CHAPTER 13

Ex-situ Cultivation Trials and Sustainable Harvesting Techniques

13.1 Introduction

Over 80% of the global population (6.1 billion) largely depends on the traditional medicine for primary health care. In different medical practices, natural populations of medicinal plants are the major source of required raw materials. Global increase in human population will significantly lead to amplified demand of medicines *vis-à-vis* increasing pressure on the natural populations of medicinal plants, which have been the main source of raw materials to pharmaceutical sectors worldwide (Butola and Badola, 2006c; Sher *et al.*, 2010a) till date. In India, 7800 existing drug manufacturing units consume about 2000 tons of medicinal herbs annually, and about 2000 drugs in use are of plant origin (Dikshit, 1999). In addition, India is the second largest volume exporter of raw herbal drugs with the exports of over 32,000 tons per annum (US$ 27.06 million) after China with an export of over 120,000 tons per annum (US$ 264.5 million) [Wakdikar, 2004].

To overcome the problems of adulteration, incorrect identification, and non-availability of the raw materials throughout the year, the pharmaceuticals units are now looking towards the possibility of raw material supply from cultivated sources because of the expected authentication, reliability and continuous material availability to ensure long term sustainability. As well, the *ex-situ* cultivation is regarded as an appropriate tool for *in-situ* conservation of the endangered species (Badola and Pal, 2002). Cultivated source offers pharmacological advantages and other benefits over wild-collection. For example, (i) the variation in quality and composition leading to uncertainty of the therapeutic benefits due to environmental and genetic differences in wild collected plants are much reduced in cultivated plants; (ii) the production and profits of cultivation are largely controlled by both producers and purchaser, as an advantage; (iii) the yield can be increased in the cultivated plants by using better manure which offer more concentrated financial returns to the cultivators (Badola and

Butola, 2003, 2005; Butola and Badola, 2006c). However, the major constraints hindering the commercialization of cultivation are non-availability of quality planting material, poor development and extension support in the cultivation and processing, and unorganized markets, etc.

Swertia chirayita [(Roxb. ex Fleming) H. Karst] or East Indian Balmony (locally called 'Chirowto'; Family: Gentianaceae) is a triennial herb (refer chapter 11); native to temperate Himalaya prevailing between 1200m and 3000m asl, and contains important molecules, namely iridoids, xanthones, mangiferin and C-glucofla-vones (Joshi and Dhawan, 2005). The entire plant is used in traditional medicine (Pradhan and Badola, 2008). Due to extensive habitat loss, non-systematic harvesting practices and excessive collection in wild, etc., during the past few decades, *S chirayita* has been considered critically endangered in the Himalaya and identified as a top-priority species for conservation through cultivation (Badola and Pal, 2002). The problems with *S. chirayita* are the low seed viability, slow growth, long gestation period, etc., which appeared as the major constraints to the successful domestication using conventional technique (Badola and Pal, 2002). Interestingly, the natural populations of *S. chirayita* from Sikkim (eastern Himalaya) were tested to be highly viable (refer chapter 6) compared to those from central and north-western Himalaya (Bhatt *et al.*, 2007); however, the seeds obtained from domesticated sources showed problems in germination (refer chapter 11).

