CHAPTER IV

RESULTS

Effect of agitation speed without Papain treatment on the Mooney viscosity of raw rubber

To study the effect of agitation on Mooney viscosity of natural rubber, control experiment was performed using 25% DRC field latex at temperature 50°C for 1 hr except Papain was omitted. Figure 4.1 shows that agitation speed equal to 65 rpm or below have no effect on the Mooney viscosity of CV-NR comparing to no agitation at all. At agitation speed 75 rpm, an increase in Mooney viscosity of 7-8 unit was observed.

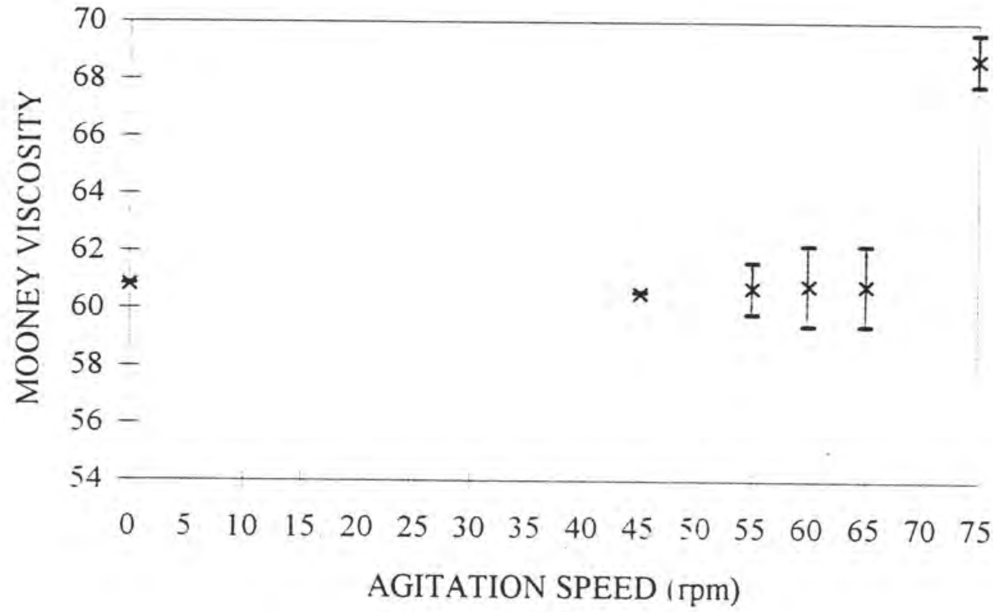


Figure 4.1 The effect of agitation speed on Mooney viscosity of CV-NR.

Fresh field latex was prepared to 25% DRC (total volume 4 l) and then stirred in the stirred tank at various agitation speeds. The final latex (4 l) was withdrawn and coagulated with steam. Dried rubber (3×150 g) was determined for total nitrogen content retaining in the rubber and for initial Mooney viscosity. Values reported are mean ± SD of 3 measurements.

Effect of agitation speed on deproteinization

To study effect of agitation speed on deproteinization by Papain, the optimal condition for deproteinization is between pH 7-8. The optimal temperature is 50°C and the optimal concentration of Papain is 0.3 p.h.r.

Field latex and Papain were preincubated at temperature 50°C before mixing and after reaction time of 1 hr. in a stirred tank of 41 cm inside diameter with an impeller of 28 cm. Agitation speeds of the impeller was varied in the range of 45-75 rpm.

After deproteinization, nitrogen content and initial Mooney viscosity of dried rubber was determined by Kjeldahl method and Mooney viscometer. Figure 4.2 shows that the percent nitrogen reduction depends on agitation speed. At the most suitable agitation speed of 60 rpm, the nitrogen content can be reduced to 0.05% which are lower than DPNR specification (N < 0.12%) and Mooney viscosity was 57.0.

At agitation speed ranging from 60-65 rpm, the nitrogen reduction was between 82% and 88% for 60 rpm and 65 rpm respectively. At agitation speed lower than 60 rpm, latex and enzyme solution was mixed ineffectively resulting in the nitrogen reduction about 70.2-82.1% and the remaining nitrogen content was about 0.08-0.14% respectively which is still higher than DPNR specification. At agitation speed higher than 65 rpm, latex was stirred rapidly until latex was unstable and partial coagulation occurred resulting in less nitrogen reduction about 74%. The final nitrogen content was 0.11%, which is slightly lower than DPNR specification.

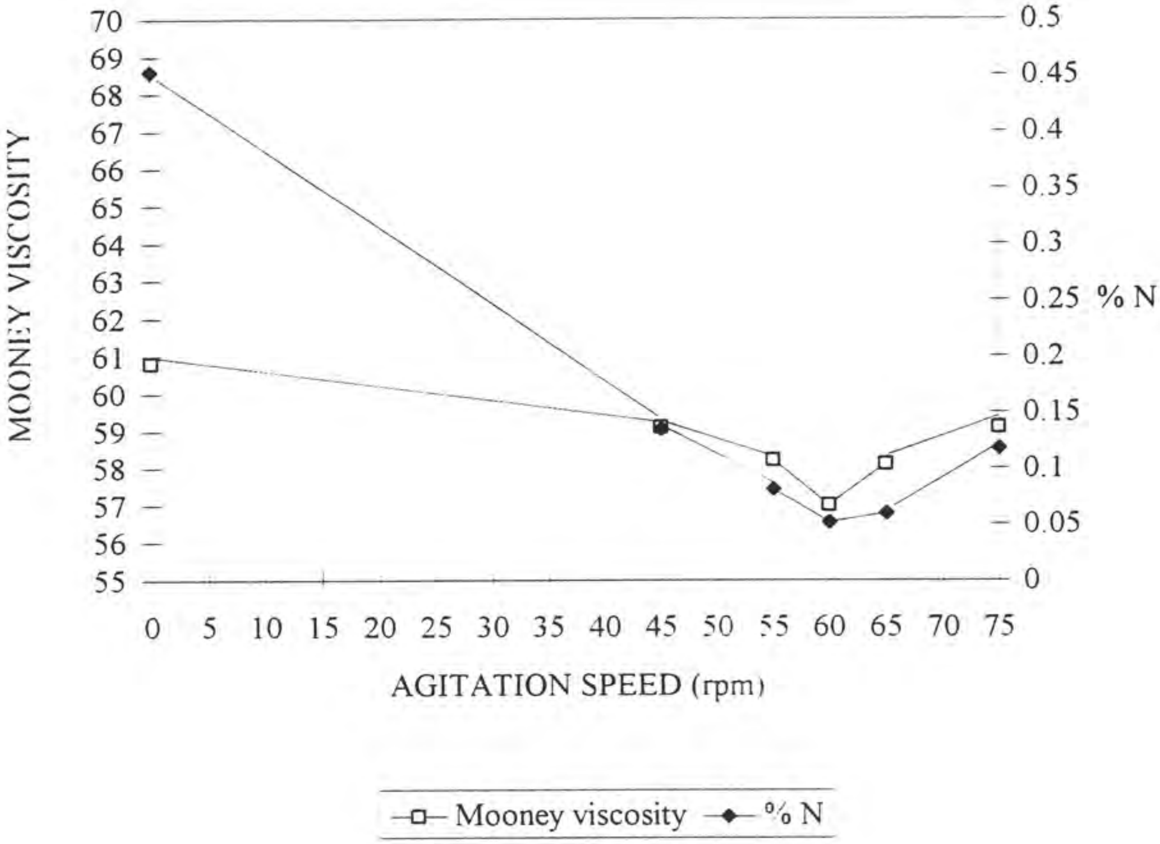


Figure 4.2 The effect of agitation speed on the Mooney viscosity and % nitrogen reduction of CV-DPNR

Field latex was adjusted to 25% DRC at pH 7-8 and 0.3 p.h.r Papain for deproteinization at 50°C. Agitation speed was varied from 0-75 rpm. After 1 hr, latex was collected, steam coagulated, creeped and dried. Dried rubber was determined for the Mooney viscosity and the remaining nitrogen content.

