COMBUSTIBILITY OF FRESH LEAVES OF 26 FOREST SPECIES IN CHINA

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LIU MH, YI LT, YU SQ, ZHOU GM, JIANG H & LI XP. 2013. Combustibility of fresh leaves of 26 forest species in China. In subtropical evergreen forest in East China, forest fires cause huge economic losses. Flammability of fresh leaves can play an important role in determining fire spread. Therefore, a study on the influence of fire on evergreen trees is of great importance to investigate the ecological properties of forest fire and protection of tree species. The combustibility of fresh leaves of 26 dominant evergreen plant species in East China were compared and suitable species for use as fire-resistant tree species were recommended. Using the cone calorimeter, variations of 12 burning parameters through time were described. The principal components affecting combustibility of fresh leaves were smoke, heat and time. Most burning characteristics were correlated with heat. Based on thermal–calorimetry analysis and smoke spread test data, 17 species were slow combustible species, with relatively longer ignition delay time, lower heat release rates and peak of heat release rate, longer time to peak of heat release rate, less total heat release and higher smoke production. All results indicate that species which have higher release of total smoke will have lower heat release rate. Thus, less flammable species are recommended to be used as fire-resistant tree species and in the construction of renewed forest.

Keywords: Flammability, forest fire, heat release rate, total smoke release

LIU MH, YI LT, YU SQ, ZHOU GM, JIANG H & LI XP. 2013. Keterbakaran daun segar 26 spesies pokok hutan di China. Kebakaran hutan di hutan malar hijau subtropika di China Timur menyebabkan kerugian ekonomi yang besar. Kemudahbakaran daun segar boleh memainkan peranan penting dalam perebakan api. Oleh itu, kajian kesan api terhadap pokok malar hijau penting untuk meninjau ciri ekologi kebakaran hutan dan perlindungan spesies pokok. Keterbakaran daun segar 26 spesies pokok malar hijau yang dominan di China Timur dikaji dan spesies yang sesuai disyorkan sebagai spesies pokok tahan kebakaran. Variasi 12 parameter kebakaran dengan masa dihuraikan menggunakan kalorimeter kon. Komponen utama yang mempengaruhi keterbakaran daun segar ialah asap, haba dan masa. Kebanyakan ciri kebakaran berkorelasi dengan haba. Berdasarkan analisis haba–kalori dan data perebakan asap, 17 spesies didapati terbakar dengan lambat. Secara perbandingan, spesies ini mempunyai masa menyala yang lambat, kadar pembebasan haba yang rendah, puncak kadar pembebasan haba yang rendah, masa yang lama untuk mencapai puncak kadar pembebasan haba, jumlah pembebasan haba yang rendah dan penghasilan asap yang tinggi. Semua keputusan menunjukkan bahawa spesies yang mengeluarkan asap yang banyak mempunyai kadar pembebasan haba yang rendah. Spesies yang mempunyai keterbakaran yang rendah disyorkan sebagai spesies pokok tahan kebakaran dalam pemulihan hutan.

INTRODUCTION

Forest fire is one of the most serious natural disasters leading to destruction and huge economic losses (Ashe et al. 2009, John & Hall 2010). Assessing the flammability of forest species and thus constructing fire-preventing forest belts are critical for forest management in regions which suffer frequent forest fires. Many studies focused on the combustibility of wood or litter from forest species (Liodakis et al. 2002, Behm et al. 2004, Kane et al. 2008, Liodakis et al. 2008, Ormeno et al. 2009) and found that flammability varied across plants due to their physical and chemical properties (Montgomery & Cheo 1971, Rothermel & Philpot 1973). However, in locations where forest fires occur frequently, there is usually little litter (DeBano et al. 1998) and raging fires can spread from the forest floor to the crown of older trees causing crown fires. Therefore, studying flammability characteristics of fresh leaves can help in understanding fire processes

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and determining the species most appropriate as screening trees for fire-resistant plantations. Moreover, most laboratory studies employ a single fuel property to represent flammability, the most popular being temperature of ignition, time to ignition (ignition delay time) and heat content (Liodakis et al. 2005).

