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Predicting litter decomposition rate for temperate forest tree species by the relative contribution of green leaf and litter traits in the Indian Himalayas region

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ABSTRACT

We examined eight green leaf traits (leaf area, specific leaf area, leaf dry matter, leaf water content, leaf carbon, nitrogen, phosphorous, and chlorophyll) and eight litter traits (cellulose, lignin, litter carbon, nitrogen, phosphorous, lignin: nitrogen, carbon: nitrogen and ash content) and the litter decomposition rates of 10 tree species from a temperate forest ecosystem. Amongst all green leaf and litter traits tested, cellulose content, lignin content and specific leaf area were identified as the best predictors of litter decomposition, with percentage contributions to litter decomposition of 40%, 36% and 8%, respectively. The results indicated that litter decomposition in the temperate forest ecosystem studied was not dependent solely on litter traits, as green leaf traits also contributed to nutrient cycling. Individual green leaf traits of living species and dead leaf characteristics both influenced the fate of leaves, affecting decomposition and nutrient and carbon cycling in the forest ecosystem. For a better overall understanding of the decomposition mechanisms operating in a temperate forest, both green leaf traits and litter traits thus need to be considered.

1. Introduction

Leaf litter decomposition has been associated with various litter traits, such as litter nitrogen (Torreta and Takeda, 1999), lignin and cellulose (Arunachalam and Singh, 2002; Talbot and Treseder, 2012). However, studies suggest that green leaf traits, i.e. leaf nitrogen (Bakker et al., 2010), specific leaf area (SLA) (Santiago, 2007) and leaf dry matter (Pakeman et al., 2011), are also significant predictors of decomposition rate in forest and grassland ecosystems.

Studies comparing green leaf traits and litter traits have found that green leaf traits are associated with plant growth and development (Ordoñez et al., 2009), while litter traits reflect the initial chemical composition of decomposing leaves (Meier and Bowman, 2008). Green leaves have a higher rate of decomposition and a higher nitrogen concentration, but lower lignin and nitrogen ratio, than dead leaves (Fonte and Schowalter, 2004). Green leaves determine the quality of the litter produced, as many of their chemical and morphological characteristics remain in the leaves after shedding (Bakker et al., 2010; Santiago, 2007). However, leaf litter quality (litter nitrogen, phosphorus) positively governs the litter decomposition rates (Cornwell et al., 2008; Cortez et al., 2007). Consequently, both green leaf traits and litter characteristics contribute to nutrient cycling through specific mechanisms and can assist to understand and predict litter decomposition rate (Kurokawa & Nakashizuka, 2008; Cornwell et al., 2008; Bakker et al., 2010).

Recent studies worldwide have reported that green leaf traits such as phenol/N and lignin/N ratio (Cornelissen et al., 2004), SLA, leaf dry matter content (LDMC) and leaf C/N ratio (Quested et al., 2007), foliar pH (Cornelissen et al., 2006), SLA, LDMC and leaf nitrogen content (LNC) (Cortez et al., 2007) and SLA (Vaieretti et al., 2005) of plant species regulate litter decomposition rates and act as a predictor of decomposition rate in various ecosystems. Studies also suggest that LNC

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(Bakker et al., 2010; Cornwell et al., 2008) and SLA (Kurokawa and Nakashizuka, 2008; Santiago, 2007; Vaieretti et al., 2005) contribute positively to litter decomposition, while LDMC contribute negatively to the decomposition (Cornwell et al., 2008; Kurokawa and Nakashizuka, 2008).

Temperate forest tree species exhibit high variations in production and breakdown of organic matter (Walthert and Meier, 2017). The variation has the differing influence of the tree traits on the ecosystem process, predominantly the decomposition rate (Cornwell et al., 2008). The temperate forest consists of two major functional types, 'deciduous' and 'evergreen'. Deciduous species are characterised by an acquisitive leaf strategy with higher SLA, higher leaf nitrogen and phosphorus contents, higher photosynthetic rates and a shorter lifespan. Evergreen trees are characterised by a conservative plant strategy, with leaves having a longer lifespan, lower SLA and greater production costs (Bai et al., 2015; Rahman and Tsukamoto, 2013; Williams-Linera, 2000). The temperate forest of the Indian Himalayas region is an unexplored area where knowledge of leaf and litter traits associated with litter decomposition is still lacking for regional and local floras. Most previous studies in the Himalayas region have only examined the relationship between litter traits and litter decomposition (Garkoti and Singh, 1999; Semwal et al., 2003; Tiwari and Joshi, 2015). It is imperative to understand the contribution of forest tree species at a local scale to understand the mechanisms of decomposition at regional and global level, so that the overall delivery of ecosystem services can be understood and predicted well in advance for effective management of forests.

The present study attempted to address the two main objectives. The first objective deals with the examination of the litter decomposition of ten widely occurring tree species with different growth habits (three deciduous and seven evergreen species) in a temperate forest ecosystem in the Indian Himalayas region (IHR). The second objective aimed to identify the green leaf and litter traits predictors of litter decomposition rate in the temperate forests of IHR. The study hypothesised that the green leaf traits and litter traits are predictors of litter decomposition in the temperate forests of IHR Fig. 1.

2. Material and methods

The study was carried out in the moist temperate forest in the state Uttrakhand, India (30°2′02.6″N; 78°05′47.9″E), located at an altitude 2277 masl (Fig. 2). Mean annual temperature in the region is 25 °C with mean annual precipitation of 2115 mm. The forest is situated in a hilly area and the soils are typically classified as Leptosols and Regosols (Raina and Gupta, 2009), due to the presence of pebbles, stones and high concentrations of calcium carbonate and limestone. A vegetation survey was carried out in the forest using the nested quadrat method with a plot size of 50 m × 50 m. Trees with the diameter at breast height (DBH) > 10 cm were identified and measured. The relative abundance of each species was estimated and a total of 10 dominant tree species were selected for further study based on their abundance (basal area and tree cover) Table 1 (Table 2). These species were categorised as evergreen (*Abies pindrow, Cedrus deodara, Cupressus torulosa, Eunonymous pendulous, Pinus wallichiana, Quercus leucotrichophora*, and *Rhododenderon arboreum*) or deciduous species (*Aesculus indica, Pyrus paschia,* and *Toona ciliata*) which differed in their leaf habit, leaf structure and leaf economic spectrum.

