Calorific values and ash contents of different organs of Masson pine (*Pinus massoniana*) in southern China

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Abstract: Calorific values of plants are important indices for evaluating and reflecting material cycle and energy conversion in forest ecosystems. Based on the data of Masson Pine (*Pinus massoniana*) in southern China, the calorific values (CVs) and ash contents (ACs) of different plant organs were analyzed systematically using hypothesis test and regression analysis in this paper. The results show: (i) the CVs and ACs of different plant organs are almost significantly different, and the order by AFCV (ash-free calorific value) from the largest to the smallest is foliage (23.55 kJ/g), branches (22.25 kJ/g), stem bark (21.71 kJ/g), root (21.52 kJ/g) and stem wood (21.35 kJ/g); and the order by AC is foliage (2.35%), stem bark (1.44%), root (1.42%), branches (1.08%) and stem wood (0.33%); (ii) the CVs and ACs of stem woods on top, middle and lower sections are significantly different, and the CVs are increasing from top to lower sections of trunk while the ACs are decreasing; (iii) the mean GCV (gross calorific value) and AFCV of aboveground part are larger than those of belowground part (roots), and the differences are also statistically significant; (iv) the CVs and ACs of different organs are related, to some extent, to diameter, height and origin of the tree, but the influence degrees of the factors on CVs and ACs are not the same.

Key words: Gross calorific value, Ash-free calorific value, Ash content, Hypothesis test, Regression analysis, *Pinus massoniana*

Introduction

The calorific value of plant is defined as the amount of heat energy released during the combustion of a specified amount of it. Calorific value is an important property of plants which can reflect the ability of fixing solar radiation during the photosynthesis. Calorific values are also important indices for evaluating material cycle and energy conversion in forest ecosystems, and they are classified into two types: gross calorific value (GCV) or caloric value on oven-dry weight basis, and ash-free calorific value (AFCV) or calorific value on ash-free basis (Bao et al. 2006). Ash is the total amount of mineral content of a plant, which is determined by burning a given quantity of the plant under prescribed conditions and measuring the residue. Ash contents can help us understand the material absorption of plants, and reflect the difference of physiological function among various plants or of same plant in different regions. Therefore, when studying calorific values of plants, GCV and AFCV are usually considered together, so that the amount of heat energy reserved in plants can be reflected completely.

The studies abroad on calorific values of plants were started in 1930s. After having had vigorous development from 1960s to 1970s, the relevant researches have been rarely found (Guan et al. 2005; He et al. 2007). Since 1980s, the following studies have been representative to some extent: Abe (1986) determined the calorific values of 19 Japanese coniferous species, and calculated the mean value, standard deviation and coefficient of variation as 4972, 161 cal/g (1 cal=4.186 J) and 3.2%, respectively. Senelwa and Sims (1999) analyzed the fuel characteristics of biomass from 12 tree species grown under a short rotation forestry regime in New Zealand, where the higher heating value (or gross calorific value) ranged between 19.6～20.5 kJ/g for wood, 17.4～20.6 kJ/g for bark and 19.5～24.1 kJ/g for leaves. Bhatt and Tomar (2002) analyzed the firewood properties of 26 indigenous mountain tree and shrub species of North-Eastern Himalayan region in India, where the GCVs ranged between 17.90±0.15～22.94±0.04 kJ/g, and the AFCVs between 18.68±0.31～23.62±0.11 kJ/g and the ACs between 1.21%±0.10%～5.43%±0.26%. Kumar et al. (2009) determined such properties as calorific value, ash content, wood density and elemental composition of seven commonly used fuelwoods, where the calorific values ranged between 19.70～23.40 kJ/g and ash contents between 1.4%～2.8%. Other study achievements are also worthwhile for references (Wotowicz and Szaniawska 1986; Goel and Behl 1996; Kataki and Konwer 2001; Lemenih and Bekele 2004; Kumar et al. 2010).