Effect of agitation speed on the rate of rubber storage hardening

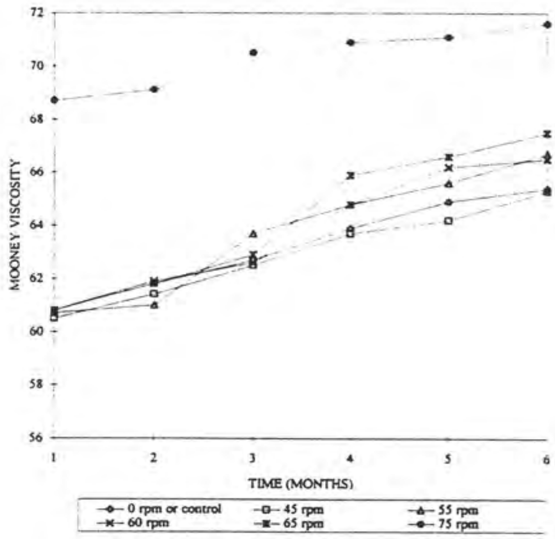
To study the effect of agitation speed on storage hardening or rate of increasing Mooney viscosity of CV-NR, field latex obtained from RRIM 600 rubber clone was stirred in the reactor without Papain treatment. Non-treated latex was coagulated with steam and dried at 60°C. Dried rubber at various agitation speeds was kept in room temperature and Mooney viscosity was determined each month as shown in Figure 4.3 (a).

At agitation speed 75 rpm, latex was stirred too vigorously resulting in the increase of Mooney viscosity of rubber. Besides at agitation 45 rpm, Mooney viscosity of CV-NR at agitation speeds ranging below 65 rpm is similar to its control.

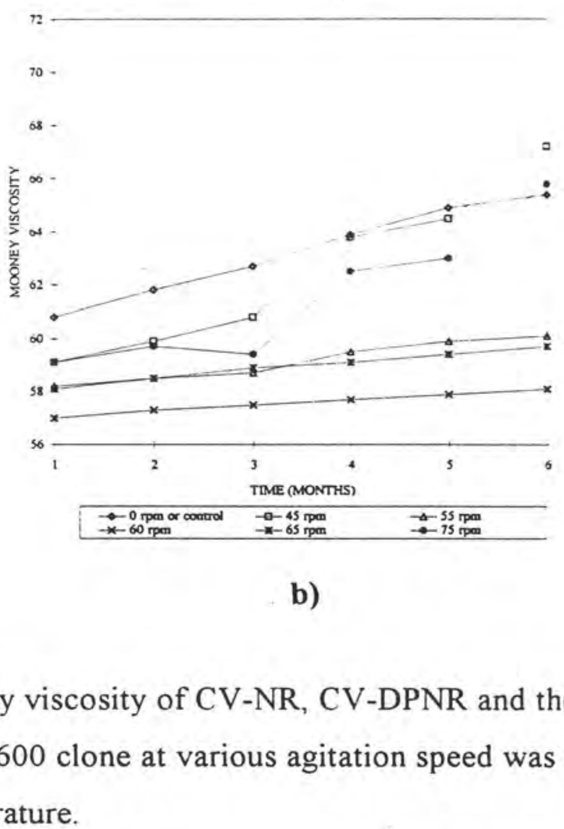
To investigate the effect of agitation speed on Mooney viscosity of CV-DPNR, field latex obtained from RRIM 600 clone was treated with Papain at the optimal condition. Agitation speeds was varied from 45-75 rpm. Rubber was stored at room temperature and Mooney viscosity determined for comparion with its control. Control was prepared by the same process but enzyme was not added.

As shown in Figure 4.3 (b), after enzyme digestion, the rubber has its initial Mooney viscosity less than the control. Rubber at agitation speed of 45 and 75 rpm has the highest initial Mooney viscosity of 59.1. The highest Mooney viscosity changes compared with control is at agitation speed of 45 rpm followed by 75 rpm, 55 rpm, 65 rpm and 60 rpm respectively.

Figure 4.3 (c), (d) and Table 4.1 show that CV-NR at 75 rpm and CV-DPNR at 60 rpm have the smallest rate of increasing Mooney viscosity of 0.48 rpm and 0.17 Mooney unit per month respectively.



a)



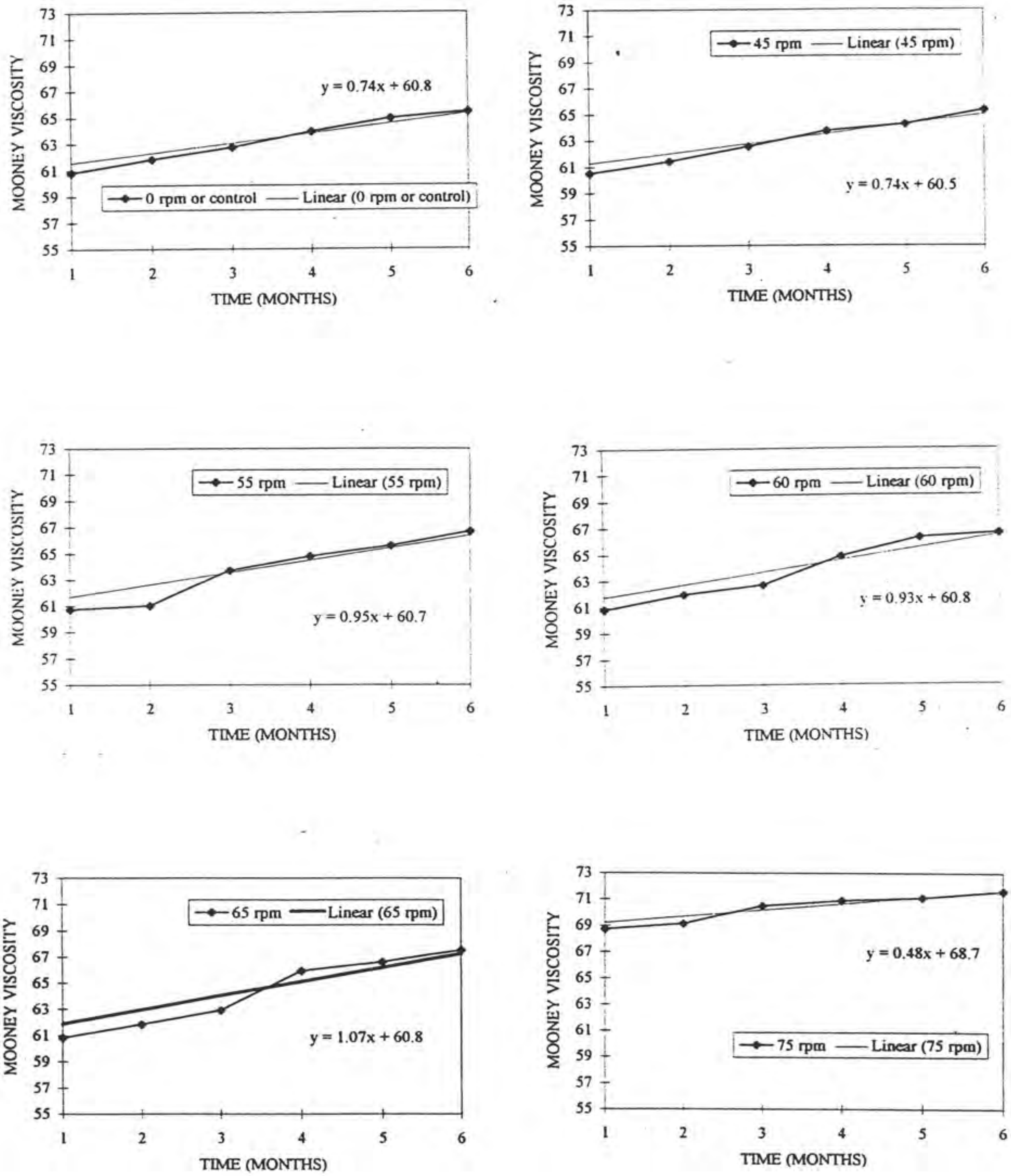
b)

Figure 4.3 Mooney viscosity of CV-NR, CV-DPNR and the control prepared from RRIM 600 clone at various agitation speed was stored at room temperature.

