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Seedling emergence and survival in *Cinnamomum tamala* under varying micro-habitat conditions: conservation implications

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Abstract: We studied seedling emergence and survival of an economically important species, *Cinnamomum tamala* Nees (Family Lauraceae) under varying micro-habitat conditions in a sub-tropical moist evergreen forest located in Garhwal Himalaya, India. Mature seeds in two states i.e., with and without pulp were placed in forest floor under four micro-habitat conditions *viz*., undisturbed close canopy, undisturbed canopy gap, disturbed close canopy and disturbed canopy gap (4 micro-habitats x 2 seed states x 3 replicates of 50 seeds each). The heterogeneity in microenvironment due to combination of factors caused significant variation in seedling emergence (range 25 to 98%) and survival (5 to 23%). The de-pulped seeds had significantly higher seedling emergence as well as seedling survival across all the micro-habitats as compared to those with intact pulp. Higher canopy cover in undisturbed forest emerged as the best micro-habitat for regeneration of *C. tamala* provided the seeds are liberated from the fruit pulp. Such a condition seems to conform with seed dispersal by frugivorous birds in nature. Conservation implications are discussed.

Resumen: Estudiamos la emergencia y la supervivencia de plántulas de una especie de importancia económica, *Cinnamomum tamala* Nees (Lauraceae), en condiciones variables de microhábitat en un bosque húmedo perennifolio subtropical de Garhwal Himalaya, India. Se colocaron semillas maduras en dos estados, es decir, con y sin pulpa, en el suelo del bosque, en cuatro condiciones de microhábitat: dosel cerrado sin disturbio, claro del dosel sin disturbio, dosel cerrado con disturbio y claro del dosel con disturbio (4 microhábitats × 2 estados de la semilla × 3 réplicas cada una con 50 semillas). La heterogeneidad microambiental debida a esta combinación de factores causó una variación significativa en la emergencia (intervalo 25 a 98%) y la supervivencia (5 a 23%) de las plántulas. Las semillas sin pulpa tuvieron una emergencia de plántulas significativamente mayor, así como una mayor supervivencia de las plántulas en todos los microhábitats en comparación con las que conservaron la pulpa intacta. La cobertura grande de dosel en el bosque sin disturbio destacó como el mejor microhábitat para la regeneración de *C. tamala*, siempre y cuando a las semillas se les remueva la pulpa del fruto. Semejante condición parece ajustarse a la dispersión de semillas por aves frugívoras en la naturaleza. Se discuten las implicaciones para la conservación.

Resumo: Estudou-se a emergência das plântulas e sobrevivência de uma espécie economicamente importante, a *Cinnamomum tamala* Nees (Família Lauraceae), sob vários micro-habitats numa floresta húmida sub-tropical sempreverde localizada no Himalaia Garhwal, Índia. Sementes maduras em dois estádios i.e., com ou sem polpa, foram colocadas no solo florestal sob as condições dos quatro micro-habitats, *viz.* copado fechado não disturbado,

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copado aberto não disturbado, copado fechado disturbado e copado aberto disturbado (4 micro-habitats x dois estados de sementes x 3 réplicas de 50 sementes cada). A heterogeneidade dos microambientes devido à combinação de factores causou variações significativas na emergência das plântulas (variação de 25 a 98%) e uma sobrevivência de 5 a 23%. As sementes despolpadas, quando em comparação com aquelas com as sementes intactas, apresentaram uma emergência significativamente mais alta bem como uma sobrevivência das plântulas mais elevada através de todos os micro-habitats. A cobertura de copados altos na floresta não disturbada emerge como sendo o melhor micro-habitat para a regeneração da *C. tamala* desde que as sementes tenham sido libertas da polpa do fruto. Tal condição parece conforme com a dispersão natural das sementes por aves frugívoras. As implicações na conservação são discutidas.

Key words: *Cinnamomum tamala*, canopy gap, conservation, extension growth, microhabitat, seed state, seedling emergence.