The studies on calorific values of plants in China started fairly late, and it was somewhat difficult to find related papers until the end of 1970s (Guan et al. 2005). Up to now, fruitful studying results have been achieved, and lots of calorific values of plants have been reported in China (Liu et al. 1990, 1992; Ren et al. 1999; Lin et al. 1999,2000; Guo 2003; Liao et al. 2004; Fang et al. 2005; Kuang et al. 2005; Chen et al. 2006; Lin et al. 2007; Han et al. 2007). He et al. (2007) collected the available GCVs of vascular plants in China, including 129 families, 460 genus, 1110 species, and 8 bryophytes which had carried out by the authors themselves. From statistical analysis and hypothesis test, they presented the characteristics of GCVs of higher plants as follows: (i) for different organs, the order by mean GCV from the largest to the smallest is propagule, leave, branch, bark, stem and root; (ii) for different levels of vegetation community, the order is arbor, shrub, litter, herbage and bryophyte; (iii) for different forms of species, the GCVs of evergreen plants are larger than those of deciduous plants, and the GCVs of coniferous species are larger than those of broadleaved species. Because the development of forestry bioenergy has become more attractive in recent years in China, the studies on calorific values of plants have been coming into a period of great prosperity, and more and more achievements are available (Hao et al. 2008; Wang et al. 2008,2009; Chen et al. 2008,2009; Zeng et al. 2009; Kong et al. 2009; Lu et al. 2009; Yang et al. 2010; Zhang et al. 2010; Li et al. 2010; Zhang et al. 2010; Liu et al. 2010; Jiang et al. 2010; Zhang et al. 2011).

However, the studies in China on calorific values of plants were most based on small-scale sample data, so it was difficult to represent average bioenergy level of plants in large scale region. In this study, the authors will use the sample data of calorific values and ash contents of Masson pine (*Pinus massoniana*) in southern China, where the sample trees were collected for forest biomass estimation in large scale region, to analyze the calorific values (GCVs and AFCVs) and ash contents of different organs, and test the significance of the differences. Then, correlate the calorific values and ash contents with tree size (diameter, height) and origin. Finally, compare the calorific values and ash contents with the related study results, and present some conclusions.

Materials and methods

Materials

The data used in this study were measurement values of calorific value and ash content which came from the National Biomass Modeling Program for Continuous Forest Inventory (NBMP-CFI) funded by the State Forestry Administration of China. Here only the data of Masson pine (*Pinus massoniana*) in southern China were utilized, including 150 sample trees obtained from destructive sampling in 2009 (Zeng et al. 2011). The sample trees were located in Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hunan, Guangdong and Guizhou provinces and Guangxi autonomous region (about 20ºN-35ºN, 102ºE-123ºE). The number of sample trees was approximately distributed by the proportion to stocking volume of Masson pine forests in the nine provinces or autonomous region, and the origins of the forests were also taken into account. Among them, a total of 76 trees were from natural forests and 74 trees were from plantations. The sample trees were distributed evenly in the 10 diameter classes of 2, 4, 6, 8, 12, 16, 20, 26, 32, and ≥38cm. In addition, the sample trees in each diameter class were distributed by 3～5 height classes as evenly as possible. Thus, the sample trees were representative in the large-scale region.

Diameter at breast height and crown diameter of each sample tree were measured in the field. After a sample tree was felled, the total length of the tree (tree height) and length of live crown were also measured. The fresh mass of stem was summed by three sections (top, middle and bottom), and subsamples of stem wood and stem bark were selected on the trunk at the points of 7/10, 3.5/10 and 1/10 tree height. The fresh mass of branches was summed by three layers (top, middle and bottom), and subsamples of branches without leaves were selected for three layers while a mixed subsample of foliage was selected from all removed leaves of the sample branches. All subsamples were weighed in the field. Among the 150 sample trees, the whole roots of 54 trees (about 1/3) were excavated out, and sorted into root stump, large roots (⩾10mm), and small roots (2～10mm, not including the fine roots less than 2mm). After the total fresh masses of root stump, large and small roots had been weighed, three types of root subsamples were selected and weighed respectively.

