Study of Low Cost and Environmentally Friendly Fruit Nursery Paper Using a Printing Method

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Fruit nursery paper is a protective technical paper that is used in agriculture to improve the percentage of the fruit that meets quality standards and the fruit's exterior qualities, such as the smooth surface finish and fruit color. In this work, a more efficient and environmentally friendly method, *i.e.*, the printing method, was proposed in order to minimize environmental pollution, reduce the loss of carbon black, and lower the high production cost caused by the traditional method of directly adding carbon black. The effects of printing pressure and inking amount on the properties of the fruit nursery paper were investigated. The durability and safety of the fruit nursery paper produced by the printing method were also studied. The optimal inking amount and printing pressure under laboratory conditions were 1 mL and 350 N, respectively. The amount of ink transferred to the paper surface increased with increasing printing pressure, which led to better opacity but slightly decreased porosity and softness. A more important finding was that the fruit nursery paper produced by the printing method had excellent durability, and the properties can satisfy the requirements of the end use and safety standards of 94/62/EC stipulated by the Europeon Parliament and Councile directive. Based on these low-cost, environmentally friendly characteristics, the development of this new fruit nursery paper could be beneficial.

Keywords: Fruit nursery paper; Plant oil-based ink; Inking amount; Low cost; Environmentally friendly; Paper property

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INTRODUCTION

Fruit-bagging technology protects fruits such as bananas, mangoes, pears, melons, and apples from insects, environmental conditions, exposure to extreme heat or cold, and injuries to its skin. It can significantly improve the percentage of the fruit that meets quality standards and the fruit's exterior qualities, such as the surface smoothness and fruit color (Luo *et al*. 2011). In China, the market price of bagged apples is 2.5 RMB/kg higher than unbagged ones, and so provides great net benefit for the fruit growers. Fruit nursery paper can provide a safe, dark, stable, and breathable growth environment for the fruit during the three months of the growing period. Therefore, paper properties such as porosity, opacity, tensile strength, water resistance, and softness have a crucial effect on fruit quality.

There are two types of fruit nursery papers: single bags and double bags. Single bags are yellow or brown and usually used for pears and kiwis, which have little requirements on fruits' exterior qualities such as the color. Double bags are usually used for apples and composed of two parts, the inside bag and the outside bag, as shown in Fig. 1. The inside bag is red and semitransparent, which guarantees the fruits' exterior qualities such as the color. The outside bag was our only research object in the paper. Two sides of the outside bag have different colors. The inner surface is black, which provides opacity, and the outer surface is unbleached fiber, which plays a part in reflecting light. The outside bag protects the fruit by preventing invasion by rain, hail, and pests; it accordingly has strict requirements for mechanical strength and water resistance. The fruit grower removes the outer bag 3 weeks before harvest for proper coloring (Huang 2000; Huang and Huang 2006). Double bags are frequently used for growing apples.

Fig. 1. Fruit nursery paper used for apples

The traditional method for manufacturing outside bag fruit nursery paper is by adding carbon black directly to the paper slurry to achieve good opacity, which may result in environmental pollution, loss of carbon black, and lower production efficiency. Recycled fiber is used to lower the production cost (Wan *et al*. 2009; Wistara and Young 1999; Yan *et al*. 2005; Zhao *et al*. 2005). However, this study explored a new method for producing the outside bag of fruit nursery paper using a printing method. It has significant advantages over adding carbon black directly, such as improving paper machine speed and manufacturing environment, as well as a lower production cost. Printing using black ink could achieve better opacity, porosity, softness, and water permeability resistance.

