International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 50 No. 1 Aug. 2020, pp. 1-9

http://www.ijisr.issr-journals.org/

Vertically tapping significantly decreases dry rubber yield and alters physical and mechanical properties of raw rubber and vulcanizate

Xian Hong Chen, Qing Chen, Jun Wang, and Wei Fu Lin

Rubber Research Institute, Chinese Academy of Tropical Agricultural Sciences, Danzhou, Hainan, China

ABSTRACT: In China, harvest cost of natural rubber is high due to a declining rubber price, less favorable agroclimate, and skilled tapper labor shortage. Reduction in cost of latex harvest by tapping machine in a straight line will make rubber production more cost effective. To evaluate the feasibility of tapping in a straight line, a comparison of two tapping practices (horizontally/traditionally tapping and vertically/straightly tapping) was conducted in clone Reyan88-13. Compared with horizontally tapping, vertically tapping increases dry rubber content and Mg^{2+} content, significantly decreases initial latex flow velocity, dry rubber yield per cut length, reduces thiols content and Cu^{2+} content, and alters physical and mechanical properties of raw rubber and vulcanizate. Taken together, vertically tapping reduces tapping intensity, alters physical and mechanical properties of raw rubber and vulcanizate at the cost of less rubber latex yield.

KEYWORDS: *Hevea brasiliensis*, horizontally tapping, vertically tapping, yield, mechanical properties.

1 INTRODUCTION

The tropical tree (*Hevea brasiliensis*) is grown commercially for its latex. Latex is harvested by periodic excision of a thin shaving of the bark along a sloping groove placed spirally on the bark of rubber tree trunk requiring the continual application of manual labor, and the procedure is known as harvesting (tapping) by a tapping knife. The latex yield obtained from the rubber tree is greatly influenced by the skill of the tapper. A skilled tapper will tap to an optimum depth of within 1mm of cambium without wounding it. The greatest number of latex vessels is situated near the cambium so tapping as close to it as possible realizes the best yield. Meanwhile, to gain more tapping is usually done during the early hours of the day because of favorable factors such as climatic factors (high relative humidity, low temperature and low light intensity) and physiological factors (closed stomata, low evapotranspiration rate and high turgor pressure [1]. Under prolonged lowering prices of rubber in recent years and poor tapping production environment, high tapping cost and shortage of skilled tappers are more aggravated in China. To mitigate the effect of low rubber prices, low frequency tapping systems combined with proper ethephon stimulation [2-4] to decrease the time spent on the field and different tapping tools [5,6] such as electric tapping knife and automatic tapping machine to increase the tapping labor productivity are researched and developed. At present, the production and management of natural rubber are still dominated by manpower, with a very low degree of mechanization. The cost of rubber tapping accounts for 60% of the natural rubber production cost [7] and it is urgent to accelerate the process of mechanization. However, the existing rubber cutting method is still adopted with the traditional spatial curve to cut the bark and collect latex of the trunk, requiring cut depth, thickness and evenness, whatever the frequency of latex harvesting system and tapping knife. Tapping is a skilled operation and hence quality of tapping varies from tapper to tapper. Therefore, the current design of automatic tapping technology or device has to be very complex, which leads to the high production cost of related devices and is difficult to be popularized in field production.

The study reported herein investigated the simplified cutting technology, such as changing the traditional cutting line along the semi helix (spatial curve) of tree girth to the cutting line along the trunk axis (straight line - the movement form of simple machinery), so that the tapping mode is more suitable for the simple mechanical operation. To evaluate the feasibility of

Corresponding Author: Xian Hong Chen

tapping in a straight line, a comparison of two tapping practices (horizontally/traditionally tapping and vertically/straightly tapping) was conducted in clone Reyan88-13.