After being taken to the laboratory, all subsamples were oven-dried at 85℃ until a constant mass was reached. According to the ratio of dry mass to fresh mass, each component biomass was computed and the aboveground biomass of the tree was obtained by summation. Based on the measurement of dry mass of each subsample, the gross calorific value (GCV) was measured with an oxygen bomb calorimeter under the environmental condition of about 20℃. Three repeats were measured for each subsample, and the arithmetic mean was regarded as the GCV. The ash content was determined according to dry ashing method. Samples were weighed before they were placed in a furnace at 550℃ for 5 hours. Subsequently, the ash was weighed and the ash content was calculated by: ash content = ash mass / total oven-dried mass ×100. Also, the arithmetic mean of three repeats was taken as the ash content. Finally, the ash-free calorific value was calculated by: AFCV = GCV / (1- ash mass / total oven-dried mass).

Methods

The analysis of calorific values and ash contents of different organs of Masson pine in southern China included the following four aspects: (1) whether or not the calorific values and ash contents of stem wood at different heights (top, middle and bottom) were significantly different; (2) whether or not the calorific values and ash contents of root stump, large root and small root were significantly different; (3) what's the orders of calorific values and ash contents of stem wood, stem bark, branch, foliage and root, and whether or not the differences were significant; (4) whether or not the calorific values and ash contents of different organs were related with diameter, height and origin of the tree. The methods used in this study were hypothesis test and regression analysis.

Hypothesis test

The hypothesis test for mean value was used to determine whether or not the calorific values and ash contents of different organs were significantly different. The hypothesis test involves three situations for one mean, two means and more than two means, respectively. In this study, the hypothesis test for two means was used. Because the calorific values and ash contents of stem wood at different heights, or those of roots in different size classes, and even those of wood, bark, branch, foliage and root of the same tree, were not independent with each other. Thus, the suitable method would be the hypothesis test for paired data. When comparing the two means of paired data, it was assumed that the difference of the means of two populations be zero, i.e., assuming H_0: μ_1-μ_2=0. Taking the difference of a pair of observed values $d=x_1-x_2$ as a new variable, then a statistic of t value would be calculated as follows (Gao 2001):

[1] $$t = \frac{\bar{d}}{S_{\bar{d}}} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\sum (d-\bar{d})^2}{n(n-1)}}} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\sum d^2 - n\bar{d}^2}{n(n-1)}}}$$

Comparing the absolute t value from equation [1] with the critical value t_α (α=0.05) with a degree of freedom df=n-1, if $t > t_\alpha$, then the hypothesis H_0 was rejected; otherwise, it was accepted.

Regression analysis

To correlate the calorific values and ash contents of different organs with tree diameter, height and origin, the multivariate linear regression analysis (Tang et al. 2008) was used in this study. Assuming that the calorific value or ash content y and diameter x_1, height x_2, origin x_3 have the relationship of the following linear equation:

[2] $y = a+b\,x_1+c\,x_2+d\,x_3+\varepsilon$

where ε is the error term, and coefficients a, b, c, and d can be estimated by ordinary least squares (OLS) method.

Significance test of the regression: The variation of calorific values or ash contents were classified into two parts, the first was caused by the variation of tree diameter, height and origin which could be explained by equation [2]; and the second was caused by other factors and errors. From the regression based on the data set of observed values of n sample trees, the statistic F value and significance probability P value could be obtained. If F value was larger than the critical value $F(fm, fe)$ where fm and fe were degrees of freedom of the regression and errors respectively, or P value was smaller than the significance level α, then the regression was statistically significant; otherwise, it was not.

Significance test of the coefficients: If the regression model [2] was statistically significant, then the coefficients b, c and d were not all equal to zero. If any one of the coefficients was significantly different from zero, then the corresponding variable was related significantly with the calorific values or ash contents. Whether a coefficient was significant or not would be determined according to the statistic t value and significance probability p value of the coefficient in the regression.

Results and analysis

The mean values of gross calorific values (GCVs), ash contents (ACs) and ash-free calorific values (AFCVs) for different organs and different parts of 150 Masson pine sample trees are listed in Table 1.