2.1. Collection of green leaf and litter material

Fresh green leaves were collected from sun-exposed plants of the 10 dominant species selected for the study. Young, fully expanded and hardened leaves from adult plants were chosen. Leaves were collected from five individuals per species, with 4–5 leaves per individual. Samples with whole twig section were placed in sealed plastic bags from which the air was expelled so that leaves closed their stomata because of the high CO_2 concentration and eventually maintained water saturation. Measurements were made within 24 – 48 h of collection of leaves. Leaves were not removed from twigs until the measurements were obtained. Litter materials of the representative species were collected from the forest floor during the peak leaf litterfall period (March 2014) and used for determining litter traits. The litter decay rate was evaluated at every month from April 2014 to April 2015 using litterbag technique for putting the litter material in the bag every month. List of all the traits studied with their abbreviations are reported in Table 1 and the flow chart of the methodology is described in Fig. 3.

2.2. Green leaf and litter trait measurement

Leaf area (LA, cm^2) was determined using a leaf area meter (LI-3100C), by scanning leaves collected from the forest and determining the area based on pixel counting. Leaf area is an essential component of

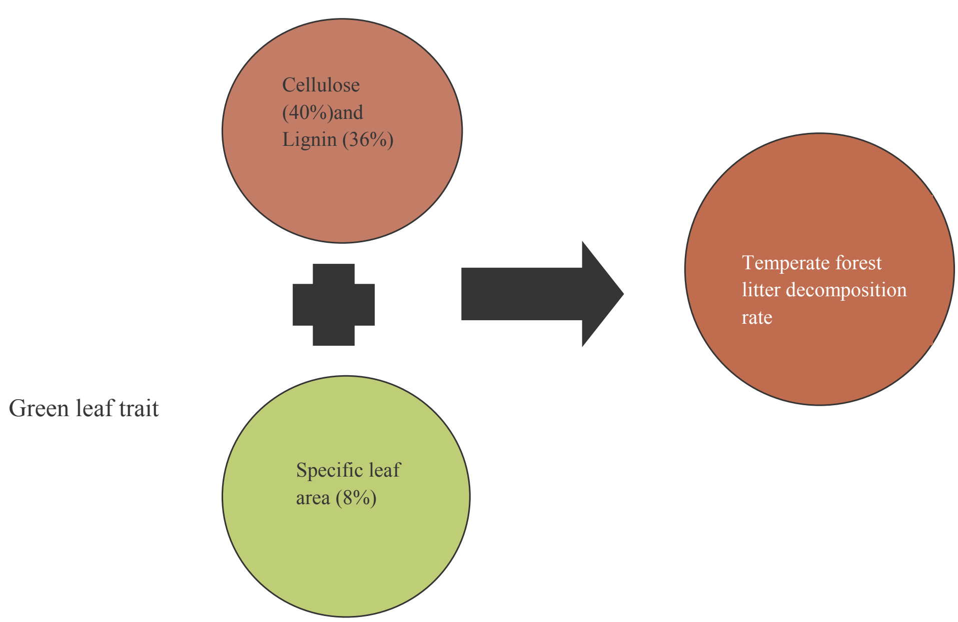

Fig. 1. Contribution of green leaf and litter traits to litter decomposition in a temperate forest in the Indian Himalayas region.