Special attention must be given to the safety of ink used in this method. Ink toxicity management is a known requirement for manufacturing safe products in the printing industry (Li *et al*. 2014; Motarjemi 2014). The three aspects of ink toxicity are heavy metals, aromatic solvents, and volatile organic compounds (VOC). Aromatic solvents refer to toluene, xylenes, polycyclic aromatic hydrocarbons and their derivatives. The species of VOC are numerous, such as alcohols, ketones, ethers, esters, and mineral oil. All of them will volatilize during the drying process of ink, which will not only pollute the environment but will also be detrimental to the health of workers. The ideal ink is a black, plant oil-based ink (*e.g.,* soybean ink). It has hardly any Pb, Cd, Hg, Cr, and VOC. Therefore, the printing method is viable in terms of safety if regular or plant oil-based ink is used. The aromatic solvents in ink can be removed by drying the paper completely and discharging it through a ventilating hood, which can guarantee the safety of products.

EXPERIMENTAL

Materials

The fiber furnish in this study was 100% old corrugated container (OCC) #13 pulp. The Canadian standard freeness (CSF) of the pulp was 225 mL. Water-resistant agent (solids content 8%), wet strength agent polyamideamine-epichlorohydrin resin (PAE) (solids content 2%), filler precipitated calcium carbonate (PCC), and cationic dispersed rosin size (solids content 10%) were supplied by Keda Specialty Inc. in Baoji, China.

Aluminum sulfate, potassium dichromate, lead nitrate, cadmium chloride, and carbon black were provided by chemical companies in China. The black ink was plant oil-based.

Methods

Outside bag handsheet preparation

Fruit nursery paper handsheets of 45 g/m^2 were prepared using a laboratory sheet former. PCC filler (solid), rosin size (emulsion, concentration of 10%), water-resistant agent (emulsion, concentration of 8%), wet strength agent PAE (aqueous solutions, concentration of 2%), and aluminum sulfate (solid) were added into the pulp furnish in sequence at a dosage of 15 wt%, 2.5 wt%, 8 wt%, 3 wt%, and 4 wt% based on the amount of oven-dry pulp, respectively. The L&W pulp disintegrator was utilized to mix the furnish with every ingredient after it been added. The wet paper was pressed for 3 min under 4 kg/cm^2 of pressure and dried for 5 min at 95 °C.

Inner layer of outside bag printing

An IGT G1-5 printability tester (PanColor Digital Ltd.; Netherlands) was utilized to print the inner layer of outer bag base paper with black, plant oil-based ink. The ink coverage on the paper was 5 g/m^2, and the finished product was obtained after drying. The transmission density (D) and the printing color model value (*L*, *a*, and *b*) of the ink layer were measured by an X-Rite 528 transmission densitometer (X-Rite Ltd., USA).

Product preparation by traditional method

Carbon black (15% to the amount of oven-dry pulp) was added into the furnish directly in the machine chest with stirring. The pulp materials, the manner of preparation, and the addition of chemicals were the same as in the case of the printing method. The basis weight of the finished product was 50 g/m^2.

Paper aging test

The printed paper was placed under a 30 watt ultraviolet light at a distance of 30 cm and irradiated for 24 h in a QUV basic aging machine (Q-lab Ltd., USA) (Havlínova *et al.* 2009; Vegas *et al.* 2014). The difference in the properties of fruit nursery paper before and after aging were measured.

Measurement of heavy metal content of printed paper

The heavy metal content of printed paper was analyzed following GB2762-2012 (2012) with atomic absorption spectroscopy. Fruit nursery paper samples prepared using the printing method with a dry weight equivalent of 5 g were carbonized in crucibles and then calcined in a muffle furnace in air at 550 to 600 °C for 5 h. The residues were added to a hydrochloric acid solution (molar ratio of 1:1), placed in a hot water bath to dissolve, and centrifugated at 3000 rpm for 15 min. After centrifugation, the supernatant solution was filtered with filter paper and the heavy metal content quantitated on a Z-2000 Polarizing Zeeman Atomic Absorption Spectrophotometer (Hitachi Limited, Japan).