Despite having an established market, both in India and at international level (Badola and Pal, 2002; Joshi and Dhawan, 2005), *S. chirayita* is still collected from the wild and rarely cultivated, and negligible efforts have been made for the development of suitable agro-techniques for its domestication (Joshi and Dhawan, 2005). In natural habitats, *S. chirayita* plants are uprooted before the seeds get matured, without plant-age consideration, which reduces the chances of regeneration in wild leading to increased danger of its extinction (Bhattarai and Shrestha, 1996). Keeping in view the high pharmaceutical demand of *S. chirayita* and its consequent depletion in the natural environment, the cultivation of the species is mandatory (Badola abd Pal, 2002). Such initiatives will help local entrepreneurs to improve their livelihood options and get opportunities for self employment and income generation (Badola and Butola, 2003, 2005; Butola and Badola, 2006c). Further, this will help in conservation of the species by reducing the disturbances to its natural populations (Badola and Pal, 2002). In recent years, *ex-situ* cultivation efforts have been reported for other Himalayan species (Badola and Butola, 2003, 2005; Butola and Badola, 2006c) but lacked for *S. chirayita*. In this pursuit, appropriate substrate combinations have been identified to raise quality planting material for cultivation in *S. chirayita* (refer chapter 8). Considering the multifaceted medicinal utility and the high market demand of *S. chirayita*, it is high time to testify its probability of successful cultivation and assess the economic viability of cultivation under different growing conditions. The present study aimed to, (1) evaluate the cultivation and domestication prospects, and (2) assess economic feasibility of cultivation in *S. chirayita*, and (3) to develop simple, reliable and sustainable harvesting techniques for *Swertia chirayita*.

13.2 Materials and Methods

Cultivation trials in *Swertia chirayita* were carried out at Pangthang (2000m asl; Lat: $27^0$21'51"N and Long: $088^0$34'10"E), Sikkim, India under three different nursery growing conditions. The area falls under temperate climatic zone with annual maximum temperature reaching upto 20.1^0C (August) and minimum temperature upto 6.42^0C (January); average maximum and minimum relative humidity ranging between 98.4% (July) and 70.3% (December) with occasional snowfall. The area receives highest of 4619.56 mm (August) and lowest of 51.04 mm (January) average rainfall. The soil is clay loam type and slightly acidic in nature (pH: 6.43).

In order to provide suitable environmental conditions to raise sufficient planting materials for cultivation, seedlings were developed under green house, using soil, sand and farm yard manure (1:1:1 ratio). In each of the three growing conditions viz., (i) open beds ($Temp_{max}$: 20.1^0C, $Temp_{min}$: 6.42^0C; RH_{max}: 98.4%, RH_{min}: 70.3%), (ii) poly house ($Temp_{max}$: 35.05^0C, $Temp_{min}$: 17.49^0C; RH_{max}: 68%, RH_{min}: 47%), and (iii) temperature controlled green house (Temp: $25^0 \pm 5^0$C; RH_{max}: 98%; RH_{min}: 87%), three beds of 1m x 1m were prepared by digging soil. The farm yard manure (FYM) was applied at the rate of $1 kg/m^2$ in all nine raised beds. Healthy seedlings (8 months old) of *S. chirayita* were transplanted in each bed in all the three growing conditions at a distance of 25 cm each in rows and the distance between each bed was 60 cm (Photo Plate VI and Photo Plate VII). Watering and weeding was done as per the necessity. By the end of the third growing season, survival and yield (in terms of seeds and plant biomass) were observed under three growing conditions at the time of plant harvesting, and the values then converted on per hectare basis.

Total production of the seeds and dry biomass was estimated on the basis of three replicates (1m x 1m beds) for each of the three nursery growing conditions. Total number of the seedlings was estimated to be approximately 1,60,000 for one hectare of land. For the estimation of projected seed production and yield per hectare, average seed production and yield per plant in each of the three growing conditions were calculated and multiplied with total number of plants in a hectare land. Cost benefit analysis was made on the basis of the total output in the form of cash, and total investment estimated for one hectare land for the site development, seedling preparation, labour charge and manure cost for three years. Net profit analysis was performed on the basis of projected percent survival (100%, 75%, and 50%), as well as for the actual survival and prevailing minimum market price.

