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Some Properties of Natural Rubber from Latex-timber Clones

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Several properties of natural rubber from latex-timber clones, which produce high timber and latex yields, were examined. Of the 28 clones, 14 clones were found to produce high dry rubber content (DRC) latices, i.e. *above 41%, most of which were from the RRIM 2000 series. No latices were found to have a DRC below 34%. Except for Mooney viscosity, all the clonal rubbers could satisfy the specifications of SMR-CV scheme. The Mooney viscosity of 15 clonal rubbers was observed to exceed the limit specified in the SMR-CV 60 scheme. However, the viscosity of such rubbers can be reduced by blending the latices with other latices having low viscosity rubbers before processing them into dry rubbers. The molecular weight distributions of the clonal rubbers were either unimodal with a peak in high molecular weight region, or bimodal with a small peak in the low molecular weight region. On account of this, the polydispersity, 3.1~5.4, was narrower than the range of 2.5~10 reported previously. The number average and weight average molecular weights of the rubber were found to be in the range of 2.77×10^5~7.06×10^5 and 1.50×10^6~2.34×10^6, respectively. The correlations between Mooney viscosity and Wallace plasticity, Mooney viscosity and molecular weight were also found.*

Key words: properties: latex-timber clones; latex yields; dry rubber content (DRC); Mooney viscosity; SMR-CV; Wallace plasticity; molecular weight

The properties of natural rubber (NR) are governed by many factors, such as the clonal origin of the tree, weather, use of stimulant, tapping methods, rubber processing methods, of which the clonal origin is an inherent property of the rubber tree. Therefore, it is important for the rubber grower to select rubber clones which give high latex yield. In addition, the rubber should also have good processing properties, *e.g.* it should conform to the specifications stipulated in the Standard Malaysian Rubber (SMR) Scheme. Besides producing rubber, the trees are also an important source of timber, particularly for high quality furniture applications. On account of this, demand for rubberwood in the industries has increased tremendously in recent years[1]. Therefore, attention is also being paid to the vigorous

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growth rate of trees for high timber yield in the selection of rubber clone. Over the years, many rubber clones that have the potential of producing high latex and timber yields, or the latex timber clones, have been bred by the Rubber Research Institute of Malaysia (RRIM), and the latex and timber yields have been reported[2,3]. However, the properties of the rubber from these clones have yet to be studied.

The preliminary results of this study, including latex concentrate, have been published recently[4]. This paper reports some of the properties of rubbers from 28 latex-timber clones with special reference to the specifications of the SMR constant viscosity (CV) scheme.

EXPERIMENTAL

All the latex samples were collected from rubber trees planted in the RRIM Experiment Stations in Sungai Buloh and Kota Tinggi, and Banedoch Estate, Malaysia every three months. Each clone was studied for at least four times. The results of the studies are reported as average values. RRIM 600 was used as a control clone in the present study. The rubber trees were tapped on the ½S, d/2 system. The latices from different trees of the same clone were co-mingled and stabilised with 0.08% ammonia. In addition, 0.15 p.p.h. rubber of hydroxylamine neutral sulphate was added to the latices before coagulation with formic acid at pH 5~5.2. The coagula were then crumbled, washed and dried at 100°C. Mooney viscosity, Wallace plasticity, Plasticity Retention Index (PRI), nitrogen content, degree of storage hardening, dirt content and ash, were determined using the standard test methods[5]. Cure study was carried out using a Monsanto rheometer according to the method described in *ISO 3417*.

The rubber samples for molecular weight analysis were allowed to dissolve in tetrahydrofuran (THF) at 0.1~0.15%w/v for 24 h in the dark. The samples were then filtered through a 0.45 µm filter. Gel Permeation Chromatography (GPC) measurements were carried out with a Waters GPC system, consisting of a Waters 2690 Separation Module and a Waters 410 Differential Refractometer. Three columns, packed with crosslinked polystyrene, with the exclusion limits of 2×10^8, 5×10^6, and 5×10^5, connected in series, were used for the GPC measurement. Commercial standard polystyrenes were employed for the calibration of the columns. The measurements were made at 40°C, and the flow rate of the mobile phase, THF, was 0.8 ml/min. The molecular weights of the rubber samples are expressed as polystyrene-equivalent values.