RESULTS AND DISCUSSION

Effect of Printing Pressure on Paper Properties

Paper properties obtained at different printing pressure are illustrated in Table 1. For comparison, the final column shows the corresponding properties of the unprinted paper. The effect of the printing process on strength properties was slight; therefore, it was not of value to take tensile and tear strength into account. Table 1 shows that printing pressure had a negative effect on the porosity and a positive effect on opacity and water resistance. A possible explanation is that when the ink was pressed onto the paper, the increase of printing pressure compressed the surface holes quickly.

Table 1. Effects of Printing Pressure on Paper Properties

Printing pressure (N)	200	250	300	350	Unprinted
Porosity (μm/[Pa·s])	8.0	7.83	7.12	6.73	12.3
Opacity (%)	97.3	97.7	98.2	98.4	93.4
Transmission density	1.66	1.71	1.73	1.75	1.40
Transmittance (%)	2.18	1.96	1.88	1.77	2.43
Softness (mN)	619	618	626	637	550
Water resistance (s)	78	78	80	84	71

With increasing printing pressure, the amount of ink printed onto the paper surface was enhanced, and the paper opacity was improved significantly. Ink solid density reflects the amount of ink on the paper, which is related to the ink transfer rate at the same inking amount. Ink transfer is one of the most important printing properties of newspaper, offset paper and coated paper. In the period of printing process, reducing the dosage of ink supply and improving the ink transfer rate to achieve a good printing performance are desirable. It could avoid wasting too much ink, accordingly, getting a better printing quality and lowering the cost (Kim *et al.* 2012; Shen *et al*. 2008; Aspler and Lepoutre 1991). The ink transfer rate is the percentage of Y and X when Y refers to the ink transfer amount and X refers to printing sample ink amount. The equation for ink transfer is as follows (Walker 1981),

$$Y=(1-e^{-kx})\{b(1-e^{-x/b})+f'[x-b(1-e^{-x/b})]\} \tag{1}$$

where b refers to the maximum ink amount on the depression of the paper surface. The value of b increases with higher printing pressure and the probability of paper surface depression. The variable f' refers to the cleavage of ink amount, determined by the ink rheological property while *k* reflects the extent of the binding of ink film and paper surface. The *k* value increases with higher printing pressure and paper softness.

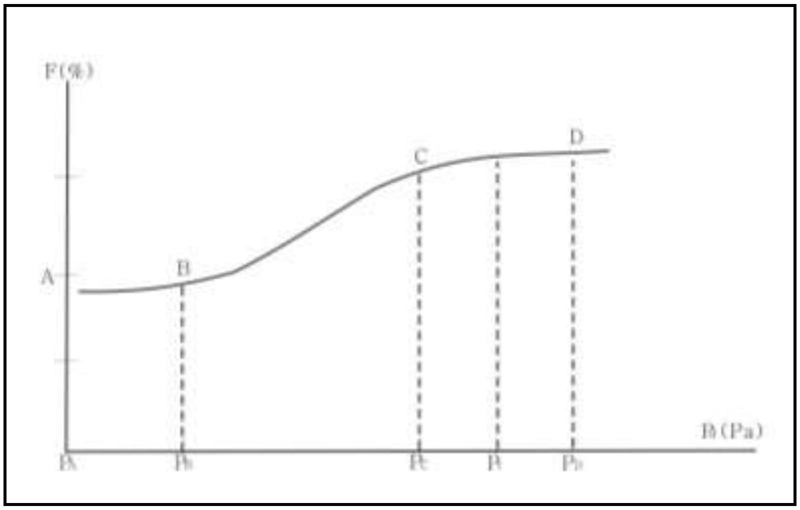

Fig. 2. The relationship between pressure (P_d) and ink transfer percentage (*F*)

Printing pressure and printing speed had a significant effect on the ink transfer percentage. Figure 2 shows the trend of ink transfer rate with increased printing pressure (Feng 2005). The ink transfer rate increased to a certain extent and then reached a stabilized state. The optimized printing pressure is P_t. To control the ink transfer rate, the printing pressure or the printing speed can be changed. Previous studies have indicated that the contact time between the ink and paper can be decreased by increasing the printing speed under a certain printing pressure (Zhang and Wang 2014).