To assess the plant morphological parameters, 10 plants (as 10 replicates) were harvested randomly from each of three growing conditions. For each plant harvested, growth parameters viz., plant height and root length were measured using measuring tape; and the collar diameter and root diameter were measured using vernier caliper (Model no.: CD-8"CS, Mituyoto, Japan). After proper removal of the adhered soil particles, the plants were room-dried for 10 days; average total biomass per plant was obtained by weighing 10 plants each (10 replicates) per growing condition. For assessing the seed production per plant in each growing condition, number of seeds per 10 fruit per plant was counted to obtain the average number of seeds per fruit, which was then multiplied with the total number of the fruits recorded per plant. There after, average weight of a single seed was assessed by weighing 100 seeds each in 10 replicates which was then multiplied with the total number of seeds per plant.

Photo Plate VI. Cultivation trial of *Swertia chirayita* under different nursery conditions;
A: Development of planting material; B: Plants (3rd year) in temperature control green house; C: Plants (3rd year) in open bed; D: Plants (2^{nd} year) in poly house

Analysis of variance was conducted using SPSS 10.0 software for Windows (SPSS Inc. 1989) and the difference in means amongst growing conditions were determined using Bonferroni test ($p<0.05$). To assess the commercial viability of *S. chirayita* cultivation, total investment [Indian Rupee (Rs); 1 US$ = 44.68 INR; 1 EUR = 62.89 INR], including the expenditures made on land preparation, labour and manure charge and post harvesting costs, was calculated on per hectare basis. Total cost of the seeds (0.500kg @ Rs 2000/kg) to raise planting materials was estimated to be Rs 1000, manure cost Rs 15,000 for three years and miscellaneous expenses Rs 22,500 for three years. Total labour charge for 158, 180 and 257 days in 1st, 2nd and 3rd year, respectively, @ Rs 130 per day was estimated to be Rs 77,384. Total input value came to Rs. 1,15,884 in one hectare of land for three years (Table 31). This expenditure includes land preparation, seedling transplantation, irrigation, harvesting, plant processing and packing, etc. Net economic benefit was analysed on the basis of total investment made during cultivation and present market rate (seeds: Rs 2000/kg; plant biomass: Rs 200/kg) for the maximum production for projected survival (100%, 75%, 50%) as well as for actual survival, as, Net benefit = total income (seed + biomass) – total investment.

In the entire calculations, the cost of basic cultivation infrastructures such as automatic green house and large poly house facilities were not included. As, these are the permanent and high cost one time investments, and could not be included for year basis productivity and income estimation; also, these will largely depend upon the economic status and willingness of the investors.

13.3 Results

13.3.1 Seedling survival and plant growth under three growing conditions

Seedling survival percentage varied significantly (F = 13.36; $p<0.05$) amongst different growing conditions. Maximum seedling survival was observed under green house (92%), followed by poly house (77%) and open beds (63%) [Figure 42]. ANOVA indicated significant ($p<0.0001$) effect of the growing conditions on some plant morphological parameters (Table 32). The plants grown in green house (167.91

$\pm$ 13.08 cm) were significantly ($p<0.05$) taller compared to other two conditions. Whereas, the plants grown in open beds had significantly ($p<0.05$) higher number of shoots (7.10 $\pm$ 0.99) and branches (42.90 $\pm$ 8.57) compared to those grown in other conditions (Table 32). Fruit production per plant insignificantly differed for three growing conditions ($F = 0.25$); however, the maximum number of the fruits per plant were produced in open beds (379.50 $\pm$ 94.52), followed by green house (360.20 $\pm$ 88.89) and poly house (351.10 $\pm$ 92.42). Number of seeds per fruit was significantly ($F = 5.97$; $p<0.05$) greater in the poly house (209.50 $\pm$ 20.91) and green house (203.60 $\pm$ 28.99), compared to the open bed (176.60 $\pm$ 16.43). Highest seed weight/100 seeds under the green house (3.04 $\pm$ 0.16 gm) grown plants was non-significantly different ($F = 0.93$) from the seeds obtained from the plants grown in open bed (2.96 $\pm$ 0.15 gm) and poly house (2.96 $\pm$ 0.13 gm). Stem diameter and collar diameter insignificantly differed amongst growing conditions. However, the root length was significantly ($p<0.05$) longer in open beds (Table 32).