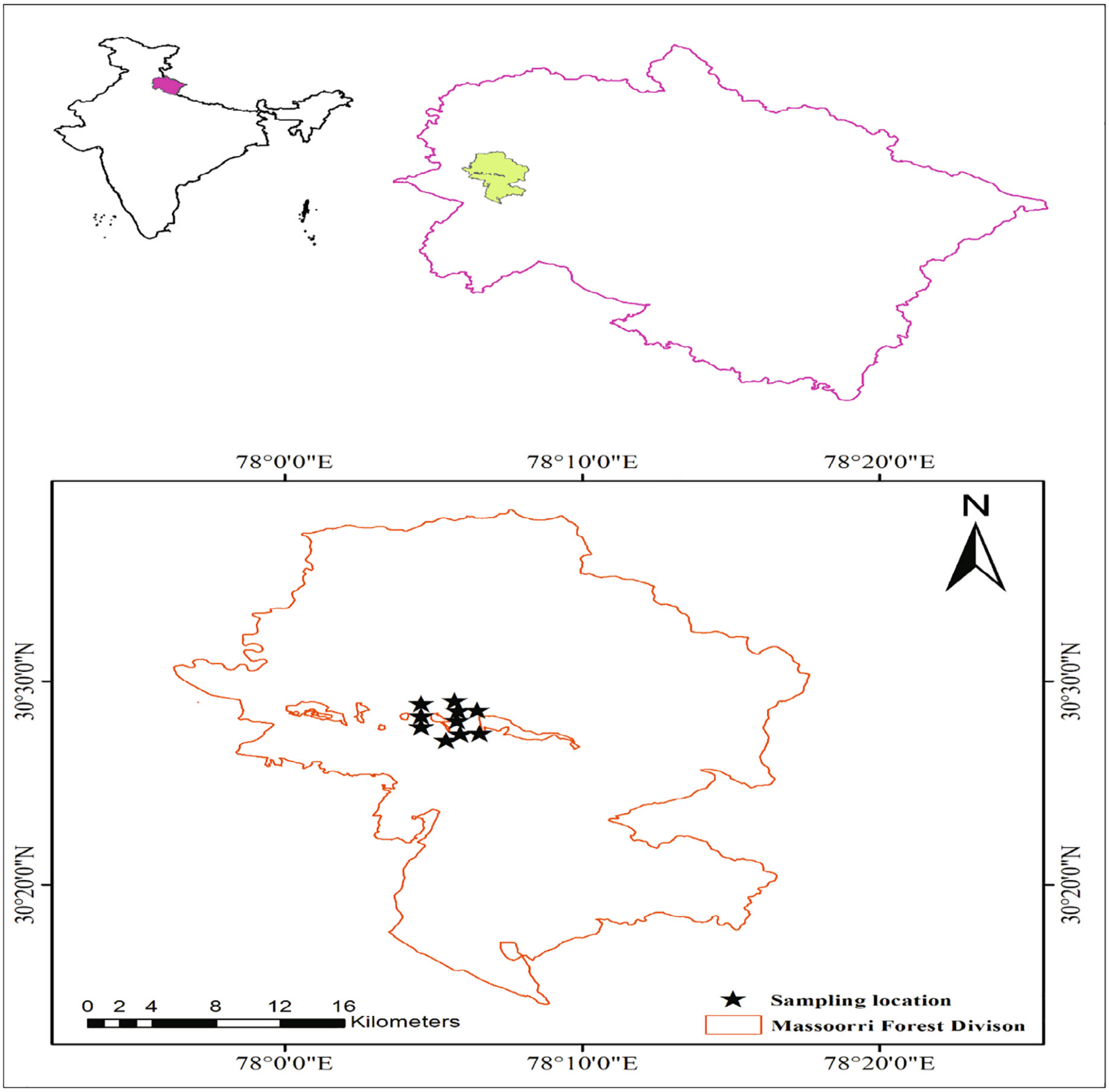

Fig. 2. Map of the study site.

Table 1
List of studied plant traits with their abbreviations and units of measurements.

Trait	Abbreviation	Unit
Litter traits		
Lignin		mg g^{-1}
Cellulose		mg g^{-1}
Litter Carbon	Litter C	%
Litter Nitrogen	Litter N	%
Litter Phosphorous	Litter P	%
Ash Content		%
Litter Lignin: Nitrogen	Litter L: N	
Litter Carbon: Nitrogen	Litter C: N	
Green leaf traits		
Leaf area	LA	cm^2
Specific leaf area	SLA	cm^2 g^{-1}
Leaf dry matter content	LDMC	%
Leaf water content	LWC	%
Leaf carbon content	LCC	mg g^{-1}
Leaf nitrogen content	LNC	mg g^{-1}
Leaf phosphorus content	LPC	mg g^{-1}
Chlorophyll content	Chl	mg g^{-1}

plant growth analysis and nutrient status (Pérez-Harguindeguy et al., 2013). Specific leaf area (SLA, cm^2g^{-1}), the one-sided area of a fresh leaf divided by its oven-dry weight, determines the reproductive strategy of the plant (Pérez-Harguindeguy et al., 2013). Leaf dry matter content (LDMC, %), the oven-dried weight of a leaf divided by its fresh leaf area, acts as an indicator of plant resource use and is related to leaf lifespan (Pakeman et al., 2011). Leaf water content (LWC) was measured using Stocker's method. Chlorophyll content (Chl, mg^{-1}) was determined using a UV–visible spectrophotometer (Thermo Scientific, Evolution 201), by measuring the absorbance of fresh leaf extract at 645 and 663 nm. After these measurements, the leaf samples were air-dried in the laboratory, crushed and ground in a Wiley mill and analysed for their chemical composition following the standard procedures given in Pérez-Harguindeguy et al. (2013). Leaf carbon content (LCC, %) and nitrogen content (LNC, %) and litter C and N content were determined using a CHNS Euro EA-3000 analyser. Leaf phosphorus content (LPC, %), and litter P content were determined by the acid digestion method.

Lignin content and cellulose content were determined gravimetrically by fibre analyser (Pelican Model - FES 6 E). Ash content was determined by igniting 1 g powdered litter sample at 550 °C for 6 h in a

Table 2
Tree species selected for analysis in a temperate forest in the Indian Himalayas region and tree family, leaf type, leaf initiation period, leaf lifespan and decomposition rate (percentage biomass loss after 12 months).

Species	Family	Leaf type[†]	Leaf initiation	Leaf lifespan (months)	Decomposition rate (%)
Deciduous					
Aesculus indica, Colebr	Hippocastanaceae	B	May-June	6–7	75.71
Pyrus pashia, Buch.HemexD.Don	Rosaceae	B	Feb-April	6–7	87.13
Toona ciliata, R.	Meliaceae	B	Feb-April	6–7	86.19
Evergreen					
Abies pindrow, Spach Ham	Pinaceae	N	April-May	36–72	40.15
Cedrus deodara, Loud	Pinaceae	N	March-April	36–72	62.63
Cupressus torulosa, D. Don	Cupressaceae	N	March-April	36–72	40.56
Euonymus pendulous, Wall	Celastraceae	B	March-April	13–14	54.56
Pinus wallichiana, Jackson	Pinaceae	N	March-April	14–15	23.33
Quercus leucotrichophora, A.Comm	Fagaceae	B	March-April	13–14	53.19
Rhododendron arboreum, Smith	Ericaceae	B	March-April	14–15	66.15

†N = Needle; B = Broadleaf.

muffle furnace, and a total of 50% of the ash-free mass was taken as the carbon content by the gravimetric method. Litter L:N and C:N ratio was also calculated, as they are a function of the elemental composition of decomposers (Han et al., 2005).