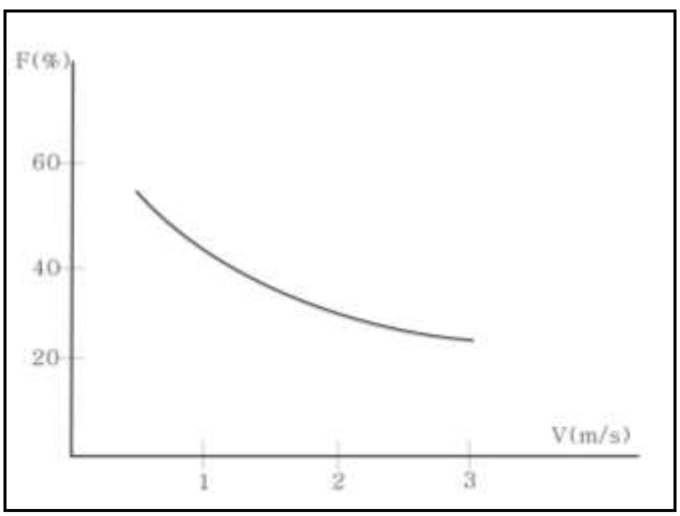

Fig. 3. The relationship between print speed (v) and ink transfer rate (F)

As illustrated in Fig. 3, the values of *k*, *b*, and *f'* in Eq. 1 all decreased, as did the ink transfer %. The transmission density was enhanced as the ink was printed onto the paper. At the same incident luminous flux, light transmittance decreased, which indicates the higher opacity of the fruit nursery paper after printing. Although an increase of printing pressure could increase the opacity, it had negative effects on the paper softness.

Effect of Inking Amount on Porosity and Opacity

Table 2. Effects of Inking Amount on Paper Properties

Inking amount (mL)	0.7	0.9	1	1.2	1.4	1.6	1.8
Porosity (μm/[Pa·s])	7.98	7.2	6.73	6.96	6.11	5.85	5.92
Opacity (%)	97.7	98.3	98.4	99	99.3	99.2	99.3
Transmission density	1.75	1.73	1.75	1.74	1.86	1.98	2.03
Transmittance (%)	1.94	1.87	1.77	1.79	1.37	1.05	0.93
Softness (mN)	582	623	637	688	701	706	749
Water resistance (s)	80	83	84	78	89	83	85

Table 2 shows that at constant printing pressure (350 N), the paper porosity decreased, while the opacity showed a rising trend with the increase of inking amount. Nevertheless, the changes of opacity reached a relatively stable state when the inking amount exceeded 1 mL. When the printing plate did not receive enough ink, the ink printed onto the paper had no direct relationship with the amount of inking and was not directly proportional to the inking amount. There was a saturation value; thus, the factors that affected the transmittance were printing pressure and speed, rather than the inking amount, when the printing plate had excessive ink. As shown in Table 4, the opacity of base paper was 93.4%, and the inking amount of 1 mL was the approximate saturation value, which significantly improved the opacity. When the inking amount exceeded 1 mL, the softness of the printed paper decreased so that it could not meet Chinese government standard. Therefore, the optimum conditions for the printing method to produce fruit nursery paper were an inking amount of 1 mL and a printing pressure of 350 N. Additionally, reducing the cost of the fruit nursery paper was a crucial objective of this study, and reducing the amount of ink was the key method of achieving this objective. Table 3 shows the resultant paper properties with different ink dosages under the printing pressure of 350 N on an IGT printability tester.

