CHEMICAL COMPONTS OF MOSO BAMBOO *(PHYLLOSTACHYS HETEROCYCLA* VAR. *PUBSCENSE)* CULM AT DIFFERENT AGES AND HEIGHTS

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Abstract. Bamboo is an effective alternative material to alleviate the burden on wood supplies. Chemical components distributed in the gradient structure of bamboo culm are likely to be the determining factors in selecting the optimal application of bamboo. Bamboo culm exhibits a complicated chemical composition of in holocellulose, lignin, pentosan and extractives in the longitudinal direction of its culm cultivated for varying periods of time. In this study, the chemical constituents of moso bamboo were analyzed statistically at different heights cultivated for a minimum of 6 months to as long as 9 years. No significant impact on chemical components was found in the longitudinal direction of the bamboo culm. However, bamboo culm age should be taken into consideration in the trends of holocellulose, pentosan, lignin and extractives located in the inner, middle and outer layers. The moso bamboo cultivated from 3 to 5 years was optimal for industrial application. The yield percentage and difference between layers, in particular, are fundamentals for evaluating and improving the properties for bamboo products.
Keywords: *extractives, holocellulose, lignin, pentosan*

Introduction

Bamboo is mainly distributed in tropical and subtropical areas, the growing stock and yield of which in China is one of the highest worldwide (Mao et al., 2017; FAO, 2010). Bamboo is almost exclusively composed of cellulose, hemicellulose and lignin, which is quite similar to wood in chemical composition. As a fast-growing plant, bamboo is regarded as a huge renewable resource base to reduce stress on wood resources to some extent (Cao et al., 2014; Jiang et al., 2015; Cheng et al., 2015; Kaur et al., 2016). In traditional industries, bamboo utilization only occurs for primary products such as hand-plaited bamboo articles and daily necessities. In high-tech industries, bamboo charcoal fiber, pulp-making, bamboo-based composite lumber and bamboo vinegar present the outstanding value of bamboo (Sulaiman et al., 2005; Ahmad and Kamke, 2011; Sugesty et al., 2015; Han et al., 2017), which is intimately linked to the chemical details of bamboo.

Bamboo is a lignocellulosic biomass with a complicated network structure. Lignocellulosic cell walls in bamboo give it the majority of its properties. Due to the covalent linkages among cellulose, hemicellulose and lignin, the definitive structure of the three natural compositions is almost unfathomable (Guerra et al., 2006; Huang et al., 2016). The chemical constituents of bamboo are known to vary greatly depending on

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species, position within the culm and the age of the culm. The varieties, like *Bambusa arundinacea, Dendrocalamus asper, Gigantochloa apus,* and *Phyllostachys heterocycla*, are more common species of bamboo suited to large-scale comprehensive utilization (Jayanetti and Follett, 1998). In very general terms bamboo consists of 50-70% holocellulose and 20–25% lignin (Fengel and Shao, 1984; Liese, 1987). Lignin is a highly complex non-crystalline molecule comprising of a large number of phenyl-propane units. The structure of the lignin present in bamboo is unique, and undergoes changes during the elongation and ageing of the culm (Itoh, 1990). The lignin content is relatively high in the epidermal layer and at the top of bamboo (Jiang et al., 2006). Between 40 and 50 percent of the dry mass of bamboo is in the form of cellulose forming from the anhydrogluclose unit. Cellulose plays a main role in mechanical characteristics of bamboo culm, even for bamboo fiber. The lignification process of bamboo is from the epidermal layer to inner waxy layer, that is, there is less cellulose in the epidermal layer (Lin et al., 2002). Hemicelluloses, therefore, comprise mixtures of polysaccharides manufactured in bamboo from basic sugars such xylose, arabinose, glucomannan and galactose (Balakshin et al., 2011). 90% of the hemicellulose is xylan with a structure intermediate between hardwood and softwood xylans. The distribution of hemicellulose content is in a reversal of that of lignin content (Peng et al., 2012; Peng and She, 2014). Bamboo also has minor amounts of resins, waxes and tannins (Chung and Wang, 2017).