2 PLANT MATERIALS AND TREATMENTS

Thirty-three years-old trees of reyan88-13 were planted and never tapped at the experimental nursery of rubber research institute of Chinese Academy of Tropical Agricultural Science in Danzhou, Hainan, China. The girths of these trees were measured and grouped randomly before tapping. half of these trees were regularly tapped in a downward half spiral pattern and slope of tapping cut (25°, 90°), every three days, without ethephon (no stimulation), and the other half with 0.5% ethephon stimulation. each treatment contained three trees, and latex samples from these three trees were separately collected for dry rubber yield, dry rubber content, latex physiological parameters, and physical and mechanical properties of raw rubber and vulcanizate. to reduce the girth and unknown rootstock difference of trees (budding rubber), trees horizontally tapped in 1-13th tapping number were tapped vertically in 14th-26th tapping numbers, and trees vertically tapped in 1-13 tapping number were correspondingly switched to be horizontally tapped (Table1 and Figure1).

Table 1. Experimental design and treatments in details

Tapping number	Ethephon application	Slope of tapping cut (°)
1-13	No stimulation	25
		90
	0.5%	25
		90
14-26	No stimulation	25
		90
	0.5%	25
		90

Note: Slope of tapping cut (25°) denotes horizontally tapping and slope of tapping cut (90°) vertically tapping. At the beginning of 14th tapping number to the end of 26th tapping number, trees horizontally tapped in 1-13 tapping number were vertically tapped, and trees vertically tapped in 1-13 tapping number were horizontally tapped.

	Horizontally tapping		*Vertically tapping*	
No stimulation				
0.5% ethephon stimulation				
Tappings	***1st-13th***	***14th-26th***	***1st-13th***	***14th-26th***

Fig. 1. The representative view of horizontally tapping and vertically tapping with no stimulation and 0.5% ethephon stimulation at 1/2 S Length of tapping cut in the field. Slope of tapping cut (25°) denotes horizontally tapping and slope of tapping cut (90°) vertically tapping

Dry rubber yield, dry rubber content, latex physiological parameters according to the conventional method [8,9]. determinations of chemical and physical properties of dry rubber are tested according to the national standard method (GB/T 531.1-2008, GB/T528-2009 AND GB/T3512-2001). physical and mechanical properties of raw rubber and vulcanizate were performed by Shandong Qibiao Testing Co., Ltd., Qingdao, China.

3 RESULTS

3.1 VERTICALLY TAPPING INCREASES DRY RUBBER CONTENT AND MG2+ CONTENT

Except the disturbances of switched positions in tapping trees at the beginning of 13th tapping number, dry rubber content by vertically tapping in 24 out of 26 tapping numbers demonstrated the same upward trend in comparison with that by horizontally tapping (Figure2B, 2D). As shown in Figure4B, dry rubber content by vertically tapping was 23.06% ($P < 0.001$) more with no stimulation, and 19.54% ($P < 0.001$) more with 0.5% ethephon stimulation than those by horizontally tapping, respectively. As shown in Figure5A, B and C, Mg^{2+} content by vertically tapping was 39.13% ($P < 0.001$) more with no stimulation, 20.46% more with 0.5% ethephon stimulation than those by horizontally tapping, respectively.

