sea Buckthorn Supply Chain

The sea buckthorn supply chain linking local farmers/collectors of Gilgit-Baltistan with the global market has to our knowledge not been well studied. Operational in an informal market context, communication and coordination among the respective supply chain actors appeared as the driving factor for the related activities along the supply chain. The communication primarily remains informal. This may be justified in the context of relationship-based business environments evident in such contexts [103]. In the absence of formal market regulatory bodies, informal institutions such as kinship, family relationships, and community pressures are primarily used to organize supply chain relationships [54]. Active communication among the buyers and suppliers leads to the creation of inclusive business opportunities and integration of suppliers (farmers). The supplier integration is evident on two fronts—logistical and technological. The logistical integration of buyers and suppliers is evident in the form of such practices as coordination on fruit pick-up time to decrease post-harvest storage time, transportation, and warehousing. Since no substantive technologies are used along the sea buckthorn value chain, the technological integration remains confined to the use of mobile phones for better communication among the dyadic actors and use of the sun-drying technique to lower down moisture content of berries. A strategic purchasing construct representing long-term orientation of buyers, while making purchasing-related decisions, comes next. Supplier integration serves as an antecedent to strategic purchasing and shows that the buyers take on board the suppliers with whom they have integrated on a technological and logistical end, while making long-term purchasing decisions. Stakeholder engagement appears last in this model which remains somewhat hard to justify, since the construct would ideally be an antecedent of supply chain activities in the background of informal markets. Nevertheless, the importance of stakeholders, particularly non-traditional stakeholders, has been observed during field research and depicted in the model.

Missing infrastructure appeared to be a significant challenge affecting the efficiency of the local businesses at large. Furthermore, the institutional voids [104], particularly of financial institutions, keep the respective actors short of the capital required for upgrading their supply chains with the establishment of cold storage facilities and packaging units. Both are vital for reducing post-harvest losses and international marketing.

Equitable distribution of value generated among the respective actors remains a challenge in the sea buckthorn supply chain. Uneven distribution of rents generated de-incentivize supply chain actors to make their business operations more efficient. Mechanisms have yet to be developed to safeguard the interests of vulnerable supply chain actors (farmers) in the context of the evident power asymmetries along the value chain [79–83].

5. Conclusions

Local collectors of sea buckthorn berries were unaware of effective, yet sustainable, harvesting/drying techniques that preserve the quality for the harvested fruits. There is an urgent need to set quality standards for the market and encourage fair trade of sea buckthorn. Current sun drying of berries is inappropriate as vitamin C concentrations drop dramatically, which calls for effective extension activities such as drying facilities. Establishing collector collectives and using simple, appropriate solar dryers could minimize these losses. As byproduct sales are beneficial but limited to regional markets, there is a need for the expansion of value-added products to national local markets. This would also allow collectors to be more independent from agents, or on the contrary, develop strong, fair, and lasting relationships. The implementation of Fair Trade Standards, Wild Collection, or Geographical Indication labels may foster the production and marketing of a unique and regional produce. To further assess the potential of sea buckthorn production and marketing in Pakistan, it may be worthwhile to conduct cross-border studies with China and India that cultivate the species in similar agro-ecological conditions but under different socio-economic and political settings.

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Appendix A

Table A1. Reliability test of the sustainable supply chain management constructs (SSCM) and their corresponding factors for interviewed households (collectors, $n = 45$; commission agents, $n = 17$) during 2017–2018 in Gilgit-Baltistan, Pakistan.

No.	Items/Factors	Loadings	Cronbach's α	CR	AVE
	Stakeholder Engagement (SE)				
1	Take on board other supply chain actors while making business decisions	0.908	0.858	0.904	0.704
2	Share business-related information with other supply chain actors	0.910			
3	Government and non-government organizations (NGOs) provide relevant support for business development	0.722			
4	Supplier/colleagues share business-related information with you	0.801			
	Long-Term Relationship (LR)				
1	Do business together for a long time	0.027	0.322	0.354	0.224
2	Crucial time agent stands with collector	0.753			
3	Harvester committed to fulfill demand	0.139			
4	Good mutual understanding for business expansion	0.711			
5	Kinship/friendship is a basic trust tool for business	−0.171			
	Technology Integration (TI)				
1	Record keeping books used in business process	0.777	0.850	0.900	0.692
2	Mobile phones are the main source for business dealings	0.864			
3	Payments are done through online bank transactions	0.789			
5	Mobile phones are the main source for communication with business suppliers/colleagues	0.893			
	Logistics Integration (LI)				
1	Face transportation/logistic problems	0.657	0.765	0.842	0.518
2	Sharing same logistic resources	0.649			
3	Supplies reached warehouses on time at other destinations	0.832			
4	Quality deteriorates during transportation	0.721			
5	Smooth flow of material and information from suppliers to buyers	0.731			
	Strategic Purchasing (SP)				
1	Multiple purchasers' selection is done for selling	0.943	0.951	0.968	0.911
2	Strategic purchasing can play an important role for future business sustainability	0.956			
3	Purchasing as a tool of competition	0.965			
	Supplier Integration (SI)				
1	Meet regularly with suppliers/colleagues	0.703	0.778	0.858	0.602
2	Capacity building and training are given to suppliers	0.841			
3	Information regarding supply, demand, quality, and price is shared	0.783			
5	Suppliers have rights in business planning decisions	0.770			
	Communication and Coordination with Suppliers (CCS)				
1	Good communication and coordination with business-related	0.892	0.897	0.925	0.712
2	Information shared with suppliers	0.906			
3	Information shared timely and frequently for supplier business betterment	0.911			
4	Market-related information is shared	0.710			
5	Demand invoices are shared	0.783			

CR: composite reliability, AVE: average variance extracted.

Table A2. Path coefficient (β) and T-statistics of the predicted model.

Hypothesized Path	β	T-Statistics	*p*-Value
Logistics integration -> Supplier integration	0.060	4.844	<0.001
Supplier integration -> Technology integration	0.097	5.384	<0.001
Strategic purchasing -> Stakeholder engagement	0.074	8.269	<0.001
Supplier integration -> Strategic purchasing	0.076	8.923	<0.001
Communication and coordination -> Supplier integration	0.054	13.302	<0.001

Table A3. Latent variable correlation between the SSCM constructs.

	CCS	LI	SP	SE	SI	TI
Communication and coordination (CCS)	1.000					
Logistics integration (LI)	0.591	1.000				
Strategic purchasing (SP)	0.654	0.530	1.000			
Stakeholder engagement (SE)	0.749	0.522	0.624	1.000		
Supplier integration (SI)	0.895	0.717	0.667	0.756	1.000	
Technology integration (TI)	0.535	0.386	0.310	0.448	0.535	1.000

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