Bamboo industries on chemical components have different requirements. The higher cellulose content the better it is for pulping and papermaking. In general, cellulose is also closely related to the strength and deformation of bamboo-based panels. However, this relationship may be masked by the presence of amounts of extractives. Also, abnormally high lignin fractions in bamboo may influence structures and properties, at least in the longitudinal axis of bamboo (Richard and Harries, 2015; Huang et al., 2017). Therefore, thorough understanding of distributed chemical components in bamboo to optimize the further processing technology is required.

Materials and methods

Preparation

Moso bamboo (*Phyllostachys heterocycla* var. *pubscense*) was obtained from Sanming bamboo stands (27N, 117E) in Fujian province, China. After air drying, bamboo samples (inter node) were collected from 6-month-old to 9-year-old stem-sections at three different heights above ground level (1, 3, and 5 m), and also, on the basis of position which is outer, middle and inner layer of the bamboo stems. Outer layer is the epidermal layer, and inner layer is the waxy layer (*Fig. 1*). Dried samples were ground into powder with a particle size of 40-60 mesh for chemical analysis.

Determination of chemical components

The chemical characteristics of bamboo were determined according to the national standards outlined in GB test methods. Holocellulose content was determined based on GB/T 2677.10-1995 *Fibrous Raw Material* (or FRM for short) – *Determination of Holocellulose* (GB, 1995). The lignin content was determined following the GB/T 2677.8-1994 *FRM – Determination of Acid-insoluble Lignin* (GB, 1994b). Pentosan content was determined in accordance with GB/T 2677.9-1994 *FRM – Determination of*

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Pentosan (GB, 1994c). The determination of extractives was carried out following GB/T 2677.6-1994 *FRM-Determination of solvent extractives* (GB, 1994a) and GB/T 2677.5-1993 *FRM – Determination of One Percent Sodium Hydroxide Solubility* (GB, 1993). The number of replicates was five, and the analyses of variance by Statistica 6 were used.