RESULTS AND DISCUSSION

Dry Rubber Content (DRC)

The DRC value is the percentage of rubber in the latex, which is obtained from acid coagulation of the latex, washed with water and followed by oven drying process. The results on DRC of the latices are summarised in *Table 1*. Of the 28 clones, 6 were found to give average DRC values, similar to that of the control sample, RRIM 600. These clones are either RRIM 900 series or PB clones. Most of the RRIM 2000 series clones showed high DRC values, *i.e.* above 41%, indicating that the fast growing and high yielding clones tend to produce latices of high DRC. None of the clonal latices had the DRC value below 34%. These findings are different from those of a previous study on other clones where most of the latices had average DRC values[6].

TABLE 1. DRY RUBBER CONTENT OF LATICES FROM VARIOUS CLONES

Below average (31% – 34%)	Average (34% – 38%)	Above average (38% – 41%)	High (>41%)
–	PB 260	PB 355	Q 60/2
	PB 366	PB 359	PB 350
	RRIM 936	RRIM 901	RRIM 908
	RRIM 937	RRIM 929	RRIM 911
	RRIM 938	RRIM 2002	RRIM 921
	RRIM 940	RRIM 2009	RRIM 928
	RRIM 600[a]	RRIM 2014	RRIM 2001
		RRIM 2023	RRIM 2008
			RRIM 2015
			RRIM 2016
			RRIM 2020
			RRIM 2024
			RRIM 2025
			RRIM 2026

[a]Control

Bulk Rubber Properties

The specifications for SMR-CV grade NR are shown in *Table* 2. Of the specifications listed in *Table 2*, the dirt and volatile matter contents are not related to the clonal characteristics of the NR. Dirt content is a measure of the contamination level of the rubber during the processing of latex into dry rubber. On the other hand, there are many factors that lead to high volatile matter content. These include highly ammoniated latices, high DRC, inefficient shear during crepeing, variable crumb size, and faulty drier with uneven temperature distribution. Despite this, the dirt and volatile matter contents of the rubber samples were also determined to check the possibility of contamination. The results showed that the dirt content of all the samples was well below the limit of 0.02% while the volatile matter content was also well below 0.8%. The results for other characteristics are summarised in *Table 3*.

Mooney viscosity (V_R). It is a measure of hardness and is closely related to the processability of the rubber. Thus, a high V_R rubber normally requires a longer mastication time. The results of the V_R measurements are shown in *Table 3*. The variation in the V_R values was found to be wide, *i.e.* from 37.6 to 96.8. The various clones are classified according to the V_R value of their rubber in *Table 4*. About half of the clones showed either high or medium high V_R values which do not satisfy the requirement of SMR-CV 50 and SMR-CV 60. However, one clone, *i.e.* RRIM 2023 showed a very low V_R value. Since commercially produced bulk rubber is normally a blend of latices from different rubber clones, the low V_R rubber from such clone could be very useful for blending with the high V_R rubber to achieve a satisfactory V_R value.

Initial Wallace plasticity. The initial Wallace plasticity (P_o) of NR is not listed in the specifications of SMR-CV scheme. However, it is also

TABLE 2. SPECIFICATIONS OF SMR-CV 50 AND SMR-CV 60

Parameters	SMR-CV 50	SMR-CV 60
Dirt	0.02% max	0.02% max
Ash	0.5% max	0.5% max
Nitrogen content	0.6% max	0.6% max
Volatile matter	0.8% max	0.8% max
Plasticity Retention Index (PRI)	60% min	60% min
Mooney Viscosity (V_R)	50 ± 5	60 ± 5
Degree of storage hardening (ΔP)	8 units max	8 units max

a method of measuring the hardness of NR. Like V_R, it is influenced by molecular weight and gel content of the NR. The P_o values for the clonal rubbers were found to vary from 26 to 51, as shown in *Table 3*. Except for 4 clones, the clonal rubbers in the present study had the P_o value above 30 units. Under the non-CV SMR scheme, a rubber is considered to be too soft if the P_o value is below 30 units.