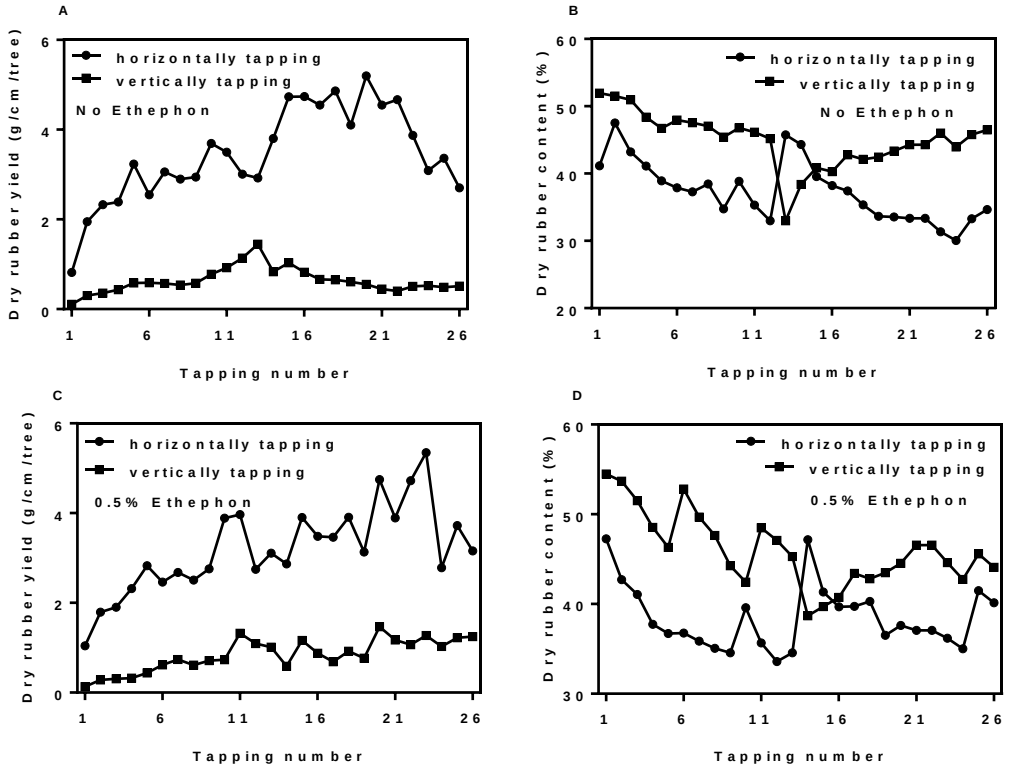

Fig. 2. Changes in dry rubber yield per cut length and dry rubber content of vertically tapping and horizontally tapping with no stimulation and 0.5% ethephon stimulation

3.2 VERTICALLY TAPPING SIGNIFICANTLY REDUCES THIOLS CONTENT AND CU2+ CONTENT

Except the disturbances of switched positions in tapping trees at the beginning of 13th tapping number, thiols content by vertically tapping in 24 out of 26 tapping numbers demonstrated the same downward trend in comparison with that by horizontally tapping (Figure3A, C). Thiols content by vertically tapping were 19.54% ($P < 0.01$) less with no stimulation, and 15.37% ($P<0.01$) less with 0.5% ethephon stimulation than those by horizontally tapping (Figure4C), respectively. Tapping number of Cu^{2+} content are the 11th to 26th, and Cu^{2+} content by vertically tapping showed the same downward trend in comparison with that by horizontally tapping except the disturbances of switched positions in tapping trees at the beginning of 13th tapping number (Figure3B, D). Cu^{2+} content by vertically tapping were 52.09% ($P < 0.001$) less with no stimulation, 47.83% ($P < 0.001$) less with 0.5% ethephon stimulation than those by horizontally tapping (Figure4D), respectively.