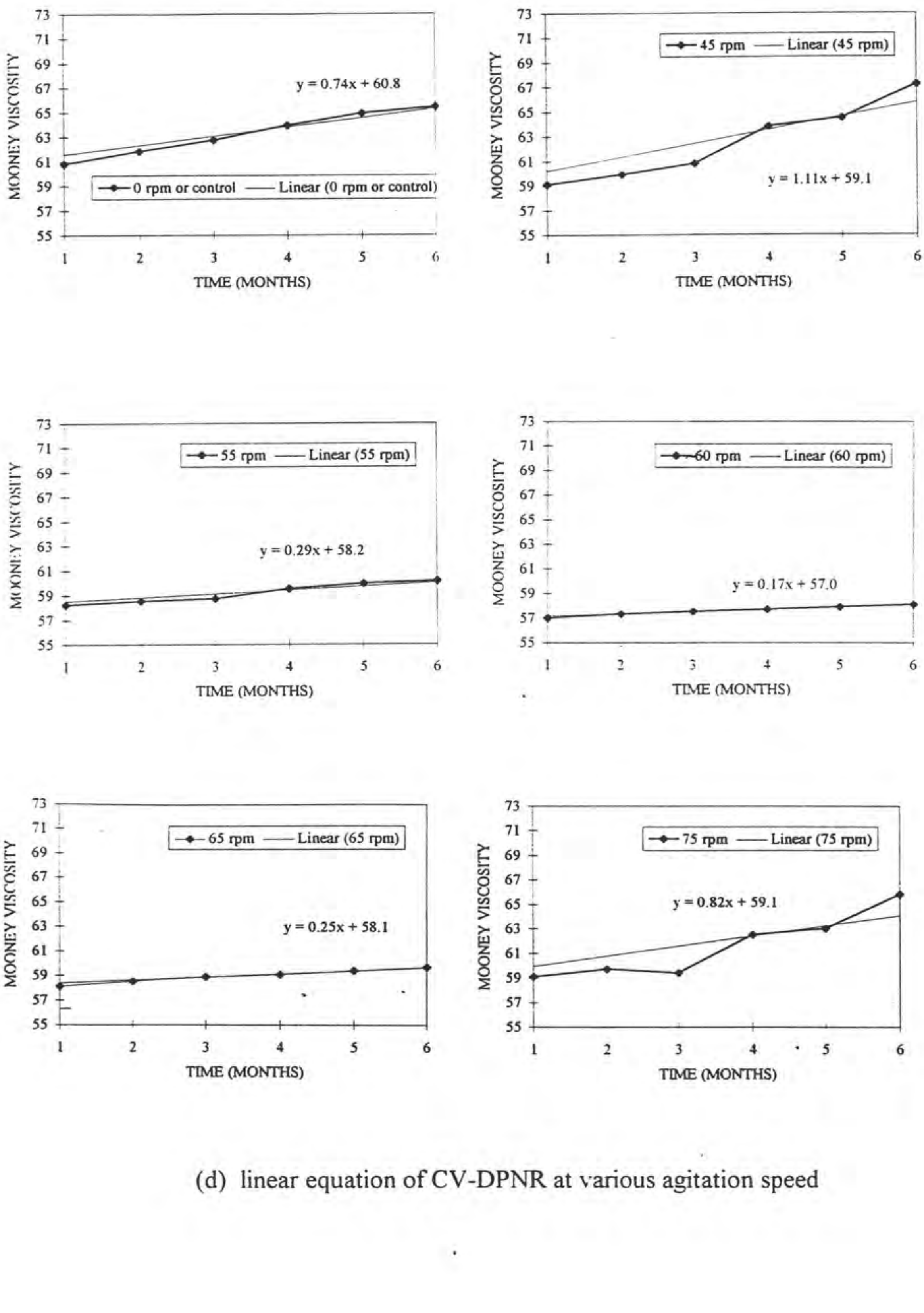
(a) For CV-NR (b) For CV-DPNR

(c) Linear equation of CV-NR (d) Linear equation of CV-DPNR

where: y = Mooney viscosity ; x = Time in month



(c) linear equation of CV-NR at various agitation speed



(d) linear equation of CV-DPNR at various agitation speed

Table 4.1 Linear equation of CV-NR and CV-DPNR at various agitation speed

Agitation speed (rpm)	Linear equation	
	CV-NR	CV-DPNR
control	y = 0.74x + 60.8	-
45	y = 0.74x + 60.5	y = 1.11x + 59.1
55	y = 0.95x + 60.7	y = 0.29x + 58.2
60	y = 0.93x + 60.8	y = 0.17x + 57.0
65	y = 1.07x + 60.8	y = 0.25x + 58.1
75	y = 0.48x + 68.7	y = 0.82x + 59.1

Where : slope = rate of storage hardening in Mooney unit/month

Intercept on y axis = initial Mooney viscosity at an agitation speed

Effect of protein on the rate of storage hardening in CV-NR and CV-DPNR

To investigate the effect of rubber storage on Mooney viscosity, Field latex from three different clones (RRIM 600, GT 1 and PB 5/51) were prepared as deproteinized rubber by Papain at optimal condition which are pH 7-8, Papain 0.3 p.h.r, at 50°C for 1 hr. Dried rubber was stored at room temperature and Mooney viscosity was determined each month as shown in Figure 4.4. The result shows that clone RRIM 600 has the lowest initial Mooney viscosity and clone PB 5/51 has the highest initial Mooney viscosity.

Mooney viscosity of all rubber clone depend on storage and processing.

For all three rubber clones, the Mooney viscosity of deproteinized rubber is lower than its control. There are variation in bulk viscosities between rubbers of different clone. PB5/51 has the highest Mooney viscosity followed by GT 1 and RRIM 600 respectively. For all the CV-rubber storage at room temperature for a long period of time resulting in an increase in Mooney viscosity about 1 Mooney unit/month for RRIM 600, and about 2 Mooney unit/month for GT 1 and PB 5/51 as shown in the upper lines of Figure 4.4 (a)-(c).

Comparison among the CV-DPNR of these three rubber clones, PB 5/51 has the highest rate of increasing Mooney viscosity (1.88 Mooney unit per month) and RRIM 600 has the lowest rate of increasing Mooney viscosity (0.13 Mooney unit per month) as shown in the lower linear lines in the lower linear lines in Figure 4.4 and Table 4.2.

