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# Optimization of primary post-harvest processing techniques for *Cassia angustifolia* Vahl.

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**Abstract**
*Cassia angustifolia* Vahl. (Senna), is a versatile medicinal plant that enjoys a considerable reputation in Ayurveda, Unani and Allopathic medicine system worldwide. It contains sennosides (2.5% in the leaves and 3.6% in the pods), which are utilized to treat habitual constipation and other related problems. Senna cultivation is done successfully in India; however, the primary post-harvest processing techniques are not optimized yet. Hence, experiments were planned for three drying methods (sun drying, 50% shade drying, and 100% shade drying) and five packing materials (plastic silver, transparent polythene, woven plastic, jute, & black polythene bag) for one year storage of dried senna leaves and pods. Results revealed that senna leaves were more prone to deterioration during storage irrespective of packing material used for storage. Drying in 100% shade condition retained the quality of pods (3.22% sennosides) and leaves (2.20% sennosides) in comparison with other methods as sennosides are the main chemical components of leaves and pods of *Cassia angustifolia* Vahl. Pods' quality can be retained without any considerable deterioration if dried in 100% shade and packed in black poly bags (3.17%). Calculation of economics revealed that cost of post-harvest processing was slightly higher (662.04$ for 10 t) if drying was done in 100% shade in comparison with other two methods of drying. However, by drying under the 100% shade, it can retain the herb quality up to a longer time and make this crop more economically viable for farmers and medicinal plant-based industries.

**Keywords:** *Cassia angustifolia* Vahl. Sennosides, drying condition, packing material, storage period

## 1. Introduction

*Cassia angustifolia* Vahl. commonly-known as senna, is a versatile medicinal plant and finds good demand in Ayurvedic, Unani, and Allopathic medicine systems. Senna leaves and pods contain sennosides (2.5% in the leaves and 3.6% in the pods), which are the main constituents and utilized to treat habitual constipation worldwide (Nilofer *et al.*, 2018) [16]. The herbal formulation of senna is also utilized as an expectorant for wound healing, antidysentery, and a carminative agent. The leaves and pods of *C. angustifolia* Vahl. enjoy high demand in both domestic, i.e., Indian and international market and the major importing countries are Germany, France, the USA, the UK, Australia, and South East Asia, which received about 75% of total senna production in India (Gupta, 1971; Hussain, 1992; Anon, 1982; and Zauba.com 2016) [10, 12, 5, 24]. A period of about 4-6 months is required from its harvest to reach up to end users after export. Hence, the quality of leaves and pods must be maintained up to a more considerable period so that products can be accepted internationally. However, it has been reported that the quality of senna leaves and pods become deteriorated during long storage (Upadhyay *et al.*, 2011) [23]. As observed in several medicinal plants, proper drying methods can positively affect the quality of the dried medicinal herb. Because in northern Indian plains, senna can be a profitable crop if grown as summer season crop (Nilofer *et al.*, 2018) [16] and the harvesting must be done before the onset of rains. After that, the drying of the raw herb is a crucial step that must be performed very wisely so that deterioration in quality can be minimized and sennosides do not degrade during the whole process of drying, packing, and storage. The raw herbal material utilized determines the quality of herbal-based medications, nutraceuticals, and food supplements products (Abdullah *et al.*, 2012) [1]. The quality of herb is influenced by a number of factors, one of which is drying. Drying is the first step in many operations related to post-harvest processing. The drying process is mainly done to limit the plant's moisture content, which in turn, arrests the activities of microbes and enzymes that deteriorate quality of the product. All these preventive measures aid in extending the shelf-life of preserved food. Storage, packing and handling of raw materials, quality control during herbal medicines development, shelf-life, preservatives employed and pesticides residues are all elements that influences safety and efficacy. For all these reasons, it indisputable that raw herbal drugs require a lot of massive studies to determine the safety and efficacy of herbal raw medicines by updating and refining the storage and handling procedures employed in Ayurveda. The shelf life of herbs is directly impacted by their exposure to light, oxygen and microbes. The raw herbs oxidise in the presence of air whilst light decomposes them, reducing their stability. Air oxidizes the raw herbs, whereas light decomposes the herbs due to which stability is reduced. Studies on the packing and storage of senna leaves had been performed by Upadhyay *et al.* (2011) [23], but proper drying method and more options for different packing materials along with the economics of post-harvest packing in relation with the variable cost of packing material have not been studied yet for both the leaves and the pods. Therefore, experiments were conducted to optimize the best drying condition, packing material for senna leaves and pods and safe period for its storage during the process of production to consumption and to evaluate the cheapest packing material for transportation nationally and internationally. The study is of great importance to generate information about the drying, packing, and economics for preserving the quality of this herbal drug to prevent the degradation of sennosides.

## 2. Materials and Methods

### 2.1. Experimental location

Crop of *Cassia angustifolia* Vahl. was grown at the experimental farm of CSIR-CIMAP. The experimental site i.e., CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, is located between latitude 26°5´ N and longitude 80°5´ E at an altitude of about 120 m above mean sea level experiencing the sub-tropical climate.