Passive crown fires need support from ground fuels to maintain the fire in the forest canopy whereas active crown fires can burn in the canopy independent of ground fuel support. However, compared with forest litter on the floor, most fresh leaves in the crown have higher moisture content and can slow down the spread of fire. Most importantly, if the fresh leaf is difficult to ignite and has low flammability, the ground fire will be easily controlled. Thus, the flammability characteristic of fresh leaves can play an important role in determining fire spread. Although much attention has been given to the flammability of litter (Behm et al. 2004, Ormeno et al. 2009), the combustion of crown fire can spread with the wind but hampered by fresh leaves with large biomass and water content that can also delay the fire. It has been shown that crown fires take place in a large percentage of forest fires and can bring about huge damage. Fresh leaves can contribute much to the fireproofing of forests. As each plant species differs in physical and chemical properties, fresh leaves may have differential flammability. However, there are very few studies on the combustibility of fresh leaves (Gill & Moore 1996).

For the last 63 years (1950–2013), China has acquired serious forest fire problem which has intensified mainly in forest ecosystem. The yearly frequency of forest fires has reached 13,000 events per year and has damaged an area of 38,060,00 hm^2. This is especially the case in East China where there is a large percentage of evergreen forest. For example, in Zhejiang Province alone, the frequency of forest fires was about 2500 events from January till March 2006 and the damaged area was about 6700 hm^2. Using suitable species as fire-preventing forest belts can retard burning and spread of forest fires as well as decrease loss. The development of flammability studies on evergreen forest species is needed. This is especially so for the broadleaved and conifer species which are dominant species and can be considered as the main species for use as firebreaks.

The ecological position of arbor species found in East China and their burning characteristics are not well understood. Some researchers have investigated the burning characteristics of broadleaved and conifer species in China (Ni 1998, Tian et al. 2001, Hu & Ju 2008, Jiang et al. 2012). This papes compares the burning characteristics of fresh leaves of 26 different arbor species, which are also dominant species growing in the evergreen ecosystems of East China. Fire resistance would be assessed through differentiation of flammability of these arbor species, i.e. flammable or non-flammable in order to select fire-resistant species.

MATERIALS AND METHODS

Study species and collection

Leaves from 26 species were collected (Table 1). They represent the dominant species in the evergreen forest ecosystem of East China (Ni 1998). The sampling site is at Tian Mu Mountain (119° 28 'E, 30° 22 'N), Zhejiang Province, East China. The mean annual temperature is 15.9 °C with range between 3.3 and 28.1 °C. The mean annual rainfall (46 years) is 1596.5 mm, of which 15% falls between November and April of the following year, which is the time fires occur most frequently. This period is the peak season for forest fires and accounts for 91.3% of the total annual fires.

All fresh leaves were collected directly from the central tree crown on a sunny day. All trees were mature, having grown for at least 10 years. Samples collected were brought to the laboratory immediately and tested within 2 hours.

Burning experiments

Combustion is associated with the properties of the material such as moisture content, which affect time to ignition, heat release rate and smoke production. The moisture content of the forest species was measured by drying the samples in a vacuum oven of 10 Torr and 60 °C to constant mass (about 24 hours).

All burning experiments were conducted in the cone calorimeter following the methods outlined by ISO 5660-1 (ISO 2002). The following parameters were determined: time to ignition (TTI), heat release rate (HRR), peak of heat release rate (HRR_{peak}), time to peak of

Table 1 Relative flammability and heat content of fresh leaves of 26 forest species