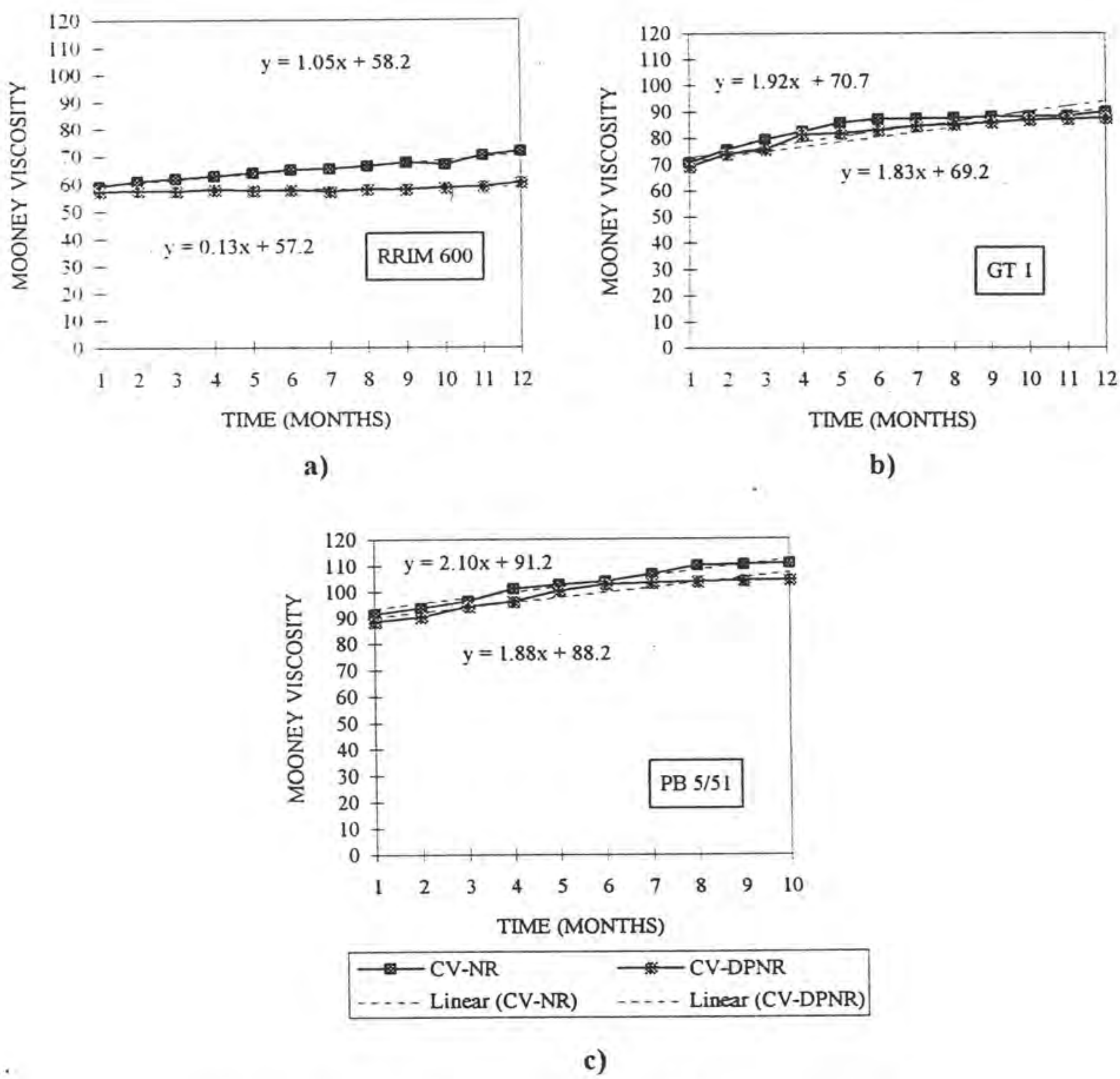


Figure 4.4 The effect of rubber storage on Mooney viscosity

The 25% DRC latex was prepared from field latex and then treated with Papain at optimal condition. After Papain digestion, the digested latex was coagulated by steam. Rubber coagulum was washed, dried in an air oven at 60°C. Mooney viscosity of dry rubber was determined by Mooney viscometer.

a) For RRIM 600 clone

b) For GT 1 clone

c) For PB 5/51 clone

Table 4.2 Linear equation of CV-NR and CV-DPNR from three different clones.

Clones	Linear equation	
	CV-NR	CV-DPNR
RRIM 600	$y = 1.05x + 58.2$	$y = 0.13x + 57.2$
GT 1	$y = 1.92x + 70.7$	$y = 1.83x + 69.2$
PB 5/51	$y = 2.10x + 91.2$	$y = 1.88x + 88.2$

Where : slope = rate of storage hardening in Mooney unit/month

Intercept on y axis = initial Mooney viscosity at agitation speed 60 rpm

Effect of agitation speeds on the rubber molecules

Rubber samples from clone RRIM 600 were treated with hydroxylamine hydrochloride for CV-NR production, and both hydroxylamine hydrochloride and Papain at various agitation speed. All rubber samples were prepared by the same procedure. Comparative study of MWD among CV-NR prepared at each agitation speed with its control (no agitation) are shown in Figure 4.6 (a)-(e) where the bimodal distribution can be observed, but the high molecular weight peak seems to be more sensitive to agitation speed 60-65 rpm. Figure 4.7 (a)-(e) shows the effect of agitation speed on the MWD of CV-DPNR in the similar way as CV-NR, this is agitation speeds between 55-65 rpm affect the MWD of rubber molecules more than 45 rpm and 75 rpm. Table 4.3 shows that RRIM 600 has weight average molecular weight (M_w) of about $1.0\text{-}1.3 \times 10^6$ and the number average molecular weight (M_n) of $1.6\text{-}2.8 \times 10^5$ with bimodal distribution. The polydispersity of RRIM 600 of CV-NR and CV-DPNR at various agitation speeds was in the range of 4.6-6.1 and 5.0-5.8 respectively. Agitation speed 75 rpm shows increasing effect on the Mn, Mw and reducing polydispersity of CV-NR, but has no apparent effect on CV-DPNR at all agitation speed tested.

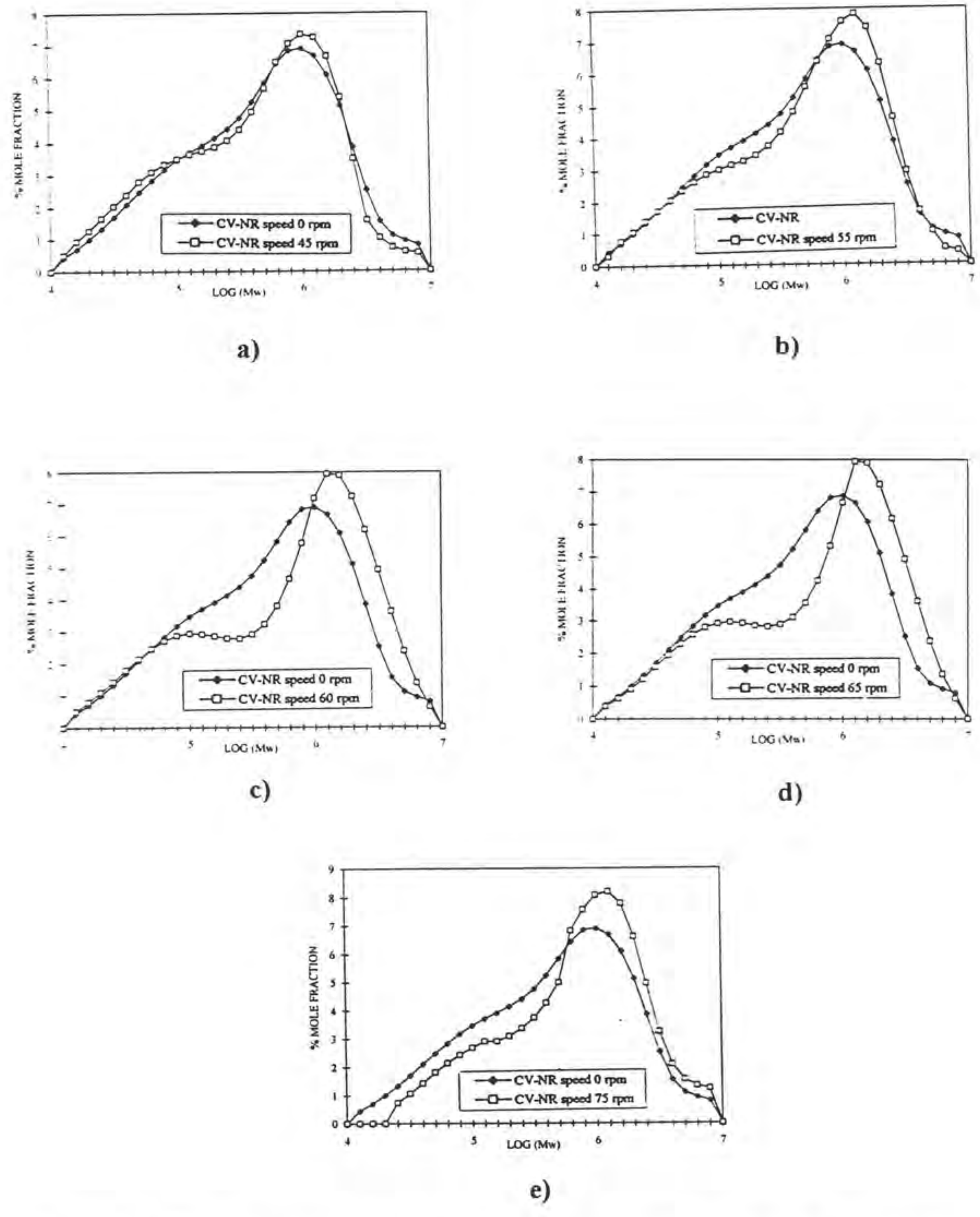


Figure 4.5 The comparative study of MWD between CV-NR with its control produced from RRIM 600 clone at various agitation speed.

