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Fuel properties and combustion characteristics of *Lantana camara* and *Eupatorium* spp.

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In this study, we report fuel properties (basic density, high heating value, proximate and elemental parameters) and ash elemental composition of two important forest weed species, i.e. *Lantana camara* and *Eupatorium* spp. The physical, chemical and elemental properties of *L. camara* and *Eupatorium* spp. were compared with those of a mature tree (20 years of age) of *Eucalyptus* hybrid. The combustion characteristics under oxidizing atmosphere were also studied using thermogravimetric analysis. The burning profiles of the samples were derived by applying the derivative thermogravimetric technique. The two weed species were found to be different in their physical, chemical and elemental properties. The fuel properties and combustion characteristics, which largely depend upon the biochemical composition of biomass, were also different in these two weed species. The results suggested that both *L. camara* and *Eupatorium* spp. can be used as feedstock in thermochemical conversion processes. The emphasis was given to these species because of the huge biomass they produce. These species are widely present in different agroclimatic zones of India and can play a major role in future bioenergy schemes.

Keywords: Biomass, burning profile, fuel properties, thermogravimetric analysis.

Biomass is the most common form of renewable energy sources. The potential of biomass to meet the domestic and industrial energy requirements of India has been well recognized[1]. Biomass fuels are promising, non-toxic and eco-friendly clean fuels[1,2]. Biomasses in various forms are suitable as energy feed stock. They can be either burned directly in a furnace or converted into high energy content fuels using biochemical or thermochemical conversion processes[2]. Among different biomasses, wood has received the most attention because of its long and continuing precedent as a fuel and biomass feed stock[3,4]. However, due to stringent government policies, which are largely aiming towards protection of native forests, there is hardly any supply of fuelwood from the forest[5]. Therefore, it is important to find out ways of utilizing alternative biomass resources for meeting heat and energy requirements. *Lantana camara* and *Eupatorium* spp. are

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two important weed species, which grow in the wild throughout India. They are widely available and dominating weed species, reported as potential biomass sources[1,6]. One of the ways to make effective use of these weeds is to utilize them as a source of energy.

Some efforts in the past have been made to make use of these available biomass sources as feed stock for gasification[7,8]. However, a detailed study on physical, chemical and elemental properties of these weed species is required. It is also important to evaluate the thermal behaviour of these biomasses under oxidizing atmosphere. Such studies will help in effectively utilizing these weeds as raw material for energy production through thermochemical or biochemical conversion processes.

In this work, we have studied physical, chemical, and combustion properties of biomass from *L. camara* and *Eupatorium* spp. The burning profiles of the samples were derived by applying the derivative thermogravimetric technique.

The test samples of *L. camara* and *Eupatorium* spp. were procured from Shimoga Forest Division of Karnataka. The samples obtained for experimental work were from similar soil and climatic conditions. To study the variability in fuel properties within species of *L. camara*, different plant parts, i.e. stem, twig and leaves were analysed. Disc samples of a 20-year-old *Eupatorium* hybrid tree were procured from Mandya Forest Division, which was further studied for basic density, proximate and elemental parameters. Samples of different biomasses were oven-dried to a constant weight at 80°C. The oven-dried samples were then chipped, hammer-milled and powdered to pass through a –40 + 60 mesh[9].

Volumes of freshly cut water-saturated samples were determined by mercury displacement method[10]. Basic densities (g/cm^3) of the samples (d) were determined using eq. (1).

$$d = W_{OD}/V_g, \tag{1}$$

where W_{OD} is the oven dry mass of biomass and V_g is the green volume of biomass.

The high heating values were determined from elemental composition (carbon, hydrogen, nitrogen, sulphur) and ash content of the biomass using eq. (2) (refs 11 and 12).

$$\text{HHV} = 0.3491\text{C} + 1.1783\text{H} + 0.105\text{S} - 0.1034\text{O} - 0.0151\text{N} - 0.0211\text{A}. \tag{2}$$

The moisture, ash and volatile matter were determined according to ASTM D5142, using a proximate analyser (LECO TGA-701). The ultimate parameters (carbon, hydrogen, nitrogen) were determined using a CHN analyser (LECO-CHN-2000) and sulphur content was determined by EDXRF using standard procedures[13]. Fixed carbon content (FCC) was estimated using eq. (3).

$$\text{FCC (\%)} = [100 - (\text{\% Moisture} + \text{\% Ash} + \text{\% Volatile matter})]. \tag{3}$$

To overcome the experimental and instrumental errors, experiments were repeated four times and the average values were obtained.