13.3.2 Account of yield (seed and biomass) under three growing conditions

The seed weight per plant was maximum in green house (2.23 gm/plant) followed by poly house (2.18 gm/plant) and open beds (1.18 gm/plant). However, the maximum plant yield (biomass) in open beds (42.60 gm/plant) was significantly ($F = 4.59$; $p<0.05$) greater than poly house (31.52 gm/plant) grown plants (Figure 42). Maximum projected seed production and biomass on assuming 100% plant survival was estimated to be 3.56 quintal/hectare, 3.49 quintal/hectare and 3.17 quintal/hectare and 60.46 quintal/hectare, 50.43 quintal/hectare and 68.16 quintal/hectare, in green house, poly house and open beds, respectively (Table 33). Table 33 also depicts the total out put in terms of seed production and plant yield (biomass) on the basis of 75% and 50% plant survival. To estimate the actual production of the seeds and plant biomass (after three year growing period), mortality of transplanted seedlings was also accounted. With 92%, 77% and 63% plant survival, in actual, total production of the seeds was estimated to be 3.28 quintal/hectare, 2.68 quintal/hectare and 2.0 quintal/hectare, respectively, and estimated biomass as 55.61 quintal/hectare, 38.83

Photo Plate VII. Growth and below ground biomass production under different nursery growing conditions in *Swertia chirayita*
A and B: Open bed; C and D: Temperature controlled green house;
E and F: Poly house

quintal/hectare and 42.94 quintal/hectare, respectively, in green house, poly house and open beds (Table 33).

13.3.3 Commercial viability of cultivation under three growing conditions

Under different growing conditions, the income estimation differed for the seed and plant biomass based production (Table 34). With projected plant survival of 100%, 75% and 50%, highest income through seeds was calculated for the green house grown plants; while, in terms of plant biomass, the highest income was calculated with open bed grown plants, followed by green house and poly house grown plants for a hectare land (Table 34). The net economic benefit was higher for open beds followed by the green house and poly house on the basis of projected plant survival of 100%, 75% and 50%.

Based on the actual plant survival under different growing conditions i.e., 92% (green house), 77% (poly house) and 63% (open beds), the maximum income from the seeds was estimated from the green house followed by poly house and open beds. However, in terms of plant biomass, the maximum income was estimated for green house, followed by open beds and poly house, for a hectare land (Table 34). Similarly, on actual plant survival basis, the net profit from cultivation of *S. chirayita* was highest for the green house followed by poly house and open beds (Table 34).

13.3 Discussion

Appropriate growing media and conditions play a significant role in the vegetative growth (Al-Menaie *et al.*, 2008; Badola and Butola, 2003; Butola and Badola, 2006c) and species prefer distinct growth environments, as in *S. chirayita* (present study), where taller plant height, large stem diameter, as well as, collar diameter were recorded in the green house. Plants attain maximum growth when exposed to the high day temperature due to the increase in photosynthesis rate thereby affecting the entire plant phenology; at the same time, high temperature reduces the growth of tubers/roots (Lafta and Lorenzen, 1995). This has been experienced in the present study, where plants of *S. chirayita* grown under the poly house recorded little higher plant height compared to the open beds, but had shorter root length and overall low productivity, comparatively. Compared to indoor plants (poly house and green house), the out door plants (open beds) are exposed to harsh, near to natural climatic conditions which affects growth and flowering/fruiting pattern (Al-Menaie *et al.*, 2008), as seen in the present study where plants did have shorter height, but robustness with more number of shoots and branches and fruits *vis-a-vis* longer roots per plant, compared to the other growing conditions. In open beds, the available soil nutrients percolates or gets washed away by the rain water. Therefore, the root elongates in search of required nutrients for better growth resulting in longer root length. However, under the temperature controlled green house, due to the availability of required soil nutrients in the vicinity, shoot rather than root elongates thereby resulting in higher shoot length. The robustness of the plants may be attributed to the nature of this species, as the *S. chirayita* is adapted better to open condition in its natural habitat slopes. Hence, overall, the plant productivity (biomass) on the basis of projected plant survival was higher in the open beds compared to the green house and poly house condition.