Forest species	Moisture content (%)	TTI (s)	HRR (kW m^{-2})	HRR_{peak} (kW m^{-2})	TTH_{peak} (s)	YCO (kg kg^{-1})	YCO_2 (kg kg^{-1})	MLR (g s^{-1})	EHC (MJ kg^{-1})	SEA (m^2 kg^{-1})	THR (MJ m^{-2})	RSR (m^{-2} s^{-1})	TSR (m^2 m^{-2})
Cluster 1													
Cyclobalanopsis glauca	55.31	164.00	12.94	24.40	161.33	0.02	0.90	0.05	4.13	87.39	1.75	0.44	90.60
Castanopsis eyrei	51.78	48.33	13.92	21.85	146.67	0.03	0.87	0.12	4.66	96.61	1.72	0.48	103.36
Lithocarpus glaber	48.98	38.00	16.04	35.03	150.67	0.04	1.11	0.14	5.86	124.25	2.15	0.58	122.65
Cinnamomum camphora	62.15	24.67	8.90	13.82	172.00	0.02	0.89	0.06	3.15	116.41	1.08	0.45	96.48
Michelia maudiae	58.89	112.00	11.12	28.32	162.00	0.02	0.93	0.05	4.40	131.19	1.35	0.47	95.46
Elaeocarpaus glabripetalus	69.25	166.00	8.87	20.77	185.33	0.04	1.04	0.05	3.11	99.82	0.93	0.44	92.15
Altingia gracilipes	59.15	112.00	13.08	25.57	150.00	0.04	1.03	0.05	5.06	53.15	1.64	0.29	65.04
Machilus leptophylla	56.40	37.00	11.72	22.77	171.33	0.03	1.07	0.03	4.38	196.98	1.45	0.61	115.85
Neocinnamomum chekiangense	48.35	29.00	17.19	32.24	151.33	0.03	0.97	0.50	4.93	88.28	2.59	0.31	66.84
Symplocos stellaris	70.72	78.67	8.00	26.93	128.67	0.02	0.89	0.36	2.74	106.01	1.09	0.42	76.14
Camellia oleifera	61.31	41.00	10.52	35.54	55.33	0.03	0.85	1.06	3.40	170.41	1.46	0.69	131.33
*Ilex chinens*is	54.93	49.00	9.40	19.38	142.00	0.03	0.77	0.45	3.20	116.38	1.11	0.56	112.21
Photinia serrulata	59.09	53.00	8.66	18.31	146.67	0.03	1.17	0.75	3.46	112.10	1.04	0.51	106.84
Ligustrum lucidum	65.26	48.00	5.76	10.90	166.00	0.01	0.82	0.03	2.15	96.42	0.64	0.37	75.24
Manglietia yuyuanensis	67.47	122.33	8.89	20.91	145.33	0.02	0.85	1.07	2.87	75.42	1.07	0.33	66.84
Manglietia fordiana	62.46	65.33	10.28	24.50	190.67	0.02	0.84	1.08	3.49	143.64	1.18	0.60	117.78
Cupressus funebris	59.54	145.67	11.33	28.74	165.33	0.01	0.95	0.04	4.03	84.61	1.43	0.40	88.86
Cluster 2													
Cyclobalanopsis gracilis	54.26	48.67	14.35	48.46	63.33	0.02	1.03	0.05	4.11	79.60	2.25	0.38	79.32
Castanopsis sclerophylla	55.83	34.00	12.94	34.25	73.33	0.04	0.85	0.32	3.63	66.70	2.00	0.29	60.83
Lithocarpus brevicaudatus	52.49	28.67	15.93	37.64	65.33	0.04	0.94	0.92	5.10	62.24	2.42	0.32	69.79
Schima superba	66.73	42.17	22.63	43.26	109.33	0.02	0.92	0.03	6.20	73.72	3.23	0.35	75.88
Machilus thunbergii	54.87	29.67	18.37	52.46	53.33	0.02	1.24	0.35	4.78	8.03	3.33	0.09	22.67
Ilex latifolia	58.21	38.67	24.96	84.92	50.00	0.01	1.27	0.47	6.94	28.18	4.19	0.18	40.37
Ilex cornuta	61.66	48.33	25.67	151.09	59.33	0.03	1.23	0.35	5.50	31.27	5.23	0.19	45.47
Osmanthus asiaticus	48.21	57.33	25.89	68.14	136.00	0.01	1.31	0.68	6.84	39.40	4.01	0.32	74.02
Cryptomeria japonica var. *sinensis*	70.83	65.33	18.30	114.88	84.67	0.01	0.78	0.21	4.37	10.51	5.46	0.09	42.02

TTI = time to ignition, HRR = heat release rate, HRR_{peak} = peak of heat release rate, TTH_{peak} = time to peak of heat release rate, YCO = yield of CO, YCO_2 = yield of CO_2, MLR = mass loss rate, EHC = effective heat combustion, SEA = specific extinction area, THR = total heat release, RSR = rate of smoke release, TSR = total smoke release heat release rate (TTH_{peak}), effective heat of combustion (EHC), total heat release (THR) and mass loss rate (MLR). Other parameters on emission of smoke were also measured, i.e. TSR = total smoke release, SEA = specific extinction area which is a measure of the instantaneous amount of smoke being produced per unit mass of specimen burned (Babrauskas 2002), RSR = rate of smoke release, YCO = yield of CO, YCO_2 = yield of CO_2, which needed to be determined in order to understand the combustion of fresh leaves.

