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The effect of new continuous harvest technology of ramie (*Boehmeria nivea* L. Gaud.) on fiber yield and quality

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A B S T R A C T

We investigated a new ramie (*Boehmeria nivea* L.) harvest mode, which can resolve the bottleneck problems hindering the development of the ramie cultivation industry. In an experiment using cultivar 'Huazhu 4', we designed five ramie harvest modes with the conventional harvest mode as the control group. The range of ramie production was 2214.67–2533.67 kg/ha, which was lower than the 2724.33 kg/ha for conventional harvest (average reduction of 10%). The gel content of all treatments was higher than in the control. The range of average fiber diameter was 15.95 ± 0.28 μm to 17.02 ± 0.39 μm, fiber diameter in Mode C was optimal. For each harvest mode, the fiber breaking strength was greatest in the first ramie harvested. With the postponing of harvest time, fiber average breaking elongation rate were lower than control except for Modes B and D. In the first harvest (except for Mode D), fiber crystallinity for each mode was significantly different to the control, but not when harvested later. Generally, the average gel content of raw ramie, fiber breaking strength and fiber crystallinity was not significantly different to the control. Continuous harvesting mode was feasible for ramie production.

1. Introduction

Ramie (*Boehmeria nivea* L.) of the Urticaceae, is a perennial bast fiber crop (Tewolde and Fernandez, 2003; Sarkar, 2005) originating in China. Therefore, it is known in many western countries as 'China grass'. Ramie plays an important role in China's economy, where ramie farming, industry and trade provide livelihood support about five million people. Ramie is grown on about 71,800 ha with annual fiber production of 114,080 t in 2010 (FAOSTAT, http://faostat.fao.org). In the Yangtze River Basin, it can be harvested three times per year and represents 90% of total world production (Peng, 2009). With China's economic transformation, large amounts of rural labor have migrated to urban areas, thus increasing labor costs of traditional cultivation. This raises the need to simplify crop cultivation technologies. Great breakthroughs have been made in the study of simplified cultivation technologies for rice (Fang and Cheng, 2009), cotton (Mao, 2007) and rape (Tu et al., 2007). In conventional ramie harvesting, the bast fiber is scraped off manually. The outer layer is then peeled and dried naturally to get raw ramie. A skilled worker can only produce about 10 kg of raw ramie per day (the selling price of raw ramie scraped by hand is 0.95–1.25 US$/kg). The cost of harvest alone is close to the selling price. If ramie cannot be harvested and scraped in time, its fiber quality and yield in the following season will be severely affected (Peng, 2009). One solution to overcome the bottleneck of the ramie industry is large-scale cultivation using simplified cultivation technology and industrialized fiber scraping. For ramie production to become industrialized, a stable supply of raw material has to be ensured. That is, a certain quantity of ramie stems is transported to the factories for fiber scraping. However, the problem is that the traditional ramie harvest mode is three harvest seasons per year, in July, August and the first 10-d periods of October respectively. The appropriate time for harvest only lasts 5–10 d per season or a total of 15–30 d per year. However, in non-harvest periods, no raw material is supplied to factories, which will undoubtedly increase the operating costs and decrease efficiency of factories. Therefore, the first problem to be solved is to ensure a continuous supply of raw material for factories (May–October every year so that a factory can run continuously for about 150 d). Our research is an attempt to solve this problem. Compared to traditional harvest technologies, people are uncertain whether continuous harvest will affect ramie yield and fiber quality. We carried out the present research to verify the feasibility of the new continuous ramie harvest technology.

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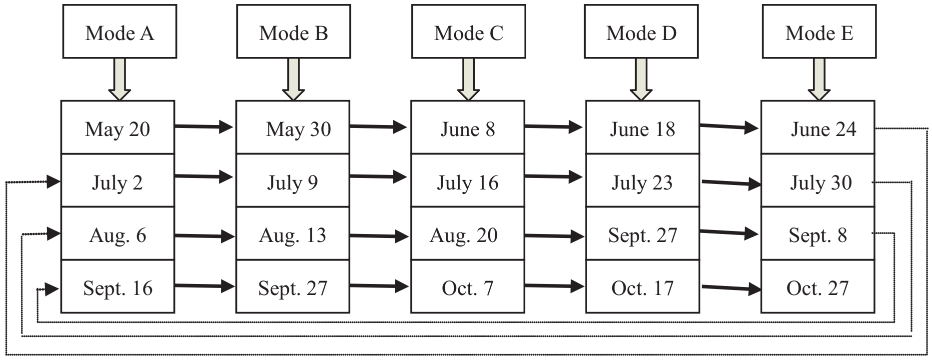

Fig. 1. Harvest dates for each mode in 2011. Note: there were five harvest modes in the design and accordingly the experimental field was divided into five plots. Ramie grown in modes A–E was initial harvested respectively on May 20 and 30 and June 8, 18 and 24. The harvest modes for other plots were designed by analogy. Four seasons of ramie were harvested from each plot per year. The conventional harvest mode was the control group (harvest dates: June 12, August 6 and October 20; i.e. three seasons per year).