Table 1 The calorific values and ash contents for different organs of Masson pine

Organs	GCV（kJ/g）	AFCV（kJ/g）	AC（%）
Stem wood	21.28 ±0.10	21.35 ±0.10	0.33 ±0.02
Top	21.09 ±0.11	21.19 ±0.11	0.47 ±0.03
Middle	21.22 ±0.16	21.30 ±0.16	0.40 ±0.03
Bottom	21.40 ±0.10	21.44 ±0.10	0.21 ±0.02
Stem bark	21.40 ±0.14	21.71 ±0.14	1.44 ±0.03
Stem	21.30 ±0.09	21.40 ±0.11	0.48 ±0.07
Branch	22.00 ±0.15	22.25 ±0.09	1.08 ±0.04
Foliage	23.00 ±0.26	23.55 ±0.26	2.35 ±0.03
Aboveground	21.62 ±0.20	21.80 ±0.25	0.80 ±0.23
Belowground	21.21 ±0.22	21.52 ±0.19	1.42 ±0.27
Root stump	21.30 ±0.27	21.52 ±0.27	0.99 ±0.16
Large root	21.04 ±0.16	21.46 ±0.17	1.98 ±0.34
Small root	20.99 ±0.17	21.68 ±0.22	3.20 ±0.31
Whole tree	21.54 ±0.19	21.74 ±0.22	0.90 ±0.20

Note: The sample size for organs of aboveground part is 150, and the sample size for belowground part (roots) is 54. The values behind the "±" are standard deviations.

The GCV, AFCV and AC of stem wood were calculated from the values of three sections (top, middle and bottom) of stem wood through weighting their biomass. Similarly, through weighting the biomass, the mean GCV, AFCV and AC of stem were calculated from two values of stem wood and stem bark, and those of aboveground part were calculated from four values of wood, bark, branch and foliage. Consequently, the mean GCV, AFCV and AC of belowground part were calculated from three values of root stump, large and small roots through weighting their biomass, and those of a whole tree were calculated from two values of aboveground and belowground parts.

Calorific values and ash contents of stem woods at different heights

The GCVs of stem wood at different heights (top, middle and bottom) were 21.09 kJ/g, 21.22 kJ/g and 21.40 kJ/g, respectively; the AFCVs were 21.19 kJ/g, 21.30 kJ/g and 21.44 kJ/g; and the ACs were 0.47%, 0.40% and 0.21%, respectively. The significance tests of differences between the mean values of top, middle and bottom (coded by 1, 2 and 3 respectively) stem woods for GCV, AFCV and AC were completed, and the *t* values are listed in Table 2.

Table 2 Hypothesis test results of calorific values and ash contents of stem woods at different heights

Values	t_{12}	t_{13}	t_{23}
GCV	9.50*	11.98*	28.83*
AFCV	8.20*	9.36*	23.80*
AC	29.88*	65.09*	104.61*

Note: The mark "*" means the difference is significant at the level α=0.05 (t_α=1.98). Same in Table 4.

It is showed in Table 2 that the GCVs, AFCVs and ACs of stem wood at different heights (top, middle and bottom) were significantly different, and the CVs increased with the heights from top to bottom while the ACs decreased. The GCV, AFCV and AC of stem wood for each tree were calculated from the values of three sections (top, middle and bottom) of stem wood through weighting their biomass, then the mean values of 150 sample trees were computed out which are showed in Table 1.

Calorific values and ash contents of roots in different sizes

The GCVs of root stump, large root and small root were 21.30 kJ/g, 21.04 kJ/g and 20.99 kJ/g, respectively; the AFCVs were 21.52 kJ/g, 21.46 kJ/g and 21.68 kJ/g; and the ACs were 0.99%, 1.98% and 3.20%, respectively. The significance tests of differences between the mean values of root stump, large and small roots (coded by 1, 2 and 3 respectively) for GCV, AFCV and AC were completed, and the *t* values are listed in Table 3.

