Formulation and acceptability of foam mat dried seabuckthorn (*Hippophae salicifolia*) leather

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Abstract Technology for utilization of seabuckthorn berries for preparation of fruit leather/bar was optimized by modifying the foam mat drying technique. The conversion of seabuckthorn juice/pulp into foam was standardized by whipping the pulp after addition of CMC @ 0–3% at 5 °C and drying the resultant foam in dehydrator (55±2 °C) to a moisture content of about 12–14%. The fruit bar prepared from sulphited juice/pulp wrapped in a butter paper followed by packing in polyethylene pouches (20 g) and stored at ambient temperature (14.6–26.1 °C) experienced least changes in quality attributes like ascorbic acid (1045.7 mg/100 g vs 997.5 mg/100 g) and carotenoids (80.4 mg/100 g vs 72.3 mg/100 g) as compared to the leather made from the unsulphited pulp. Storage studies indicate that fruit bars are mildly hygroscopic (0.46–0.65) and can be stored within the RH of 46–65% at room temperature.

Keywords Seabuckthorn · *Hippophae salicifolia* · Foammat drying · CMC · Whipping · Water activity

Seabuckthorn (*Hippophae salicifolia*) belonging to Elaeagnaceae is a thorny, dioecious, soil binding shrub found growing wild in cold and dry regions of higher Himalayas. The berries are known to be a rich source of many nutrients and bioactive substances including vitamins C, A and E, proteins, flavonoids, lipids, minerals, β -sitosterol and polyphenolic acids thus signifying its antioxidant and anti stress properties. (Rongsen 1992; Yao et al. 1992; Dwivedi

and Singh 2010). The seabuckthorn fruit is of great interest due to its nutritional, therapeutic, pharmaceutical and cosmetic applications. Due to the high perishable nature and acidic taste, fruit cannot be consumed fresh and requires immediate processing. The berries are mainly utilized for the preparation of beverages by blending with other fruit pulp or by using appropriate addition of sugar; seed oil and many other pharmaceutical products. Development of fruit bars from seabuckthorn juice/pulp is an important alternative for increasing the consumption of high nutrient containing seabuckthorn berries.

Fruit bar or fruit leather is a confectionery product made by the dehydration of fruit puree into leathery sheets. Preparation of fruit leather from pulpy fruits such as mango, guava, banana, chiku, jack fruit and papaya individually or in combination with different fruits has been reported by various workers (Gowda et al. 1995; Raab and Oehler 1976). The fruit bar can be prepared from any type of fruits, irrespective of their compositional variation. However acceptable bars cannot be prepared from juicy fruits until suitable additives such as maltodextrin, pectin, soluble starch, carboxy methyl cellulose etc. are added (Vijayanad and Narasimham 1998).

Thus, the present investigations were undertaken to optimize the process for conversion of juicy nature of seabuckthorn pulp into foam and drying the foam to prepare ready to serve fruit bars for increasing the consumption of this product among the consumers.

Material and methods

The berries of seabuckthorn (*Hippophae salicifolia*) harvested at optimum maturity from Sangla (District Kinnaur, height 2,769 m amsl) in Himachal Pradesh, India were used for pulp extraction. The berries after washing were heated

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to 70 °C for 15 min to extract the pigments and passed through the pulper for extraction of pulp. The pulp was heat pasteurized at 90 °C for 10 s (Ting and Rouseff 1986) and packed in presterilized glass bottles prior to its processing in boiling water for its use in product development.

Fruit bar/leather was prepared from the seabuckthorn pulp after sulphiting (600 ppm SO₂) by making appropriate modifications to prepare foam from the pulp and drying the foam in a drier. The pulp being thin and juicy was converted into stable foam by whipping the pulp in a blender for 3 min (Morgan et al. 1959) after addition of CMC @ 0–3% at 5 °C followed by spreading the foam on stainless steel trays (30×20 cm², with a tray load of 150 g per tray) in a thin layer (3–5 mm) and dried in a mechanical dehydrator (55±2 °C) for about 4 h. to a moisture content of 12–14%. The fruit bar prepared without adding SO₂ served as control. The dried fruit bar was then cut into strips of suitable dimensions followed by wrapping in a butter paper and packing in polyethylene pouches (20 g) and stored at ambient temperature (14.6–26.1 °C).