2.3. Litter decomposition

Leaf litter decomposition was evaluated using the litter bag technique (Bocock et al., 1960). Litterbags of size 20 cm × 20 cm was made from a double layer of nylon mesh, stitched with nylon thread, and filled with 5 g of air-dried litter collected from the forest floor. The litter bags had a mesh size of 2 mm, which prevented the loss of small litter fragments, but allowed access to soil microorganisms. For each of the 10 dominant tree species studied, 80 such bags were prepared and placed on the floor of the study forest, in a bed established by clearing a flat area in the forest understory. Litterbags were sampled from each plot after 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330 and 360 days. On each sampling occasion, five litter bags for each species were brought to the laboratory, brushed to remove debris, dried in an oven at 80 °C for 48 h and weighed. Decomposition rate was calculated as the percentage of initial dry mass lost after 360 days:

$$Decomposition\ \ rate(\%) = \frac{Initial\ \ mass - Final\ \ mass}{Initial\ \ mass} x100$$

2.4. Statistical analysis

Associations amongst the 16 green leaves and litter traits studied were analysed by principal component analysis (PCA) (SPSS 23), to identify significant contributors of the traits. The restricted maximum likelihood (REML) lme4 package of R studio (R-3.5.1 version) was used to quantify the respective contributions of green leaf and litter traits to observe variation in the decomposition process. Linear mixed modelling with REML was performed on the significant contributors in PCA, to identify the best predictor for the decomposition process in the temperate forest ecosystem. REML provides estimates of parameter effects and variance components for both fixed and random effects in the model. In the analyses, decomposition was used as the response variable, with plant traits as fixed effects (LA, SLA, LDMC, LWC, LCC, LNC, LPC, Chl, litter C, N and P, cellulose, lignin, L/N, C/N and ash content). Species was modelled as a random effect. All the variables were tested for normality and log-transformed before analysis. The percentage variation caused by individual fixed and random variable was also estimated. The full and null models were determined and validated by the Akaike Information Criterion (AIC) and deviance (Winter, 2013).

3. Results

The results revealed considerable variation in leaf and litter traits between evergreen and deciduous species (Figs. 4 and 5). Among the litter traits, lignin content varied from 300 to 700 mg g^{-1}, cellulose content from 200 to 700 mg g^{-1}, litter C from 261 to 596 mg g^{-1}, litter N from 10 to 21 mg g^{-1}, litter P from 0.20 to 0.46 mg g^{-1}, ash content from 3.59 to 12.50%, litter L: N ratio from 17 to 68, and litter C: N ratio from 12 to 52 (Fig. 5). Among the green leaf traits, LA varied from 4.95 to 69.20 cm^2, SLA from 23 to 206 cm^2 g^{-1}, LDMC from 2 to 4 mg g^{-1}, LWC from 49 to 80%, LCC from 242 to 623 mg g^{-1}, LNC from 8 to 22 mg g^{-1}, LPC from 1 to 3.95 mg g^{-1} and Chl from 8 to 24 mg g^{-1}. The percentage contribution of the different green leaf and litter traits to decomposition rate is shown in Fig. 1.

Decomposition rate was faster in the three deciduous species (*Aesculus indica, Pyrus paschia* and *Toona ciliata*) than in the seven

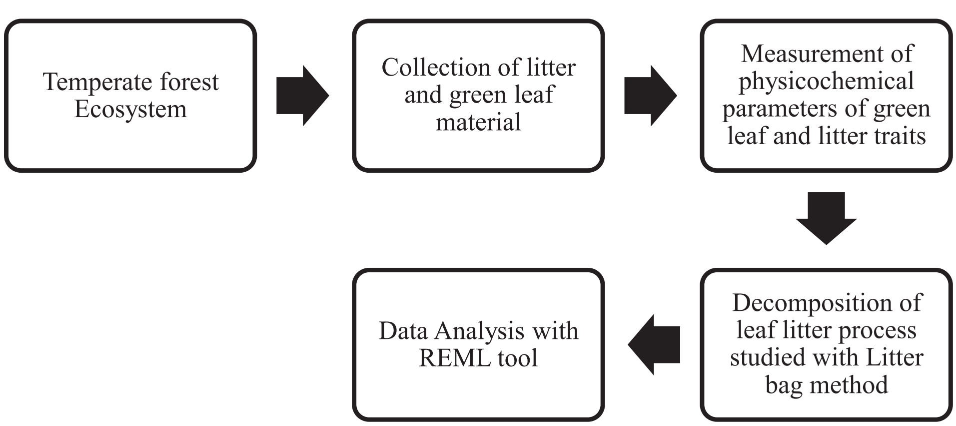

Fig. 3. Flow chart for methodology.