In green house, the survival rate and seed production were much higher, compared to the poly house and open beds, because green house experienced very limited fluctuation in temperature (temperature: $25^0C\underline{+}5^0C$). In addition, temperature is the most important factor in different phenological phases (Badola, 2010) which greatly affects the growth and productivity as recorded in *S. chirayita* under different growing conditions. Susceptibility to the pests and aphid infestation due to prevailing high humidity is a common problem in the indoor plants (Al-Menaie *et al.*, 2008; Badola abd Butola, 2005). Similar aphid infestations have been observed under green house in some of non-experimental *S. chirayita* plants in reproductive stage mostly affecting the tender apical parts, flowers, etc. Relatively, low air circulation in the enclosed green house could be the other reason of such infestation; however, cow urine (15%) appeared as best remedy for such infestation. In poly house, high temperature increases metabolic activities and causes little stress to plants which results in relatively weaker plant development thereby affecting the productivity, as observed in the present study. Therefore, the open beds are the most suitable conditions for the large scale cultivation of *S. chirayita*.

Maximum projected benefit from 100%, 75%, and 50% plant survival was calculated for the open beds followed by green house and poly house, respectively. On the basis of actual plant survival, net benefit was calculated maximum for the green house (Rs 16,51,988) followed by poly house (Rs 11,97,716) and open beds (Rs 11,42,203), respectively. These outputs may offer encouraging possibilities of domestication (Butola and Badola, 2006bc) of *S. chirayita* compared to the plants collected from wild, where 4.37 quintal/hectare of estimated average biomass (air dried) could be obtained (Anonymous, 2001) with monetary value reaching only Rs 87,401.

In general, all three growing conditions appeared to be suitable for the cultivation of *S. chirayita*; but, the infrastructure development cost would be much higher for the green house and polyhouse, which is almost zero when the cultivation is carried out in open beds. In the present study, seedlings were prepared under temperature controlled green house; however, its cost of construction was excluded from the total investment part, as it being a relatively permanent asset which need not be developed annually. At the same time, seedlings can be prepared annually under the same structure with time to time maintenance. Further, it is not justifiable to quote the construction cost of the green house and polyhouse especially in the mountainous region because the same depends largely on the area of the land to be cultivated, quality of the material used for construction, the location of the land where the structure has to be constructed, economic status of a farmer, etc. Therefore, the present study suggests that, for a hill farmer, open beds with minor precautionary measures will be more viable for large scale cultivation of *S. chirayita*, as lucrative option for the income generation. However, for the large scale industrial entrepreneurship, the green house with control environment could possibly be feasible; it is recommended, they should be technically designed with proper ventilation, etc. In addition, it would be suggestive to maintain reasonable distance (roughly, the double than the open beds) between plants to avoid over crowding, thus allowing ample air circulation, minimizing possibility of pests and aphid infestation, inside the green house. This may perhaps give low benefit than estimated one in cases. For poor farmers, it is recommended that the seedlings may be prepared under low cost poly houses instead of open beds as the minute seeds of *S. chirayita* can not withstand harsh environmental conditions; however, for the cultivation, seedlings should be transplanted in the open beds, as a follow-up. It can be presumed that the cultivated plants are somewhat different in their properties from those collected from the wild; however, certain values in plants can be deliberately enhanced under controlled conditions of the cultivation (Palevitch, 1991).

The estimated good economic return from *S. chirayita* cultivated at *ca.* 2000m asl in the present study suggests suitability of this elevation for the large scale farming, as, in natural condition in Sikkim, *S. chirayita* is found along 1200m to 3000m asl, so, species can be cultivated within these elevation range, but the total production and net profit may vary with the elevation, which need more cultivation trials. In addition, efforts are also needed to decrease the seedling mortality after transplantation, with further standardization of agro-technology over few cropping cycles over time.