Individual leaf samples were weighed to 10 g. The edge and bottom of samples were encased with aluminium foil to avoid bursting during sample burning and placed evenly on a high density ceramic fibreboard measuring 100 mm × 100 mm × 50 mm thick. Pretesting showed that the suitable heat radiation intensity was 40 kW m^{-2} (Liu et al. 2008). Under this condition, fire performance index (Wickström & Göransson 1992, Tian et al. 2001) was significantly higher than those of 45, 50, 60 and 70 kW m^{-2}. Therefore, the materials were tested at a constant preset heat flux of 40 kW m^{-2} in this study. In these experiments, other conditions were as specified by ISO 5660-1 standard (ISO 2002). All combustion tests were carried out in triplicates.

Data analysis

Principal component analysis was used in order to reduce the dimensionality of the data while retaining as much as possible the variation present in the original dataset. In order to determine the main factors affecting combustibility of fresh leaves, 12 burning traits (TTI, HRR, HRR_{peak}, TTH_{peak}, EHC, THR, MLR, TSR, SEA, RSR, YCO, YCO_2) were standardised. Then principal component analysis was used to extract the main factors.

To determine whether species were inflammable or non-flammable, a *k*-means cluster analysis was computed according to the burning characteristics of each species. To determine if clusters were significantly different from one another, individual one-way analysis of variance (ANOVA) tests were conducted on each of the burn characteristic variables. The statistical significance for each test was determined at $\alpha = 0.05$ and all analyses were performed using SPSS.

RESULTS

Flammability analysis

The mean moisture content of samples ranged from 48.21 to 70.83% (Table 1). The ignition delay time ranged from 24.67 s (*Cinnamomum camphora*) to 166 s (*Elaeocarpaus glabripetalus*). *Cupressus funebris*, *Cyclobalanopsis glauca* and *E. glabripetalus* took a longer time to ignite (145.67, 164.00 and 166.00 s respectively). The least flammable species were *C. camphora* (24.67 s), *Lithocarpus brevicaudatus* (28.67 s), *Neocinnamomum chekiangense* (29.00 s) and *Machilus thunbergii* (29.67 s).

Fresh leaves with higher heat release rate and total heat release that may promote higher flammability in burned areas are temporary resisters of forest fires such as *Ilex latifolia* (HRR = 24.96 kW m^{-2}, THR = 4.19 MJ m^{-2}), *Ilex cornuta* (HRR = 25.67 kW m^{-2}, THR = 5.23 MJ m^{-2}) and *Osmanthus asiaticus* (HRR = 25.89 kW m^{-2}, THR = 4.01 MJ m^{-2}). *Ligustrum lucidum* had the lowest HRR (5.76 kW m^{-2}) and THR (0.64 MJ m^{-2}), which meant that this species had high fire-resisting ability. The heat release rate at 40kW m^{-2} for *L. lucidum* reached a peak heat release rate at 166.00 s whereas *E. glabripetalus* and *Manglietia fordiana* reached a peak heat release rate at 185.33 and 190.67 s respectively. Only *I. latifolia* (50.00 s), *M. thunbergii* (53.33 s) and *Camellia oleifera* (55.33 s) reached the peak of heat release rate in a shorter time than others. These results suggest that *L. lucidum* has high fire-resisting ability. Heat release rate curves of 26 species at 40 kW m^{-2} showed that *I. cornuta* and *Cryptomeria japonica* var. *sinensis* presented better combustion behaviour than other species (Figure 1), where average maximum HRR_{peak} values exceeded 100 kW m^{-2}.

Figure 2 shows that most of the 26 species such as *Lithocarpus glaber*, *C. oleifera*, *Machilus leptophylla*, *Photinia serrulata* and *Ilex chinensis* (Figures 2a and b) can produce relatively more smoke than other species. All fresh leaves from the 26 species had lower amounts of CO and CO_2 production (Table 1).