The elemental composition of ash from different biomasses was determined using EDAX (Energy Dispersive X-ray Analysis) attached to scanning electron microscope (SEM). The ash samples were finely ground and pressed into pellets without adding external binder[12]. The oven dried pellets were then used for analysis. The results were obtained as elemental oxides. The average of values determined at five different areas of the samples is given in Table 1. The ash elemental analysis was carried out at Central Power Research Institute, Bangalore, India.

The combustion characteristics were studied under air atmosphere. Thermogravimetric analysis (TGA) was carried out using TGA Q500 V20.2 Build 27. A known quantity of sample was placed in a platinum crucible and heated from ambient to 800°C at a heating rate of 10°C min^{-1} and 60 ml min^{-1} air flow rate. General guidelines of ASTM D 3850 were followed in the experiment. The burning profiles of the samples were derived by applying the derivative thermogravimetry technique[12–14].

The holocellulose and lignin of biomass from two weed species and *Eupatorium* hybrid wood were determined using standard methods and the results are presented in Table 2. Biomass powder was extracted out with a mixture of alcohol : toluene : acetone :: 1 : 1 : 4 (v/v) for 6 h in a soxhlet apparatus followed by washing with hot water. The extracted free samples were further used for determination of lignin by digesting with 72% sulphuric acid for 2 h (TAPPI. T222 om-88)[15]. Holocellulose was also determined in the wood samples using standard method[16].

The quality of a fuel depends on basic properties of the raw material. The heating value is greatly influenced by elemental composition, liberation of acid fumes, quantity of ash produced and the amount of sulphur generated[11]. Moisture is also one of the important factors influencing the heating value[4]. A systematic study on heating value, basic density, proximate analysis (ash, volatile matter and fixed carbon) and ultimate parameters (carbon, hydrogen, nitrogen and sulphur) of two forest weeds was carried out, and the results were compared with that of a 20-year-old tree of *Eupatorium* hybrid.

Density is one of the important parameters that directly affects the fuel quality of a feed stock. The species having higher density are preferred as fuel because of high energy content per unit volume and their slow burning property[17]. The basic density (g/cm^3) results are summarized in Table 2. The basic density of *L. camara* biomass (ranged from 0.497 to 0.520 g/cm^3) was more than that of *Eupatorium* spp. (0.330 g/cm^3). The basic density of *Eupatorium* hybrid tree was around 0.730 g/cm^3, which is significantly higher than the two weed species.

Table 1. Composition of ash forming minerals in selected forest weeds, i.e. *Lantana camara* and *Eupatorium* spp.

	Ash chemical composition (wt% of ash)											
Species	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Fe_2O_3	CuO	Cl
Lantana (stem)	1.32	7.21	2.18	4.01	10.81	4.14	41.42	24.96	0.19	2.28	*	1.48
Lantana (leaves)	0.71	12.26	0.75	2.03	8.94	5.11	43.21	21.16	0.14	1.27	*	4.42
Eupatorium spp.	0.51	8.45	1.46	10.58	6.96	4.57	35.02	15.93	0.16	0.99	2.96	12.41

*Not found.

Table 2. Physico-chemical properties, proximate and ultimate analysis and high heating value of *Lantana camara* and *Eupatorium* spp.