Correlation between Mooney viscosity and initial Wallace plasticity. The correlation between V_R and P_o has been reported previously[6]. The relationships are shown in *Figure 1* and are found to be $V_R = 1.92\ P_o - 1.60\ P_o$, correlation coefficient r = 0.95, P<0.001. This is quite different from the correlation reported in the two previous studies[6,7], where $V_R = 1.38\ P_o + 7.01$, r = 0.95, P<0.001, and $V_R = 1.21\ P_o + 12.0$, respectively. The difference could be due to minor variations in the experimental procedures. This could result in variations in the samples such as gel content. For example, in a previous study[6]. more than 80% of the P_o values were above 40 units compared to the figure of less than 40% in the present study. Therefore, unless the latices are processed into NR in the same manner, the correlation is not applicable to any other unknown NR.

Degree of storage hardening (ΔP). Storage hardening is a unique phenomenon of NR where the rubber viscosity tends to increase during storage under ambient conditions over a period of years. The process is due to crosslinking reaction of the abnormal groups on the rubber molecules. It can be stopped by adding a monofunctional amine, such as hydroxylamine, to the latex before coagulation. Technically specified rubbers that have been treated with hydroxylamine are known as constant viscosity or CV grade. The process can be accelerated by heating the rubber at an elevated temperature in the presence of a desiccant. The degree of storage hardening of the CV grade rubbers provides an indication on the effectiveness of the reagent added to the rubber in stabilising the viscosity or plasticity. The results are shown in *Table 3*. All the rubbers were found to give ΔP values below the maximum limit of 8 units, the specification indicated in *Table 2*. Except for four clones, most of the rubbers were found to have ΔP values below 6 units, indicating that the amount of hydroxylamine added to the latex is sufficient to stop the storage hardening process. For samples that showed ΔP values close to the maximum limit, more hydroxylamine might be required.

TABLE 3. PROPERTIES OF SMR-CV RUBBERS FROM DIFFERENT CLONES

Clone	V_R		PRI		Ash (%)		Nitrogen (%)		ΔP		P_o	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
PB 260	57.8	1.3	91	2	0.27	0.03	0.38	0.01	3.0	0.3	32.8	1.4
PB 350	64.0	4.0	87	3	0.32	0.01	0.38	0.03	3.8	0.3	36.2	1.6
PB 355	66.0	3.0	88	1	0.32	0.04	0.37	0.02	4.5	1.4	39.0	3.0
PB 359	67.0	4.4	89	1	0.25	0.01	0.39	0.02	4.5	1.4	37.7	2.8
PB 366	58.3	1.5	89	2	0.32	0.01	0.44	0.01	3.5	1.0	32.5	1.0
Q 60/2	68.1	7.1	87	13	0.23	0.08	0.36	0.04	4.5	1.3	40.1	2.6
RRIM 600	61.1	5.6	86	5	0.23	0.04	0.43	0.04	3.2	0.8	31.7	2.5
RRIM 901	61.2	1.9	89	1	0.42	0.12	0.39	0.01	3.2	0.7	24.7	2.5
RRIM 908	95.3	3.5	84	3	0.37	0.01	0.38	0.02	3.3	1.4	51.8	6.0
RRIM 911	74.5	3.3	86	1	0.37	0.08	0.40	0.01	3.5	0.3	41.7	3.0
RRIM 921	93.5	1.1	81	1	0.34	0.02	0.39	0.03	5.1	0.6	48.0	3.5
RRIM 928	57.0	1.8	89	4	0.31	0.02	0.41	0.03	2.9	1.5	31.4	3.5
RRIM 929	70.3	5.5	85	3	0.30	0.05	0.38	0.04	3.2	1.0	38.0	1.7
RRIM 936	48.9	5.2	90	4	0.28	0.04	0.47	0.01	5.4	2.3	26.3	2.0
RRIM 937	52.1	7.2	90	4	0.28	0.07	0.45	0.05	5.5	3.3	28.3	2.4
RRIM 938	50.8	4.9	87	4	0.24	0.03	0.46	0.09	5.1	2.3	27.1	2.1
RRIM 940	61.0	3.5	86	8	0.26	0.04	0.47	0.06	5.4	2.2	32.5	3.4
RRIM 2001	63.0	3.5	90	4	0.34	0.07	0.40	0.03	7.7	2.0	32.8	3.2
RRIM 2002	85.2	8.1	79	2	0.19	0.07	0.37	0.01	4.0	1.0	39.7	3.0
RRIM 2008	75.1	3.2	90	1	0.28	0.02	0.36	0.03	6.7	1.0	40.9	1.7
RRIM 2009	51.5	3.2	87	3	0.31	0.06	0.42	0.06	5.1	1.0	27.0	1.9
RRIM 2014	63.0	4.0	88	3	0.29	0.04	0.43	0.04	6.4	1.2	31.4	2.5
RRIM 2015	93.5	3.6	79	4	0.30	0.06	0.34	0.02	5.2	0.7	42.1	2.3
RRIM 2016	81.3	4.5	85	9	0.31	0.05	0.37	0.03	5.6	0.9	42.4	2.2
RRIM 2020	96.4	3.2	81	3	0.23	0.02	0.35	0.06	5.9	1.7	43.9	2.8
RRIM 2023	37.6	2.8	94	4	0.35	0.05	0.44	0.09	5.8	1.5	19.8	1.2
RRIM 2024	69.7	9.9	89	6	0.33	0.04	0.39	0.04	7.4	1.8	37.3	4.6
RRIM 2025	96.8	5.9	81	6	0.22	0.03	0.35	0.05	4.7	1.0	52.1	2.7
RRIM 2026	83.4	9.3	84	7	0.25	0.05	0.32	0.03	4.6	1.3	49.8	2.0
Range	37.6 to 96.8		79 to 94		0.19 to 0.42		0.32 to 0.47		2.9 to 7.7		26.3 to 52.1	