### 2.2. Experimental details

Seeds of variety 'Sona' were sown in mid-March, and the crop was harvested at 90 days of crop maturity. All intercultural operations were done, as suggested by Nilofer *et al.* (2018) [16]. Weather parameters during the entire cropping period have been depicted in Figure 1. Plants were harvested from 10 cm above the ground and then dried into three different drying environments viz. in the open sun (3-4 days), in 50% shade (7-8 days), and in 100% shade (11-12 days). During the drying process, samples were weight with an electronic-balance at 4 hrs. interval to record the moisture content of the leaves and pods. After the leaves and pods were fully dried, i.e., when constant weight was obtained (moisture content in leaf was 10% and in pods 15%) (Sastry *et al.*, 2015) [20] in all the three-drying condition, the dried leaves and pods were packaged into five different types of packing materials, i.e., plastic silver pouch, transparent polythene bag, woven plastic bag, jute bag, & black polythene bag in 3 replicates (details are given in Table 1). The sample size was 1 kg in each type of packing material. The quality of the dried leaves and pods was analysed initially, i.e., just after drying (control) for all the drying conditions and then at two months of a year of storage period with respective packing materials and drying conditions. After storage in different packing materials, 100 g sample was taken and oven dried to know the moisture content of the leaves and pods in each storage condition which were recorded constant (i.e., 10% in the leaves and 15% in the pods) irrespective of packing material used.

### 2.3. Weather parameters in different drying conditions

Because the drying of senna leaves and pods was carried out in June (15-30), the variation in different weather parameters under different drying conditions during this period was also recorded and shown in Table 2. Under different drying conditions, Temperature (°C), Relative Humidity (%), and Sun Shine (Lux) were varied according to the level of shade provided during the drying process of the leaves and the pods which were measured through Lutron LM-8000A (for temperature and relative humidity) and Lutron Lx-105 Light Meter, RS-232 (for sun shine). The drying process in different conditions and packaging materials are shown in Figures 2 and 3 respectively.