13.5 Recommended cultivation techniques

On the basis of present study, the following recommendations are made:

1. Direct seed sowing in the field is not suitable owing to minute seed size which gets easily washed away by the rain water or irrigation water. The planting materials should be developed under low cost green house or poly house with proper ventilation facility.
2. The appropriate soil composition for the seedling preparation should be soil, sand and farm yard manure (1:1:1 ratio).
3. The best time for the seed sowing is April-May and seedling transplantation is March-April after the soil receives the first few early spring showers for open bed cultivation.
4. For cultivation, 10-15 cm raised and deeply ploughed beds (bed size: 1 – 1.5 m x 9-10 m; depending on the land availability) with mild slope (15-20^0) and well drainage facilities would be an additional advantage.

5. Minimum distance of 50-60 cm should be maintained between each bed; and the seedlings should be planted at a minimum distance of 25 cm, which helps in gaining enough profit even if the mortality rate is up to 50%.
6. Adequate irrigation is not recommended in *S. chirayita,* as sloppy soil condition results in decaying of roots subsequently resulting in higher mortality rate; however, during winters, irrigation once in a week is necessary.
7. Uses of chemical fertilizer are strongly prohibited; maximum production can be achieved by using farm yard manure, which, is available at low cost for farmers.
8. To prevent plants from the aphid infestation, if any, inside green house (not necessary in the case of open beds), cow urine (15-20%) can be applied from time to time.
9. The appropriate time for the plant harvest is December.
10. The most recommended feasible cultivation condition is open condition.

13.6 Sustainable harvesting, drying and storing techniques

On the basis of the present study, following harvesting, drying and storing techniques are recommended:

1. The best time for harvesting of *Swertia chirayita* is December – January (at 2000m asl) when the above ground part fully dries up and the capsules are about to dehisce. Regular monitoring is required in order to determine the exact harvesting period which may vary with the altitude of the region.
2. Seed is the only mode of reproduction in *S. chirayita*. Therefore, seeds should be collected along with the capsules before harvesting of the plants for next year plant development. Segregate the seeds from the capsules by mashing with hand and remove the impurities and dry the seeds at room temperature for at least 10-15 days. After drying, store the seeds in hermetic plastic bags or air tight plastic bottles and keep it in refrigerator at 4^0C for long term storage. The seeds to be used for plant development in the next season can be stored at room temperature.
3. Harvesting of the plants should be done in the morning or the evening time when the intensity of heat is poor. Harvesting during the day leads to breakage of the plant or its parts due to high intensity of the sunlight.

4. Loosen the soil and remove other weed species before uprooting the plants to avoid breakage of the underground parts. Use small hand fork for digging to prevent the underground part from getting damaged.
5. The rubber gloves should be used while harvesting the plants which will prevent the material from getting moistened by the sweat.
6. Do not use pressure while uprooting the plants, hold at the bottom of the plant and pull it slowly thus reducing the chances of the breakage.
7. The adhered soil should be removed with hard paint brush instead of hitting the harvested material on the ground or cleaning with water.
8. The harvested material should be kept under the shade at least for 15 days for proper drying; however, drying under the poly-house should be avoided because the vapor formed due to heat cannot escape out form the poly-house and turns into water droplet. The drying material will absorb that water when it falls on the ground thereby resulting in decomposition and infestation of the materials and finally degrading the quality.
9. The material should not be dried directly under the sunlight because root part takes more time to dry out. However, high intensity of sunlight results in over drying and breaking of the shoot part which may get blown away by the wind resulting in reduction in the quantity of the material.
10. While drying, the plant material should be spread directly on the ground or on the bamboo mats. The drying material should not be spread on the plastic sheet because formation of water droplet due to evaporation gets accumulated on the sheet maximizing the chances of fungal attack or decomposition of the material.
11. While drying, ample circulation of air should be allowed which helps in faster drying of the trapped moisture.
12. Overturn the material regularly for proper drying and preventing the material from fungal attack.
13. Once the material dries up completely, tie it in bundles and store under the shade with proper ventilation facility till the material is supplied to the vendors or to the wholesalers.
14. While storing the dried material, one should take care of avoiding direct contact of the material with the soil or the ground.