Principal component and factor analyses

Three principal components were extracted and represented 74.97% variance in all (results not shown). The eigenvalues demonstrated that

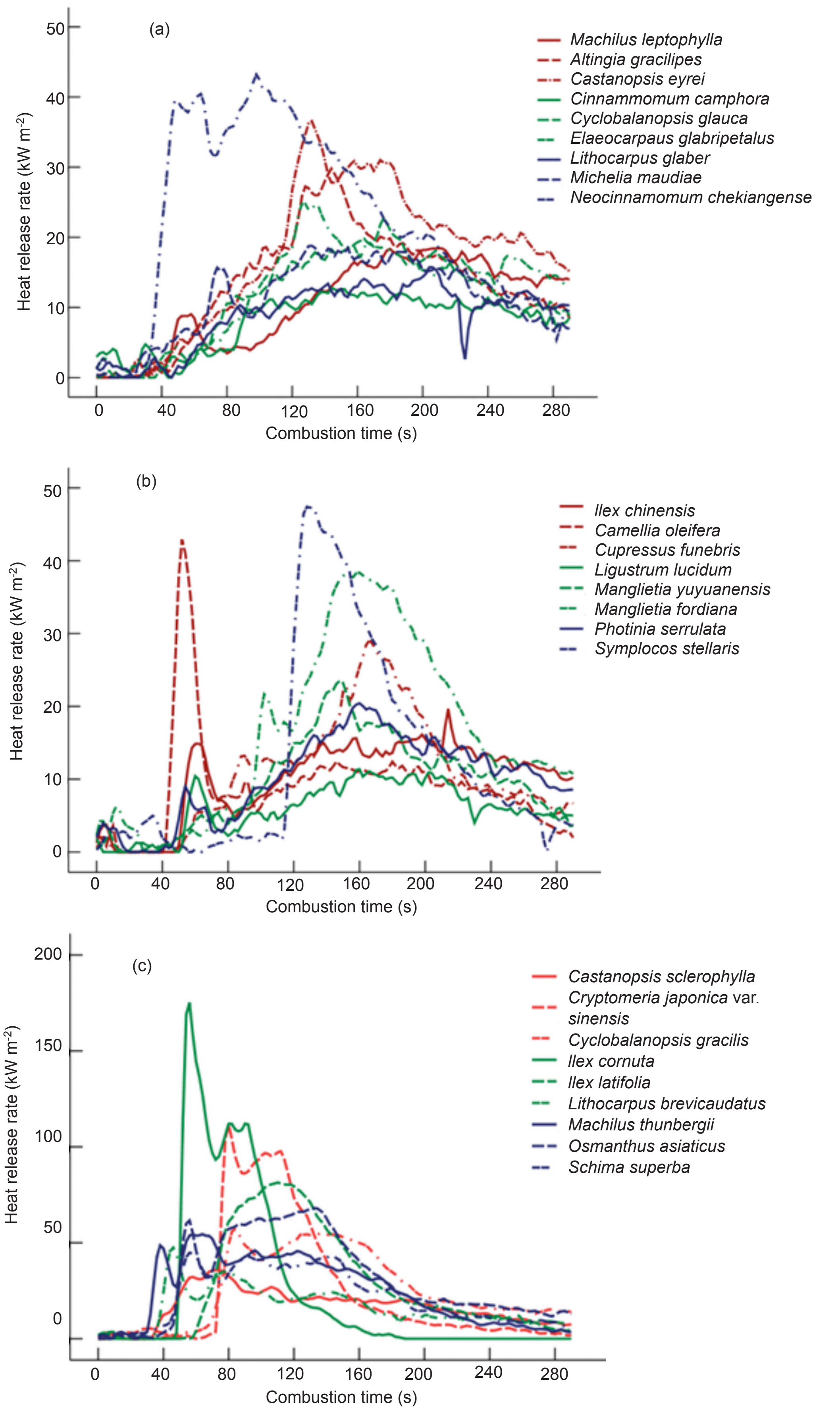

Figure 1 Heat release rate (HRR) curves of 26 forest species at 40 kW m^{-2}: (a and b) HRR curves of 17 species of cluster 1, (c) HRR curves of 9 species of cluster 2