Biomass feedstock	Ultimate analysis					Proximate analysis				BD	HHV	Holo-cellulose (% oven dry weight)	Lignin (% oven dry weight)
	C (%)	H (%)	N (%)	S (%)	O* (%)	MC (%)	Ash (%)	VMC (%)	FCC (%)	(g/cm^3)	(MJ/kg)		
Lantana (Stem)	48.10	6.22	1.04	0.13	43.66	7.02	0.85	74.42	17.71	0.520	19.59	81.49	20.12
Lantana (Twig)	45.90	6.92	1.05	0.14	44.65	7.81	1.34	73.49	17.36	0.497	19.53	ND	ND
Lantana (Leaves)	43.00	5.69	1.05	0.14	42.57	7.49	7.55	67.45	17.51	ND	17.15	46.24	30.20
Eupatorium spp.	43.00	6.16	1.06	0.15	46.14	8.33	3.49	69.32	18.86	0.326	17.43	81.53	19.25
Eupatorium hybrid	48.30	5.89	0.14	0.14	45.53	1.50	0.43	77.62	20.45	0.730	19.10	70.10	28.32

*Calculated by difference method.
HHV, Higher heating value; MC, Moisture content; VMC, Volatile matter content; FCC, Fixed carbon content; BD, Basic density.
ND, not determined.

Fuel value of a biomass is greatly dependent on its calorific value, which is considered as an important parameter for comparing one fuel with another. The amount of heat generated by any fuel depends on the quantitative conversion of carbon and hydrogen present in the fuel to water and carbon dioxide, and is a function of chemical composition of the fuel[4]. The variations in the heating value of different biomass fuels indicate the differences in their elemental composition. In any fuel, carbon–oxygen and carbon–hydrogen bonds contain lower energy than carbon–carbon bonds. Higher proportion of oxygen and hydrogen in biomass reduces the energy value of fuel[11].

The heating values in *L. camara* were studied from the samples of *Lantana* stem, twigs and leaves. The heating values of *Lantana* stem, twigs and leaves were found to be 19.59, 19.53 and 17.15 MJ kg^{-1} respectively (Table 2). The higher ash percentage in the leaves of *Lantana* is responsible for its lower heating value. Of the two weed species, a comparatively lower heating value, i.e. 17.43 MJ kg^{-1} was recorded in *Eupatorium* spp. This may be attributed to the higher amount of elemental oxygen and more ash forming materials in *Eupatorium* spp. The heating value of *Lantana* stem was close to that of *Eupatorium* hybrid (19.10 MJ kg^{-1}). The heating value of a fuel also depends on the major biochemical constituents, i.e. cellulose, hemicellulose, lignin and extractives[18].

The proximate and ultimate analysis of *L. camara*, *Eupatorium* spp. and *Eupatorium* hybrid was studied. The results of proximate analysis are summarized in Table 2. The ash is an important parameter, which directly affects the quality of fuel. A biomass having higher density and low ash and moisture content is considered better feedstock[9,11]. The ash percentage of *Lantana* stem, twigs and leaves was found to be 0.85, 1.34 and 7.55 respectively (Table 2). The higher percentage of ash in the leaves may be due to a higher concentration of potassium and magnesium[2,4]. Of the two weed species, a higher percentage of ash was observed in *Eupatorium* spp. (3.49). The ash percentage in wood biomass of *Eupatorium* hybrid was found to be 0.43, which is lower than both the weed species.

Table 2 also indicates that the values of volatile matter and the fixed carbon do not vary much between stem and twigs of *L. camara*. The values of volatile matter were found to be 73.49% and 74.42% in twigs and stems of *Lantana* respectively. The fixed carbon in both the weed species ranged from 17.36% to 18.86% and its values were higher in *Eupatorium* spp., i.e. 18.86%. The fixed carbon in *Eupatorium* hybrid wood was 20.45%. The higher value of fixed carbon in *Eupatorium* hybrid can be attributed to its low moisture and ash. Moisture is one of the important parameters with regard to the selection of energy conversion process for a particular feed stock. The biomass fuels having higher moisture are more suited for biochemical conversion processes and low moisture for thermal conversion processes[2].