S.D. : Standard deviation; V_R: Mooney viscosity; PRI: Plasticity Retention Index
ΔP : Degree of accelerated storage hardening as measured by the Wallace plastimeter
P_o : Initial plasticity

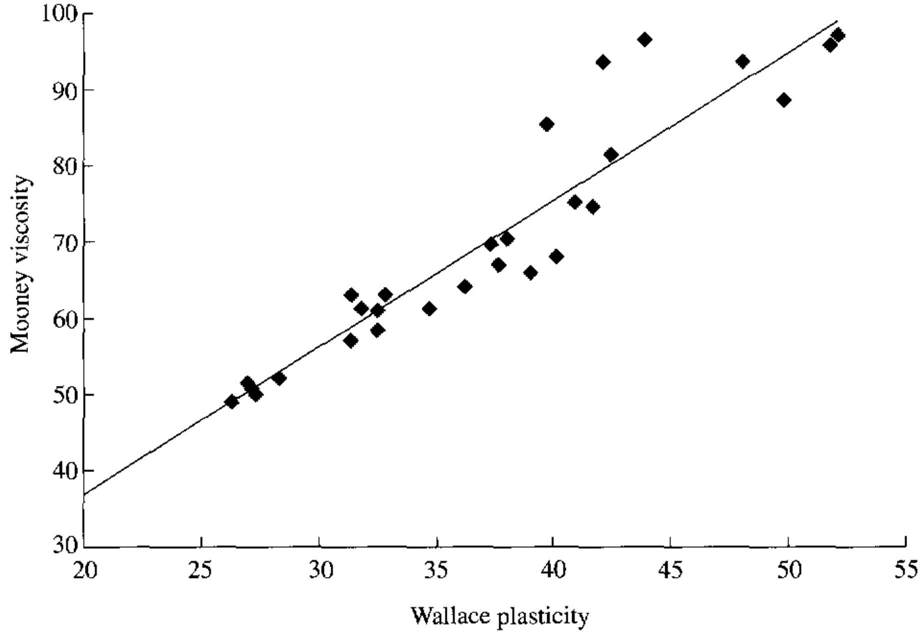

Figure 1. Correlation between Mooney viscosity and Wallace plasticity of NR.