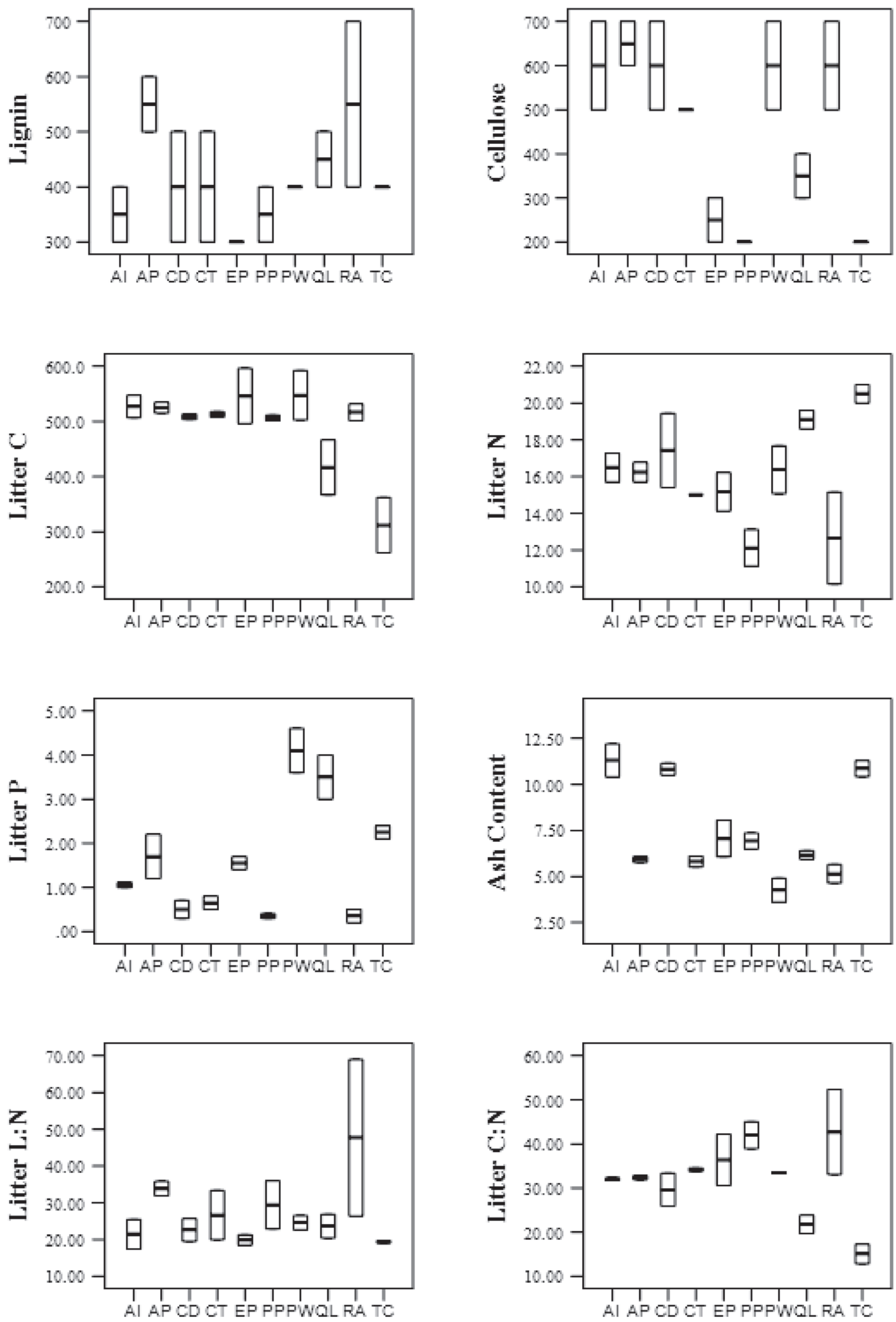

Fig. 4. Values of green leaf and litter trait recorded for 10 dominant forest tree species in a temperate forest in the Indian Himalayas region. **Deciduous species:** *Aesculus indica* (AI), *Pyrus pashia* (PP) and *Toona ciliata* (TC). **Evergreen species:** *Abies pindrow* (AP), *Cedrus deodara* (CD), *Cupressus torulosa* (CT), *Euonymys pendulous* (EP), *Pinus wallichiana* (PW), *Quercus leucotrichophora* (QL) and *Rhododendron arboreum* (RA). **Litter traits** (Lignin mg g^{-1}, Cellulose mg g^{-1}, Litter C, N, P mg g^{-1}, Ash content %, L:N and C:N). **Green leaf traits** (Leaf area (LA) cm^2,Specific leaf area (SLA) cm^2 g^{-1}, Leaf dry matter content (LDMC) mg g^{-1}, Leaf water content (LWC) %,Leaf carbon content (LCC) mg g^{-1}, Leaf nitrogen content (LNC) mg g^{-1}, Leaf phosphorus content (LPC) mg g^{-1} and Chlorophyll content (Chl) mg g^{-1}.The centre line indicates the median, upper and lower box height indicates interquartile range.