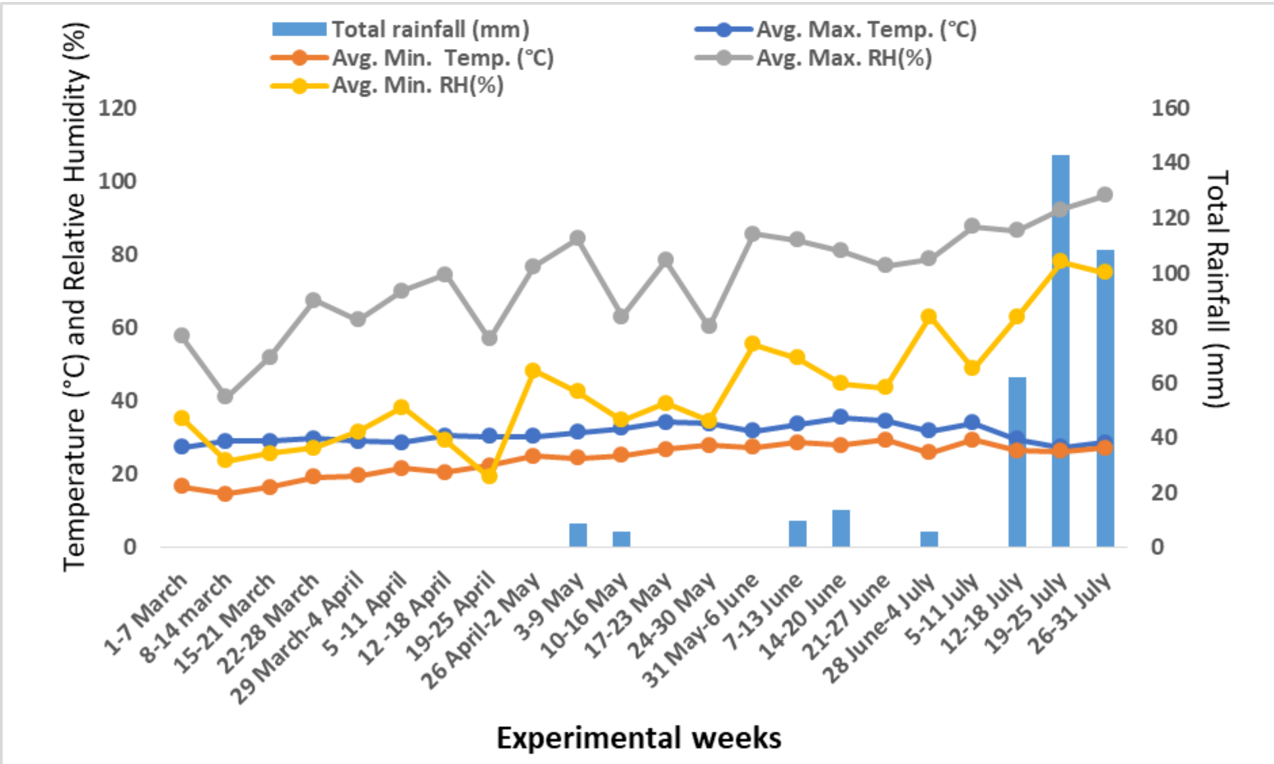


**Fig 1:** Weather data of cropping and drying period of *Cassia angustifola* Vahl.

Open Sun 50% Shade 100% Shade

**Fig 2:** Drying of herb (*Cassia angustifolia* Vahl.) under different conditions

**Fig 3:** Packing Bags for Post-Harvest Storage of leaves and pods

### 2.4. Quality analysis
Sennoside content (%) was analysed and calculated on dry weight basis. The HPLC method was used for chemical analysis as described by Reddy *et al.* (2015). Powdered samples of dry leaves and pods (300 mg each) were extracted in 30 mL of 70% methanol in water employing sonication (25 °C) for 20 minutes in triplicates. Before being injected into the chromatography apparatus, the sonicated samples were filtered through a 0.45 µm membrane. A Waters HPLC system with an SPD-M20 A photodiode array detector was used for the HPLC analysis. A 98 C18 column (4.6mm×250 mm, 5.0 µm particle size). (A) methanol: water: acetic acid (20:80:0.1, v/v/v) and (B) methanol: water: acetic acid (80:20:0.1, v/v/v) were used in the mobile phase. The temperature of separation was kept constant at 25 °C. The flow rate was (1 mL/ min) and at 285 nm sample volume were measured. Peaks were determined by spiking the samples with a genuine sample (standard), then examining UV spectra and retention time.

### 2.5. Economics
Economics of post-harvest operations, i.e., drying of herbs, packing of the dried herb was calculated by the prevailing market price of different materials, and labor charges required for performing these operations on 10 t quantity. Drying cost was different for different drying methods which depends on days taking in drying in different shades (4 days in sun drying, 7 days in 50% shade, and 12 days in 100% shade) to achieve the moisture content at 10% for leaves and 15% for pods. Depending upon days of drying, the total number of labour and labour charges also differ. The storage cost was calculated by current rental charges for storage of the herb for different storage periods in the warehouse.

### 2.6. Statistical analysis
The data of sennoside content (leaves and pods) were subjected to analysis of variance (ANOVA) for factorial randomized block design (FRBD) as prescribed by Panse and Sukhatme (1985) [17]. The differences between treatment means were compared by the critical difference of 5% (*P=0.05) level of significance.

## 3. Results
### 3.1. Microclimatic parameters recorded under different drying conditions
Data recorded on air temperature (°C), relative humidity (%), and sunshine (Lux) under different drying conditions, i.e., Sundry condition, 50% shade, and 100% shade are presented in Table 2. The drying period was different for different drying conditions. In the open sun, samples were thoroughly dried in 3-4 days, whereas in 50% shade, complete drying took about 7-8 days, whereas a period of 11-12 days was required under 100% shade condition (for obtaining same moisture content in all dried samples by different drying methods i.e., 10% in leaves and 15% in pods). Different weather parameters under all the three drying conditions were measured during the drying period. The air temperature in full sun conditions ranged from 44-46 °C, whereas in 50% shade drying air temperature range was 35-37 °C. However, in the 100% shade, it was 32-35 °C. Relative humidity ranged between 42-45% in the open sun, whereas, in 50% shade, relative humidity was recorded in the range of 35-40% during the drying period, whereas, in 100% shade, relative humidity ranged between 35-40%. The intensity of sunshine varied considerably in different drying conditions. In open sun drying, in 50% shade drying, and in 100% shade drying, it ranged from 16 to 20 (×100 Lux), 310 to 400 (×100 Lux), and 700 to 800 (×100 Lux), respectively. The variations in temperature, RH, and sunshine created different environments for the drying process of senna leaves and pods. There was a significant effect of the interaction of these parameters on the sennoside content of the leaves and the pods.

### 3.2. Sennoside content in pods and leaves
Initial sennoside content was recorded immediately after the drying of the pods and leaves. It was about 3.11%, 3.15%, and 3.22% in pods (Table 3) whereas, it was about 2.11%, 2.13%, and 2.20% in open sun-dried, 50% shade, and 100% shade samples of leaves, respectively (Table 4). Hence, data suggest that shade improved sennoside content in both pods and leaves of *Cassis angustifolia* Vahl.

### 3.3. Effect of drying condition

Drying conditions affected the quality of senna pods and leaves significantly. After drying in different conditions, sennoside content analysed and results (Table 3 and 4) indicated that initial content was varied according to the drying method for both sennoside rich plant parts i.e., pods and leaves. Sennoside content was about 3.11%, 3.15%, and 3.22% in open sun-dried samples, 50% shade dried samples, and 100% shade dried samples of pods, respectively. Overall, the sennoside content was highest (3.02%) in the 100% shade dried samples; in 50% shade, it was 2.55%, whereas the lowest (1.87%) sennoside content was recorded in open sun-dried samples. The HPLC analysis of the leaves indicated that sennoside content was affected significantly by the drying condition (Table 4). The sennoside content of the leaves reduced at a faster rate than pods, i.e., the quality of leaf was started deteriorating in the early month of storage. Overall, the data indicated that in sun-dried samples, the content was 1.10%; in 50% shade dried samples, it was about 1.19%, whereas in 100% shade-dried sample average sennoside content was about 1.28%.