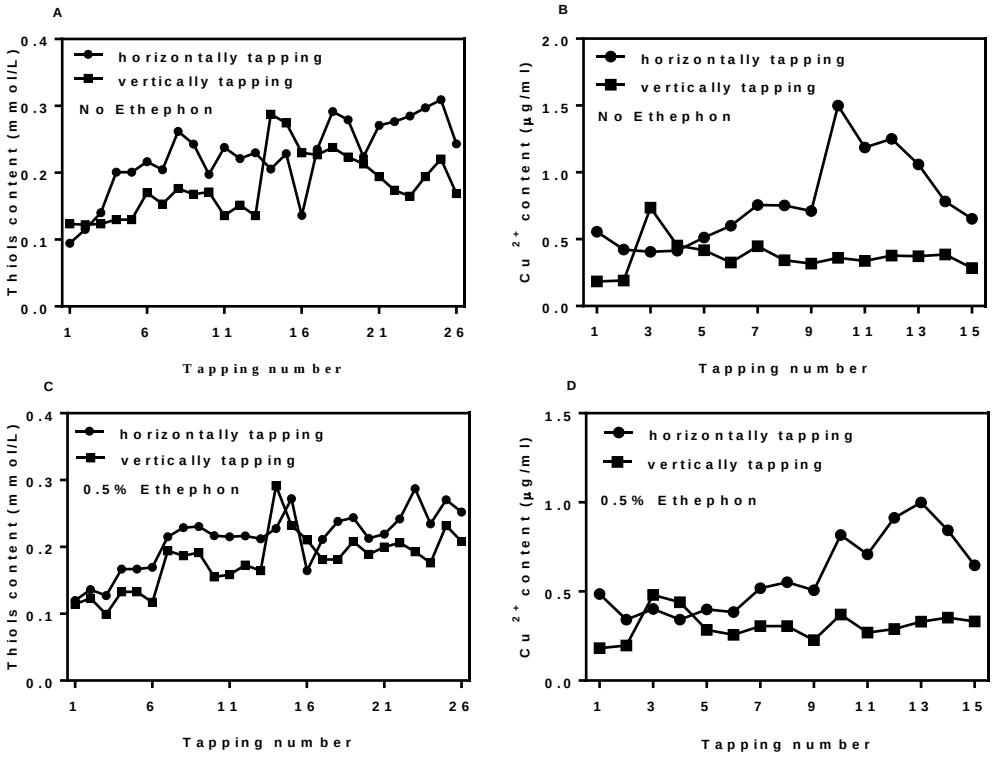

Fig. 3. Changes in thiols content (A, C) and Cu2+ content (B, D) of vertically tapping and horizontally tapping with no stimulation and 0.5% ethephon stimulation. Tapping number of Cu2+ content are the 11th to 26th

3.3 VERTICALLY TAPPING SIGNIFICANTLY DECREASES INITIAL LATEX FLOW VELOCITY, DRY RUBBER YIELD PER CUT LENGTH

Initial latex flow velocity by vertically tapping was 61.45% ($P < 0.05$) slower with no stimulation, 64.08% ($P < 0.01$) slower with 0.5% ethephon stimulation than those by horizontally tapping (Figure5D), respectively. Dry rubber yield per cut length by vertically tapping in 26 tapping numbers demonstrated the same downward trend in comparison with that by horizontally tapping (Figure2A, C). Dry rubber yield per cut length by vertically tapping was 81.68% ($P< 0.001$) less with no stimulation, 73.77% ($P<0.001$) less with 0.5% ethephon stimulation than those by horizontally tapping (Figure4A), respectively.