13.7 Conclusion

The study clearly indicates that the *ex-situ* cultivation could easily meet out the present market demand of *Swertia chirayita,* if, proper scientific and technical guidelines are followed, which will not only check the extraction of *S. chirayita* from its natural habitats but at the same time, this will help in the conservation of this species *in-situ*. Further, the local entrepreneurs can generate substantial income and empowerment through *ex-situ* cultivation of *S. chirayita.*

Table 31. Total investment (in Indian Rupee, Rs*) per hectare on the basis of present market rate for the cultivation of *Swertia chirayita* at Pangthang (*ca.* 2000m asl), Sikkim (India)

	1st year	2nd year	3rd year	Total
Seed material (0.500 kg @ Rs 2000/kg)	1000.0			1000.0
Farm Yard Manure (10.0 tonnes/year @ Rs 0.50/kg)	5000.0	5000.0	5000.0	15000.0
Manpower (158, 180, 257 days @ Rs 130/day)	20550.0	23440.0	33394.0	77384.0
Miscellaneous expenses (Rs)	7500.0	7500.0	7500.0	22500.0
Total (Rs)	34050.0	35940.0	45894.0	
Grand Total (Rs)				**115884.0**

*1 US$ = 44.68 Indian Rupee; 1 EUR = 62.89 Indian Rupee

Table 32. Result of ANOVA characterized by the effect of growing conditions in *Swertia chirayita* cultivated at Pangthang (*ca.* 2000m asl), Sikkim (India)

Parameter	Growing condition			F	Sig.
	Open bed	Poly house	Green house		
Plant height (cm)	142.98^{a}	143.23^{a}	167.91^{b}	18.28	0.000
	(6.29)	(11.22)	(13.08)		
Number of shoots	7.10^{a}	4.20^{b}	4.40^{b}	28.45	0.000
	(0.99)	(1.23)	(0.52)		
Number of branches	42.90^{a}	20.70^{b}	24.40^{b}	37.84	0.000
	(8.57)	(5.19)	(3.44)		
Stem diameter (mm)	14.84^{a}	15.17^{a}	17.38^{a}	0.83	0.447
	(5.03)	(2.34)	(6.18)		
Collar diameter (mm)	15.19^{a}	15.50^{a}	17.82^{a}	0.89	0.424
	(4.94)	(2.31)	(6.32)		
Root length (mm)	103.50^{a}	85.80^{b}	87.20^{b}	17.13	0.000
	(11.22)	(4.08)	(5.20)		

Values in parentheses indicates standard deviation (SD); values amongst the growing conditions with same letters are not significant (Bonferroni test, $p<0.05$)

Table 33. Total production (per hectare) at the end of third year of cultivation of *Swertia chirayita* on the basis of projected and actual plant survival percent, at Pangthang (*ca.* 2000m asl), Sikkim (India)

Survival (%)	Seed production (quintal/hectare)			Total biomass production (quintal/hectare)		
	Open bed	Poly house	Green house	Open bed	Poly house	Green house
100	3.17	3.49	3.56	68.16	50.43	60.46
75	2.38	2.61	2.67	51.12	37.82	45.34
50	1.58	1.74	1.78	34.08	25.21	30.23
Actual survival (%)						
92	----	----	3.28	----	----	55.61
77	----	2.68	----	----	38.83	----
63	2.00	----	----	42.94	----	----