### 3.4. Effect of Packing material

Packing material affected the sennoside content of pods and leaves significantly. It was observed that in pods, maximum (3.20%) content was recorded in the black poly bag in 100% shade dried samples (Table 3). Sennoside content was higher in black polybags irrespective of the drying conditions. However, data indicated that the maximum decrease was recorded in open sun-dried samples. The lowest content was recorded in plastic silver pouch irrespective of the drying method used. The effect of packing material on the sennoside content of the leaves are shown in Table 4. The results indicated that packing material was unable to maintain the quality of stored leaves irrespective of drying conditions. However, the minimum degradation in sennoside quality was recorded in 100% shade dried leaf, which was packaged and stored in the black polybag (initial content 2.20%, which was reduced to 0.27%), but degradation was very high. Overall, the data indicated that the sennoside content of the leaves dried in 100% shade and packaged in the black polybag was 1.46%, which was the highest among different treatment combinations. The lowest sennoside content was recorded in open sun-dried leaves packaged in the plastic silver pouch (initial content was 2.11% and overall content was 0.96%). The trend of decrease in sennoside content in both pods and leaves was as follows:

Plastic silver pouch> transparent polybag> woven plastic > jute bag> black polybag.

### 3.5. Effect of storage period

The sennoside content decreased with the increase in the storage period, but it was dependent on the drying condition and packing material. In pods, the initial content decreased gradually from 3.16% to 1.87% (Table 3). However, the decrease was lowest in 100% shade-dried sample, which was packaged in a black polybag (initial 3.22%, and after 12 months it was reduced to 3.17%). In contrast, the highest decline was recorded in the open sun-dried sample, which was stored in a plastic silver pouch (initial 3.13%, which was reduced to 0.98% after 12 months of storage). Sennoside content of leaf as affected by the storage period is shown in Table 4. The sennoside content of the leaves decreased at a faster rate, and the initial content (2.14%) was reduced with the increase in the storage period. After one year of storage, it was reported about 0.15%. However, it was observed that the level of degradation was different according to the drying condition and packing material. The minimum decrease was recorded in the 100% shade dried samples of leaves, which was packed and stored in black polybag, i.e., initial content was 2.20%, which was reduced to 0.27% after one year of storage. The maximum decline was recorded in the open sun-dried leaf sample, which was packed in a plastic silver pouch (initial 2.11% after one year 0.10%). Thus, the results indicated that sennosides in the leaves were more affected by different storage periods in comparison with pods.

### 3.6. Economics

The comparative cost of different treatments has been presented in Table 5 and 6. Comparative cost of different drying conditions, packing material, and storage period showed that the cheapest method for drying senna leaves and pods is open sun drying, whereas drying cost was maximum in 100% shade condition (Table 5). The open sun-dried samples took only 3-4 days to dry and there were no additional charges and due to a smaller number of drying days; labour charges were also lowest in this method whereas in shade conditions (50% and 100%) drying days were more (7 days in 50% shade and 12 days in 100% shade) which also increased the labour charges for maintenance of herbage and there was additional expenditure on shade preparation. Thus, highest charges of drying were calculated for 100% shade drying (Table 5). The cheapest material for packing of senna leaves and pods was in black polybags (0.10 \$ $bag^{-1}$ of 50 kg capacity), whereas, the highest cost of packing was obtained when jute bags were utilized (0.20 \$ $bag^{-1}$ of 50 kg capacity) (Table 1 and 5). As the storage period increased, the rental charges for keeping the material and maintenance charges of the herb were also increased. The total expenditure (drying+ packing+ storage) in the open sundry sample ranged between 471.3\$ to 898.9\$. In contrast, it was about 673.9\$ to 1101.5\$ if samples were dried in 50% shade and if drying was done in 100% shade, about 860.8\$ to 1288.5\$ were spent depending upon different packing material used (Table 6).

**Table 1:** Details of packaging material and unit cost used for storage (1USD=73.41 INR)

| Storage bag | Material used | Unit price (capacity 50 kg) |
|---|---|---|
| Plastic Silver pouch | 12 Micron Metalized Polyester laminated with 20 MICRON natural or Milky Low density Poly Ethylene (LDPE) | 0.16 \$ |
| Transparent polythene bags | Polyethylene (PE). | 0.13 \$ |
| Woven plastic Bag | High Density Polyethylene (HDPE) | 0.16 \$ |
| Jute bag | Fibres of Jute plant | 0.20 \$ |
| Black polythene bags | Black Pigment Polyethylene (PE) | 0.10 \$ |

**Table 2:** Weather parameters under different drying conditions

| Drying condition | Open Sun | 50% shade | 100% shade |
|---|---|---|---|
| Temperature (°C) | 45±2 | 36±2 | 32±2 |
| RH (%) | 45±5 | 36±5 | 35±5 |
| Sunshine (Lux) | 750±50 (×100) | 350±50 (×100) | 18±5 (×100) |