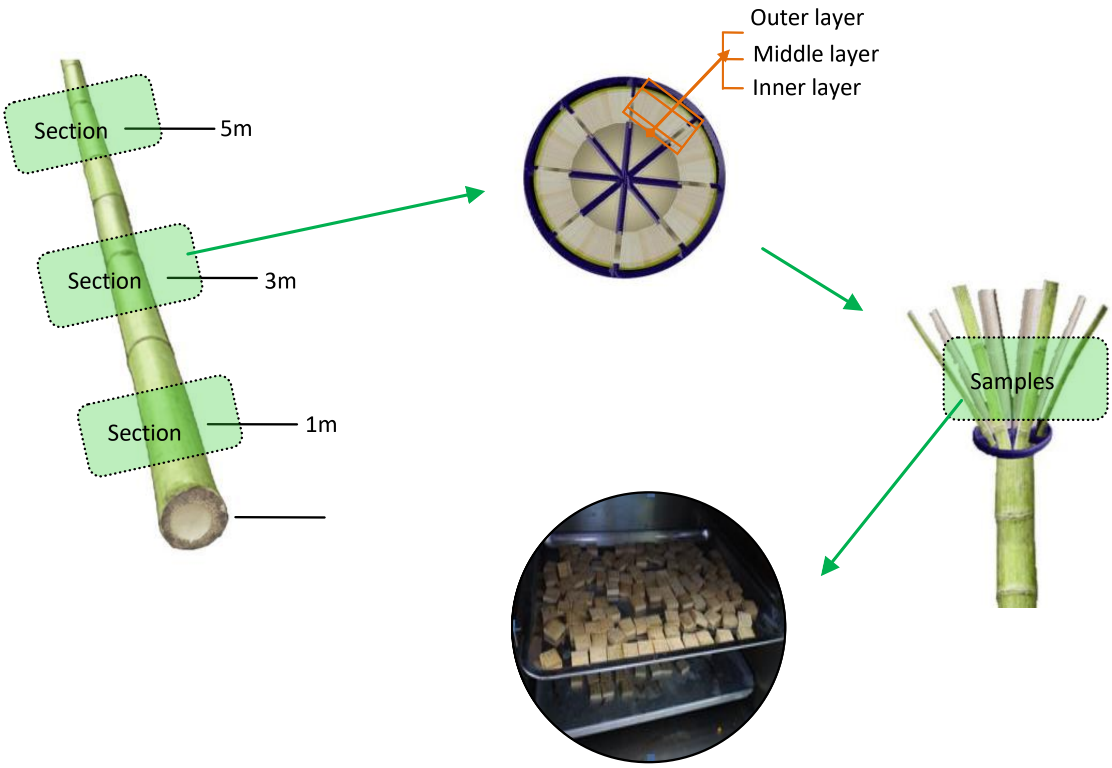

Figure 1. *Preparation of bamboo samples*

Results

Chemical characteristics at different heights

The chemical constitution of inner, middle and outer layer in the moso bamboo stems at different heights was determined respectively. The analysis of variance (ANOVA) on holocellulose, lignin, pentosan and extractives are showed in *Table 1*. There are no significant differences in chemical composition in the longitudinal direction of bamboo stems.

Table 1. *Summary result for analysis of variance for chemical components at different heights*

Position	P-value				
	Holocellulose	Lignin	Pentosan	1% sodium hydroxide extractives	Solvent extractives
Inner	0.750284	0.091319	0.991868	0.841184	0.697808
Middle	0.97058	0.24962	0.987907	0.403769	0.536052
Outer	0.843169	0.335781	0.863107	0.95569	0.509231

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Chemical characteristics at different ages

The chemical constitution of inner, middle and outer layer in the moso bamboo stems at different ages was determined respectively. The analysis of variance (ANOVA) on holocellulose, lignin, pentosan and extractives are showed in *Table 2*. Nearly all the chemical components for different layers shows significant differences among the culm age, except the lignin content in the inner and outer layer. Therefore, it is extremely valuable to perform trend analysis.

Table 2. *Summary result for analysis of variance for chemical components at different ages*

Position	**P-value**				
	Holocellulose	**Lignin**	**Pentosan**	**1% sodium hydroxide extractives**	**Solvent extractives**
Inner	0.00098	0.289121	0.002851	0.005266	0.004758
Middle	0.002666	0.028988	0.000192	0.017753	6.76E-05
Outer	0.021891	0.251166	0.020283	2.76E-07	0.000511

The yield trends of holocellulose in the inner, middle and outer layer are showed in *Figure 2* from 6-month-old to 9-year-old. The holocellulose content in middle layer is more than that in inner and outer layer in three years. However, holocellulose content in outer layer increases since 5-year-od, even more than that in middle layer. Meanwhile, there is a decreasing trend in percentage difference among the three layers. Considering there is no significance level along the height, the average of each layer at different height is carried out to determine the comparative benefit. The changing trends of holocellulose content for inner and outer layer are the similar, and peak at the fifth year.

The variation of lignin content in the three layers is shown respectively in *Figure 3* from 6-month-old to 9-year-old. Inner layer has a great similarity in lignin content compared to middle layer. However, only the middle layer shows a significant relativity for lignin content. In the middle layer, lignin content increases slightly from the sixth month to the third year, and then it is nearly at a constant level.

Here is that the pentosan content as a whole increases from the outer layer to the inner layer (*Fig. 4*). As such, there is much comparability between the inner layer and middle layer. Pentosan content reaches up to the maximum value in the fifth year and gets the minimum value in the seventh year. In the third year, however, the global minimal value of pentosan content appears in the outer layer.

The 1% sodium hydroxide extractive of bamboo is closely related to decay resistance, which is mainly composed of tannin, pigment, alkaloid, saccharine, starch, degraded hemicellulose and lignin, etc (Jiang et al., 2015). The variation trend in the inner layer is similar to that in the middle layer, but different from that in the outer layer (*Fig. 5*). The yield is ranging from 19.38% to 35.06%. The 1% sodium hydroxide extractive in the inner layer is more than that in other two layers except in the seventh year, and the tendency is almost smooth before the five year and changes suddenly in the seventh year.

The changing trend of solvent extractives in the inner layer is similar with that in the outer layer, and has a little difference from that in the middle layer (*Fig. 6*). The lowest content of solvent extractives is set in the 5-year-old bamboo stems for each layer. The

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variation of solvent extractives is similar between each layer after the third year. In contrast, there is less extractives in the middle layer than that in other two layers.