Analysis

Physico-chemical analysis of seabuckthorn berries (*Hippophae salicifolia*) and fruit bars was conducted by using standard analytical procedures (Ranganna 1997; Ting and Rouseff 1986; AOAC 1995). Average weight of whole berry, peel, pulp and seed were determined gravimetrically and the results were expressed as mg and per cent (w/w) on whole fruit basis. Total Soluble Solid (TSS) contents of seabuckthorn fruit and bar was determined by hand refractometer and sugars were estimated by Lane and Eyon method as given by Ranganna (1997). Acidity was determined by titrating the aliquots against a standardized 0.1 N NaOH solution to a pink end point using phenolphthalein as an indicator (Ranganna 1997). The ascorbic acid content in seabuckthorn berry and bar was determined using 2, 6-dichlorophenol indophenol dye as per the method given by Ranganna (1997). Total phenols were extracted in 80% ethanol and were estimated using Folin-Ciocalteu reagent as per standard procedure (AOAC 1995). The rate of dehydration per unit time was calculated by placing a weighed quantity of foamed pulp (150 g) on a stainless steel tray (30×20 cm²) and drying in mechanical dehydrator (55±2 °C) to a moisture content of 12–14% (w/w). The loss in weight during drying (% dwb) was calculated by plotting the moisture on dry weight basis against time in hours (Fellows 1988). For calculating the water activity of seabuckthorn bar, equilibrium relative humidity (ERH) of fruit bar was determined according to Ranganna 1997 by placing known weight of fruit bar in atmosphere of different relative humidities (0–100%) in closed dessicator at room temperature (18.5–31.5 °C) maintained by using different concen-

tration of H₂SO₄. After equilibrium loss or gain in weight of sample was plotted against the respective relative humidities to determine ERH of a given sample. Water activity is then calculated by dividing the ERH by 100. Critical and danger points of fruit bar/leather were calculated according to the weight equilibrium method (Wink 1946). Foam stability during drying was evaluated by using 5 point sensory score card (1 No foam to 5 fully stable foam) according to Sharma et al. (2002).

Physico-chemical analysis of seabuckthorn berries (*Hippophae salicifolia*) and fruit bars was conducted by using standard analytical procedures (Ranganna 1997; Ting and Rouseff 1986; AOAC 1995) for the estimation of TSS, acidity, sugars, ascorbic acid, carotenoids, proteins, total phenols, drying rate, dehydration ratio and water activity studies. The rate of dehydration per unit time was calculated by placing a weighed quantity of foamed pulp (150 g) on a stainless steel tray (30×20 cm²) and drying in mechanical dehydrator (55±2 °C) to a moisture content of 12–14% (w/w). The loss in weight during drying (% dwb) was calculated by plotting the moisture on dry weight basis against time in hours (Fellows 1988). For calculating the water activity of seabuckthorn bar, equilibrium relative humidity (ERH) of fruit bar was determined according to Ranganna 1997 by placing known weight of fruit bar in atmosphere of different relative humidities (0–100%) in closed dessicator at room temperature (18.5–31.5 °C) maintained by using different concentration of H₂SO₄. After equilibrium loss or gain in weight of sample was plotted against the respective relative humidities to determine ERH of a given sample. Water activity is then calculated by dividing the ERH by 100. Critical and danger points of fruit bar/leather were calculated according to the weight equilibrium method (Wink 1946). Foam stability during drying was evaluated by using 5 point sensory score card (1 No foam to 5 fully stable foam) according to Sharma et al. 2002.

For sensory scoring, the fruit leather was served with black salt for evaluation by a panel of 7–9 semi-trained judges for various quality attributes viz., colour, taste, flavour, body and overall acceptability on 9 point hedonic scale. Data pertaining to sensory evaluation of seabuckthorn leather were analyzed according to Randomized Block Design (RBD) as described by Mahony (1985) while, the data on chemical characteristics of fruit leather were analyzed statistically by following Completely Randomized Design (CRD) according to Cochran and Cox (1967).