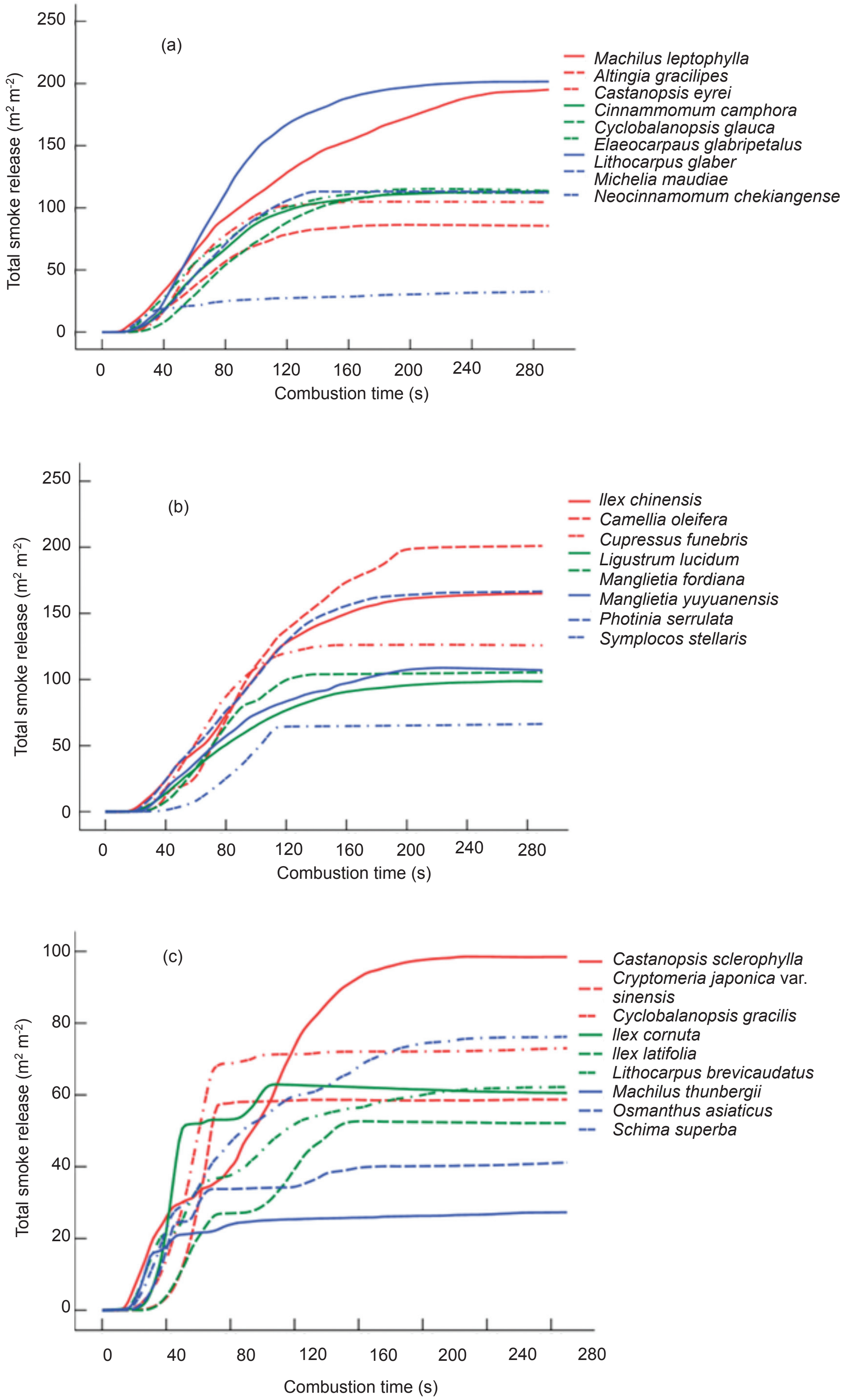

Figure 2 Total smoke release (TSR) curves of 26 forest species at 40 kW m^{-2}: (a and b) TSR curves of 17 species of cluster 1, (c) TSR curves of 9 species of cluster 2

one principal factor had greater weight than two (5.99) and thus was suited to appropriately represent the smoke parameter in further analyses. Component 1, now interpreted as a smoke factor score, explained 32.33% of the variance of the 12 original variables. Some variables such as RSR, TSR and SEA had positive factor scores, with weights of 0.92, 0.91 and 0.86 and made almost the highest contribution to the combined smoke parameter scores. Component 2 was defined as the heat factor and a measure of complete combustion, including some variance (EHC = 0.914, HRR = 0.847, YCO_2 = 0.801) with highly positive contribution to the combined heat parameter scores. Since TTI and MLR contributed to component 3 with higher scores compared with other variables, this combined parameter was defined as the time factor. Most importantly, TTI made a negative contribution to component 3 (-0.76), which showed that the longer the time to ignition, the less the combustion. PCA showed that most variables giving higher weight for the smoke score showed a smaller and negative importance for the heat score. This demonstrates that incomplete combustion accompanied by less flame reduces the release of heat.