Figure 2. *Variation of holocellulose content*

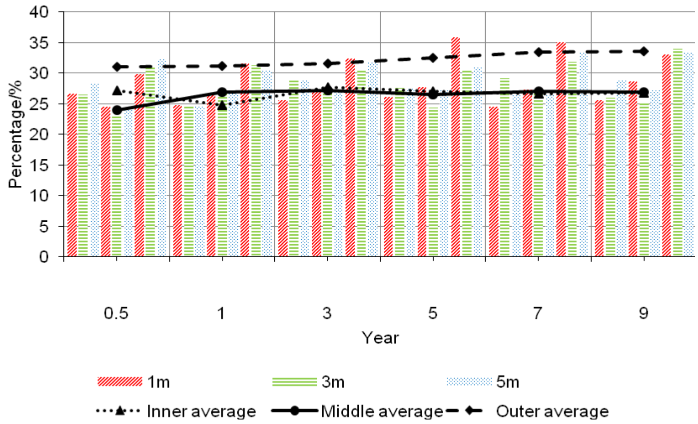

Figure 3. *Variation of lignin content*

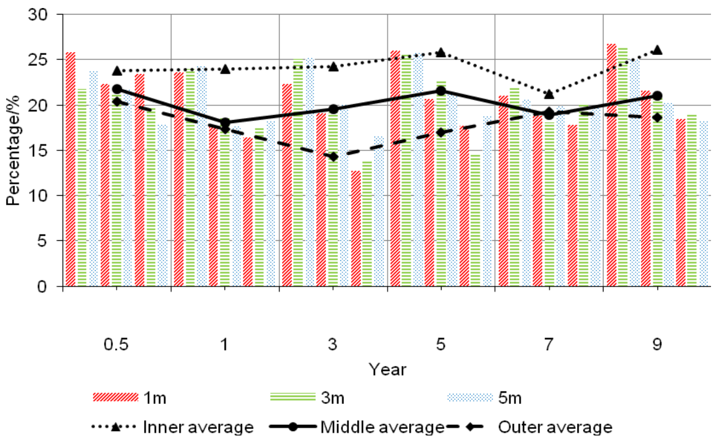

Figure 4. *Variation of pentosan content*

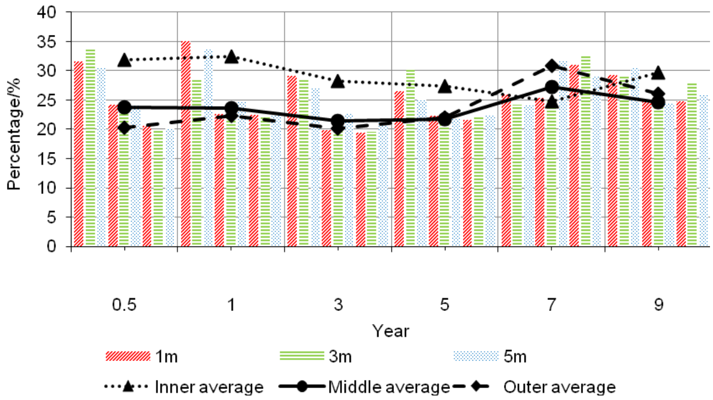

Figure 5. *Variation of 1% sodium hydroxide extractives*

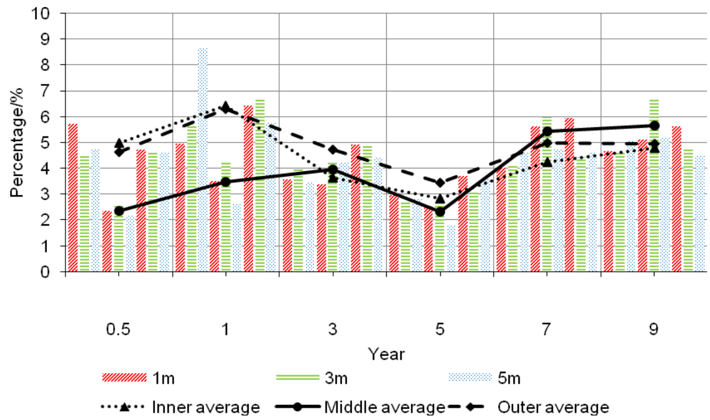

Figure 6. *Variation of solvent extractives*

Discussion

It should be noted that the –OH groups of the cellulose molecules which give rise to hydrogen bonding are also highly attractive to moisture. Below the fiber saturation point, a subsequent dimensional change was occurred (Anokye et al., 2014). Bamboo strips are liable to distortion such as twist and bow, which has a strong influence with mechanical properties (Saito and Arima, 2002; Kamruzzaman et al., 2008). According to the findings, the distribution of chemical components in the longitudinal direction of bamboo stems should not be the reason to warping. That is, the distortion of bamboo strips may be due to the gradient fibrous structure (Chen et al., 2018).

However, the chemical constituents are fundamental to physical and mechanical properties of bamboo. The holocellulose content in middle layer reaches the maximum of all yield percentage at the third year, which has potential for use as dissolving pulp compared to softwoods (Lovell, 1945). As the panel practice, 3-year-old bamboo is optimum for tangential bamboo sliver, and 5-year-old bamboo is a good choice for radial bamboo sliver in regard of dimensional stability (Sinha and Miyamoto, 2014; Suthon, 2016; Li et al., 2018). A markedly higher proportion of lignin is in the outer layer, which is consistent with the outcome of lignification process (Lin et al., 2002; Tsuyama et al., 2017). For the 3-year-old and 5-year-old bamboo culm, there is obvious