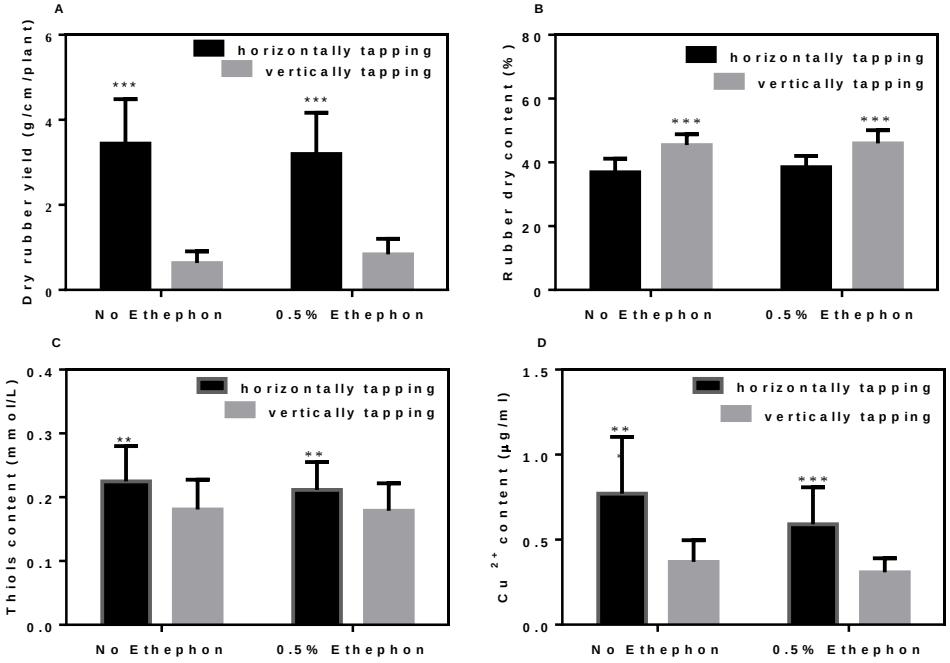

*Fig. 4. Comparison of dry rubber yield per cut length (A), dry rubber content (B), thiols content (C) and Cu2+ content (D) with no stimulation and 0.5% Ethephon stimulation of horizontally tapping and vertically tapping. Data are means of 1st- 26th tapping numbers measured. Tapping number of Cu2+ content are the 11th to 26th, and data Cu2+ content are means of 11th to 26th. Means ± SD, **P < 0.01, ***P < 0.001*

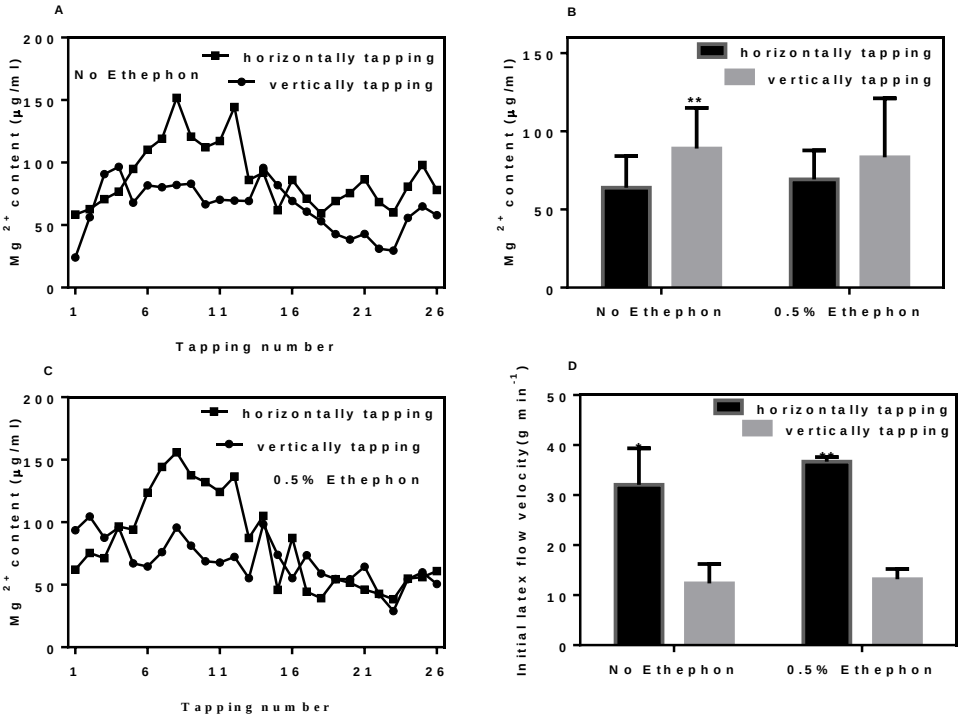

*Fig. 5. Changes in Mg2+ content (A, C) with no stimulation and 0.5% ethephon stimulation of horizontally tapping and vertically tapping, and comparison of Mg2+ content (B) and initial latex flow velocity (D) with no stimulation and 0.5% Ethephon stimulation of horizontally tapping and vertically tapping. Data of Mg2+ content are means of 1st- 26th tapping numbers measured. The data of initial latex flow velocity were mean of 25th and 26th tapping numbers measured. Means ± SD, *P < 0.05, **P < 0.01*