Table 3 Hypothesis test results of calorific values and ash contents of roots in different sizes

Values	t_{12}	t_{13}	t_{23}
GCV	7.24*	2.24*	11.26*
AFCV	1.39	7.23*	6.20*
AC	24.65*	20.40*	47.47*

Note: The mark "*" means the difference is significant at the level α=0.05 (t_α=2.01).

It is showed in Table 3 that the GCVs, AFCVs and ACs of root stump, large and small roots were significantly different, except for the difference of AFCVs between root stump and large root. The GCV, AFCV and AC of belowground part (roots) for each tree were calculated from the values of root stump, large root and small root through weighting their biomass, then the mean values of 54 sample trees were computed out which are showed in Table 1.

Significance analysis of calorific values and ash contents of different organs

The GCVs of stem wood, stem bark, branch and foliage of aboveground part of Masson pine tree were 21.28 kJ/g, 21.40 kJ/g, 22.00 kJ/g and 23.00 kJ/g, respectively; the AFCVs were 21.35 kJ/g, 21.71 kJ/g, 22.25 kJ/g and 23.25 kJ/g; and the ACs were 0.33%, 1.44%, 1.08% and 2.35%, respectively. The significance tests of differences between the mean values of wood, bark, branch and foliage (coded by 1, 2, 3 and 4 respectively) for GCV, AFCV and AC were completed, and the *t* values are listed in Table 4.

Table 4 Hypothesis test results of calorific values and ash contents of different organs of aboveground part

Values	t_{12}	t_{13}	t_{14}	t_{23}	t_{24}	t_{34}
GCV	10.27*	49.92*	77.46*	46.23*	69.75*	42.04*
AFCV	31.63*	82.58*	97.40*	48.21*	78.58*	58.53*
AC	377.18*	180.73*	694.09*	93.23*	263.40*	306.24*

It is showed in Table 4 that the GCVs, AFCVs and ACs of different organs were significantly different. The orders of GCV and AFCV from the largest to the smallest were both foliage, branch, bark and wood.

In addition, the GCV, AFCV and AC of aboveground part for each tree were calculated from the values of wood, bark, branch and foliage through weighting their biomass, then the mean values of 150 sample trees were computed out which are showed in Table 1. The mean GCV and AFCV of aboveground part were all larger than those of belowground part (roots) while the mean AC of aboveground part was smaller than that of belowground part, and the differences were all statistically significant. Finally, the GCV, AFCV and AC of a whole tree were calculated from the values of aboveground and belowground parts through weighting their biomass, then the mean values of 54 sample trees were computed out which are also showed in Table 1. The comparison between GCVs and AFCVs of a whole tree and the different organs are showed in Fig.1.