Introduction

Recruitment of tree species on the forest floor is governed by various factors including the seed traits and microhabitat conditions (Kitajima 2007). Likewise, germination of seeds in nature is strongly influenced by internal as well as external environmental factors (Baskin & Baskin 1998). The germinating seeds and seedlings are most vulnerable to predation, desiccation, competition and damage as the seeds and seedlings constitute important resource for the herbivores and pathogens. Seedling predation and disturbance in the form of trampling and microhabitat alteration have direct implications for recruitment and multiplication of species. Consistency in microhabitat condition enhances seedling survival. One of the important microhabitat factors in the forest floor is light regime which is governed by tree canopy cover. Tree species vary considerably in terms of light requirement at seedling stage (Davies 2001; Pacala *et al.* 1994). Germinating seeds, depending upon their state such as inherent properties, reserved food material and nature of pericarp, represent their own microenvironments which have rarely been investigated.

Cinnamomum tamala Nees. (Lauraceae), commonly called as Tejpat (trade name Tamalpatra) is an evergreen monoecious species, up to 8 m high and distributed all along the Lesser Himalaya from Jammu to Arunachal Pradesh, Khasi and Jaintia hills, Myanmar and Australia (Brandis 1972). It is an important species in the transitional evergreen broadleaf forest between 800 – 2000 m asl. Natural stands of *C. tamala* are mostly found in shady moist habitats. Leaves are aromatic and traded as a spice (Anonymous 2006; Dhar *et al*. 2002; Edwards 1993) and also as a source of various Ayurvedic formulations (Sarin 2008). It flowers during March to May and usually pollinated by small insects such as honey bees. The fruits are ellipsoidal drupe and require approximately one year attaining maturity. Hence, the flowers and fruits can be seen on the same time during April - May. Ripe fruits are dark purple in color and contain single seed. The seeds are primarily dispersed by frugivorous birds, which feed on them for the nutritious pulp and egest the seeds intact. In addition, strong winds, hail storms and sometimes arboreal mammals such as primates may help in mechanical dispersal of fruits. Seeds are also secondarily dispersed by rodents and other small mammals (G. Sharma, personal observation). Thus seeds of this species are deposited on the forest floor in two states i.e., with or without pulp exhibiting different patterns of germination and establishment.

Considering the economic potential and dwindling natural populations of *C. tamala* in several ranges, this species has been recommended for *in-situ* as well as *ex-situ* conservation by several authors (e.g. Samant *et al.* 2001). However, in the absence of standard agro-techniques and owing to lack of information on seed germination behaviour, conservation efforts have not succeeded so far. In view of this, a comprehensive study on the patterns of seed germination and seedling establishment under varied micro-habitat conditions was undertaken. The study aimed at ascertaining the relative success of two different seed states (with and without intact pulp) under varied microhabitat conditions. This paper deals with the patterns of seed germination and seedling establishment under varied conditions. Results and conservation implications are discussed.

Material and methods

Site description

The study was conducted in Mandakini valley, located in Rudraprayag district of Uttarakhand (30° 29' N latitude and 79° 05' E longitude; altitude 990-1060 m asl). The study area has a typical subtropical - temperate transitional climate. Mean annual precipitation is about 1600 mm (Fig. 1), most of which is received during monsoon (mid June to mid September). The vegetation is typically riverine moist evergreen. Common tree associates of *C. tamala* in the study area are *Mallotus philippensis, Litsea lanuginosa, Pyrus pashia, Cocculus laurifolius, Spondias pinnata, Lagerstroemia parviflora, Albizia chinensis, Quercus glauca, Bauhinia variegata, Prunus cerasoides, Toona ciliata, Celtis australis* and *Sapium insigne*. One part of the forest was accessible to cattle and human beings and hence categorized as 'disturbed' whereas the remaining part was relatively 'undisturbed'. The two types of forests differed considerably in canopy cover as well as the tree density but resembled greatly in soil characteristics (Table 1). The tree canopy cover varied considerably (54 - 81%) irrespective of the disturbance and in both disturbed and undisturbed forests there were distinct close canopy areas and canopy gaps thereby affecting the total solar radiation reaching the ground (Fig. 2).