a) 45 r.p.m b) 55 r.p.m

c) 60 r.p.m d) 65 r.p.m

e) 75 r.p.m

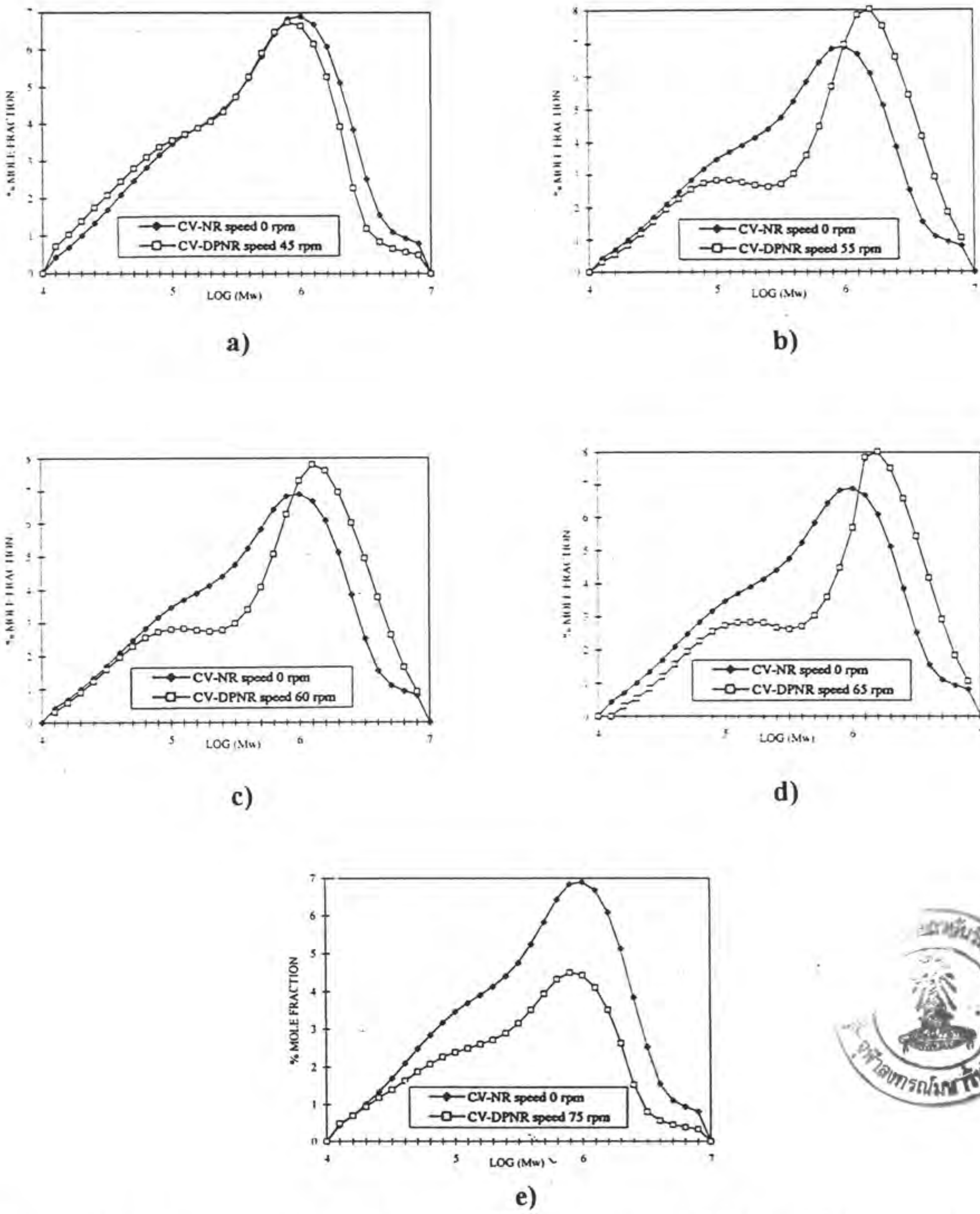


Figure 4.6 The comparative study of MWD between CV-DPNR with its control produced from RRIM 600 clone at various agitation speed.

a) 45 r.p.m
b) 55 r.p.m
c) 60 r.p.m
d) 65 r.p.m
e) 75 r.p.m

Table 4.3 Number average molecular weight (M_n), Weight average molecular weight (M_w), Molecular weight distribution (MWD) of CV-DPNR or polydispersity and its control prepared from rubber clone RRIM 600 at various agitation speed.

Agitation speed	CV-NR			CV-DPNR		
(rpm)	$Mn \times 10^{-5}$	$Mw \times 10^{-6}$	polydispersity	$Mn \times 10^{-5}$	$Mw \times 10^{-6}$	polydispersity
0	1.69	1.02	6.05	-	-	-
45	2.07	1.18	5.71	2.14	1.12	5.25
55	1.98	1.19	6.07	2.04	1.24	5.28
60	1.61	1.13	5.91	2.05	1.29	5.75
65	1.66	1.12	6.05	2.08	1.25	5.43
75	2.75	1.28	4.63	2.21	1.17	5.02

Effect of deproteinization on the rubber molecules.

Field latex from three different clones was prepared as 25% DRC and treated with 0.3 p.h.r of Papain concentration for 1 hr. at fixed agitation speed 60 rpm. Dried rubber sample was determined for Mn, Mw and MWD by GPC results are shown in Table 4.4 and Figure 4.5 (a)-(c).

Comparison of MWD between the CV-DPNR with its control produced from three rubber clones; RRIM 600, GT 1 and PB5/51. RRIM 600 showed the molecular weight (Mw) ranging from about 1.0-1.7 $\times$ 10^6 with the molecular weight (Mn) ranging from about 10^4-10^5. The Mw, Mn and MWD of rubber sample depend on rubber clonal characteristics. PB 5/51 has the highest weight average molecular weight and number average molecular weight of about 5.2-5.5 and about 1.5-1.7 respectively. RRIM 600 has the lowest number average molecular weight while GT 1 has the lowest weight average molecular weight. RRIM 600 has the highest polydispersity of about 5.0-7.6 followed by GT1 and PB 5/51 respectively. After deproteinization, the Mw, Mn and polydispersity have not changed significantly when compared with its control.