RH = Relative humidity

**Table 3:** Sennoside content (%) in pods as affected by drying condition, packing material and storage period

| Storage Period Drying Condition | Immediate after drying | 2 Months after drying | 4 Months after drying | 6 Months after drying | 8 Months after drying | 10 Months after drying | 12 Months after drying | Mean |
|---|---|---|---|---|---|---|---|---|
| Packing material | Sun Drying | | | | | | | |
| Plastic silver pouch | 3.11 | 2.08 | 1.25 | 1.11 | 1.05 | 1.00 | 0.98 | $1.51^{d}$ |
| Transparent polybag | 3.11 | 2.11 | 2.00 | 1.72 | 1.35 | 1.21 | 1.11 | $1.80^{c}$ |
| Woven plastic | 3.11 | 2.12 | 2.00 | 1.75 | 1.47 | 1.31 | 1.22 | $1.85^{c}$ |
| Jute bag | 3.11 | 2.55 | 2.30 | 2.00 | 1.55 | 1.43 | 1.29 | $2.03^{b}$ |
| Black polybag | 3.11 | 2.57 | 2.31 | 2.06 | 1.69 | 1.68 | 1.67 | $2.16^{a}$ |
| Mean | 3.11 | 2.28 | 1.97 | 1.73 | 1.42 | 1.33 | 1.25 | 1.87 |
| 50% Shade drying | | | | | | | | |
| Plastic silver pouch | 3.15 | 3.14 | 3.00 | 2.75 | 2.10 | 1.55 | 1.07 | $2.39^{c}$ |
| Transparent polybag | 3.15 | 3.14 | 3.02 | 2.77 | 2.33 | 1.82 | 1.55 | $2.54^{b}$ |
| Woven plastic | 3.15 | 3.15 | 3.05 | 2.81 | 2.35 | 1.91 | 1.69 | $2.59^{a}$ |
| Jute bag | 3.15 | 3.15 | 3.07 | 2.85 | 2.36 | 1.93 | 1.71 | $2.60^{a}$ |
| Black polybag | 3.15 | 3.15 | 3.09 | 2.88 | 2.41 | 2.00 | 1.94 | $2.66^{a}$ |
| Mean | 3.15 | 3.15 | 3.05 | 2.81 | 2.31 | 1.84 | 1.59 | 2.55 |
| 100% Shade drying | | | | | | | | |
| Plastic silver pouch | 3.22 | 3.15 | 3.11 | 2.89 | 2.75 | 2.41 | 2.34 | $2.84^{c}$ |
| Transparent polybag | 3.22 | 3.16 | 3.13 | 2.99 | 2.87 | 2.75 | 2.65 | $2.97^{b}$ |
| Woven plastic | 3.22 | 3.18 | 3.12 | 3.00 | 2.91 | 2.81 | 2.70 | $2.99^{b}$ |
| Jute bag | 3.22 | 3.21 | 3.15 | 3.10 | 3.05 | 3.01 | 2.99 | $3.10^{a}$ |
| Black polybag | 3.22 | 3.22 | 3.22 | 3.21 | 3.20 | 3.18 | 3.17 | $3.20^{a}$ |
| Mean | 3.22 | 3.18 | 3.15 | 3.04 | 2.96 | 2.83 | 2.77 | 3.02 |
| Mean of storage period | 3.16 | 2.87 | 2.72 | 2.52 | 2.23 | 2.00 | 1.87 | |

| | | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drying condition (DC) | | 0.03 | 0.10 | 0.03 | 0.10 | 0.03 | 0.09 | 0.03 | 0.08 | 0.03 | 0.09 | 0.03 | 0.08 | |
| Packing (P) | | 0.04 | 0.13 | 0.04 | 0.13 | 0.04 | 0.12 | 0.04 | 0.11 | 0.04 | 0.11 | 0.03 | 0.10 | |
| DC × P | | 0.03 | 0.10 | 0.03 | 0.10 | 0.03 | 0.09 | 0.03 | NS | 0.03 | NS | 0.03 | 0.08 | |