Results and discussion

Physico chemical characteristics of berries The seabuckthorn berries of *Hippophae salicifolia* having mean weight

Table 1 Physico-chemical characteristics of berries of seabuckthorn (*Hippophae salicifolia*)

Parameters	Mean ^a ±SD
Weight (mg)	172.7±0.58
Peel wt.% (w/w)	20.0±1.68
Pulp wt.% (w/w)	62.7±1.20
Seed wt.% (w/w)	16.9±0.16
TSS (°Brix)	12.1±0.11
Titrateable acidity (% malic acid)	6.1±0.04
Brix/acid ratio	2.0±0.03
pH	2.7±0.03
Sugars (%):	
Reducing	3.3±0.18
Non-reducing	1.6±0.13
Total	4.9±0.11
Ascorbic acid (mg%)	490.5±0.56
Carotenoids (mg%)	18.3±0.23
Proteins (%)	1.7±0.34
Total phenols (mg/100 g)	0.4±0.12

^a Means of 3 replicates

of 172.7±0.58 mg comprised of about 20.0% peel, 63.0% pulp and 17.0% seed (Table 1) and can be used for pulp extraction. Though the berries contribute 12.1°B total soluble solids but contained very high proportion of acid i.e. 6.1% malic acid. Besides, these the berries were found to be good source of vitamin C (490.5 mg/100 g) and

carotenoids (18.3 mg/100 g). The presence of high protein (1.7%) and total phenols (0.4%) in the berries further highlighted the nutritional significance of seabuckthorn.

Conversion of pulp into foam for drying The liquid pulp was converted into foam by using appropriate concentration of carboxy methyl cellulose (0–3%) as thickening agent to enable its use in preparation of fruit bar/leather. It was found that whipping of seabuckthorn pulp for 3 min at 5 °C without the addition of carboxy methyl cellulose (CMC) did not yield any foam (Table 2). However, with the increase in the level of CMC (0.5–3.0%), the pulp turned into foam and showed marked increase in its total volume after whipping (Plate 1). Maximum increase in foam volume i.e. overrun (20–22%) was observed after whipping seabuckthorn pulp with 2.0–2.5% CMC. Using CMC below this level i.e. 0.5–1.5%, the foam immediately turned into liquid during drying, and was found unsuitable. However, the foam obtained from seabuckthorn pulp along with 2–2.5% CMC remained completely stabilized during drying while pulp with 3.0% CMC formed a thick gel which was also found unsuitable for drying. Chandak and Chivate (1974) also obtained a stable foam in coffee extract (30% soluble solids) when whipped with 2% glycerine monostearate at 650 rpm.

Further, conversion of liquid pulp into foam by using CMC brought considerable reduction in drying time of foam for preparation of leather. The foam prepared by using 2.0–3.0% CMC dried within 4 h to a moisture content of about 12.0–12.9% in a mechanical dehydrator (55±2 °C).

Table 2 Quality evaluation of foam mat dried fruit leather from seabuckthorn (*H. salicifolia*) pulp

Pulp+ Stabilizer	Over run (%)	^a Foam stability (S)	Drying time (hrs)	Dehydration ratio	Dried Yield of leather(%)	Total solids (%)	Moisture (%)	Remarks
Pulp +0% CMC	0.00	1	—	—	—	—	—	No foam, drying not possible due to watery nature
Pulp+0.5% CMC	4.20	2	5.15	6.01:1	16.6	86.1	13.9	Unstable foam, drying and scrapping of leather difficult
Pulp+1.0% CMC	10.00	2	5.00	5.73:1	17.4	86.4	13.6	Unstable foam, drying and scrapping difficult
Pulp+1.5% CMC	15.70	3	4.30	5.59:1	17.9	86.7	13.3	Stable foam but drying and scrapping difficult
Pulp+2.0% CMC	22.00	4	4.00	5.38:1	18.6	87.1	12.9	Very stable foam, turned into leather easily, drying and scrapping easy
Pulp+2.5% CMC	20.10	3	4.00	5.20:1	19.2	87.6	12.4	Stable foam, turned into leather easily, drying and scrapping easy
Pulp+3.0% CMC	16.00	3	4.00	5.14:1	19.3	88.0	12.0	Turned into a gel, no foam, not suitable for drying

CMC Carboxy methyl cellulose

^a Foam stability scale: Fully stable foam -5; Very stable foam-4; Stable foam-3; Unstable foam-2; No foam-1

Plate 1 Seabuckthorn foamed pulp (2% CMC)

While pulp dried without CMC or using below 2.0% CMC, took about 5.15 h to dry into leather (Table 2). The increase in surface area by foaming and faster movement of moisture from the capillaries was thus attributable to faster rate of drying. The dehydration ratio in different dried products varied between 6.01:1 to 5.14:1 with the yield of dried leather varying between 16.64 to 19.30%. Thus, the addition of 2.0% CMC to the seabuckthorn pulp for foaming prior to drying to a leather of desired characteristics was optimized.