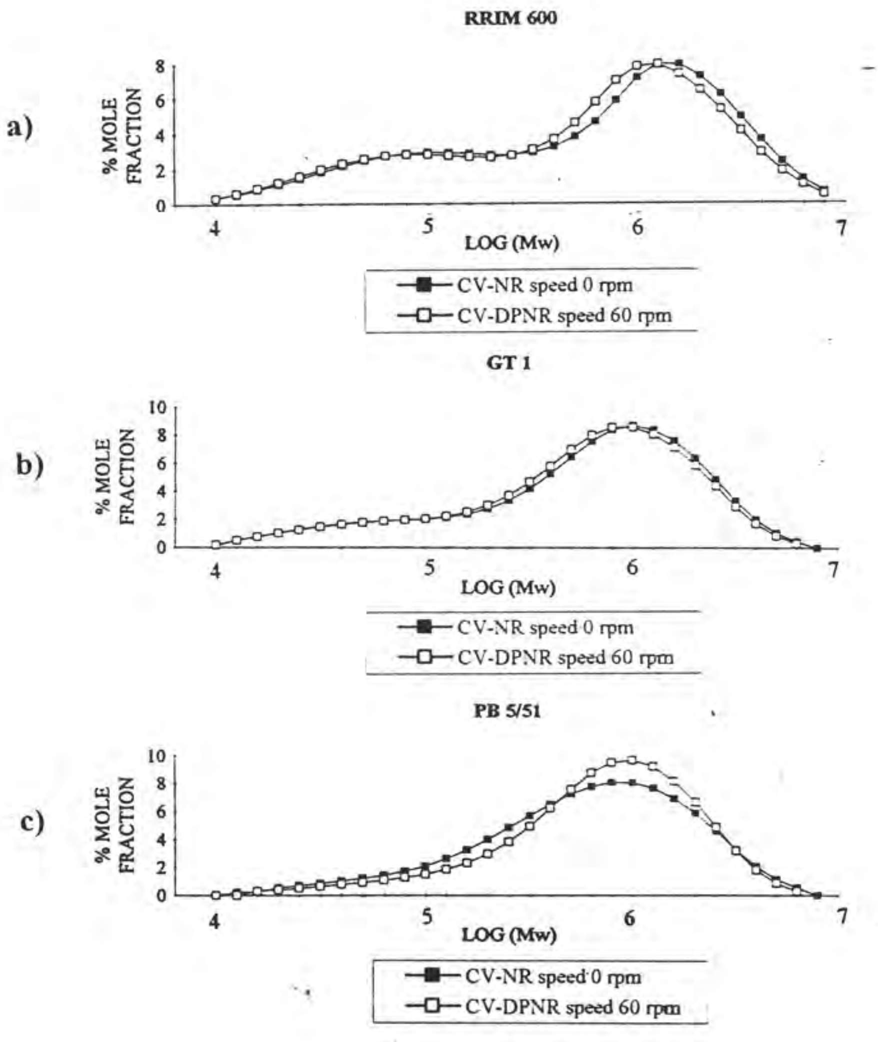


Figure 4.7 The comparative study of MWD between CV-DPNR at 60 rpm with its control at 0 rpm produced from three different rubber clones

a) RRIM 600 b) GT 1

c) PB 5/51

Table 4.4 Number average molecular weight (M_n), Weight average molecular weight (M_w), Molecular weight distribution (MWD) or polydispersity of CV-DPNR and its control prepared from three different clones.

Clones	CV-NR			CV-DPNR		
	$Mn \times 10^{-5}$	$Mw \times 10^{-6}$	Polydispersity	$Mn \times 10^{-5}$	$Mw \times 10^{-6}$	Polydispersity
RRIM 600	1.65	1.23	7.58	2.04	1.26	5.09
GT 1	2.08	1.19	5.78	2.04	1.09	5.36
PB 5/51	5.45	1.65	3.2	5.29	1.55	3.17

Optimization of Triton X-100 concentration for deproteinization by Alcalase

Triton X-100 or Nonidet P-40 is a stabilizing agent added to stabilize latex during enzymatic treatment. Concentration of Triton X-100 is varied between 0-1.20 p.h.r. Table 4.3 shows that Triton X-100 in the range of 1.10-1.15 p.h.r is the suitable concentration, because most reduced nitrogen content can be obtained, and stability of latex can be maintained during 1 hr. of enzyme treatment, and last but not least latex can be coagulated by steam at 121°C under pressure 15 lb/in^2 for 20 minutes. When concentration of Triton X-100 was lower than 1.1 p.h.r, autocoagulation of latex was observed during deproteinization resulting less efficient removal of nitrogen content, and concentration of Triton X-100 higher than 1.15 p.h.r was too difficult to coagulate with steam although latex was stabilized well.

Table 4.5 Stabilization effect of Triton X-100 on deproteinization of field latex by Alcalase.

Field latex was diluted to 25% DRC and stabilized with 0.90-1.20 p.h.r Triton X-100 before addition of Alcalase 0.4 p.h.r. at pH 8.5, temperature 60°C and agitation speed 60 rpm. After deproteinization, latex was collected, coagulated with steam. Coagulum was washed and dried at 60°C. Nitrogen content was determined by semi-micro Kjeldahl method.

Triton X-100 (p.h.r)	Clotting during Alcalase treatment	Clotting after coagulation by steam	% Nitrogen reduction
0.00	yes	yes	51.8
0.90	yes	yes	65.1
1.00	yes	yes	70.5
1.10	no	yes	74.8
1.15	no	yes	75.5
1.20	no	no	ND*

ND* - %N reduction was not determined because the latex was not coagulated.

Effect of time on deproteinization by Alcalase

By varying time of enzyme treatment in the range of 0-7 hours, Field latex was treated with Alcalase concentration of 0.4 p.h.r at 60°C. Figure 4.8 shows that the highest nitrogen reduction can be obtained after 4 hr. and the final nitrogen content of 0.11% can be obtained under this condition. At reaction time lower than 4 hr., latex has less reaction time resulting in a decrease in percent nitrogen reduction which is lower than at 4 hr.

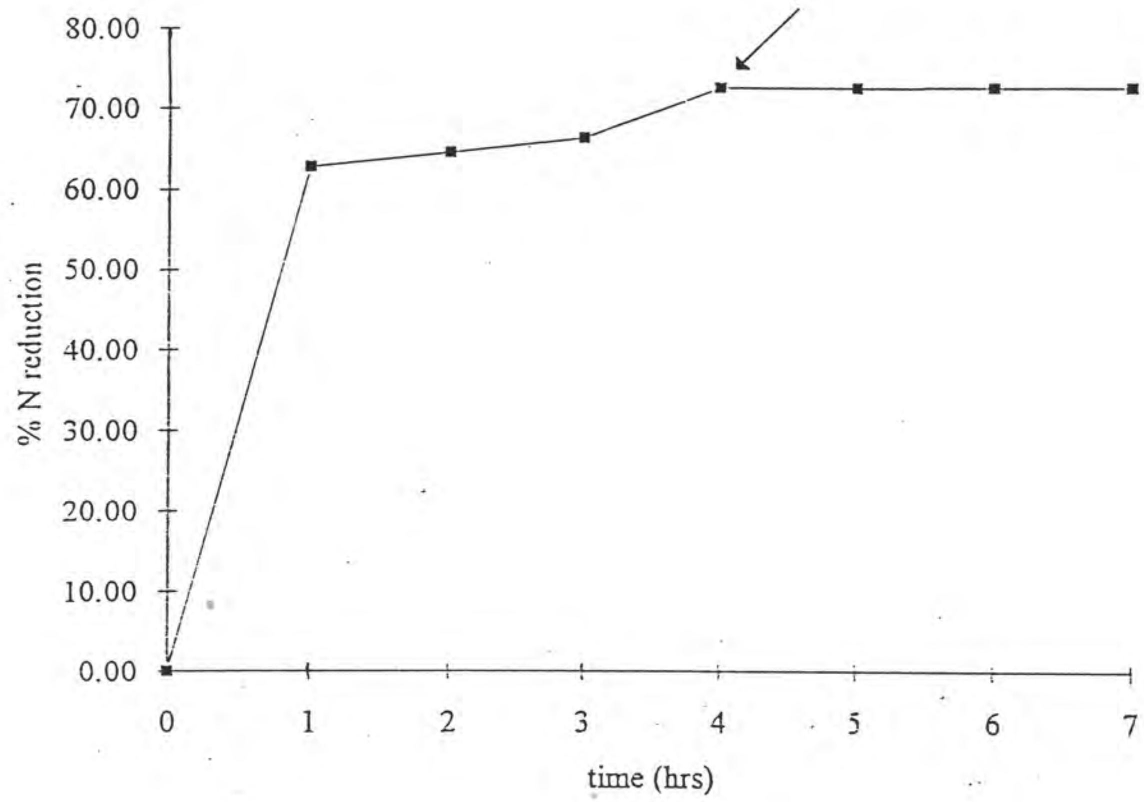


Figure 4.8 Effect of time on deproteinization

Latex (RRIM 600) was prepared to 25% DRC, 1.1 p.h.r. Triton X-100, adjusted to pH 8.5. The optimal condition for deproteinization by Alcalase is at 60°C and 0.4 p.h.r of Alcalase concentration in 41 cm diameter reactor at agitation speed of 60 rpm.