Letters showing the difference (**P* > 0.05), NS= Non-significant

**Table 4:** Sennoside content (%) in leaves as affected by drying condition, packing material and the storage period

| Storage period Drying Condition | Immediate after drying | 2 Months after drying | 4 Months after drying | 6 Months after drying | 8 Months after drying | 10 Months after drying | 12 Months after drying | Mean |
|---|---|---|---|---|---|---|---|---|
| Packing material | Sun Drying | | | | | | | |
| Plastic silver pouch | 2.11 | 1.23 | 1.11 | 1.00 | 0.65 | 0.55 | 0.10 | $0.96^{cd}$ |
| Transparent polybag | 2.11 | 1.47 | 1.31 | 1.01 | 0.77 | 0.61 | 0.11 | $1.06^{c}$ |
| Woven plastic | 2.11 | 1.59 | 1.41 | 1.05 | 0.80 | 0.62 | 0.12 | $1.10^{b}$ |
| Jute bag | 2.11 | 1.59 | 1.50 | 1.15 | 0.81 | 0.65 | 0.13 | $1.13^{b}$ |
| Black polybag | 2.11 | 1.75 | 1.65 | 1.37 | 0.98 | 0.72 | 0.15 | $1.25^{a}$ |
| Mean | 2.11 | 1.53 | 1.39 | 1.12 | 0.80 | 0.63 | 0.12 | 1.10 |
| 50% Shade drying | | | | | | | | |
| Plastic silver pouch | 2.13 | 1.33 | 1.29 | 1.05 | 0.66 | 0.55 | 0.11 | $1.02^{e}$ |
| Transparent polybag | 2.13 | 1.49 | 1.40 | 1.19 | 0.72 | 0.62 | 0.12 | $1.09^{d}$ |
| Woven plastic | 2.13 | 1.69 | 1.59 | 1.20 | 0.95 | 0.75 | 0.13 | $1.21^{c}$ |
| Jute bag | 2.13 | 1.77 | 1.61 | 1.56 | 0.99 | 0.77 | 0.13 | $1.28^{b}$ |
| Black polybag | 2.13 | 1.89 | 1.81 | 1.63 | 1.02 | 0.88 | 0.14 | $1.36^{a}$ |
| Mean | 2.13 | 1.63 | 1.54 | 1.33 | 0.87 | 0.71 | 0.13 | 1.19 |
| 100% Shade drying | | | | | | | | |
| Plastic silver pouch | 2.20 | 1.35 | 1.30 | 1.19 | 0.75 | 0.60 | 0.12 | $1.07^{e}$ |
| Transparent polybag | 2.20 | 1.67 | 1.60 | 1.30 | 0.77 | 0.65 | 0.19 | $1.19^{d}$ |
| Woven plastic | 2.20 | 1.71 | 1.66 | 1.65 | 0.99 | 0.90 | 0.20 | $1.33^{c}$ |
| Jute bag | 2.20 | 1.85 | 1.80 | 1.69 | 1.05 | 0.92 | 0.22 | $1.39^{b}$ |
| Black polybag | 2.20 | 1.99 | 1.89 | 1.85 | 1.06 | 0.93 | 0.27 | $1.46^{a}$ |
| Mean | 2.20 | 1.71 | 1.65 | 1.54 | 0.92 | 0.80 | 0.20 | 1.28 |
| Mean of storage period | 2.14 | 1.62 | 1.52 | 1.33 | 0.86 | 0.71 | 0.15 | |

| | | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | SEm± | CD at 5% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drying condition (DC) | | 0.02 | 0.06 | 0.02 | 0.06 | 0.02 | 0.05 | 0.01 | 0.03 | 0.01 | 0.03 | 0.004 | 0.01 | |
| Packing (P) | | 0.03 | 0.08 | 0.03 | 0.08 | 0.02 | 0.07 | 0.01 | 0.04 | 0.01 | 0.03 | 0.005 | 0.01 | |
| DC×P | | 0.02 | NS | 0.02 | NS | 0.02 | 0.05 | 0.01 | 0.03 | 0.01 | 0.03 | 0.004 | 0.01 | |

Letters showing the difference (**P* > 0.05), NS= Non-significant

**Table 5:** Cost of different variable (Drying, Packing and Storage) for 10 t herb (Leaves and pods)

| Treatments | | Drying charges (A) | | | Packing Charges (B) | | | Storage charges ($) (C) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drying Condition | Packing Material | Drying Shade Charges | Labour Charges ($) for drying | Total | Packing Material Charge ($) | Labour Charge ($) for packing | Total | 2 Months | 4 Months | 6 Months | 8 Months | 10 Months | 12 months |
| Open Sun | Plastic Silver Bag | 0.00 | 272.44 | 272.44 | 32.69 | 68.11 | 100.80 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Transparent Bag | 0.00 | 272.44 | 272.44 | 27.24 | 68.11 | 95.35 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Woven Plastic Bag | 0.00 | 272.44 | 272.44 | 32.69 | 68.11 | 100.80 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Jute Bag | 0.00 | 272.44 | 272.44 | 40.87 | 68.11 | 108.98 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Black Polybag | 0.00 | 272.44 | 272.44 | 21.80 | 68.11 | 89.91 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| 50% Shade | Plastic Silver Bag | 16.01 | 459.07 | 475.07 | 32.69 | 68.11 | 100.80 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Transparent Bag | 16.01 | 459.07 | 475.07 | 27.24 | 68.11 | 95.35 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Woven Plastic Bag | 16.01 | 459.07 | 475.07 | 32.69 | 68.11 | 100.80 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Jute Bag | 16.01 | 459.07 | 475.07 | 40.87 | 68.11 | 108.98 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Black Polybag | 16.01 | 459.07 | 475.07 | 21.80 | 68.11 | 89.91 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| 100% Shade | Plastic Silver Bag | 32.01 | 630.02 | 662.04 | 32.69 | 68.11 | 100.80 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Transparent Bag | 32.01 | 630.02 | 662.04 | 27.24 | 68.11 | 95.35 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Woven Plastic Bag | 32.01 | 630.02 | 662.04 | 32.69 | 68.11 | 100.80 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Jute Bag | 32.01 | 630.02 | 662.04 | 40.87 | 68.11 | 108.98 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |
| | Black Polybag | 32.01 | 630.02 | 662.04 | 21.80 | 68.11 | 89.91 | 108.98 | 190.71 | 272.44 | 354.18 | 435.91 | 517.64 |

*Man power 3.41 \$ day$^{-1}$ (1USD=73.41 INR)