3.4 VERTICALLY TAPPING ALTERS PHYSICAL AND MECHANICAL PROPERTIES OF RAW RUBBER AND VULCANIZED RUBBER

As shown in Table2, with no stimulation there was no significant difference in raw rubber mooney viscosity (ML) between by vertically tapping and by horizontally tapping, while with 0.5% ethephon stimulation ML by vertically tapping was7.23% ($P < 0.001$) more than that by horizontally tapping. Plasticity retention index (PRI) with no stimulation between by vertically tapping and by horizontally tapping were not significant, while with 0.5% ethephon stimulation PRI by vertically tapping was 3.29% ($P < 0.05$) more than that by horizontally tapping. Vulcanized rubber elongation at break (EB) by vertically tapping with no stimulation and with 0.5% Ethephon stimulation were 8.20% ($P < 0.01$) more, 3.88% ($P < 0.05$) more than those by horizontally tapping, respectively. Tear strength (TS) with no stimulation by vertically tapping was 7.38% ($P < 0.001$) less than that by horizontally tapping, and with 0.5% ethephon stimulation there was no significant difference between by vertically tapping and by horizontally tapping. Snapping back rate (SNR) with no stimulation by vertically tapping was 8.64% ($P < 0.01$) less, but with 0.5% ethephon stimulation was 11.27% ($P < 0.05$) more than those by horizontally tapping, respectively. Shore A with no stimulation by vertically tapping was 8.14% ($P < 0.01$) less than that by horizontally tapping, and with 0.5% ethephon stimulation there was no significant difference between by vertically tapping and by horizontally tapping.

Table 2. Comparison of physical and mechanical properties of raw rubber and vulcanized rubber

Ethephon application	Slope of tapping cut (°)	Raw rubber		Vulcanized rubber			
		ML (1+4) 100℃	PRI （%, 134℃30min）	EB (%)	TS (KN/m)	SNR (%)	Shore A
No stimulation	25	98.5±0.5	56.15±0.15	610±10	74.5±0.5***	81±1**	86±1**
	90	98.5±0.5	53.50±1.5	650±10**	69±1	74±1	79±1
0.5%	25	94.5±0.5	53.25±0.25	645±5	73.5±1.5	71±1	76±1
	90	101.33±1.15***	55±1*	620±10*	69±4	79±4*	78±4

*Note: Slope of tapping cut (25°) denotes horizontally tapping and slope of tapping cut (90°) vertically tapping. Mooney viscosity=ML, Plasticity retention index = PRI, Elongation at break =EB, Tear strength =TS, Snapping back rate=SNR. Data are means and SD, n=3. *, **, ***indicate a significant difference at 0.05, 0.01 and 0.001levels, respectively.*

4 DISCUSSION

Previously, we thought vertically tapping would make tapping easy and friendly for tappers and tapping machine. To investigate the effect of vertically tapping on rubber tree, we compared vertically tapping and horizontally tapping (conventionally tapping) on rubber yield, physiological parameters and physical and mechanical properties of raw rubber and vulcanizate. Collectively, our finds show that it is not an ideal alternative to use vertically tapping in rubber latex harvest.

4.1 VERTICALLY TAPPING REDUCE THE TAPPING INTENSE AND GAIN LOW RUBBER LATEX YIELD

Direction of tapping cut greatly caused the fluctuation of rubber latex yield [10]. Panel management strongly influenced rubber latex yield and latex physiology [11]. A prominent effect observed in the present study was the drastic reduction ($P < 0.001$) of latex yield, which may explain direction of tapping cut had an important role in decreasing latex yield by vertically tapping. The laticifer in the bark of rubber tree forms an angle of 2-7° with the central axis of the trunk, and spirals up from the lower left to the upper right [12]. Latex vessels run spirally from low left to high right at an inclination of 3.7-5° from the vertical [13]. For this reason, the current secant direction is inclined from the top left to the bottom right, so that more latex vessels can be cut to obtain higher yields. The latex vessels in the bark traverse from bottom left to top right at an angle of 30° in anticlockwise direction, and a cut from high left to low right will sever a greater numbers of latex vessels, which led to the current practice of a sloping cut from high left to low right on all spiral cuts1. Laticifer plugging during latex flow after tapping is an important factor to limit the latex yield of rubber trees, which caused by rubber particle and its protein-network in wounded laticifer cells [14-16]. In the present study, rubber latex yield by vertically tapping was less ($P<0.001$) than that by horizontally tapping (traditionally tapping) whatever stimulation, which indicated vertically tapping might cut less latex vessels or cause latex flow barrier at the cut so as to achieve lower yields.