Table 34. Economic viability (per hectare) at the end of third year of cultivation of *Swertia chirayita* on the basis of projected and actual plant survival percent, at Pangthang (*ca.* 2000m asl), Sikkim (India)

Total investment/hectare in three years (Rs)	**Survival (%)**	**Total income/hectare from seed [@ Rs 2000/kg] (Rs)**			**Total income/hectare from biomass [@ Rs 200/kg] (Rs)**			**Net profit/hectare (Rs)**		
		Open bed	**Poly house**	**Green house**	**Open bed**	**Poly House**	**Green house**	**Open bed**	**Poly house**	**Green house**
115884	100	633738	697423	712481	1363226	1008550	1363226	1881080	1590089	1959823
	75	475304	523068	534361	1022419	756413	906840	1381839	1163597	1325317
	50	316869	348712	356240	681613	504275	604560	882598	737103	844916
	Actual survival (%)									
	92	----	----	655482	----	----	1112390	----	----	1651988
	77	----	537016	----	----	776584	----	----	1197716	----
	63	399255	----	----	858832	----	----	1142203	----	----

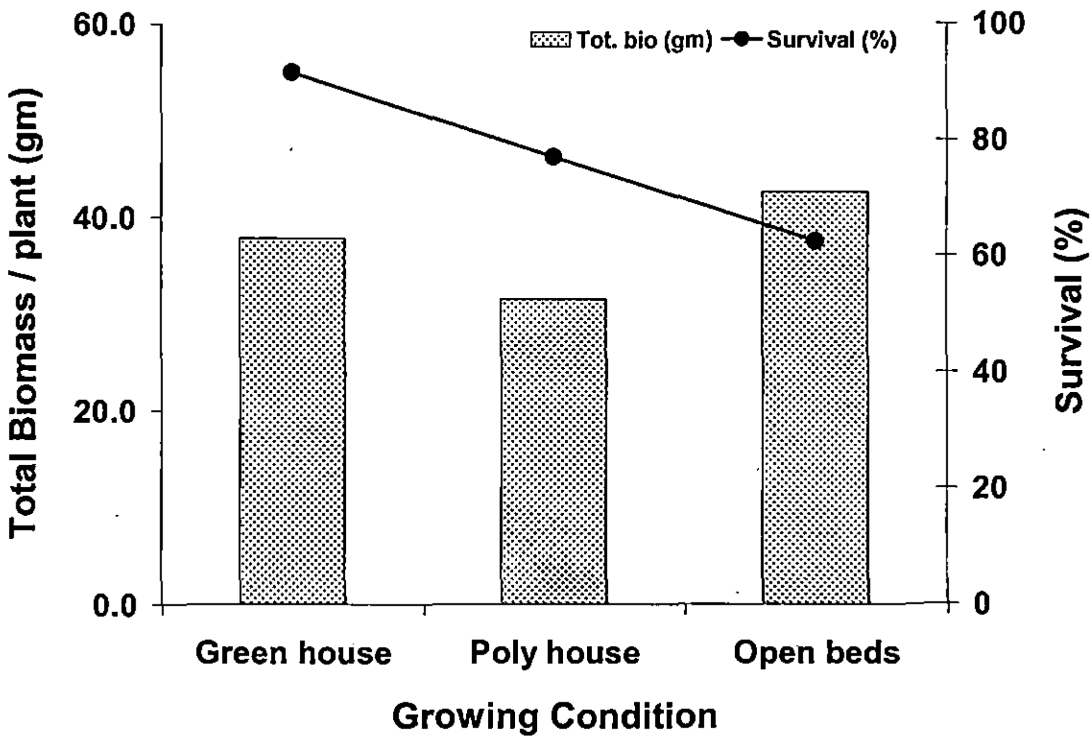

Figure 42. Effect of growing conditions on the total biomass/plant and survival in *Swertia chirayita* cultivated at Pangthang (*ca.* 2000m asl), Sikkim (India)