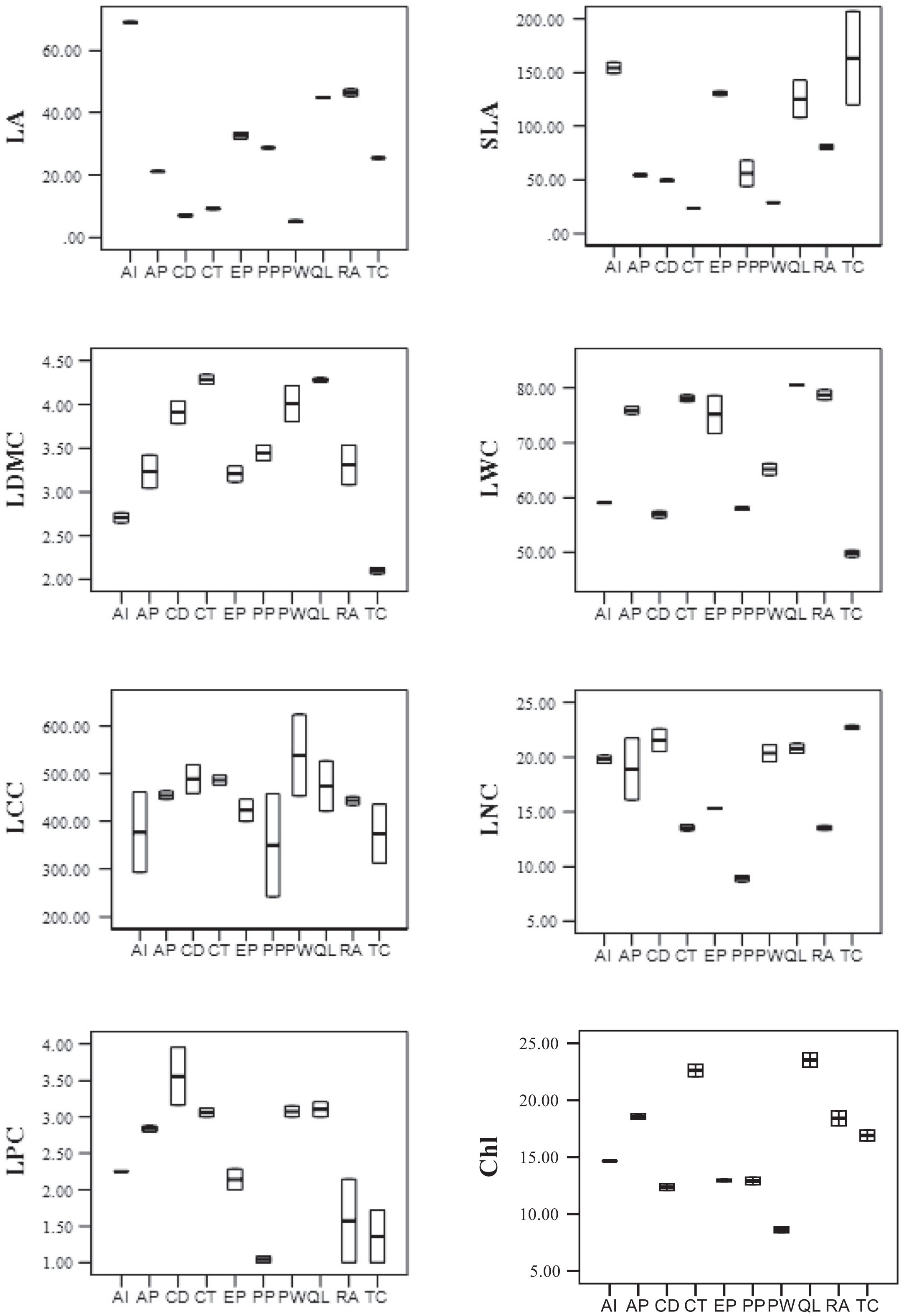

Fig. 4. (*continued*)

evergreen species (*Abies pindrow, Cedrus deodara, Cupressus torulosa, Euonymys pendulous, Pinus wallichiana, Quercus leucotricophora* and *Rhododenderon arboreum*) (Fig. 5). The time required for decomposition of leaf litter depended on the chemical composition (leaf and litter traits), climate conditions and the activities of decomposers.

Principal component analysis (PCA) with Varimax rotation revealed that a total of 91% of the variation was explained by leaf and litter traits (Fig. 6). The first component explained 32% variability with