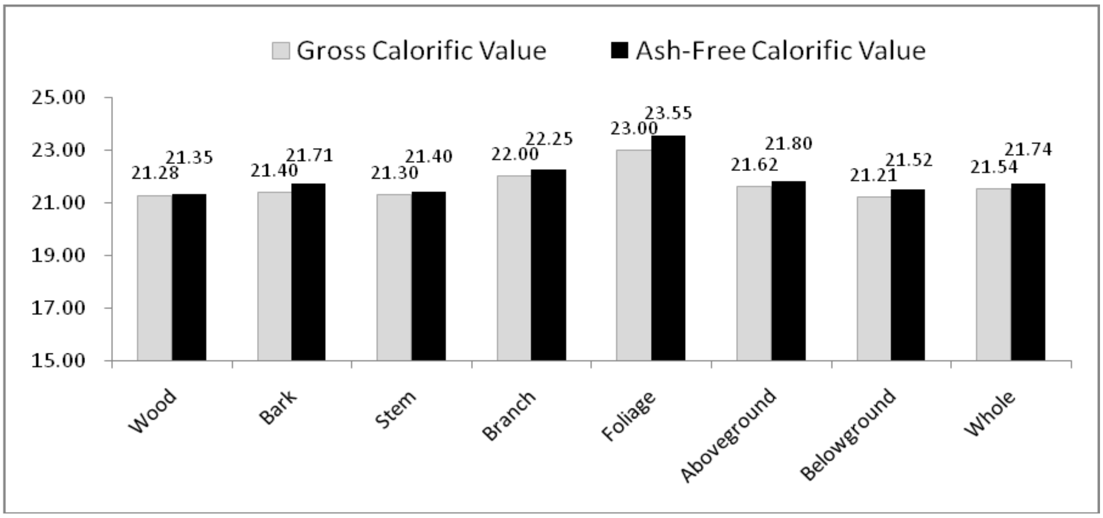

Fig.1 Comparison between GCVs and AFCVs of different organs

Correlation analysis of calorific values and ash contents of different organs

After all calorific values and ash contents of different organs had been obtained, the relationships between them and tree diameter, height and origin were analyzed. The *F* values and *P* values of regressions [2] and *t* values and *p* values of the coefficients for GCVs, AFCVs and ACs of different organs are listed in Table 5.

Table 5 Hypothesis test results of regressions for calorific values and ash contents of different organs

Values	Organs	Significance statistics of regressions		Significance statistics of coefficients							
				a		*b*		*c*		*d*	
		F-value	*P*-value	*t*-value	*p*-value	*t*-value	*p*-value	*t*-value	*p*-value	*t*-value	*p*-value
GCV	Wood	0.64	0.5907	1274.30*	0.0000*	-0.21	0.8360	1.30	0.1960	-1.35	0.1785
	Bark	1.12	0.3415	875.23*	0.0000*	-0.19	0.8459	1.43	0.1550	-0.67	0.5025
	Branch	0.02	0.9966	854.34*	0.0000*	0.18	0.8609	-0.10	0.9200	1.14	0.8859
	Foliage	4.00*	0.0090*	527.71*	0.0000*	1.09	0.2762	1.63	0.1059	-0.07	0.9472
	Above	35.83*	0.0000*	807.64*	0.0000*	-1.33	0.1860	2.18*	0.0309*	-6.82*	0.0000*
	Below	0.04	0.9899	286.70*	0.0000*	-0.10	0.9286	-0.30	0.7656	0.25	0.8020
	Whole	8.61*	0.0001*	432.99*	0.0000*	-0.62	0.5379	2.60*	0.0122*	-4.20*	0.0001*
AFCV	Wood	0.57	0.6389	1269.43*	0.0000*	-0.17	0.8691	1.26	0.2104	-1.25	0.2138
	Bark	1.07	0.3637	878.39*	0.0000*	-0.27	0.7749	1.38	0.1691	-0.64	0.5232
	Branch	0.07	0.9772	1458.55*	0.0000*	0.14	0.8924	-0.33	0.7397	0.15	0.8824
	Foliage	3.89*	0.0104*	527.29*	0.0000*	1.11	0.2685	1.56	0.1205	-0.02	0.9816
	Above	44.99*	0.0000*	697.66*	0.0000*	-1.46	0.1460	1.99*	0.0484*	-7.29*	0.0000*
	Below	1.30	0.2848	353.25*	0.0000*	-0.79	0.4354	0.82	0.4189	-0.03	0.9737
	Whole	11.14*	0.0000*	399.94*	0.0000*	-0.83	0.4132	3.00*	0.0042*	-4.81*	0.0000*
AC	Wood	3.07*	0.0298*	82.09*	0.0000*	0.83	0.4066	-0.74	0.4581	2.02*	0.0456*
	Bark	1.86	0.1398	270.00*	0.0000*	-1.93	0.0556	-1.09	0.2772	0.71	0.4811
	Branch	1.09	0.3570	146.71*	0.0000*	0.43	0.6684	-1.21	0.2278	0.40	0.6869
	Foliage	2.10	0.1031	460.33*	0.0000*	0.67	0.5061	-2.29*	0.0236*	1.54	0.1265
	Above	3.11*	0.0282*	19.71*	0.0000*	2.32*	0.0218*	1.86	0.0653	-1.73	0.0852
	Below	0.61	0.6134	16.77*	0.0000*	0.74	0.4611	0.35	0.7262	-0.75	0.4569
	Whole	16.41*	0.0000*	24.71*	0.0000*	-0.17	0.8623	2.29*	0.0264*	-4.88*	0.0000*