Additionally, pairwise correlation analysis for all variables was conducted. Moisture content showed no significant correlation except for a negative correlation ($r = 0.49$, $p < 0.05$) with effective heat of combustion. Yields of CO and mass loss rate had a very low correlation (no obvious difference, $p > 0.05$) with other variables. Time to ignition showed an obvious difference only for time to peak of heat release rate (TTH_{paak}) ($r = 0.46$, $p < 0.05$). However, other heat variables, especially HRR, HRR_{peak} and THR had high correlation coefficients with significant difference such as HRR and THR ($r = 0.90$, $p < 0.01$), HRR and EHC ($r = 0.91$, $p < 0.01$), HRR_{peak} and THR ($r = 0.93$, $p < 0.01$), which showed that most variables in the fire were correlated with heat. Significant negative correlations were observed between smoke and heat parameters ($p < 0.05$) such as RSR and THR ($r = -0.71$, $p < 0.01$), RSR and HRR_{peak} ($r = -0.63$, $p < 0.01$) as well as SEA and HRR ($r = -0.63$, $p < 0.01$). From the difference of the heat release rate and total smoke release curves, the same deduction can be made that species which have higher total smoke release value will have lower heat release rate.

Generally, moisture content affects time to ignition, heat release rate and smoke production. Therefore, depending on the water content of fresh leaves, the species are grouped. Group 1 were species which had moisture contents ranging from 61.31 to 70.83% (Table 1), namely, *C. camphora, E. glabripetalus, Symplocos stellaris, C. oleifera, L. lucidum, Manglietia yuyuanensis, M. fordiana, Schima superba, I. cornuta* and *C. japonica var. sinensis.* The other 16 species belonged to group 2 with moisture contents ranging from 48.21 to 59.54%.

The *k*-means cluster analysis according to burn characters divided the dataset into two distinct groups: Cluster 1 (included 17 species) and cluster 2 (included 9 species) (Table 1). A total of 10 of the 12 burn characteristics differed significantly ($p < 0.05$) based on cluster assignment (Table 2).

Table 2 Comparison of *k*-means cluster for each burn characteristic

Variable	Cluster 1	Cluster 2
Number of observations (n)	9	17
Time to ignition (s)*	43.65 (12.47)	78.47 (48.28)
Heat release rate (kW m^{-2}) *	19.89 (5.02)	10.98 (2.95)
Peak of heat release rate (kW m^{-2}) *	70.57 (39.73)	24.12 (6.76)
Time to peak of heat release rate (s) *	77.19 (28.55)	152.39 (29.62)
Yield of CO (kg kg^{-1})	0.02 (0.01)	0.03 (0.001)
Yield of CO_2 (kg kg^{-1}) *	1.06 (0.20)	0.94 (0.11)
Mass loss rate (g s^{-1})	0.38 (0.29)	0.30 (0.44)
Effective heat combustion (MJ kg^{-1}) *	5.28 (1.188)	3.83 (0.97)
Specific extinction area (m^2 kg^{-1}) *	44.41 (27.03)	111.71 (34.98)
Total heat release (MJ m^{-2}) *	3.57 (1.26)	1.39 (0.48)
Rate of smoke release (l s^{-1}) *	0.24 (0.11)	0.47 (0.12)
Total smoke release (m^2 m^{-2}) *	56.71 (19.79)	95.51 (20.67)

Asterisk denotes significant difference ($p < 0.05$) based on one-way analysis of variance; standard errors in parentheses

DISCUSSION

In general, heat released and smoke production can affect the combustion process. This study showed that time, heat and smoke were the main influencing factors, when illustrating the relative flammability of different species. This is consistent with similar studies of other taxa (Tian et al. 2001, Liodakis et al. 2005, Hu & Ju 2008, Kane et al. 2008, Chung 2010).