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difference in pentosan content among the three layers. The yield of pentosan in the outer layer is less than the inner layer and middle layer. Pentosan can not only lower moisture absorption of bamboo, it can also improve the toughness of bamboo (Das and Chakraborty, 2008; Banik et al., 2017). Therefore, failure region should be close to the outer layer when a force is applied perpendicular to grain. However, none of studies has been reported from this point at least for now. The extractive contents of moso bamboo are higher than that of softwood and hardwood. Therefore, it is more complicated for preservative treatment (Shah et al., 2018). The high yield percentage of 1% sodium hydroxide extractive indicates that there are more hemicellulose and lignin with lower molecular weight. The solvent extractives consist of wax, fatty acid, essential oil and so on. Higher percentage of solvent extractives has a negative effect on pulping process (Muhammad et al., 2013).

Conclusions

1. Heights have no significant impact on chemical constituents for the inner, middle and outer layer respectively. However, bamboo culm age is closely associated with holocellulose, pentosan, lignin and extractives.
2. The maximum yield of holocellulose is found in the middle layer of the 3-year-old bamboo culm. But it is obvious that the holocellulose contents in the three layers are similar at the fifth year. For lignin content, there is almost no difference in each layer between the third year and the fifth year. There is a clear distinction for percentage of pentosan in the three layers from the third year to the fifth year, which has a potential impact on strength. The lowest percentage of extractives presents in the fifth year. However, the percentage of 1% sodium hydroxide extractives changes hardly from the third year to the fifth year.
3. For the practical application, it is impossible to get a desired percentage of chemical components of moso bamboo in a particular culm age. However, the optimization of culm age could be accomplished in terms of the different performance requirements of bamboo products.