Table 3. Printed Paper Properties of Different Ink Dosages

Inking amount, mL	1	0.9	0.7	0.5	0.3	0.1
Base-paper Basis weight (g/m^2)	45.1	45	45	45.1	45.1	45
Finished paper Basis weight (g/m^2)	50.1	49.5	48.7	48.2	47.6	46.3
Basis weight added (g/m^2)	5	4.5	3.7	3.1	2.5	1.3
Ink dosage (%)	9.98	9.09	7.60	6.43	5.25	2.81
Tensile index (N·m/g)	63.12	61.57	63.31	62.16	61.36	61.22
Tear index (mN·m^2/g)	5.83	5.72	5.79	5.73	5.75	5.71
Burst index (kPa·m^2/g)	1.69	1.72	1.68	1.7	1.65	1.63
Softness (mN)	637	623	582	577	571	562
Porosity (μm/[Pa·s])	6.73	7.20	7.98	8.5	9.5	10.9
Opacity (%)	98.4	98.3	97.7	97.8	96.5	94.3
Transmittance (%)	1.77	1.87	1.94	2.12	2.63	3.84
Water resistance (s)	84	83	80	77	73	72

Comparison of Printed Paper Properties Before and After Printing Process

The results showed that the mass of ink added to the paper (as basis weight added) decreased with the decrease of the inking amount. However, when the inking amount was less than 1 mL, it was difficult to meet the demands of the Chinese standard. On the premise of ensuring the essential properties and opacity of the paper, the optimal ink dosage was judged to be 10% of the oven-dry pulp and the basis weight added was 5 g/m^2.

Table 4 shows the paper properties before and after the printing process under a pressure of 350 N and inking amount of 1 mL on an IGT printability tester. Also, it shows the comparison among paper properties manufactured by the printing method, the traditional method, and the Chinese government standard. As shown, the mechanical properties of printed paper, such as tensile index, tear index, and burst index remained nearly unchanged. Because of opacity and the inherent hydrophobicity of the plant oil-based ink, water resistance and opacity were increased to a certain extent. However, the paper may become more stiff and brittle after drying because of the presence of ink on the paper surface. Additionally, the bonding materials permeated into the inside of the paper after drying and damaged the softness and porosity. However, it could still meet the government standard of China.

Table 4. Contrast of Paper Properties Before and After the Printing Process

Properties	Before printing	After printing	Traditional method	Chinese standard
Basis weight (g/m^2)	48.3	50.2	50.0	50±2
Tensile index (N•m/g)	63.43	63.12	60.28	≥60.0
Tear index (mN•m^2/g)	5.60	5.83	5.58	≥5.5
Burst index (kPa•m^2/g)	1.63	1.69	1.60	≥1.60
Softness (mN)	550	637	615	≤680
Opacity (%)	93.4	98.4	97.1	≥97.0
Porosity (μm/[Pa·s])	12.3	6.7	7.5	≥5.0
Water resistance (s)	71	84	73	≥60

Durability of the Printed Fruit Nursery Paper

The paper was irradiated for 24 h in an aging machine. Table 5 shows the properties before and after the aging test of paper samples made with a printing pressure of 350 N and inking amount of 1 mL. The results showed that the opacity, water resistance, and mechanical strength, especially tensile index, decreased to different degrees. The physical, mechanical, optical, and chemical properties of paper are greatly influenced by the degradation of cellulose (Kačík *et al.* 2009). However, the paper was able to meet the government standards of China. There was scarcely any ink fading and sticking due to long sunlight exposure; therefore, the fruit nursery paper created by the printing method exhibited excellent performance.