Dehydration characteristics of fruit leather/bar The dehydration curve for foam mat dried seabuckthorn leather prepared from pulp containing 2.0% CMC with and without the addition of sulphur dioxide @ 600 ppm is presented in Fig. 1. In comparison to total period of drying, the rate of dehydration was very fast during the initial period as about 50–55% (fwb) of the moisture was lost within the first 2.0 h of drying of both sulphited and unsulphited pulp, thereafter the rate of drying slowed down. It took about 4 h to dry the pulp to a leather of about 12–14% moisture content.

Fig. 1 Humidity moisture equilibrium curve for seabuckthorn foam mat dried pulp leather containing 2% CMC

Further, the pulp containing sulphur dioxide showed faster rate of drying initially than that of unsulphited pulp as SO_2 being a gas might account for improving the rate of drying (Chan and Cavaletto 1978). Thus, the use of SO_2 besides having preservative action also helps in improving the rate of drying.

In order to establish the storage conditions, the water activity of seabuckthorn leather/bar was optimized by determining the ERH of the product. The study revealed that the seabuckthorn leather had water activity of 0.46 with an equilibrium moisture content of 13.0%. It was further found that the product exposed to 70% relative humidity, exhibited considerable changes in its texture and colour within 16 days of exposure. Thus, the critical point (when the leather became soft) and danger point (5% lower relative humidity than that of critical point) for seabuckthorn fruit leather was recorded at the relative humidities of 70.0 and 65.0% respectively. At relative humidities of 50.0 and 60.0 there was a darkening of leather while at 70.0 (22.5% EMC) and beyond, the product turned very soft. The product when stored at 100% RH turned into liquid but no mould growth was encountered even after 24 days of study due to its high acidity (Table 3). At higher levels of relative humidity, the dried products have a tendency to absorb moisture and with additional moisture pick up, dried fruit bar turned dark brown (Ranganna 1997). Chan and Cavaletto (1978) reported 50–52% optimum relative humidity for storage of papaya leather of 12–13% moisture. Thus, it emerges that the seabuckthorn leather with 0.46 a_w is required to be stored within the relative humidity of 46–65%.

Physico-chemical characteristics of leather The data on physico-chemical characteristics of foam mat dried seabuckthorn leather indicate that product prepared by using

Table 3 Equilibrium relative humidity of seabuckthorn foam mat dried pulp leather containing 2% carboxy methyl cellulose (CMC)

Equilibrium moisture content (% dwb)	Relative humidity (%)	Days required to reach equilibrium	Remarks
5.00	0	22	Colour and texture normal
5.10	10	21	Colour and texture normal, product acceptable
7.50	20	20	Colour and texture normal, product acceptable
10.01	30	20	Colour normal
11.50	40	18	Colour normal
13.50	50	17	Darkening of colour
17.00	60	17	Darkening of colour
22.50	70	16	Browning in colour, soft in texture
29.94	80	14	Browning in colour, soft in texture
41.50	90	11	Very soft textured
57.69	100	–	Turns into liquid but no mould growth was encountered even after 24 days

sulphited pulp exhibited better retention of nutrients than that of unsulphited pulp. The fruit leather prepared from sulphited pulp (600 ppm SO₂) showed a higher proportion of both ascorbic acid (1045.7 mg/100 g vs 997.5 mg/100 g) and carotenoids (80.4 mg/100 g vs 72.2 mg/100 g) as compared to the leather made from the unsulphited pulp (Table 4). Earlier, Mir and Nath (1993) and Rao and Roy (1980) also recorded higher retention of ascorbic acid and carotenoids in the mango leather prepared from sulphited pulp. In comparison to other fruit leathers, the seabuckthorn leather is probably the only product which contained appreciable amounts of natural proteins (5.1–5.2%) and total phenolics (1.6–1.7 mg/100 g). Further, the use of

sulphited pulp for preparation of fruit leather showed its positive effect in improving the colour of the finished product with a considerable reduction in its non-enzymatic browning. Similarly, the level of residual sulphur dioxide in the fruit leather (504.0±2.23 ppm) was found well within the specified limits of preservative under the Indian Food Laws (Anonymous 1996) (Table 5).