The results of elemental analysis (Table 2) show that there is not much of variation in the elemental composition of biomasses studied. The amount of ultimate carbon in stem, twigs and leaves of *Lantana* was found to be 48.10%, 45.90% and 43.00% respectively. The H/C and

Table 3. Characteristics of thermogravimetric experiment under oxidizing (air) conditions

Biomass feedstock	Oxidative degradation zone				Char combustion zone			
	Ignition temperature (°C)	Peak temperature (°C)	Maximum combustion rate (mg/min)	Temperature range (°C)	Ignition temperature (°C)	Peak temperature (°C)	Maximum combustion rate (mg/min)	Temperature range (°C)
Lantana (stem)	200	319	0.2977	190–336	400	441	0.2083	390–460
Lantana (leaves)	160	293	0.3152	145–355	405	442	0.3106	410–490
Eupatorium spp.	190	285	0.2944	160–315	421	430	0.1302	417–440

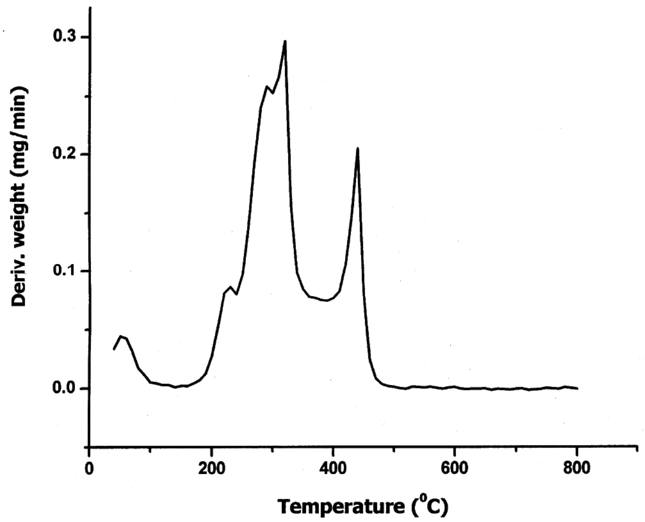

Figure 1. Burning profile of *Lantana camara* (stem).

O/C ratio calculated from the values given in Table 2 do not show any significant variation among the different biomasses studied. The H/C ratios recorded for *Lantana* stem, twigs, leaves, *Eupatorium* spp. and *Eupatorium* hybrid are 0.13, 0.15, 0.13, 0.14, and 0.12 respectively. The O/C ratios recorded for *Lantana* stem, twigs, leaves, *Eupatorium* spp. and *Eupatorium* hybrid are 0.91, 0.97, 0.99, 1.07 and 0.94 respectively. The lower percentage of nitrogen and sulphur in all the species is important from the environmental point of view. The higher proportion of hydrogen and oxygen in the biomass samples is responsible for their lower energy value[11].

The elemental composition of ash of *L. camara* (stems and leaves) and *Eupatorium* spp. was analysed and the results are reported in oxide forms in Table 1. Table 1 shows a relative higher percentage of alkali metals (K, Na), alkaline earth metals, silicon and chlorine in the ash. A higher concentration of K_2O, CaO and P_2O_5 was observed in all the samples. Alkali and alkaline earth metals, in combination with other fuel elements such as silica and sulphur, facilitated by the presence of chlorine, are responsible for many undesirable reactions in combustion furnaces and power boilers[19]. The amount and type of ash produced during the combustion process depend on the physical and chemical properties of the species, the design of the boiler and combustion conditions[20]. The ash inside the furnace forms gaseous, liquid or solid phase compounds by either reacting among themselves or with the flue gases present. These gaseous and liquid phase compounds further get deposited on the cooled parts of the furnace to cause various problems like slagging, fouling, sintering and corrosion[21]. From Table 1, it is evident that a higher percentage of Cl and SiO_2 is present in *Eupatorium* spp., when compared to *Lantana* biomass. The ash of *Eupatorium* spp. also contains CuO, which is not present in the ash of *Lantana* biomass. A higher percentage of MgO (12.26) in leaves is because of chlorophyll that contains high amount of magnesium. Certain control practices, such as leaching the raw fuels with water and use of different mineral additives during the burning process can be adopted. It is reported that the reduction in the concentrations of alkali metals and chlorine from the fuel with water resulted in remarkable improvements in ash fusion temperatures[19].