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APPENDIX

Appendix 1. *Analysis of variance for chemical components at different heights*

			Sum of squares	df	Mean square	F	P-value
Holocellulose	Inner	Between groups	3.3258544	2	1.629272	0.292877	0.750284
		Within groups	83.44475	15	5.562983		
		Total	86.70329	17			
	Middle	Between groups	1.3279	2	0.66395	0.02992	0.97058
		Within groups	332.8572	15	22.19048		
		Total	334.1851	17			
	Outer	Between groups	2.1411	2	1.07055	0.172543	0.843169
		Within groups	93.06835	15	6.204557		
		Total	95.20945	17			
Lignin	Inner	Between groups	12.03063	2	6.015317	2.819365	0.091319
		Within groups	32.00357	15	2.133571		
		Total	44.0342	17			
	Middle	Between groups	6.374633	2	3.187317	1.524516	0.24962
		Within groups	31.36062	15	2.090708		
		Total	37.73525	17			
	Outer	Between groups	6.415011	2	3.207506	1.174688	0.335781
		Within groups	40.95777	15	2.730518		
		Total	47.37278	17			
Pentosan	Inner	Between groups	0.068011	2	0.034006	0.008169	0.991868
		Within groups	62.4389	15	4.162593		
		Total	62.50691	17			
	Middle	Between groups	0.0673	2	0.03365	0.012176	0.987907
		Within groups	41.4537	15	2.76358		
		Total	41.521	17			
	Outer	Between groups	2.041733	2	1.020867	0.148671	0.863107
		Within groups	102.9993	15	6.866618		
		Total	105.041	17			
1% sodium hydroxide extractives	Inner	Between groups	4.010478	2	2.005239	0.174954	0.841184
		Within groups	171.9231	15	11.46154		
		Total	175.9336	17			
	Middle	Between groups	11.95551	2	5.977756	0.964024	0.403769
		Within groups	93.0126	15	6.20084		
		Total	104.9681	17			
	Outer	Between groups	1.6471	2	0.82355	0.045459	0.95569
		Within groups	271.7434	15	18.11622		
		Total	273.3905	17			
Solvent extractives	Inner	Between groups	1.478633	2	0.739317	0.368582	0.697808
		Within groups	30.08762	15	2.005841		
		Total	31.56625	17			
	Middle	Between groups	2.875233	2	1.437617	0.650175	0.536052
		Within groups	33.16682	15	2.211121		
		Total	36.04205	17			
	Outer	Between groups	1.310978	2	0.655489	0.706147	0.509231
		Within groups	13.92392	15	0.928261		
		Total	15.23489	17			

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Appendix 2. *Analysis of variance for chemical components at different ages*

			Sum of squares	df	Mean square	F	P-value
Holocellulose	Inner	Between groups	68.34063	5	13.66813	8.932118	0.00098
		Within groups	18.36267	12	1.530222		
		Total	86.70329	17			
	Middle	Between groups	249.6375	5	49.9275	7.08631	0.002666
		Within groups	84.54753	12	7.045628		
		Total	334.1851	17			
	Outer	Between groups	59.78872	5	11.95774	04.0511	0.021891
		Within groups	35.42073	12	2.951728		
		Total	95.20945	17			
Lignin	Inner	Between groups	16.29027	5	3.258053	1.409196	0.289121
		Within groups	27.74393	12	2.311994		
		Total	44.0342	17			
	Middle	Between groups	22.92898	5	4.585797	3.71664	0.028988
		Within groups	14.80627	12	1.233856		
		Total	37.73525	17			
	Outer	Between groups	18.47778	5	3.695556	1.534752	0.251166
		Within groups	28.895	12	2.407917		
		Total	47.37278	17			
Pentosan	Inner	Between groups	46.50238	5	9.300476	6.973381	0.002851
		Within groups	16.00453	12	1.333711		
		Total	62.50691	17			
	Middle	Between groups	34.90713	5	6.981427	12.66689	0.000192
		Within groups	6.613867	12	0.551156		
		Total	41.521	17			
	Outer	Between groups	66.5198	5	13.30396	4.144407	0.020283
		Within groups	38.5212	12	3.2101		
		Total	105.041	17			
1% sodium hydroxide extractives	Inner	Between groups	125.6189	5	25.12378	5.991998	0.005266
		Within groups	50.31467	12	4.192889		
		Total	175.9336	17			
	Middle	Between groups	67.42418	5	13.48484	4.310098	0.017753
		Within groups	37.54393	12	3.128661		
		Total	104.9681	17			
	Outer	Between groups	259.1318	5	51.82636	43.61672	2.76E-07
		Within groups	14.25867	12	1.188222		
		Total	273.3905	17			
Solvent extractives	Inner	Between groups	22.70292	5	4.540583	6.147461	0.004758
		Within groups	8.863333	12	0.738611		
		Total	31.56625	17			
	Middle	Between groups	31.24992	5	6.249983	15.65061	6.76E-05
		Within groups	4.792133	12	0.399344		
		Total	36.04205	17			
	Outer	Between groups	12.35763	5	2.471526	10.30781	0.000511
		Within groups	2.877267	12	0.239772		
		Total	15.23489	17			

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