It is showed in Table 5 that the regressions of GCVs and AFCVs for foliage, aboveground part and a whole tree and those of ACs for wood, aboveground part and a whole tree were significantly different at the level a=0.05. From the significance statistics of the coefficients, it is showed that the calorific values of aboveground part and a whole tree were positively correlated with tree height but negatively correlated with tree origin; and those of foliage increased with growing tree diameter and height. The ash content of wood was mainly impacted by tree origin, and the AC of wood of a natural tree was more than that of a planted tree. The ash content of aboveground part was positively correlated with tree diameter and height, and also impacted by tree origin to some extent. The ash content of a whole tree was firstly impacted by tree origin, and also positively correlated with tree height.

Discussions

In general, the calorific values of different organs were ordered as foliage> branch> bark> wood> root (Guan et al. 2005; He et al. 2007). As for calorific values of Masson pine, we have found more than four study results for comparison. Ren et al. (1999) studied the calorific values of Masson pine in coniferous forest and mixed forest at the Dinghushan Biosphere Reserve in Guangdong province, and concluded that the CV of foliage was the highest and that of root was the lowest, and the CVs of different organs were ordered as foliage> branch> wood> root. Guo (2003) analyzed the calorific values of Masson pine at north suburb in Fuzhou, and the GCVs and AFCVs were both ordered as foliage> branch> bark> root> wood. Fang et al. (2005) also studied the calorific values of Masson pine community at the Dinghushan Biosphere Reserve in Guangdong province, and had a order as bark> branch> foliage> wood > root, but the differences among the first three CVs were very small. Zhang et al. (2011) analyzed the calorific values of main tree species in Guangxi where the GCVs and AFCVs of Masson pine were both ordered as foliage> bark> branch> wood. The GCVs of Masson pine in this study have a rank of foliage> branch> bark> wood > root. As for the AFCVs, the rank is foliage> branch> bark> root> wood. The little difference between the two ranks resulted from the large difference between the ACs of stem and root.

In the reviews presented by Guan et al. (2005) and He et al. (2007), it was said that the orders of calorific values for some plant species might have little difference. Several studies on calorific value in recent years have proved this viewpoint. For examples, Zeng *et al.* (2009) analyzed the calorific values of tree species in five plantation communities on the subtropical hilly lands in Heshan county of Gunagdong province, and presented that the order of GCVs of different organs was foliage> branch> wood> bark> root, and the order of AFCVs was foliage> bark> branch> root> wood. Zhang *et al.* (2010) determined the calorific values of *Pinus koraiensis* population in broad-leaved Korean Pine forests in Changbai Mountain, and provided a rank of branch> foliage> bark> wood> root. Zhang *et al.* (2010) analyzed the calorific values of five dominant species in broad-leaved Korean Pine forests in Changbai Mountain, where four calorific values of branch were in the first, and three calorific values of foliage were in the second. Zhang et al. (2011) studied the calorific values of different organs of twelve tree species in Guangxi where the orders of CVs were foliage> branch> bark> stem, or foliage> bark> branch> stem.

The calorific values of plants are firstly related to the physiological characteristics. Viewing from the anatomy and physiology of plants, leaf is the most active organ in which there are many high energy compounds such as protein and fat, and can compose high energy compounds itself, thus the calorific value of foliage is generally the highest. Roots, stem and branches are supporting organs in which there are more cellulosic fibers, so the calorific values are relatively low; and because roots, which are far from leaves, carry the function of absorbing mineral nutrition and water, thus the calorific value is normally the lowest (Guan et al. 2005). Besides the nutrition elements of different organs are various, some species have their very special physiological properties which may result in abnormal high or low calorific values of some organs. For example, there are high contents of resin and turpentine in organs of pine plants, so that the calorific values are relatively high (He et al. 2007). In addition, the calorific values of plants are not only affected by the composition, structure and function of themselves, but also influenced by environmental factors such as illumination intensity, sunshine hours, soil type and nutritional condition (Guan et al. 2005).