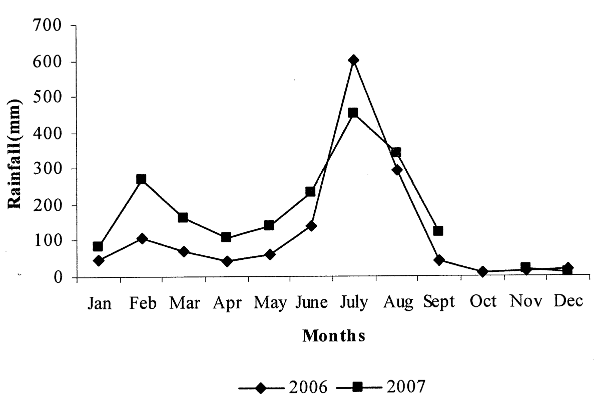

Fig. 1. Monthly rainfall variations at study site in two years.

Experimental design and sampling

The four microhabitats i.e., canopy and canopy gaps in disturbed and undisturbed forest were selected within natural forests in the study area. At each micro-habitat two types of mature seeds (with and without pulp) were planted making 8 possible microenvironments for seed germination and seedling establishment. Each micro-environment, therefore, represented a combination of three variables: seed with or without pulp, close canopy or canopy gap and disturbed or undisturbed forest. 1200 ripe fruits were collected from a few trees within the study area in the month of May 2006. Of these, 600 fruits were de-pulped carefully to obtain intact seeds for subsequent experiments. To study the emergence, survival and growth of the seedlings of *C. tamala* under each condition, 3 replicates of 50 seeds each were placed on the forest floor after removing all naturally fallen seeds from the ground in an area measuring 30 cm x 30 cm (4 micro-habitats x 2 seed states x 3 replicates of 50 seeds each). The seed plots were roofed with fine nylon mesh to avoid natural seed deposition until total seed dispersal phase had been over. Subsequent to emergence of seedlings, nylon mesh was replaced with open top iron mesh (30 cm x 30 cm x 30 cm) to mark the seed plots for subsequent observations.

Data collection and analysis

Observations on seedling emergence were made at an interval of 15 days four times i.e., for a period of 60 days. Seedling survival and shoot growth were measured at one month interval for 12 months. Seedling emergence was recorded at each site when epicotyl was visible above ground. Mean daily emergence (MDE) was calculated using the formula given by Czabator (1962), where, MDE = Total number of emerged seeds / Total number of days. For extension growth ten seedlings at each seed plot were randomly selected and shoot length was measured using a centimeter ruler.

Means with standard deviation were calculated for each data set. To determine the

Table 1. Bio-physical features of disturbed and undisturbed forests in the study area.

Parameters	Disturbed forest	Undisturbed forest
Soil Moisture in May (%)	5.6±0.4	8.4±1.7
Water Holding Capacity of Soil (%)	13.9±1.0	17.0±2.0
Soil pH	5.7±0.2	6.0±0.3
Organic Carbon (%)	0.5±0.04	0.6±0.03
Soil Organic Matter (%)	0.9±0.1	1.0±0.1
Total Nitrogen (%)	0.5±0.1	0.5±0.1
Available Phosphorus (kg ha^{-1})	11.0±3.0	11.2±3.3
Exchangeable Potassium (kg ha^{-1})	224.7±7.7	210.4±6.6
Soil Texture	Sandy loam	Sandy loam
Tree Canopy cover (%)	54.4±3.0	80.8±2.3
Tree Density (ha^{-1})	700	1520
Shrub Density (/25m^2)	11.6	22.8
Herb Density (m^{-2})	73	134
Number of Tree Species	13	13
Number of Shrub Species	14	17
Number of Herb Species	16	19

overall influence of the microenvironments on recruitment of *C. tamala,* all the data on seedling emergence, seedling survival, extension growth (shoot length) and MDE were subjected to Analysis of Variance (ANOVA) and Least Significant Difference (LSD) was calculated at p=0.05 level of significance. In addition, influence of microenvironments on seedling germination and survival were compared using student's t test. To assess the overall impact of major variables on seedling recruitment, data from all micro-habitats (close canopy or canopy gap, disturbed or undisturbed forest) were pooled separately irrespective of seed state.