Changes during storage The storage stability of seabuckthorn leather prepared from either sulphited or unsulphited pulp was evaluated at periodic intervals of 0, 3 and 6 months at ambient temperature (14.6–26.1°C) after packing them in PE pouches. The foam mat dried fruit

Table 4 Physico-chemical characteristics of foam mat dried leather from seabuckthorn (*H. salicifolia*) pulp

Parameters	Seabuckthorn leather ^a	
	Unsulphited (Mean ^b ±SD)	Sulphited (Mean ^b ±SD)
Moisture (%)	13.5±1.30	13.0±1.10
Total solids (%)	86.5±2.40	87.0±2.70
Total soluble solids (°B)	67.6±1.62	67.9±1.34
Titrateable acidity (% malic acid)	28.0±1.71	28.1±1.63
Brix/acid ratio	2.4±0.71	2.4±0.76
pH ^c	2.7±0.06	2.6±0.07
Sugars (%):		
Reducing	15.8±0.13	15.9±0.11
Non reducing	7.8±0.24	7.7±0.27
Total	24.1±0.51	24.0±0.57
Ascorbic acid (mg/100 g)	997.5±1.11	1045.7±1.15
Carotenoids (mg/100 g)	72.2±0.43	80.4±0.47
Proteins (%)	5.1±0.36	5.2±0.39
Total phenols (mg/100 g)	1.6±0.17	1.7±0.21
Pectin (% AuA)	2.9±0.27	3.2±0.23
Non enzymatic browning (OD _{440nm})	0.66±0.20	0.51±0.23

^a Sulphited: KMS added to the pulp @ 600 ppm SO₂ prior to foaming and drying.

^b Means of 3 replicates

^c Values based on 10% aqueous solution of leather

Table 5 Changes in chemical properties of foam mat dried seabuckthorn leather^a during storage at ambient temperature (14.6–26.1 °C)

Parameter	Leather	0 month	3 months	6 months	Mean	CD _{0.05%}
TSS (°B)	US	67.6	67.3	66.9	67.3	L=NS
	S	67.9	67.8	67.9	67.8	Storage(S)=0.19
	Mean	67.7	67.6	67.4		LxS=NS
Moisture(%)	US	13.5	14.1	15.1	14.2	L=NS
	S	13.0	13.6	14.7	13.8	S=0.36
	Mean	13.2	13.9	14.9		LXS=NS
Titratable acidity (%malic acid)	US	28.0	27.7	27.4	27.7	L=NS
	S	28.1	28.0	27.6	27.9	S=0.36
	Mean	28.1	27.9	27.5		LXS=NS
Brix acid Ratio	US	2.4	2.4	2.4	2.4	L=NS
	S	2.4	2.4	2.4	2.4	S=NS
	Mean	2.4	2.4	2.4		LXS=NS
Ascorbic acid	US	997.5	876.2	725.2	866.3	L=0.02
	S	1045.7	967.6	801.4	938.3	S=0.03
	Mean	1021.6	921.9	763.3		LXS=0.04
Carotenoids	US	72.3	68.1	64.3	68.2	L=0.03
	S	80.4	76.1	74.7	77.1	S=0.03
	Mean	76.3	72.1	69.5		LXS=0.05
Proteins	US	5.1	5.1	5.1	5.1	L=NS
	S	5.2	5.1	5.1	5.1	S=NS
	Mean	5.1	5.1	5.1		LXS=NS
Total Phenols	US	1.7	1.6	1.6	1.6	L=NS
	S	1.7	1.7	1.6	1.7	S=0.02
	Mean	1.7	1.7	1.6		LXS=NS

Sulphited (S): KMS added to the pulp @ 600 ppm prior to foaming and drying, US Unsulphited pulp

^a Seabuckthorn leather/bar was wrapped in butter paper and packed in polyethylene pouches (20 g) prior to storage

Table 6 Changes in sensory quality (colour, flavour, texture, taste and overall acceptability) during storage of foam mat dried seabuckthorn leather (9 point hedonic scale) at ambient temperature (14.6–26.1 °C)