TABLE 4. THE V_R VALUES OF NR FROM DIFFERENT CLONES

Low (<45)	Medium low (45 – 55)	Medium (55 – 65)	Medium high (65 – 75)	High (>75)
RRIM 2023	RRIM 936	PB 260	Q 60/2	RRIM 908
	RRIM 937	PB 350	PB 355	RRIM 921
	RRIM 938	PB 366	B 359	RRIM 2002
	RRIM 2009	RRIM 901	RRIM 911	RRIM 2008
		RRIM 928	RRIM 929	RRIM 2015
		RRIM 940	RRIM 2024	RRIM 2016
		RRIM 2001		RRIM 2020
		RRIM 2014		RRIM 2025
		RRIM 600[a]		RRIM 2026

[a]Control

Plasticity retention index (PRI). This value is a measure of the ability of the rubber to resist degradation when it is heated in an oven at 140°C for 30 min. The level of degradation during the heating is assessed using the Wallace plasticity value. PRI is calculated from the following equation:

$$PRI\,(\%) = (P_{30} / P_o) \times 100 \qquad \dots 1$$

where P_{30} is the aged plasticity and P_o is the plasticity before ageing in the oven.

During the heating of the rubber, both thermal degradation and crosslinking reactions *via* radical mechanisms may occur simultaneously. In addition, non-radical crosslinking reaction that are due to abnormal groups of NR may also take place. Therefore, the P_{30} value is the net result of all these reactions. The results in *Table 3* indicated that most of the rubbers had the PRI values of 80% – 90%, showing that the ageing resistance of the rubber was reasonably good. From the definition. it is not difficult to see that the PRI value depends on the initial plasticity, P_o. Therefore. it is reasonable to expect that the rubbers with a higher P_o value would tend to have a lower PRI value. This is because such rubbers normally contain a lower concentration of the abnormal groups, which are responsible for the non-radical crosslinking reaction in the storage hardening process. A large portion of the abnormal groups in the rubber with high P_o value had been consumed in the crosslinking reaction during the storage of the latex in the tree or during the processing of the latex into dry rubber[7]. *Figure 2* shows the correlation between the PRI and P_o value. The

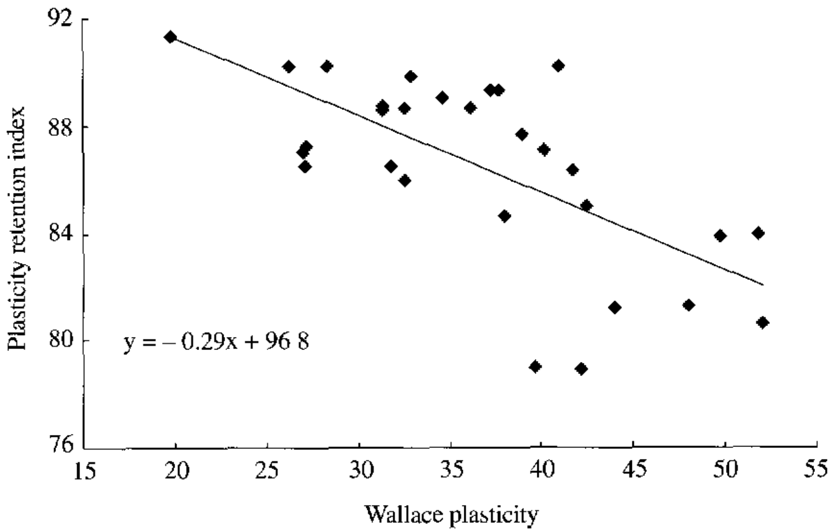

Figure 2. Correlation between Plasticity Retention Index and Wallace plasticity of NR

plot yields PRI = −0.287 P_o + 96.97 with a correlation efficient, r = −0.662, P<0.001. This correlation is better than that found in the previous study[6] where PRI = −0.09 P_o + 88.59, with r = −0.16, P = 0.01.

Ash. The ash component of natural rubber is derived from mineral constituents. In most cases, a high ash content is related to a high dirt content[8]. However, there are cases where it is due to the presence of high calcium content of the latices[8]. As indicated in *Table 3*, most of the clones showed an ash content of 0.2% – 0.4%, which is within the specification of the SMR-CV rubbers.