Of all the parameters, time to ignition is important for the delay of fire. A longer time to ignition can help when extinguishing a fire. Relatively high moisture content in fresh leaves can lead to longer time to ignition and can delay the spread of fire (Hu & Ju 2008). However, compared with heat and smoke parameters, moisture content was not the main factor in fire spread in this study. This is because many factors can affect moisture content, such as young or mature leaf, time of sampling and position on the tree (Hu & Ju 2008). Therefore, the grouping based on moisture content was different from the clustering based on combustion parameters. Total heat release and heat release rate could also play important roles in accelerating the spread of fire. The burn characteristics of fresh leaves in this study were not comparable with litter or dried leaves because the time taken to ignite fresh leaves was longer than that for dried leaves (Liodakis et al. 2005). Smoke can result in an increase of CO_2 in the atmosphere (Thonicke et al. 2001), which contributes to the greenhouse effect (Lv et al. 2002). Total smoke release and specific extinction areas are two important parameters when assessing smoke release. A rise in these two properties is an indication of incomplete combustion. The smouldering (flameless combustion) effect results in a longer burn time and allows for more smoke to accumulate which can retard spreading of the flame. Since water content of fresh leaf is higher than those of wood and litter, the flameless combustion of fresh leaf will occur easily at the initial stage of burning.

Generally, heat variables such as HRR, HRR_{peak} and THR can accelerate the fire process. However, smoke hinders the burning process, which affects the fire in different ways. This could be seen from the significant negative correlations between smoke parameters and heat parameters. This trend could also be seen from the difference between the heat release rate and total smoke release curves. Species releasing higher total smoke would have lower heat release rate and vice versa. Species which could be regarded as fire resistant had longer ignition delay time, lower heat release rate and peak of heat release rate, longer time to peak of heat release rate, less total heat release and higher smoke production. These trees are suitable for construction of fire-preventing forest belts in forest ecosystems including the 17 species in this research (*C. glauca*, *Castanopsis eyrei*, *L. glaber*, *C. camphora*, *Michelia maudiae*, *E. glabripetalus*, *Altingia gracilipes*, *M. leptophylla*, *N. chekiangense*, *S. stellaris*, *C. oleifera*, *I. chinensis*, *P. serrulata*, *L. lucidum*, *M. yuyuanensis*, *M. fordiana*, *C. funebris*). The other nine species (*Cyclobalanopsis gracilis*, *Castanopsis sclerophylla*, *L. brevicaudatus*, *S. superba*, *M. thunbergii*, *I. latifolia*, *I. cornuta*, *O. asiaticus* and *C. japonica* var. *sinensis*) with higher heat release rate and lower total smoke release values belonged to the fire-facilitating cluster and were not fit for fire-preventing forest belts. This indicates that there is negative correlation between heat release rate and smoke production for evergreen trees. Higher heat release rate encourages fire while higher smoke production hinders fire spread. Species clustering according to their burn characteristics can assist in understanding the relative role of each species within evergreen ecosystems. Collectively, these findings suggest that as restoration measures for destroyed forest, a more thoughtful differentiation may be necessary so that managers prescribe ecologically relevant restoration treatments (Kane et al. 2008).

This study supports a growing body of evidence that ecological restoration should recognise the value of evergreen species to ecological function in forest ecosystems (Chen et al. 1997). Our results suggest that fire-preventing forest belts may benefit from the retention of some fire-resistant species. As is known, maximal radiation intensity of the cone calorimeter is 100 kW m^{-2}, which is lower than that of forest fire. As radiation intensity of forest fire rises, the difference in combustibility among tree species will decrease. Since fire-preventing forest belts is effective to middle and low intensity forest fire (Tian et al. 2001), our test was conducted at a laboratory scale. These results can be used for exterior applications.

CONCLUSIONS

The three principal components of smoke, heat and time factor together affected combustibility of fresh leaves. Most variables in the fire were correlated with heat. Species releasing high total smoke had a lower heat release rate.

The 26 forest species examined were clustered into two groups according to their flammability properties. The fresh leaves of 17 species had low flammability because of their relatively longer ignition delay time, lower heat release and peak of heat release rate, longer time to peak of heat release rate, less total heat release and higher smoke production. *Cyclobalanopsis glauca, C. eyrei, L. glaber, C. camphora, M. maudiae, E. glabripetalus, A. gracilipes, M. leptophylla, N. chekiangense, S. stellaris, C. oleifera, I. chinensis, P. serrulata, L. lucidum, M. yuyuanensis, M. fordiana* and *C. funebris* are recommended as the choice for fire resistant-tree species and construction of renewed forests.

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