The thermo-analytical technique (TGA and DTG) has been widely used to study the thermal behaviour of fossil fuels and biofuels[22–25]. TGA records the weight loss of a sample against the time and temperature. A plot of the rate of weight loss of sample while burning, against uniformly rising temperature under oxidizing atmosphere is referred to as 'burning profile'[14]. The information generated from the burning profile of a sample is useful for understanding the behaviour of a fuel during the combustion process.

In this study, TGA technique has been used for understanding the thermal degradation behaviour of different weeds, under oxidizing atmosphere. The burning profiles of the biomass from *Lantana* stem, leaves and *Eupatorium* spp. are given in Table 3 and Figures 1–3. Three major steps of decomposition/weight loss have been observed for all the biomass samples under oxidative atmosphere. Between the temperatures 40–80°C, DTG curves shows a weight loss of 4%, 5.3% and 4.9% in *Lantana* stem, leaves and *Eupatorium* spp. respectively as shown in Figures 1–3. This initial weight loss between temperatures 40–80°C is mainly due to the removal of moisture from the biomass. The second weight loss between temperatures (145–355°C) is due to oxidative decomposition of biomass. The third major weight loss observed in the temperature range of 390–490°C, is due to the combustion process of char (Table 3). The extent of weight loss in these two combustion steps differs with species. The difference in the profile can be attributed to difference in the physical and chemical properties of biomass. The ignition temperature and peak temperature are two important characteristic temperatures of a burning profile[11,14]. The ignition temperature corresponds to the point at which the burning profile underwent a rapid rise. However, the temperature where the rate of weight loss due to combustion is maximum is called as peak temperature[14]. The understanding of peak temperature has significance in designing of the thermo-chemical conversion process. This point is considered as an indicator of the reactivity of the sample. The rate of weight loss at the burning profile peak temperature is called 'maximum combustion rate'. The maximum combustion rates of 0.2977, 0.3152 and 0.2944 mg/min were found at peak temperatures of 319, 293 and 285 for *Lantana* stem, leaves and *Eupatorium* spp. respectively (Table 3). The

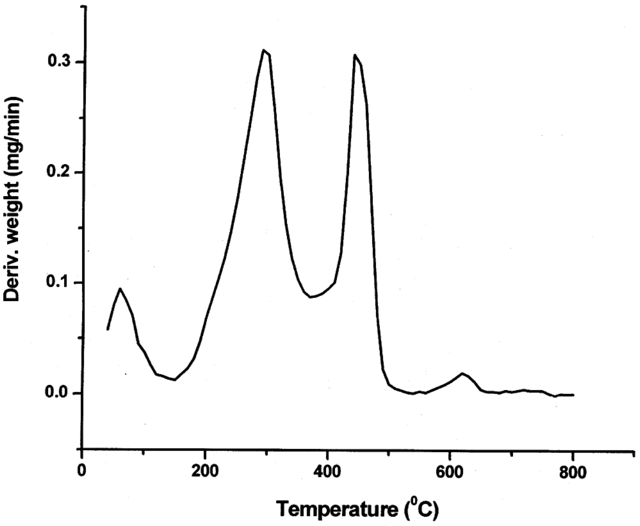

Figure 2. Burning profile of *Lantana camara* (leaves).

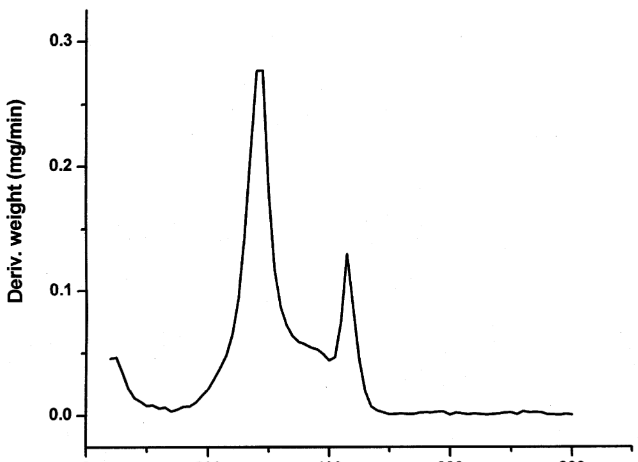

Figure 3. Burning profile of *Eupatorium* spp.

weight loss percentages of *Lantana* stem, leaves and *Eupatorium* spp. at 800°C temperature, were found to be 97.15, 93.00 and 96.01 respectively.