Nitrogen content. Most of the nitrogenous materials in NR are proteins. The main reason for including nitrogen limits in the specification of SMR-CV scheme is to prevent the adulteration by skim rubbers. However, rubber from certain newly tapped clones may have a high intrinsic nitrogen value. It may be due the application of fertiliser containing a high nitrogen content[8]. Since the rubber trees in the present investigation were regularly tapped and no high nitrogen fertiliser was used, the nitrogen content of the clonal rubbers would be expected to be in the normal range. The results in *Table 3* confirm that the nitrogen content of the clonal rubbers was in a narrow range of 0.32% to 0.47%, below the limit of 0.6%.

Cure characteristics. Cure characteristics are not specified in the SMR-CV scheme. However, the rheograph and cure test data, *i.e.* torque modulus, optimum cure time and scorch time are required to be included. As indicated in *Table 5*, the torque modulus (ΔT) for the clonal rubbers varied from 2.87 Nm to 3.44 Nm, which is similar to those of the previous study[6] of 3.01 Nm to 3.81 Nm. Most of the rubbers had the ΔT value above 3.00 Nm except for two clones, *i.e.* RRIM 929 and RRIM 2025. The scorch time was in the range of 1.5 min to 2.3 min, which was similar to that reported in the previous study, *i.e.* 1.6 min to 2.3 min. The range of optimum cure time of 9.4 min to 13.1 min, found in the present study, was similar to that of 9.6 min to 12.3 min reported in the previous work[6].

Molecular Properties

Molecular weight ($\overline{M}_W$) and molecular weight distribution (MWD). Besides Wallace plasticity and Mooney viscosity, molecular weight is another way of assessing the processability of NR. The results of molecular weight and molecular weight distribution of the clonal rubbers as determined by GPC method are indicated in *Table 6*. The number average molecular weight ($\overline{M}_n$) of the clonal rubbers was found to be in the range of 2.77×10^5 to 7.06×10^5. Although the variation was rather large, most of the $\overline{M}_n$ values of the clonal rubbers were actually in the range of 4.00×10^5 to 5.00×10^5. Only three clonal rubbers showed the $\overline{M}_n$ value above 6.00×10^5. As indicated in *Table 6*, the weight average molecular weight ($\overline{M}_w$) of the clonal rubbers, on the other hand, was in a narrower range of 1.50×10^6 to 2.34×10^6. The polydispersity ($\overline{M}_w/\overline{M}_n$) varied from 3.1 to 5.4.

In a previous study[7], the molecular weight distributions of natural rubber were classified into three types. They were: (1) distinctly bimodal distribution with peaks of nearly the same height; (2) distinctly bimodal with the smaller peak in the low molecular weight region, and (3) skewed unimodal distribution with a shoulder or a plateau in the low molecular weight region. The polydispersity, *i.e.* $\overline{M}_w/\overline{M}_n$, normally is the range of 2.5 – 10 with upper end value being type 1 and lower end value being type 3. The type of

TABLE 5. CURE CHARACTERISTICS OF THE RUBBERS FROM DIFFERENT CLONES

Clone	Optimum cure time (min)		Scorch time (min)		Torque modulus (Nm)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
PB 260	11.4	0.3	1.9	0.1	3.18	0.0
PB 350	11.7	0.3	0.9	0.1	3.13	0.1
PB 355	11.2	0.1	1.8	0.1	3.14	0.1
PB 359	11.3	0.4	1.9	0.1	3.12	0.0
PB 366	11.1	0.2	2.0	0.1	3.17	0.1
Q 60/2	10.6	1.3	1.8	0.2	3.23	0.3
RRIM 600	10.8	1.3	1.9	0.4	3.38	0.2
RRIM 901	9.4	0.6	1.5	0.2	3.30	0.1
RRIM 908	9.6	0.4	1.7	0.1	3.21	0.1
RRIM 911	9.8	0.4	1.6	0.1	3.10	0.1
RRIM 921	9.8	0.5	1.5	0.1	3.36	0.1
RRIM 928	10.9	0.7	1.8	0.1	3.23	0.1
RRIM 929	11.3	0.4	1.9	0.1	2.87	0.1
RRIM 936	10.0	0.5	2.0	0.1	3.30	0.1
RRIM 937	10.9	0.6	2.2	0.2	3.22	0.1
RRIM 938	11.1	0.4	2.3	0.1	3.14	0.1
RRIM 940	10.9	0.4	2.1	0.1	3.18	0.1
RRIM 2001	9.7	1.6	1.7	0.4	3.41	0.3
RRIM 2002	10.9	0.8	1.8	0.2	3.09	0.1
RRIM 2008	10.0	1.4	1.6	0.3	3.37	0.2
RRIM 2009	10.2	1.4	1.8	0.3	3.37	0.2
RRIM 2014	11.2	0.6	1.9	0.2	3.29	0.1
RRIM 2015	10.6	0.9	1.9	0.2	3.20	0.2
RRIM 2016	10.0	1.7	1.8	0.3	3.22	0.2
RRIM 2020	11.2	0.9	2.0	0.1	3.15	0.1
RRIM 2023	10.7	1.1	1.8	0.2	3.44	0.2
RRIM 2024	10.3	1.5	1.8	0.2	3.38	0.1
RRIM 2025	13.1	1.7	2.2	0.3	2.88	0.2
RRIM 2026	11.4	1.9	2.0	0.3	3.04	0.2
Range	9.4 to 13.1		1.5 to 2.3		2.87 to 3.44	