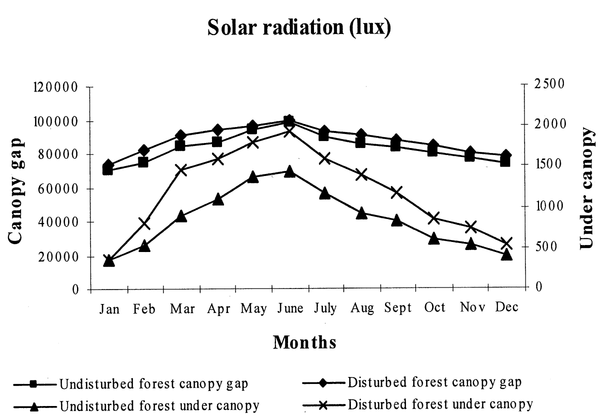

Fig. 2. Monthly solar radiation (lux) in disturbed and undisturbed forests and canopy cover and canopy gap regimes at the study site.

Results and discussion

Seeds planted in the experimental area started emerging within a fortnight. However, there was a significant variation in seedling emergence (14 - 80%) across the seed plots i.e., microenvironments (Table 2). Seedling emergence was consistently high (92-98%) in case of de-pulped seeds in undisturbed close canopy forest. Second highest germination (>75%) was observed in case of de-pulped seeds in the disturbed forest irrespective of canopy closure. This was followed by de-pulped seeds under canopy gaps in undisturbed forest (74%). In the remaining conditions seedling emergence was 24 - 56% and all these seed plots had seeds with intact pulp. In all cases, minimum percentage of seedling emergence for de-pulped seeds (74%) was significantly higher as compared to maximum recorded seedling emergence in seeds with intact pulp (56%). Thus, the seed state i.e., seeds without or with intact pulp, emerged as most important determinant of seedling emergence and irrespective of the micro-habitat condition (disturbed *vs.* undisturbed forest and close canopy

Table 2. % Seedling emergence (SE) and mean daily emergence (MDE – seedlings day^{-1}) in *C. tamala* under different microenvironments at 15 days interval.

Conditions	0-15 DAP		16-30 DAP		31-45 DAP		46-60 DAP		Mean of MDE
	SE (%)	MDE	SE (%)	MDE	SE (%)	MDE	SE (%)	MDE	
DCP	27.33±2.31	0.91±0.08	31.33±2.31	0.13±0.00	34.67±3.06	0.11±0.04	34.67±3.06		0.39±0.03
DCD	80.67±3.06	2.69±0.10	87.33±4.62	0.22±0.10	94.67±5.03	0.24±0.10	94.67±5.03		1.05±0.06
DOP	28.67±3.06	0.95±0.10	28.67±3.06	0.00±0.00	36.67±3.06	0.27±0.07	37.33±4.16	0.02±0.04	0.31±0.03
DOD	60.67±4.62	2.02±0.15	74.00±5.29	0.44±0.04	92.00±4.00	0.60±0.07	92.00±4.00		1.02±0.04
UCP	38.67±3.06	1.29±0.10	41.33±3.06	0.09±0.15	52.00±4.00	0.36±0.10	56.00±4.00	0.13±0.13	0.47±0.03
UCD	56.67±4.16	1.89±0.14	72.67±5.03	0.53±0.18	98.67±2.31	0.87±0.18	98.67±2.31		1.10±0.03
UOP	14.67±3.06	0.49±0.10	16.67±2.31	0.07±0.12	18.00±2.00	0.04±0.04	24.67±3.06	0.22±0.04	0.21±0.03
UOD	46.67±3.06	1.56±0.10	48.67±3.06	0.07±0.07	70.67±3.06	0.73±0.07	74.00±3.46	0.11±0.04	0.62±0.03
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD at 5%	5.83	0.19	6.51	0.18	5.95	0.16	6.40	0.09	0.05