The present research proposes a new method for ramie harvest: dividing the large-scale plantings of ramie into sub-regions and harvesting each sub-region on different dates. We investigated the influence of harvest mode on ramie yield and fiber quality to evaluate each harvest mode. Our research may provide a new harvest method for perennial crops whose nutritive organ is mainly harvested. A continuous supply of raw material is guaranteed using this method, which is important for supplying factories.

2. Materials and methods

2.1. Experimental sites and designs

The data were collected during 2011 at the experimental farm in Huazhong Agricultural University, Wuhan, China (30.52°N, 114.32°E). The site has a subtropical climate, with a mean annual temperature within 15.8–17.5 °C, with the absolute minimum during January–February and absolute maximum during July–August. Annual precipitation is 1150–1450 mm, with the wettest period in June–August.

The cultivar used was 'Huazhu 4' and the experimental site was located in the experimental farm of Huazhong Agricultural University. 'Huazhu 4' is a new ramie cultivar, authorized in 2010 in China, and is suitable to plant in the valley of the Yangtze River. Five harvest modes were designed. There were 27 ramie plants planted in the plot with an area of 12 m^2. Traditional harvest mode was used as the control group, with three replicates per treatment. Ramie seedlings were bred by shoot-tip asexual reproduction in April 2008. In September 2008, seedlings with similar growth status were transplanted to the field. Routine field management measures were taken in 2008–2010. Some improvements were made based on a continuous ramie harvest experiment in 2010 (Liu et al., 2012). The harvest seasons in 2011 are given in Fig. 1. Nine ramie stems of similar growth status were selected in each plot for ramie yield and fiber quality tests. Basal fertilizer was applied: nitrogen (N), phosphorus (P) and potassium (K) at 225, 150 and 300 kg/ha, respectively. After ramie harvest in each plot for each harvest mode, additional N fertilizer was applied at 75 kg/ha.

2.2. Measurements

The indicators in this study include ramie yield, fiber crystallinity, fiber fineness, fiber breaking strength, breaking elongation rate and gel content of raw ramie.

After harvest, the leaves were removed from the stems. The bast fibers were manually scraped off and naturally dried in the sun after manual peeling of the outer layer. Ramie yield was calculated as dry weight. Fiber crystallinity was determined with degummed ramie and a wide-angle X-ray powder diffractometer (Advance D8, Bruker, Germany) was used to characterize fiber crystallinity (Segal et al., 1959), with monochromatic Cu Ka radiation ($k = 0.15406$ nm) generated at 40 kV and 40 mA, and the following optical slit system: divergence slit = 0.5°; scattering slit = 0.5°; and receiving slit = 0.15 mm. The scanning was performed at scattering angles (2θ) from 5° to 40° in 0.1° increments with an accumulation time of 20 s for each angular step.

The crystallinity of degummed ramie fiber was evaluated by crystallinity index (CrI), which has been extensively used to estimate the ratio of cellulose I crystal structure to amorphous region in a biomass sample. CrI values were calculated according to the following equation: $\mathrm{CrI}\ (\%) = 100 \times [(I_{200} - I_{\mathrm{amorphous}})/I_{200}]$, where I_{200} is the intensity of diffraction peak at 2θ of 22.5°; and $I_{\mathrm{amorphous}}$ is the intensity attributed to amorphous portion at 2θ of 18.5° (Prabuddha et al., 2010).

Fiber fineness, fiber breaking strength (fiber elongation rate) and gel content of raw ramie were measured following the China National Standards (GB5884-1986, GB5886-1986 and GB5889-1986, respectively). Fiber fineness was measured by CU-1 instrument (Nantong Hongda Experiment Instruments Co. Ltd., Jiangsu, China). A single fiber strength instrument was used to determine fiber strength (Nantong Hongda Experiment Instruments Co. Ltd.).

2.3. Statistical analysis

SAS 9.0 (SAS, 1989) was used for statistical analysis.

3. Results

3.1. Ramie yield and gel content

The range in total raw yield (Table 1) for all harvest modes was 2214.67–2533.67 kg/ha (average 2423.18 kg/ha). This was lower than the 2724.33 kg/ha for the control group using traditional harvest technology (average reduction 10%). This result differed from a previous study in which some harvest modes gave yield increases of 21.50 and 5.04% and another gave a yield decrease of 18.42% (Liu et al., 2012).

For the first harvest, with the postponing of harvest date, Modes A–E showed an increasing trend of ramie yield (Table 1). Compared to the control on the first harvest date (June 12), Modes C–E showed no significance difference in yield. However, the difference was significant ($P < 0.05$) for Modes A and B. This suggested that early harvest would somewhat reduce ramie yield. In the second harvest, the difference in yield between each harvest mode was not significant. In the third and fourth harvests, the yield of controls