The combustion in the char zone starts at higher temperature, after the oxidative degradation of the biomass[12]. The char combustion zone temperature for different biomass samples ranges from 390°C to 490°C. The highest char combustion temperature range of 410–490°C was observed in case of *Lantana* leaves. The lowest char combustion temperature range 417–440°C, was recorded in *Eupatorium* spp. This may be due to production of char having high volatile matter and lower fixed carbon during the combustion of *Eupatorium* spp. The maximum combustion rate, i.e. 0.2083, 0.3106 and 0.1302 mg/min was recorded for *Lantana* stem, leaves and *Eupatorium* spp. at peak temperatures of 441°C, 442°C and 430°C, respectively (Table 3). The difference in the burning profile of char combustion zone may be due to difference in chemical composition of char produced during the process and also on the mutual interaction of the individual components[26–28].

The results on proximate analysis of selected weeds indicated variations in some of the properties. The heating value of *Eupatorium* spp. was found to be lower than *Lantana*, which has been attributed to higher ash in *Eupatorium* spp. (3.49%) as compared to *Lantana* (0.85–1.34%). The results on heating value of *Lantana* stem and twigs are comparable to those of *Eupatorium* hybrid wood. The amount of ash found in the leaves of *Lantana* was 7.55%. A marginal variation with respect to moisture, volatile matter and fixed carbon values was observed in both the weed biomasses. The ash elemental analysis shows higher concentrations of K_2O, CaO and P_2O_5 in ash from all the selected biomasses. Ash of *Lantana* leaves contained a higher percentage of MgO (12.26%). The ignition temperatures determined from the burning profiles for *Lantana* leaves, *Eupatorium* spp. and *Lantana* stem were 160°C, 190°C and 200°C respectively. The peak temperatures observed for *Lantana* stem, leaves and *Eupatorium* spp. were 319°C, 293°C and 285°C respectively. The char combustion zone temperature for two weed species ranged between 390°C and 490°C. The maximum combustion rate in char combustion zone was recorded as 0.2083, 0.3106 and 0.1302 mg/min for *Lantana* stem, leaves and *Eupatorium* spp. respectively.

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Ground insect community responses to habitat restoration efforts in the Attappady hills, Western Ghats, India

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A reconnaissance survey was undertaken to assess the responses of ground insect communities to habitat restoration efforts in the Attappady hills, Western Ghats. Diversity patterns of various ground insect assemblages such as ants, beetles, etc. were compared across an age trajectory of restored sites. The diversity of these assemblages was correlated with age trajectory of sites. Also, patterns of recolonization by different insect trophic guilds and ant functional groups were comparable with earlier studies from different biogeographic areas.

Keywords: Ants, diversity, ecological restoration, recolonization, Western Ghats.

WIDESPREAD loss of production and conservation values of natural habitats due to various anthropogenic activities makes large-scale ecosystem restoration an increasingly urgent task[1]. Ecological restoration is often undertaken as a compensatory mitigation for degraded, damaged or destroyed ecosystems. A properly planned restoration project attempts to fulfil clearly stated goals by pursuing specific objectives[2]. The specification of goals for restoration projects is frequently described as the most important component of a project, because it sets expectations, drives the detailed plans for actions, and determines the extent of post-project monitoring[3]. To ascertain the achievement of specific goals, project monitoring is undertaken as an integral part of such restoration projects. The success of restoration programme is based on the scientific evaluation of the natural ecosystem, restoration practice and its regular monitoring. Monitoring involves measuring ecosystem attributes such as diversity, vegetation structure or ecological processes[4]. Though many projects aim at restoring the total ecological fidelity, i.e. structural/compositional, functional and durability, attempts to evaluating the success of restoration efforts should not be limited to revegetation alone.

Other than monitoring vegetation growth, invertebrates like insects are often included because they represent many different trophic groups, e.g. predators, herbivores, parasites and parasitoids, pollinators and decomposers[5]. Arthropod groups have been used to track restoration success in many contexts; for example, arthropod com-

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