DAP= Day after planting; DCP= Disturbed, close canopy and pulpy seeds, DCD= Disturbed, close canopy and de-pulped seeds; DOP= Disturbed, canopy gap and pulpy seeds; DOD= Disturbed, canopy gap and de-pulped seeds; UCP= Undisturbed forest, close canopy and pulpy seed; UCD= Undisturbed, close canopy and de-pulped seeds; UOP= Undisturbed, canopy gap and pulpy seed; UOD= Undisturbed forest, canopy gap and de-pulped seeds.

vs. canopy gap) the percent seedling emergence in the former was 2 to 2.5 times higher than in the latter. Not only the total seedling emergence but also the rate of emergence, as evident by mean daily emergence (MDE), was higher in de-pulped seeds (Table 2) indicating significant differences in the germination behaviour of two states of seeds. Seed germination under controlled environment in laboratory confirmed these results as percent germination in de-pulped seeds (manually extracted) was 99% against 15% germination in seeds with intact pulp. This indicates that pulp free seeds have higher seedling emergence in *C. tamala* and the factors which lead to liberation of pulp from seeds may be regarded as crucial for regeneration of this species.

Fruit pulp has been reported as inhibitor of seed germination in a large number of species (Mayer & Poljakoff-Mayber 1989; Yagihashi *et al.* 2000). Uniyal & Nautiyal (1995) have made similar observations on *Litsea lanuginosa,* a companion species of *C. tamala* from the same study area. The compounds present in the fruit pulp may inhibit seed germination by blocking biochemical pathways of seed germination (Evenari 1949; Mayer & Poljakoff-Mayber 1989) or by altering the seed microenvironment (Samuels & Levey 2005). In nature, the seeds of *C. tamala* mature early in May, lack dispersal appendages and are dispersed mainly by two means. Firstly, the frugivorous birds feed on the fruit pulp and drop the seed on the ground in de-pulped state. Secondly, strong winds or arboreal mammals may facilitate mechanical dispersal of fruits leaving the seeds on the ground in pulpy state. The germination success of this species would, therefore, largely depend on the state of seed on dispersal. However, post dispersal events such as decomposition of the fruit pulp through microbial action, abrasion or feeding by smaller mammals can also facilitate removal of the fruit pulp.

Impact of canopy cover on seedling emergence in disturbed and undisturbed forest was assessed. The results indicate that impact of canopy cover on seedling emergence was different in the disturbed and undisturbed forest. For example, canopy cover favoured seedling emergence in the undisturbed forest as the percent seedling emergence was significantly higher under close canopy than in canopy gaps in undisturbed forest whereas the differences in emergence under close canopy and canopy gaps were of low order and statistically non-significant in disturbed forest. Thus the effect of canopy cover on germination was clear in undisturbed forest only. There were significant differences in the densities of shrubs and herbaceous plants between the two types of forest (Table 1). The ground flora and frequent trampling on the forest floor (disturbance) may have significant impact on seedling emergence. Moisture availability is regarded as one of the important determinants of seedling emergence. Incidentally, seeds of *C. tamala* have high moisture content (49% in fruit and 31% in seeds) and even a small amount of moisture on the soil surface would result in germination. The study area receives intermittent pre-monsoon showers in the month of May making conditions conducive for seed germination and seedling emergence.

As compared to seedling emergence, seedling survival on the forest floor was considerably low (5 - 23%) and varied with microenvironment conditions (Fig. 2 and Table 3). Similar to seedling emergence, the seedling survival was also more in case of de-pulped seeds than in pulpy seeds. Maximum percentage of seedling survival (23%) was found in de-pulped seeds under close canopy undisturbed forest and the difference was statistically significant from all other 7 conditions. However, overall seedling survival was higher in disturbed than in undisturbed forest (Table 3 and Fig. 3). Seedling survival on the forest floor is governed by the availability of light, water and nutrients (Kitajima 2007). In addition, plant pathogens are also known to affect the microenvironment and survival of seedlings (Fenner & Kitajima 1999). Increase in light and