**Table 6:** Total cost of post-harvest operations (\$ 10 t$^{-1}$)*

| Treatments | | Total charges of Drying, Packaging and Storage (A+ B+ C) | | | | | |
|---|---|---|---|---|---|---|---|
| Drying Condition | Packing Material | 2 Months | 4 Months | 6 Months | 8 Months | 10 Months | 12months |
| Open Sun | Plastic Silver Bag | 482.2 | 563.9 | 645.6 | 727.3 | 809.0 | 890.8 |
| | Transparent Bag | 476.7 | 558.4 | 640.2 | 721.9 | 803.6 | 885.3 |
| | Woven Plastic Bag | 482.2 | 563.9 | 645.6 | 727.3 | 809.0 | 890.8 |
| | Jute Bag | 490.3 | 572.1 | 653.8 | 735.5 | 817.2 | 898.9 |
| | Black Polybag | 471.3 | 553.0 | 634.7 | 716.4 | 798.1 | 879.9 |
| 50% Shade | Plastic Silver Bag | 684.8 | 766.5 | 848.2 | 929.9 | 1011.6 | 1093.4 |
| | Transparent Bag | 679.3 | 761.0 | 842.8 | 924.5 | 1006.2 | 1087.9 |
| | Woven Plastic Bag | 684.8 | 766.5 | 848.2 | 929.9 | 1011.6 | 1093.4 |
| | Jute Bag | 692.9 | 774.7 | 856.4 | 938.1 | 1019.8 | 1101.5 |
| | Black Polybag | 673.9 | 755.6 | 837.3 | 919.0 | 1000.7 | 1082.5 |
| 100% Shade | Plastic Silver Bag | 871.7 | 953.4 | 1035.1 | 1116.9 | 1198.6 | 1280.3 |
| | Transparent Bag | 866.2 | 948.0 | 1029.7 | 1111.4 | 1193.1 | 1274.9 |
| | Woven Plastic Bag | 871.7 | 953.4 | 1035.1 | 1116.9 | 1198.6 | 1280.3 |
| | Jute Bag | 879.9 | 961.6 | 1043.3 | 1125.0 | 1206.8 | 1288.5 |
| | Black Polybag | 860.8 | 942.5 | 1024.2 | 1106.0 | 1187.7 | 1269.4 |

*All calculations have been done on the basis of 10 t herbage, (1USD= 73.41 INR)

## 4. Discussion

The reason for the maximum decline in sennoside content under sun-dried samples was that direct sun rays fall on the plant produce, which alters the colour and quality of the produce. Direct sunlight alters the biochemical and Phyto-molecules of the plant parts, affecting the quality of the final product (Bernard *et al.*, 2014) [6]. The experimental location receives direct sun rays (700 ×100 Lux) in May and June, and due to high temperature (44-46 °C) and under direct sunlight, the quality of leaves and pods altered. Whereas in 50% shade, there was less light intensity (310× 100 Lux), but the temperature was about 37-40 °C, and humidity ranged between 35-38%, which resulted in the loss of sennosides, but the decrease was lower than direct sunlight. The reduction in sennoside content was less than the direct sun but more than the 100% shade condition. Under 100% shade condition, the decrease was minimum in comparison with other drying methods, which may be due to low temperature (32-35 °C) during drying, which was beneficial for the drying of medicinal plants as it enhances the content of secondary metabolites in the medicinal herb. In addition, low temperatures with moderate humidity (35-40%) also helped in quality maintenance in senna pods. However, the quality of pods was retained for a longer time in comparison with the leaves in which quality was degraded very rapidly. Traditional drying procedures, such as sun drying have numerous disadvantages due to their inability to handle the vast capacity of mechanical harvesters while maintaining the high-quality standards required for medicinal plants. During the harvesting season, high ambient air temperature and relative air humidity encourage the development of insects and mould in harvested crops. Furthermore, intense solar radiation has a negative impact on quality, resulting in essential oil losses and colour changes in dried plants (Rocha *et al.*, 2011) [19]. Chemical changes are the most important in the post-harvest management of medicinal plants and can be influenced by drying (Aboltins and Kic, 2016) [2]. Furthermore, drying might cause changes in the appearance (colour) and fragrance of the product, affecting the final quality. Lorenzi and Matos (2002) [14] stated that drying medicinal species is a preparatory process carried out to satisfy the needs of the pharmaceutical sector, which does not have the necessary condition to exploit fresh plants on a large scale. The sensitivity of these substances determines the drying process's temperature because the plant temperature is increased during the drying and high temperature may promote loss by volatilization or degradation of the principal active compounds (Venskotonis *et al.*, 1997) [24]. In general, high temperature affects the quantity and quality of essential oils in medicinal plants not only during drying, but also during storage (Blazik and Kucera, 1952; Martinazzo *et al.*, 2009) [7, 15]. Changes in the concentration of volatile sage oils were found to be dependent on the technique and drying temperature, according to Venskutonis (1997) [24].