The ash contents of Masson pine in this study have a rank of foliage> bark> root> branch> wood. The ash content of foliage is the highest (2.35%), that of bark is the second, and that of wood is the lowest (0.33%). This is almost the same as those of Masson pine in Guangxi by Zhang et al. (2011), but not similar as those by other researchers. According to Ren et al. (1999), the ash content of root was the highest, among the ACs of different organs of Masson pine at the Dinghushan in Guangdong province, and that of foliage was the second. Not alone, but with a good prototype. According to Guo (2003), the ash content of root was also the highest among the ACs of different organs of Masson pine in Fuzhou, and order was root> foliage> bark> branch> wood. In addition, Kataki & Konwer (2001) studied fuelwood characteristics of four indigenous woody species in northeast India, and concluded that the ash contents of four species were all ordered as bark> foliage> branch> wood, i.e., the ash content of bark is the highest, and that of foliage is the second. Zeng *et al.* (2009) analyzed the ash contents of tree species in five plantation communities on the subtropical hilly lands in Heshan county of Gunagdong province, and presented a rank of bark> foliage> wood> branch> root, where the ash content of bark is the highest. Zhang *et al.* (2010) analyzed the ash contents of five dominant species in broad-leaved Korean pine forests in Changbai Mountain, where the ash contents of barks and leaves were in the front, and those of branches and roots were in the middle, and those of woods were in the last, but the orders were not the same. Liu *et al.* (2010) compared the ash contents of stem, branch and root of four poplar species, and found that the ash contents of barks of the three parts were larger than those of woods, then concluded that it might be owning to higher content of mineral elements in bark than that in wood. The ash content is sum of mineral oxidizing materials in a plant, which can reflect the size of function on enriching elements. Besides the ash contents of various organs of a plant are different, those of various plants are also different. The ACs of whole plants of 54 Masson pine sample trees in this study are between 0.61%～1.47%, and the mean value is 0.90%.

Conclusions

Through analyzing the CVs and ACs of different organs of Masson pine in southern China, it was concluded as follows:

(1) The CVs and ACs of different organs are most significantly different. The order of GCVs from the largest to the smallest is foliage (23.00 kJ/g) > branch (22.00 kJ/g) > bark (21.40 kJ/g) > wood (21.28 kJ/g) > root (21.21 kJ/g); the order of AFCVs is foliage (23.55 kJ/g) > branch (22.25 kJ/g) > bark (21.71 kJ/g) > root (21.52 kJ/g) > wood (21.35 kJ/g); and the order of ACs is foliage (2.35%) > bark (1.44%) > root

(1.42%) > branch (1.08%) > wood (0.33%).

(2) No matter GCVs, AFCVs or ACs, the differences among top, middle and bottom sections of stem wood are statistically significant, and the CV's increase from top to lower sections of trunk while the AC's decrease.

(3) The GCVs, AFCVs and ACs of root stump, large and small roots are significantly different, except for the difference of AFCVs between root stump and large root.

(4) The mean GCV and AFCV of aboveground part are all larger than those of belowground part (roots) while the mean AC of aboveground part is smaller than that of belowground part, and the differences are all statistically significant. The mean GCV, AFCV and AC of a whole tree of Masson pine are 21.54 kJ/g, 21.74 kJ/g and 0.90%, respectively.

(5) The CVs and ACs of different organs and a whole tree are correlated to some extent with tree diameter, height and origin. The calorific values of aboveground part and a whole tree are positively correlated with tree height but negatively correlated with tree origin; and those of foliage increase with growing tree diameter and height, and those of other organs are slightly correlated with tree diameter, height and origin. The ash content of aboveground part is positively correlated with tree diameter and height, and also impacted by tree origin to some extent. The ash content of a whole tree is firstly impacted by tree origin, and also positively correlated with tree height.

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