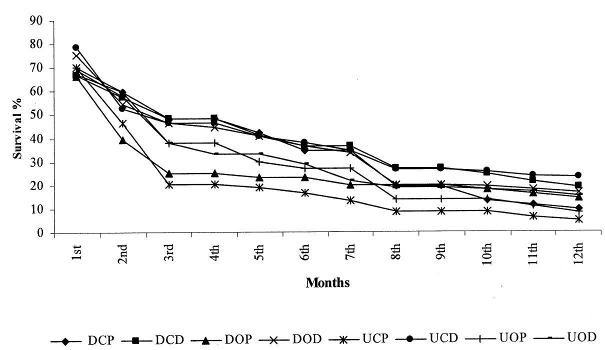

Fig. 3. Percent seedling survival of *C. tamala* at monthly intervals under different microenvironment conditions.

Table 3. Overall seedling emergence, seedling survival, extension growth and mean daily emergence (MDE) in *C. tamala* under different microenvironments.

Condition	Seedling emergence (%)	Seedling survival (%)	Extension growth (shoot length in cm)	MDE
DCP	34.67±3.06a	9.63±3.34a	8.08±2.67a	0.38±0.03
DCD	94.67±5.03b	19.02±2.11ab	7.96±0.77ab	1.05±0.06a
DOP	37.33±4.16a	14.28±3.09ac	7.83±0.37ab	0.31±0.03
DOD	92.00±4.00b	16.67±1.26acd	6.90±1.26abc	1.02±0.04a
UCP	56.00±4.00	4.76±2.06ae	6.33±1.04abcd	0.47±0.03
UCD	98.67±2.31b	22.97±1.17b	9.68±1.03ae	1.10±0.03a
UOP	24.67±3.06	8.11±0.00ae	8.50±0.00abe	0.26±0.03
UOD	74.00±3.46	15.32±1.56bcd	7.06±0.46abcd	0.62±0.03
P value	<0.001	<0.001	>0.05	<0.001
LSD at 5%	6.44	3.62		0.05

Means followed by same letters in a column are not significantly different at p=0.05 (student's t test, ns= non significant)

nutrients in mesic gaps stimulate the growth of the competing shrubs and fast growing herbaceous plants (Pages *et al.* 2003). In general, the varying microenvironment had a significant effect on survival ($p < 0.001$, LSD = 3.6) of seedlings.

The extension growth of seedlings on the forest floor also varied with the microenvironments. Mean height of seedlings from pooled data after 14 months across the microenvironments were significantly different based on '*t*' test. Maximum mean height of the seedlings was recorded under close canopy undisturbed forest in case of de-pulped seeds after 14 months (Fig. 4 and Table 3). The results also indicated that the mean height of the seedlings even decreased in certain microenvironments. This could be due to biotic interference, including the small herbivores, on the forest floor even in undisturbed forest. Based on several reports, Kitajima (2007) also concluded that complex interactions between herbivores and seedlings mediate the growth and survival of the plants on the forest floor. Overall performance of seedling emergence and survival (Table 4) also reveals that maximum differences in two contrasting conditions of an individual variable were determined by pulpy and de-pulped seeds. While canopy cover had more influence on seedling emergence and extension growth than the disturbance, the seedling survival was more influenced by the latter. The high values of standard deviation indicate a larger variation within each variable if the remaining two variables also change.

From the foregoing account it is evident that heterogeneity in micro-habitat on the forest floor causes significant variation in emergence and survival of *C. tamala* seedlings. Presence or absence of fruit pulp decisively determined seedling recruitment. The cumulative effect of different variables possibly mediates the process of recruitment. Though presence of pulp in the seed hampered the seedling emergence in most of the seed plots, as high as 56% seeds with intact pulp could emerge in undisturbed close canopy forest. This could be due to presence of small consumers