Latex diagnosis is used to determine the metabolism and health mechanisms of rubber tree. Dry rubber content is an index of latex regeneration and the higher dry rubber content indicates the more latex production potential. Mg^{2+} content of rubber latex was negatively correlated with latex yield [17] and high Mg^{2+} content lead to latex flow barrier at the cut [18]. Thiols can delay latex coagulation and normally the higher thiols content means the more latex [19]. Cu^{2+} content of rubber latex was

positively correlated with intensity of ethylene stimulation within limits9and could be considered as a standard of tapping intensity in long-term latex flow [20]. Longer latex flow is equated to higher yield provided the other circumstances and attributes remain unaffected1. In this study, thiols content and Cu^{2+} content by vertically tapping were all less than those by horizontally tapping except the disturbances of switched positions in tapping trees at the beginning of 13th tapping number, while with or without stimulation dry rubber yield per cut length by vertically tapping was significantly less than that by horizontally tapping, which obviously indicated that vertically tapping decreased rubber latex yield due to slower latex flow velocity, and less tapping intense such as less thiols content and less Cu^{2+} content, but increased latex stability such as dry rubber content and Mg^{2+}content. Taken together, vertically tapping reduces tapping intensity at the cost of less rubber latex yield.

4.2 VERTICALLY TAPPING ALTERS PHYSICAL AND MECHANICAL PROPERTIES OF RAW RUBBER AND VULCANIZED RUBBER

As the differences are performed in natural rubber by vertically/ horizontally tapping, such as dry rubber yield, dry rubber content and Mg^{2+} content, thiols and Cu^{2+} content, raw rubber (moony viscosity and plasticity retention index) and vulcanized rubber (Elongation at break, Tear strength, Snapping back rate and Shore A) are correspondingly varied. With 0.5% ethephon stimulation dry rubber by vertically tapping have higher ML, PRI than that by horizontally tapping, respectively, which indicated with 0.5% ethephon stimulation raw rubber by vertically tapping have better physical properties such as better anti-oxidation and anti-aging properties.

Shore-A hardness refers to the resistance to deformation by external force, which is closely related to other mechanical properties such as tear strength and flexibility [21]. With no stimulation shore-A hardness, TS and SNR by vertically tapping have less than that by horizontally tapping, respectively, which illustrated that with no stimulation vulcanized rubber by vertically tapping have less mechanical properties such as tightness cross-link [22]. Dry rubber by vertically tapping have higher EB with no stimulation and better SNR with 0.5% ethephon stimulation than those by horizontally tapping, respectively, which showed better flexibility. However, with 0.5% ethephon stimulation dry rubber by vertically tapping have less EB than that by horizontally tapping, which showed that with 0.5% ethephon stimulation dry rubber by vertically tapping was more fragile than that by horizontally tapping.

5 CONCLUSION

Conclusion. Regardless of ethephon stimulation, horizontally tapping panels are more productive in rubber latex than those of the vertically tapping. With 0.5% ethephon stimulation raw rubber by vertically tapping have better physical properties such as better anti-oxidation, anti-aging properties and flexibility, while vulcanized rubber by vertically tapping have less mechanical properties.

ACKNOWLEDGMENT

This work was supported by the Fundamental Scientific Research Funds for Chinese Academy of Tropical Agricultural Sciences (1630022014023,1630022015006), and the earmarked fund for China Agriculture Research System (CARS-34-YZ4).

AUTHORS' CONTRIBUTION

W.F. Lin designed the experiments, X.H. Chen and Q. Chen conducted the experiments, X.H. Chen analyzed the data and drafted the manuscript, X.H. Chen, J. Wang and W.F. Lin discussed the results and finalized the manuscript.

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