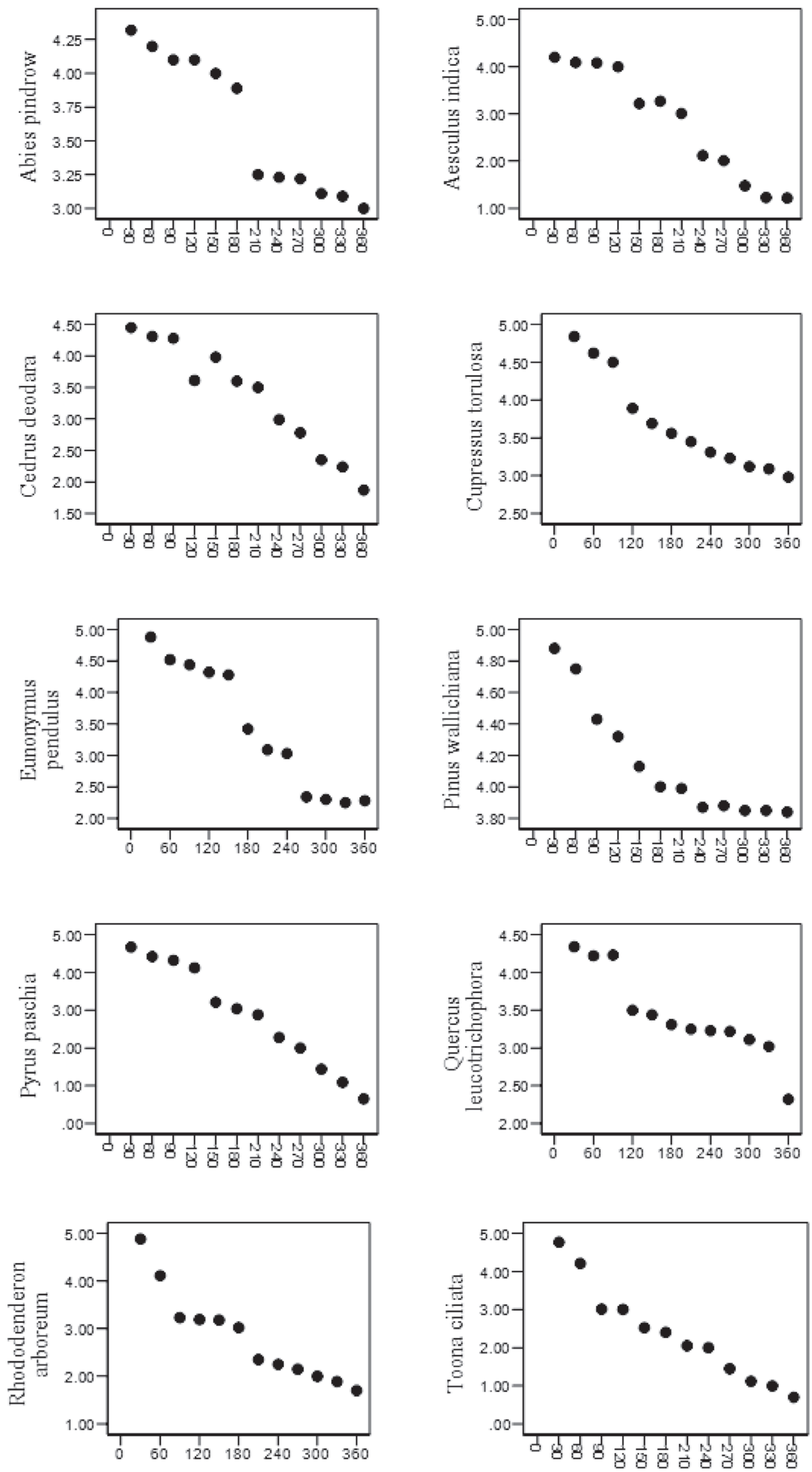

Fig. 5. Decomposition of leaf litter of different tree species in a temperate forest in the Indian Himalayas region. The X-axis shows days and the Y-axis species leaf litter decomposition in grams. **Deciduous species**:*Aesculus indica*, *Pyrus pashia* and *Toona ciliata.* **Evergreen species**: *Abies pindrow*, *Cedrus deodara*, *Cupressus torulosa*, *Euonymys pendulous*, *Pinus wallichiana*, *Quercus leucotrichophora* and *Rhododendron arboreum.*

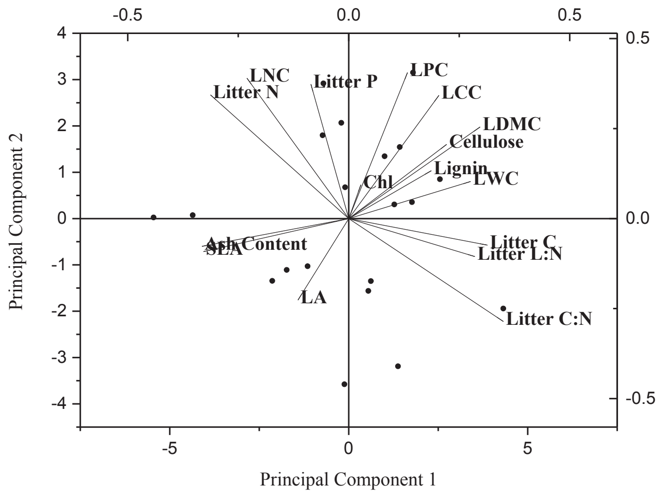

Fig. 6. A principal component plot of leaf and litter traits of trees in a temperate forest in the Indian Himalayas region. Leaf area LA, Specific leaf area SLA, Leaf carbon content LCC, Leaf nitrogen content LNC, Leaf phosphorus content LPC, Leaf water content LWC, Leaf dry matter content LDMC, Chlorophyll content Chl.

contribution of traits litter N, LNC (positive) with C: N, (negative), while the second component explained 21% variability with positive contribution of cellulose. The third component explained 14% variability with positive contribution of LA and SLA. The other components in totality explained 23% variability with lignin, L:N, Chl, P. Four green leaf traits (LA, SLA, LNC and Chl) and six litter traits (litter N, litter P, lignin, cellulose, L: N and C: N ratio) were found to be significant contributors to the decomposition process,.

The REML analysis, based on the 10 significant contributors (identified through PCA above) as a fixed effect with decomposition as a response variable, showed that variation in the decomposition process was best explained by the functional properties of one green leaf trait, SLA (8%) and two litter traits, cellulose content (40%) and lignin content (36%) (Table 3). Species as a random effect contributed most to decomposition (99% of variation). The model was evaluated based on low AIC and deviance and significant chi-square value (Table 3).

Among all 16 green leaf traits and litter traits, SLA, cellulose content and lignin content explained the highest percentage contribution to decomposition. These results suggest that both litter traits and green leaf characteristics were significantly contribute for explaining the decomposition process in temperate forest ecosystems.

4. Discussion

Both litter and green leaf traits were found to be responsible for litter decomposition and contributed to the functioning of nutrient cycling in the temperate forest ecosystem. Of the 16 green leaf traits and litter traits examined, SLA, cellulose and lignin were found to have highest contribution in determining the variation in the litter decomposition in the temperate forest. The results also suggest that litter from deciduous tree species in the forest decomposed at a faster rate than litter from evergreen tree species. This may be attributed that the deciduous species employ a resource-acquisitive plant strategy and the evergreen species has a resource-conservative plant strategy (Bai et al., 2015) in terms of leaf economic spectrum (Santiago, 2007; Wright et al., 2004).

4.1. Litter traits and decomposition

In the present study, litter quality, i.e. cellulose and lignin content, made the greater contribution to litter decomposition in the temperate forest ecosystem evaluated. These results are consistent with other studies of the Indian Himalayas region, which report a significant positive association of litter cellulose and lignin content with decomposition (Garkoti and Singh, 1999; Semwal et al., 2003; Tiwari and Joshi, 2015). This may be due to the fact that lignin and cellulose are major chemical constituents of leaf litter (Krishna and Mohan, 2017; Rahman et al., 2013). In contrast, a negative association between cellulose content and decomposition in *Pinus* species is reported by Chae et al. (2019).

In the present study, the parameters litter N, litter P, litter L: N and litter C: N ratio were found to make no significant contribution to litter decomposition, possibly due to micro-environmental conditions, as also observed by Joly et al. (2017). Other studies reported contrasting relationships with decomposition, e.g. positive for litter N and litter P (Jacob et al., 2010; Kara et al., 2014) and litter C: N (Krishna and

Table 3
Results of residual maximum likelihood (REML) analysis of litter decomposition in a temperate forest in the Indian Himalayas region.