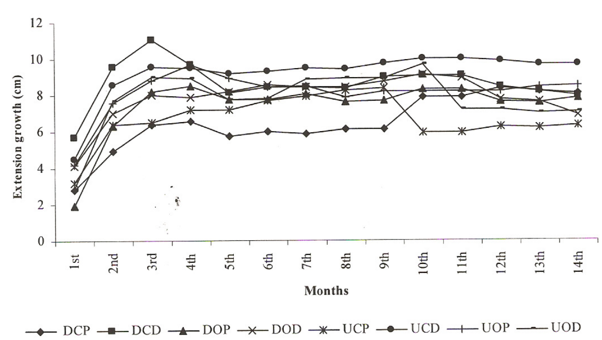

Fig. 4. Mean extension growth (cm) of *C. tamala* under different microenvironment conditions at monthly intervals.

Table 4. Pooled data on emergence, MDE, survival and extension growth of *C. tamala* under different conditions.

Condition	Emergence (%)	MDE	Survival (%)	Extension Growth (cm)
Disturbed forest	64.67±30.18	0.69±0.36	14.9±4.24	7.70±1.34
Undisturbed forest	63.33±28.31	0.60±0.34	12.79±7.42	7.89±1.50
Canopy gap	57.00±28.52	0.54±0.33	13.59±3.77	7.57±0.80
Under tree canopy	71.00±28.160	0.75±0.34	14.10±7.82	8.02±1.82
Seeds with intact pulp	38.17±12.22	0.34±0.10	9.20±4.16	7.69±1.53
De-pulped seeds	89.83±10.39	0.95±0.20	18.49±3.32	7.90±1.30
P value	<0.001	<0.001	<0.001	>0.05
LSD at 5%	5.26	0.05	7.09	

of the fruit pulp including micro-fauna on the forest floor that may facilitate removal of fruit pulp and emergence of seedlings.

Plant species differ greatly in their habitat preference for seedling emergence and survival. A number of tree species exhibit positive correlation between canopy cover and seedling densities (Kwit & Platt 2003; Nakagawa & Kurahashi 2005; Pages *et al.* 2003). Yet a large number of species show negative correlation between these variables (Nakagawa & Kurahashi 2005). Disturbance on the forest floor has been reported to enhance conifer regeneration (Burton *et al.* 2000). In addition, interaction of canopy and disturbance was also found to influence the seedling density as well as the average height of the plants. Average density and average height of *Sasa senanensis* were significantly greater on skid trails and undisturbed soil in the canopy gap than those in the closed canopy stand. Hubbell *et al.* (1999) monitored more than 1200 gaps in a tropical forest in Panama and found that gaps increased seedling establishment and sapling densities, but this effect was non-specific. Spatial and temporal variation in the age gap disturbance regime did not explain variation in species richness. Thus, a number of factors on the forest floor interact to determine the fate of a seed to germinate and of a seedling to survive and get established and the preferences vary with the species. Young seedlings on the forest floor are susceptible to many hazards and thus micro-habitats which have fewer hazards would be most suitable for the recruitment of a species.

The study reveals that best regeneration of *C. tamala* was in the undisturbed forest with high canopy cover provided the seeds are de-pulped. Such forests had highest seedling emergence, highest degree of seedling survival, shorter germination time and greater extension growth of the seedlings as compared to rest of the micro-habitats. *C. tamala* is one of the important species in the sub-tropical evergreen forests of the Himalayan region. Besides its high economic importance, this species provides excellent habitat for a large number of frugivorous birds and small mammals, which facilitate its regeneration in turn. Multiplication of this species in and around village wastelands and degraded riverine forests would not only provide additional resources for the local people but also improve habitat of several faunal species thereby maintaining the local biodiversity and travel corridors. This study also underlines the fact that *in-situ* conservation of this high value species along with its dispersal agents would be much more cost effective in the long run than attempts at *ex-situ* conservation away from the natural habitat.

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References

Anonymous. 2006. *Statistical Abstract*. National School of Agricultural Marketing. A Govt. of India Organization- Ministry of Agriculture, Jaipur, India.

Baskin, C.C. & J.M. Baskin. 1998. *Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination*. Academic Press, USA.