TABLE 6. MOLECULAR WEIGHT AND MOLECULAR WEIGHT DISTRIBUTION OF CLONAL RUBBERS

Clone	$\overline{M}_n \times 10^{-5}$		$\overline{M}_w \times 10^{-6}$		$\overline{M}_w/\overline{M}_n$	Type of MWD
	Mean	S.D.	Mean	S.D.		
PB 260	4.00	0.35	2.09	0.18	5.2	B
PB 350	4.73	0.42	2.16	0.42	4.6	B
PB 355	5.23	0.07	2.27	0.36	4.4	B
PB 359	3.76	0.14	2.00	0.32	5.3	B
PB 366	4.07	0.35	2.01	0.23	4.9	B
Q 60/2	5.60	0.14	2.19	0.38	3.9	U
RRIM 600	3.90	0.27	1.73	0.42	4.4	B
RRIM 901	4.70	0.49	2.20	0.42	4.7	U
RRIM 908	4.92	0.43	2.14	0.39	4.3	U
RRIM 911	5.00	0.63	2.29	0.47	4.6	U
RRIM 921	5.10	0.32	2.06	0.36	4.0	U
RRIM 928	3.77	0.72	1.92	0.42	5.1	B
RRIM 929	4.33	0.84	2.06	0.34	4.8	B
RRIM 936	3.27	0.18	1.63	0.23	5.0	B
RRIM 937	3.62	0.28	1.66	0.28	4.6	B
RRIM 938	3.27	0.15	1.52	0.13	4.7	B
RRIM 940	4.27	0.05	1.74	0.22	4.1	U
RRIM 2001	5.96	0.17	1.87	0.43	3.1	U
RRIM 2002	4.70	0.42	1.64	0.21	3.5	U
RRIM 2008	5.92	0.11	2.00	0.48	3.4	U
RRIM 2009	3.69	0.33	1.69	0.24	4.6	B
RRIM 2014	4.06	0.10	1.78	0.28	4.4	B
RRIM 2015	5.87	0.13	1.83	0.23	3.1	U
RRIM 2016	5.91	0.76	1.91	0.19	3.2	U
RRIM 2020	6.12	0.14	1.99	0.36	3.2	U
RRIM 2023	2.77	0.30	1.50	0.24	5.4	B
RRIM 2024	4.80	0.69	1.88	0.21	3.9	U
RRIM 2025	6.52	0.19	2.34	0.49	3.6	U
RRIM 2026	7.06	0.12	2.30	0.50	3.3	U
Range	2.77 to 7.06		1.50 to 2.34		3.1 to 5.4	

B: Distinctly bimodal
U: Skewed unimodal with a shoulder or a plateau in the low molecular weight region
S.D.: Standard deviation

molecular weight distribution for the clonal rubbers found in the present study is given in *Table 6*. The clonal rubbers showed either unimodal molecular weight distribution (type 3) or bimodal distribution (type 2). No type 1 distribution was observed in the present study.