Produce preservation is a fundamental issue that manufacturers of these product must be addressed. Temperature and humidity should be managed wherever feasible to prevent harm to the active chemical ingredients. The drying process and temperature utilized they have a significant impact on the quality of medicinal plants materials. Proper drying of medicinal herbs inhibits and reduces microbial growth and prevents biochemical changes. Furthermore, the loss of bioactive components occurs frequently when herbs are dried, albeit some phytochemicals are more thermostable than others (Herrmann KM, 1995; Bravo L., 1998) [11, 8]. The breakdown was caused by enzymatic degradation of the phytochemicals induced by relatively intense and extended solar radiation. The key contributing components in the declining trend could be the temperature and time needed in drying procedure.

Packing material influenced the sennoside content during a one-year storage period of the leaves and the pods. The highest decrease in plastic silver pouch may be attributed to the fact that the inner environment and packing material created high temperatures in the plastic silver pouch due to which decline was highest. Whereas, in transparent poly bags, the sennoside content was decreased rapidly due to the penetration of light. Compared to the plastic silver pouch and transparent poly bags, slightly less decline was noted in woven plastic bags because the penetration of light was less due to which decrease was slightly smaller but comparatively more than jute bag and black polybags. The decrease was smaller in a jute bag, whereas the lowest decline in black polybags may be due to the total absorption of light in the black colour of the polybag. As lights could not penetrate inside the bags, pods' quality was retained up to a longer time compared with other packing material. After the drying process, the packing method is an essential factor in the product's quality maintenance during storage (Martinazzo *et al.*, 2009). Upadhyay *et al.* (2011) [15, 23] stated that the biosynthesis of the anthracene derivative in leaves of senna is affected by prolonged cyclic light and dark condition exposure. Pareek *et al.* (1983) [18] reported that the stored produce (senna) losses its sennoside content after one year of storage. Adom *et al.* (1996) [3] reported that dry okra kept in polythene package survived storage best. So, the packing material and storage time significantly affected the quality parameters. The main aim of storing medicinal plants is to prevent a decrease in quality. Indirectly, this is accomplished through controlling moisture and air flow, as well as preventing the attack of insects, rodents, and microbes.

In the case of medicinal herbs, it has been reported that the quality of produce is degraded as the storage period is enhanced. However, there are some herbs in which there is a negligible effect on the quality during storage. In Indian senna, it has been reported that sennosides are decreased during extended storage of the leaves and pods (Updhyay *et al.*, 2011) [23]. The experiments have proved that the chemicals which are contained in the plants are altered i.e., they can be enhanced, or a decrease can be observed due to several factors. A number of researches conducted by Stafford (2003) [21]; Fennell *et al.* (2004) [9]; and Amoo *et al.* (2012) [4], have shown that antioxidant activities and phytochemical properties can be changed due to variation in the biochemistry of the plant**.** It can be said that the changes which are chemically associated in plants are not necessarily detrimental or undesired for the plant itself. However, it has been observed that due to storage, an increment in the activity of some of the compounds has been observed. Sometimes in certain products, due to aging, the value of the product is increased by proper storage methods. The method of storage has the ability to change the activities related to the pharmacological properties of that particular plant (Laher *et al.*, 2013) [13]. Laher *et al.* (2013) [13] reported that the corms and leaves of *H. hemerocallidea* contain more phenolics in comparison with the same plant part, which was kept for storage. Most of the processes related to storage, which include heat, drying, sometimes cooling, and various packing methods, are applied to prevent quality deterioration in plant products. However, it is impossible to always prevent alteration in the properties. Some peculiar plant parts like barks, underground parts (root, storage organs) possess an extended storage life compared to other green leafy parts (Stafford *et al.*, 2005) [22].

Open sun drying is the cheapest method but the quality is badly affected due to direct sunlight, which eventually affects the value of leaves and pods (Tables 3 and 4). Whereas, the cost in 100% shade drying is higher, but leaves and pods colour are better retained, and it has no adverse effect on the quality of the products. It has been shown in Table 5 that the cheapest packing material is black polybag. However, for environmental consideration, jute bags which maintained good quality of the products after polybags may be preferred. During loading and unloading, jute bags are easier to handle. Also, plastic is not eco-friendly and causes a hazardous effect on the environment and deadly pollution to flora and fauna.

## 5. Conclusion

The findings of the present investigation suggest that sennosides content was deteriorated rapidly under open sun drying, whereas drying under 100% shade proved to be the best method for drying sennoside rich plant parts of senna i.e., pods (sennosides 3.22%) and leaves (Sennosides 2.20%). Among the different packing materials, the maximum sennoside content was recorded in the samples packed in black polythene bags. However, the pod's quality was retained for a more extended period than the leaves, i.e., leaves were more prone to quality degradation during the storage process irrespective of packing material used. Economics of post-harvest operations revealed that the best economically viable drying is open sun drying, however, quality of the pods and leaves deteriorates during drying. Although shade drying is more expensive, it preserved the quality of the products in terms of sennosides content. It can be concluded from the results that senna leaves and pods should be dried in 100% shade and stored in black polythene bags to minimize the degradation in the quality of the produce; however, jute bag should be used for environmental safety.

## 6. Declaration of the interest

The authors declare that they have no identified competing financial interest that would have impacted the findings discussed in this study. There are no visible conflicts of interest in the manuscript submission.

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