Brandis, D. 1972. *The Forest Flora of North-West and Central India*. Bishen Singh Mahendra Pal Singh. Dehra Dun, India.

Burton, P.J., D.C. Sutherland, N.M. Daintith, M.J. Waterhouse & T.A. Newsome. 2000. *Factors Influencing the Density of Natural Regeneration in Uniform Shelterwoods Dominated by Douglas-fir in the Sub-boreal Spruce Zone. B.C. Ministry of Forests*. Forest Science Program. Working paper **47**.

Czabator, F.J. 1962. Germination values an index combining speed and completeness of pine seed germination. *Forest Science* **8**: 386-396.

Davies, S.J. 2001. Tree mortality and growth in 11 sympatric Macaranga species in Borneo. *Ecology* **82**: 920-932.

Dhar, U., S. Manjkhola, M. Joshi, A. Bhatt, A.K. Bisht & M. Joshi. 2002. Current status and future strategy for development of medicinal plant sector in Uttaranchal, India. *Current Science* **83**: 956-963.

Edwards, D.M. 1993. The marketing of non-timber forest products from the Himalayas: The Trade between East Nepal and India. *In*: *Rural Development Forestry Network (Overseas Development Institute, London)* Paper **15b**: 1-21.

Evenari, M. 1949. Germination inhibitors. *Botanical Review* **15:** 153-194.

Fenner, M. & K. Kitajima. 1999. Seed and seedling ecology. pp. 589-619. *In*: F.I. Pugnaire & F. Valladares (eds.) *Functional Plant Ecology*. Marcel Dekker Inc. USA.

Hubbell, S.P., R.B. Foster, S.T. O'Brien, K.E. Harms, R. Condit, B. Wechsler, S.J. Wright & S. Loo de lao. 1999. Light-gap disturbances, recruitment limitation, and tree diversity in a neotropical forest. *Science* **283**: 554-557.

Kitajima, K. 2007. Seed and seedling ecology. pp. 549-580. *In*: F.I. Pugnaire & F. Valladares (eds.) *Functional Plant Ecology*. 2nd edn. CRC Press Tylor & Francis Group.

Kwit, C. & W.J. Platt. 2003. Disturbance history influences regeneration of non-pioneer understory trees. *Ecology* **84**: 2575-2581.

Mayer, A.M. & A. Poljakoff-Mayber. 1989. *The Germination of Seeds*. 4th edn. Pergamon Press, Oxford.

Nakagawa, M. & A. Kurahashi. 2005. Factors affecting soil-based natural regeneration of *Abies sachalinensis* following timber harvesting in a sub-boreal forest in Japan. *New Forests* **29**: 199-205.

Pacala, S.W., C.D. Canham, J.A. Silander & R.K. Kobe. 1994. Sapling growth as a function of resources in a north temperate forest. *Canadian Journal of Forestry Research* **24**: 2172-2183.

Pages, J.P., G. Pache, D. Joud, N. Magnan & R. Michalet. 2003. Direct and indirect effects of shade on four forest tree seedlings in the French alps. *Ecology* **84**: 2741-2750.

Samant, S.S., U. Dhar & L.M.S. Palni. 2001. *Himalayan Medicinal Plants: Potential and Prospects.* Himavikas Occasional Publication No. 14. G.B. Pant Institute of Himalayan Environment & Development. Kosi-Katarmal. Almora.

Samuels, I.A. & D.J. Levey. 2005. Effect of gut passage on seed germination: do experiments answer the questions they ask? *Functional Ecology* **19**: 365-368.

Sarin, Y.K. 2008. *Principal Crude Herbal Drugs of India*. Bishen Singh Mahendra Pal Singh, Dehra Dun.

Uniyal, R.C. & A.R. Nautiyal. 1995. Improving germination in *Litsea lanuginosa* seeds. *Indian Forester* **121**: 280-282.

Yagihashi**,** T., M. Hayashida & T. Miyamoto. 2000. Inhibition by pulp juice and enhancement by ingestion on germination of bird dispersed *Prunus* seed. *Journal of Forest Research* **5**: 213-215.