Linear mixed model **Response variable**	**Fixed effect trait**	**Estimate**	**Variation explained (in %)**	**Random effect**	**Std. dev**	**% of variation explained**
Litter Decomposition	**Leaf litter trait**			Specie	0.44	99.93
	Cellulose	4.66 (7.09)	40.26			
	Lignin	4.55 (7.42)	36.76			
	Litter N	0.00 (0.00)	0			
	Litter P	0.02 (0.01)	0			
	Litter L:N	0.00 (0.00)	0			
	Litter C:N	0.00 (0.00)	0			
	Green leaf trait					
	Specific leaf area	7.90 (3.41)	8.50			
	Leaf area	0.01 (0.00)	0			
	Leaf nitrogen	0.01 (0.00)	0			
	Chlorophyll	0.00 (0.01)	0			

Model statistics for the null and full model
Model Parameter

Null Model					
Response variables	**Df**	**AIC**	**LogLik**	**Deviance**	**Chi-square (P)**
Litter Decomposition	3	−19.81	12.90	−25.81	
Full Model					
Litter Decomposition	13	−214.33	120.16	−240.33	2.2 (0.00)

Mohan, 2017) and negative for litter C: N (Jacob et al., 2010).

Overall, it can be concluded that the speed of nutrient recycling in decomposing litter in temperate forests depends on the quality of the litter and traits associated with the decomposition process. Among the different litter quality traits, cellulose and lignin content made the greater contribution to litter decomposition. Thus, it is clear that cellulose and lignin content are important and a significant contributor for governing the rate of litter decomposition in temperate forest ecosystems, and hence nutrient cycling in these ecosystems.

4.2. Green leaf traits and decomposition

Among the green leaf traits, SLA contribution was highest to decomposition. This might be due to relative high exposure to leaves by the abiotic factors such light, soil moisture and soil microbes on the leaf surface, as SLA acts as a promoter for decomposition (Liu et al., 2017). Other studies have also found a significant positive contribution of SLA to decomposition in different types of forests, including temperate, tropical, dryland and semi-evergreen tropical forests (Chae et al., 2019; Liu et al., 2017; Sánchez-Silva et al., 2018; Santiago, 2007).

Specific leaf area is a widely used model parameter to control physiological processes (Bakker et al., 2010; Pietsch et al., 2014; Wright et al., 2004) and decomposability (Liu et al., 2017). Also, SLA is used as a factor to predict nutrient and carbon cycling changes in ecosystems (Dubey et al., 2017). The present study revealed that green leaf traits are also significant contributors to decomposition and the functioning of temperate forest ecosystems. It also revealed that leaf area, leaf N and chlorophyll content make no marked contribution to litter decomposition in temperate forest ecosystems. This is in contrast to previous reports of significant contributions by leaf N and chlorophyll to litter decomposition in forest ecosystems (Bakker et al., 2010; Cornwell et al., 2008; Pietsch et al., 2014).

4.3. Leaf economic spectrum and decomposition

In this study, deciduous tree species were shown to have faster-growing, resource-acquisitive leaf traits and to contribute to a higher rate of litter decomposition than evergreen tree species, which had slow-growing, resource-conservative leaf traits (Table 2, Fig. 5). This indicates that the morphological and the physiological traits of leaves had a strong influence on nutrient cycling. Therefore, both green leaf and litter traits influence the decomposition rate in temperate forest ecosystems (Cornwell et al., 2008; Freschet et al., 2012). The ecological process of decomposition is then primarily governed by variations across time and space in these functional traits (Anderegg et al., 2018; Osnas et al., 2013). It was observed that the SLA trait of green leaves determined the quality of the litter produced, but many other morphological and chemical characteristics of green leaves may persist after shedding (Santiago, 2007; Bakker et al., 2010). However, leaf litter quality, i.e. lignin and cellulose content, is either positively (Garkoti and Singh, 1999; Semwal et al., 2003; Tiwari and Joshi, 2015) or negatively (Chae et al., 2019) related with litter decomposition rate, which calls for more detailed studies on litter decomposition processes. Deciduous species, which are considered to be resource-acquisitive species, have greater SLA and contribute to more rapid decomposition rates in forest ecosystems (Santiago, 2007; Pietsch et al., 2014), while litter with morphological and chemical features associated with conservative strategies, i.e. evergreen species, and low nutrient concentrations contribute to slower rates of decomposition (Aponte et al., 2012). The results obtained in this study suggest that both green leaf traits and litter traits are associated with the leaf economic spectrum and are important in influencing decomposition.

Overall, our findings determined that litter from deciduous species decomposes at a faster rate than evergreen species. Cellulose, lignin content and SLA had the greater contribution to litter decomposition amongst the other studied traits. Therefore, it may infer that both green leaf traits and litter traits were important in influencing decomposition process in temperate forest ecosystems, and hence facilitate for the nutrient cycling in these ecosystems. Furthermore, there is a research need for generating data on temperate forest tree species and identifying the best predictor for the decomposition process by evaluating the forests at a long term and at a bigger cross-sectional level. Investigating the green leaf traits and leaf litter characteristics influence on decomposition processes would improve our understanding of this multifaceted natural forest ecosystem and thereby contribute for improved management of forest based on scientifically informed decision making.

5. Conclusions

Among the green leaf traits and litter traits, cellulose, lignin and specific leaf area made the most significant contribution to variations in decomposition rate. The percentage contribution of traits to the decomposition process is 40% for, cellulose, 36% for lignin and 8% for SLA, respectively. Thus, both green leaf and litter traits contribute to litter decomposition and nutrient cycling in temperate forest ecosystems. Therefore, for a better understanding of ecological functioning, particularly regarding the decomposition process in forests, green leaf traits and litter traits both need to be considered.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contribution

MR conceptualised, designed, developed and collected data for the study. MR and RP analysed and interpreted the data. MR, KA, AA, JAM and RP read and modified the draft manuscript.

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