Table 5. Paper Properties Before and After Aging Test

		Before	After
Color values	*L* value	15.53	14.30
	a value	1.07	1.22
	b value	6.58	6.54
Opacity (%)		98.4	99.1
Transmission density		1.75	1.61
Transmittance (%)		1.77	2.45
Tensile index (N•m/g)		63.12	61.63
Tear index (mN•m^2/g)		5.83	5.61
Water resistance (s)		84	67

Safety Test of Ink Used in Printing Process

Food safety is essential for producing high quality fruit and has recently received great attention. Heavy metals such as Pb, Cd, Hg, Cr, and their chemical compounds are common in manufacturing. However, they are hazardous to human health and the environment. Accordingly, it is essential to have the safety of the ink tested. The results are shown in Table 6, Fig. 4, and Table 7. Directive 94/62/EC (1994) stipulates that the volume dose of harmful heavy metals, including Pb, Cd, Hg, and Cr must not exceed 100 mg/kg on packaging and packaging waste. The volume dose of heavy metals in the printed paper was 14 mg/kg, which was far below the limitation stipulated by the EC directive. These results were in accordance with the fact that plant oil-based ink contains minimal heavy metal and can meet safety standards.

Table 6. Testing Results for Heavy Metals

Cr/ 359.3 nm	Conc/ mg/L	ABS	Cd/ 228.8 nm	Conc/ mg/L	ABS	Pb/ 283.3 nm	Conc/ mg/L	ABS
STD1	1	0.0019	STD1	0.4	0.0112	STD1	4	0.0086
STD2	2	0.0035	STD2	0.8	0.0185	STD2	8	0.0175
STD3	4	0.0066	STD3	1.6	0.0414	STD3	16	0.0335
STD4	8	0.0126	STD4	3.2	0.0764	STD4	32	0.0664
UNK	0.18	0.0007	UNK	0.02	0.0004	UNK	0.08	0.0005

Table 7. Content of Heavy Metals in Printed Paper

	Cr	Cd	Pb	Volume dose
Content in sample (mg/L)	0.18	0.02	0.08	-
Content in paper (mg/kg)	9	1	4	14

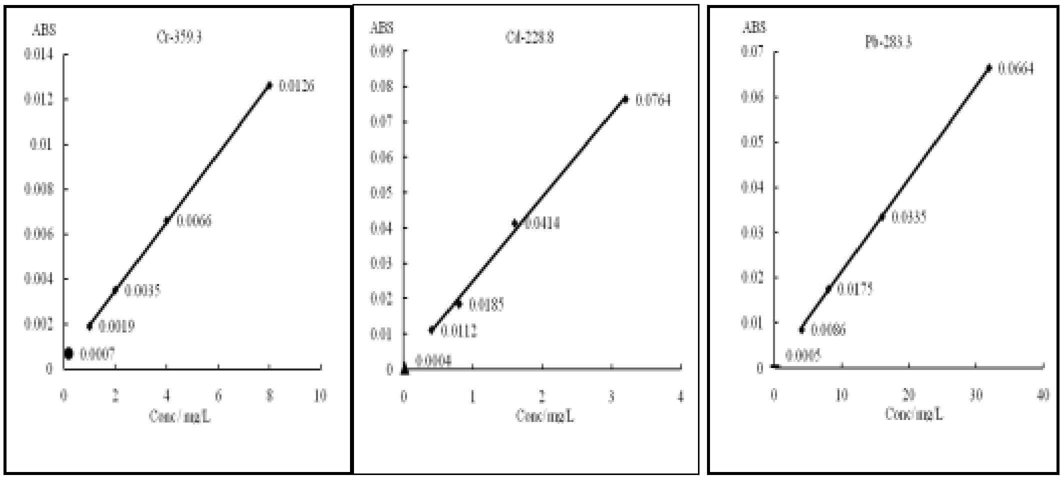

Fig. 4. Calibration curves for the analysis of Cr, Cd, and Pb

Industrialization Prospect of the Printing Method

The printing method has low cost and environmentally friendly characteristics, which is beneficial to the development of fruit nursery paper. However, the scale of current fruit nursery paper mills is usually small. So it is undesirable to require adjustments of manufacturing techniques, especially with respect to the equipment employed. As shown in Fig. 5, one could imagine that adding a printing unit and another dryer after a Fourdrinier paper machine to minimize the extra costs.