Most of the samples with unimodal distribution showed the polydispersity values below 4. From *Table 4*, it can be seen that most of these samples are of medium high or high V_R values. The bimodal distribution of NR can be considered to be the sum of two unimodal distributions, arising from two different enzyme systems involved in the biosynthesis of NR with each being responsible for one of the two distribution. The presence of higher proportion of high molecular weight polymer in the unimodal rubbers indicates that the enzyme system that produces high molecular weight rubber is predominant. Such enzymatic system is expected to have higher enzymatic activity than the other that produces low molecular weight rubber in the biosynthesis. On account of this, high DRC latices with rubbers having high V_R value, unimodal molecular weight distribution, and lower polydispersity were obtained.

Relation between molecular weight and Mooney viscosity. Since a previous study[7] showed a correlation between V_R value and $(\overline{M}_n\overline{M}_w)^{1/2}$, such correlation was examined for the clonal rubbers in the present study. The results are shown in *Figure 3*. A linear regression of the following correlation was obtained:

$$\log V_R = 1.1 \log (\overline{M}_n \overline{M}_w)^{1/2} - 4.8 \quad \ldots 2$$

$$r = 0.79, P<0.001$$

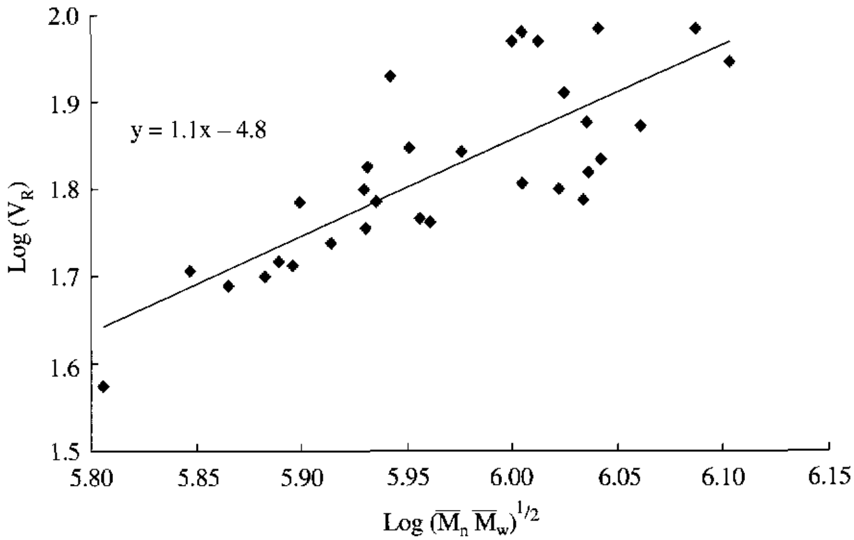

Figure 3. Correlation between Mooney viscosity and molecular weight of NR.

This is slightly different from the correlation found in the previous study[7], as shown in the following equation:

$$\log V_R = 0.98 \log (\overline{M}_n \overline{M}_w)^{1/2} - 3.9 \qquad \dots 3$$

$$r = 0.86$$

The difference could be due to the minor variations in experimental conditions employed as mentioned earlier. The correlation is useful for estimating the V_R value using the molecular weight data from GPC measurement, especially when the quantity of sample available is small because GPC measurement requires lower amount of sample than that of Mooney viscosity.

CONCLUSION

Most of the latices from the latex-timber clones, which produce high timber and latex yields, were found to have DRC above 38%. Except for the Mooney viscosity, all the viscosity-stabilised clonal rubbers could satisfy the specifications of the SMR-CV scheme. The Mooney viscosity values of 15 clonal rubbers were observed to be above 65 units, which did not fulfill the requirement of SMR-CV scheme. The latices of such rubbers need to be blended with latices of soft clonal rubbers before processing into dry rubber for SMR-CV production. Most of the clonal rubbers with a bimodal molecular weight distribution showed medium or lower V_R values, while those with unimodal molecular weight distribution showed medium high or high V_R values. The molecular weight of the clonal rubber could be correlated with Wallace plasticity and Mooney viscosity. However, such relationships are not universal and depend on the conditions employed to process the latices into dry rubbers.

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