Sensory Characteristics	Leather	0 month	3 months	6 months	Mean	CD _{0.05%}
Colour	US	7.2	7.2	7.1	7.2	L=0.39
	S	7.7	7.6	7.5	7.6	S=NS
	Mean	7.5	7.4	7.3		LXS=NS
Flavour	US	7.3	7.3	7.2	7.3	L=NS
	S	7.4	7.3	7.3	7.3	S=NS
	Mean	7.4	7.3	7.2		LXS=NS
Texture	US	7.4	7.3	7.3	7.3	L=NS
	S	7.6	7.5	7.4	7.5	S=0.10
	Mean	7.5	7.4	7.3		LXS=NS
Taste	US	7.1	7.1	7.0	7.1	L=NS
	S	7.1	7.1	7.0	7.1	S=NS
	Mean	7.1	7.1	7.0		LXS=NS
Overall acceptability	US	7.2	7.1	7.1	7.1	L=NS
	S	7.4	7.2	7.2	7.2	S=NS
	Mean	7.3	7.2	7.1		LXS=NS

Sulphited: KMS added to the pulp @ 600 ppm prior to foaming and drying

^a Seabuckthorn leather/bar was wrapped in butter paper and packed in polyethylene pouches (20 g) prior to storage

leather made from either sulphited or unsulphited pulp did not exhibit any appreciable change in its TSS and acidity during storage. However, slight decrease in total solids observed during storage is correlated well with the corresponding increase in the moisture content (14.9%) of the leather due to pick up of moisture. The seabuckthorn leather made from sulphited pulp showed better retention of ascorbic acid (938.3 mg/100 g) as compared to the product prepared from unsulphited pulp (866.3 mg/100 g) even after 6 months of storage. However, at end of the storage period the level of ascorbic acid in fruit leather was found to be 763.3 mg/100 g against its initial value of 1021.6 mg/100 g thus representing a reduction of about 25.0%. The degradation of ascorbic acid during storage is attributed partially to its oxidation and partially to its involvement in browning reactions in the presence of high acidic environment (Clegg 1964). Similar the level of total carotenoid in seabuckthorn leather were recorded to be 69.5 mg/100 g after 6 months of storage from its original level of where about 8.9% of carotenoid is lost during a storage period of 6 months thus reducing its concentration to against its initial value of 76.3 mg/100 g. However, the leather made from sulphited pulp exhibited significant improvement in retention of carotenoids during storage as compared to the leather made from unsulphited pulp. Marginal decrease in proteins during storage of leather has been attributed to its possible participation in maillard browning reactions (Cheftal et al. 1985). Similarly, slight reduction in phenolic compounds might be due to its involvement in the polymeric compounds or complexing of phenols with proteins to cause browning as has also been reported by Abers and Wrolstad (1979). Thus the fruit leather prepared from sulphited pulp exhibited better retention of vitamin C and carotene with no adverse effects on other quality characteristics up to 6 months of storage at ambient temperature.

The sensory quality of seabuckthorn leather evaluated on 9 point hedonic scale for various attributes during storage is presented in Table 6. The seabuckthorn leather prepared from either sulphited or unsulphited pulp was acceptable in all sensory quality parameters with a hedonic score more than 7.0 out of 9.0. However, the acceptability score exhibited slight decrease with the increase in period of storage. The fruit bar prepared from sulphited pulp experienced minimum changes in sensory colour, flavour and texture acceptability scores as compared to the leather made from unsulphited pulp during storage. Slight decrease in flavour scores observed during 6 months might be attributed to the loss of aromatic compounds during storage. In general, sulphur dioxide added to the pulp for preservation of leather did not cause any adverse effect to the taste of leather as the sensory score for taste scores for both types of leather were at par with each other even after

6 months of storage. The fruit leather made from sulphited pulp had a higher score (7.3) for overall acceptability in comparison to the product made from unsulphited pulp (7.1). Further, the sensory score for overall acceptability in the product during entire period of storage remained above 7.0, thus exhibiting good storage stability of this product.

Thus the method for the preparation of seabuckthorn leather using sulphited pulp (600 ppmSO₂) by converting it into foam followed by drying and packing in PE pouches was found the most appropriate for utilization of vitamin C, carotene, polyphenol and protein enriched seabuckthorn berries. The technology being simple and easy to adopt can be recommended for commercialization in the food industry.

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