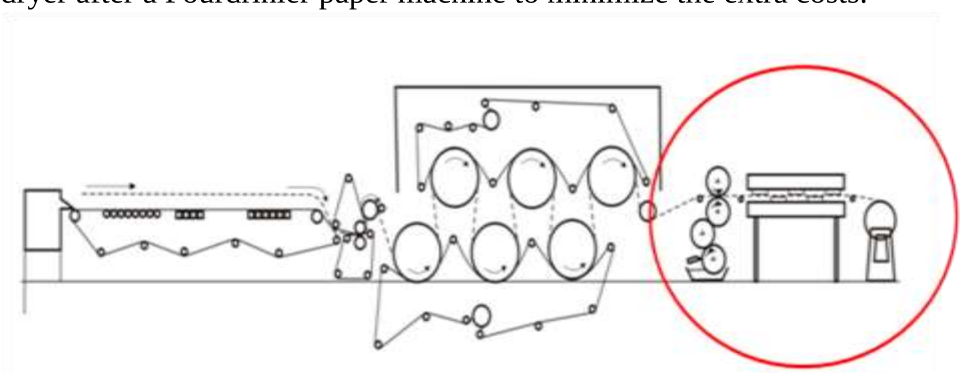

Fig. 5. The schematic diagram of modified Fourdrinier paper machine with a printing unit

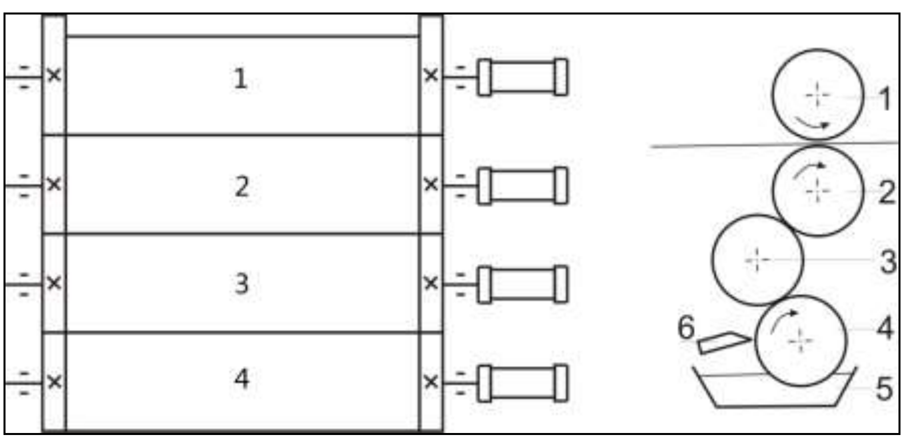

Fig. 6 The printing unit (1-Press roller, 2-Rubber roller, 3-Ink distributing roller, 4-Inking roller, 5-Ink tank, 6-Scraper)

Accordingly, the manufacturing of fruit nursery paper by printing method could be continuous rather than dividing the papermaking and printing process to produce the products. Such a printing unit is diagramed in Fig. 6. It consists of press roller, rubber roller, ink distributing roller, inking roller, ink tank, and scraper. The rubber roller, ink distributing roller, and inking roller are fixed, while the press roller could be adjusted up and down for fine tuning. The printing pressure could be adjusted though the gaps between press roller and rubber roller. The inking amount could be controlled by the angels and gaps between the scraper and inking roller.

CONCLUSIONS

1. The printing method had little effect on the mechanical strength of the printed paper, but it could improve the water resistance and opacity to a certain extent. The amount of ink transferred to the paper surface increased with increasing printing pressure, which led to a better opacity, but the printing process decreased porosity and softness slightly.
2. The fruit nursery paper produced by this printing method had excellent durability and the paper properties, which could satisfy the requirements of the end use and safety standards of 94/62/EC stipulated by EC directive. Because of its low cost and environmentally friendly characteristics, the development of this new fruit nursery paper could be beneficial.

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