Properties of CV-DPNR

1. Physical properties of raw rubber

Effect of rubber clone

The physical properties of raw rubber was shown in Figure 4.9. Figure 4.9 (a) shows that the nitrogen content of CV-DPNR from all three rubber clones is lower than its control (CV-NR, 0 rpm). The nitrogen content of CV-DPNR from RRIM 600, GT 1 and PB 5/51 was reduced from 0.578, 0.599 and 0.401 to 0.065, 0.110 and 0.040 respectively. The PB 5/51 has the maximum percent nitrogen content reduction of 90% and GT 1 has the minimum percent nitrogen content reduction of about 82%. The remaining nitrogen content of CV-DPNR from three rubber clones is still lower than DPNR specification (%N < 0.12 %)

Figure 4.9 (b)-(d) show that dirt content and volatile matter of CV-DPNR are lower than its control. Both values for CV-DPNR are lower than DPNR specification (0.015 % and 0.5 %). The ash content of CV-DPNR is lower than CV-NR but still is higher than the acceptable limit (0.15%).

Figure 4.9 (e)-(f) show that Po of CV-DPNR has decreased about 1-5 units when compared with its control. The PRI of CV-DPNR is lower than its control. RRIM 600 has the highest PRI of 77.16 %. The PRI of CV-DPNR obtained from three rubber clones is higher than the limit. (> 60)

Mooney viscosity of CV-DPNR obtained from all rubber clones is lower than its control. RRIM 600 has the lowest Mooney viscosity of 57.0 but PB 5/51 has the highest value of 97.9. (Figure 4.9(g)) RRIM 600 has the lower color index than GT1 and PB 5/51. PB5/51 has the highest color index. (Figure 4.9 (h) and Figure 4.10)

Effect of enzyme

Clone RRIM 600 was selected for comparing between CV-DPNR prepared from Alcalase and Papain with its control (CV-NR, 0 rpm, no enzyme), the nitrogen content of Alcalase-treated rubber is higher than Papain-treated rubber is slightly lower than the limit. (% N < 0.12%).(Figure 4.11 (a))

The dirt, ash content and volatile matter of Alcalase-treated rubber are also higher than Papain-treated rubber. For both enzymes only the ash content that is slightly higher than 0.15% specification. The Alcalase-treated rubber has the lowest Po and PRI of 37.5 and 59.(Figure 4.11 (e)-(f)). Figure 4.11 (g)-(h) shows the Mooney viscosity of Alcalase-treated rubber is higher than Papain-treated rubber. Mooney viscosity of Alcalase-treated rubber decreased 1-2 units while Mooney viscosity of Papain-treated decreased 3-4 units. The Alcalase-treated rubber has higher color index than Papain-treated rubber. (Figure 4.11 (h) and Figure 4.12)

All these results indicate that the CV-DPNR produced by using Papain in the deproteinization step yield the higher quality of raw rubber.

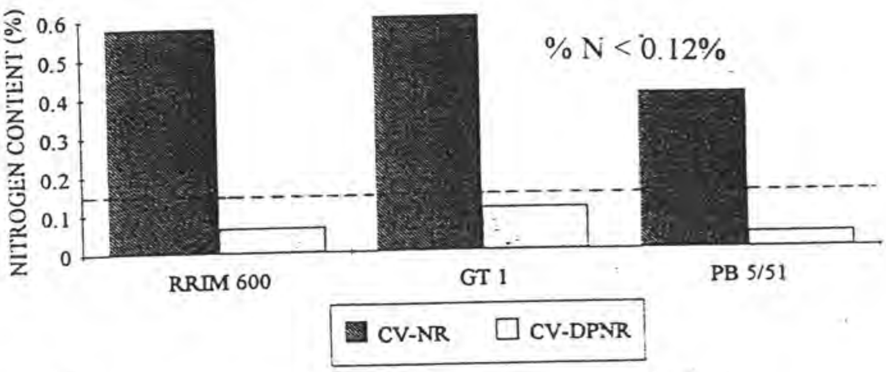
<u>Effect of agitation speed</u>

Comparing between CV-DPNR produced from clone RRIM 600 at various speeds of agitation with its control (CV-NR, no Papain) for their physical properties of raw rubber were shown in Figure 4.11 (a)-(h).

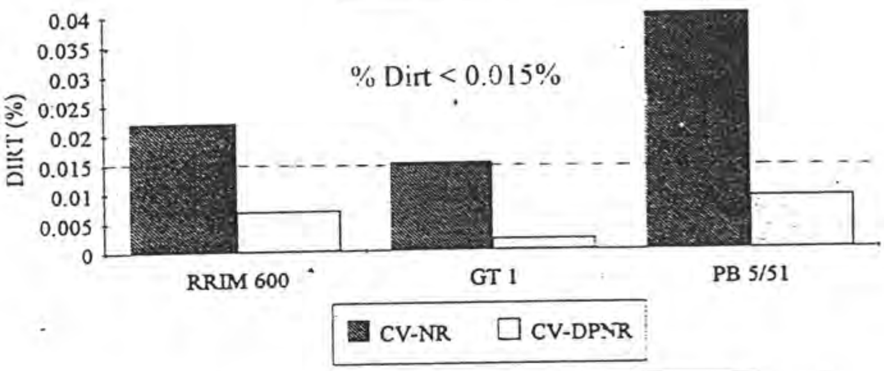
For CV-NR production, agitation speed has no significant effect on any physical properties because only small increase in PRI (60-75 rpm) and Mooney viscosity (75 rpm) were observed.

For CV-DPNR, agitation speed has no effect on ash content, volatile matter, Po, PRI and Mooney viscosity. The nitrogen content, dirt content and color was the lowest at agitation speed 60-65 rpm where the crosslinking density due to protein were minimized by Papain.

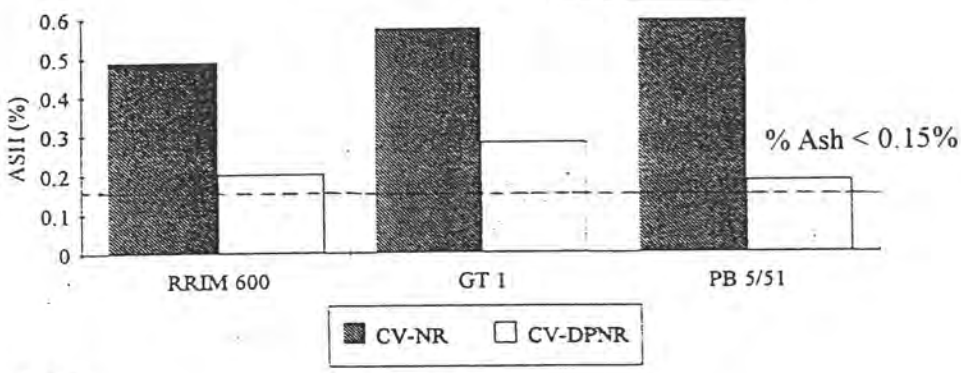
a)


NITROGEN CONTENT (%)
0.6
0.5
0.4
0.3
0.2
0.1
0
% N < 0.12%
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR

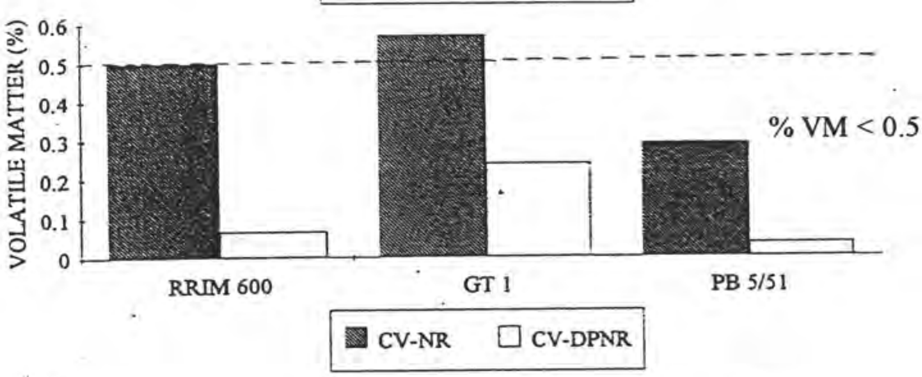
b)


DIRT (%)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
% Dirt < 0.015%
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR

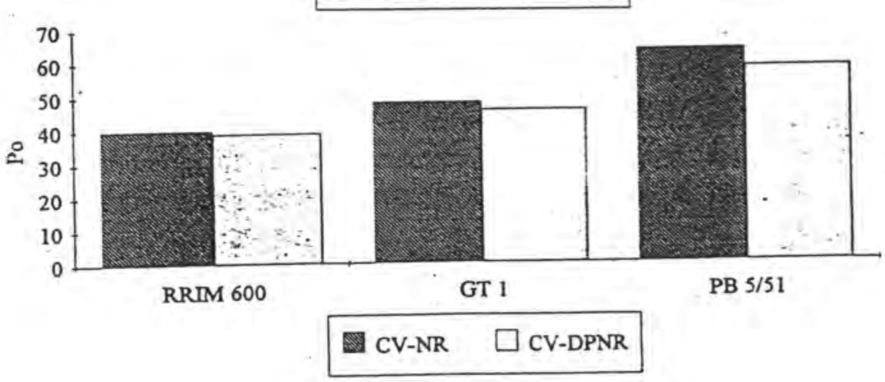
c)


ASH (%)
0.6
0.5
0.4
0.3
0.2
0.1
0
% Ash < 0.15%
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR

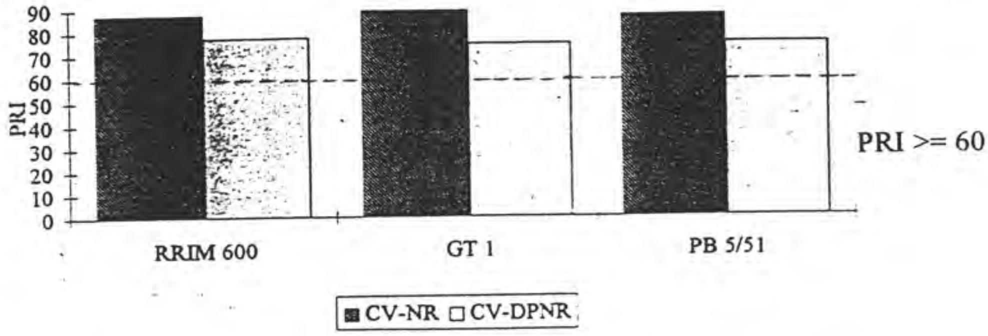
d)


VOLATILE MATTER (%)
0.6
0.5
0.4
0.3
0.2
0.1
0
% VM < 0.5
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR

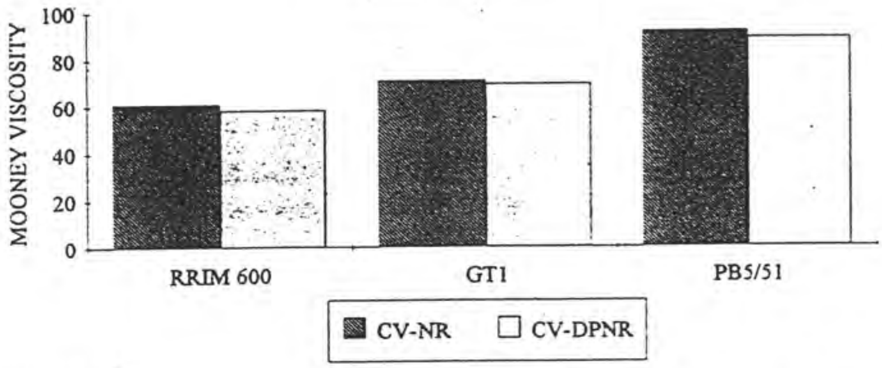
e)


Po
70
60
50
40
30
20
10
0
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR

f)



g)



h)

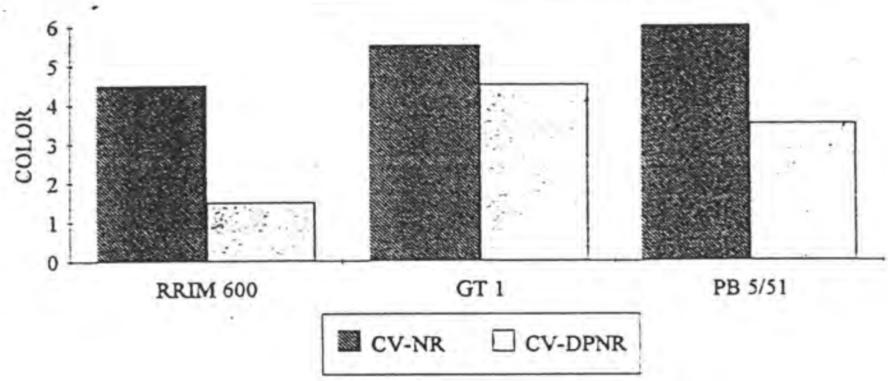
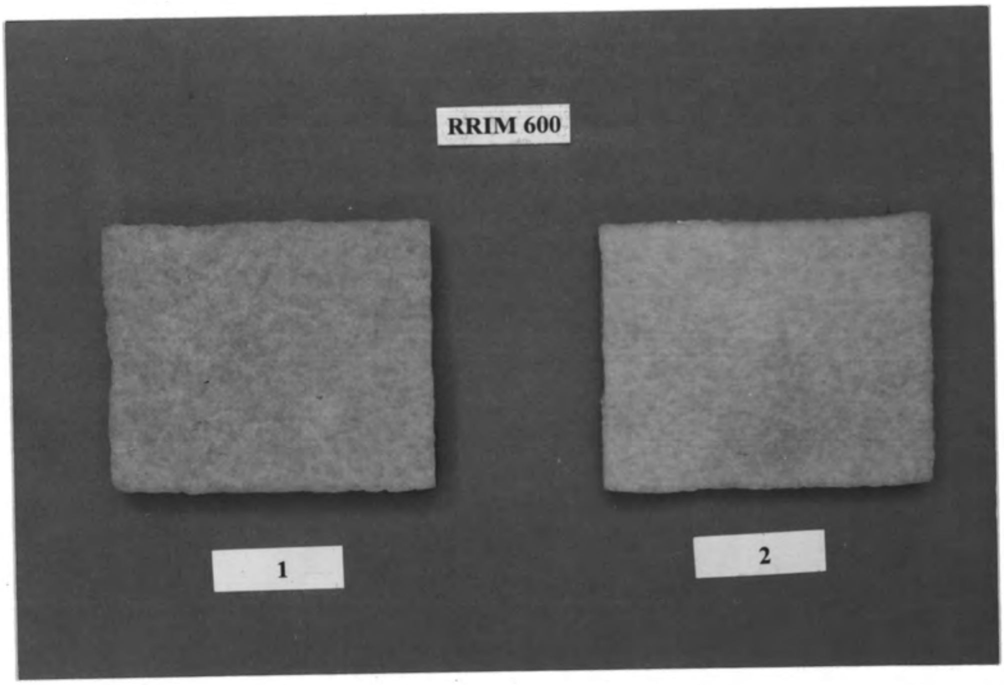


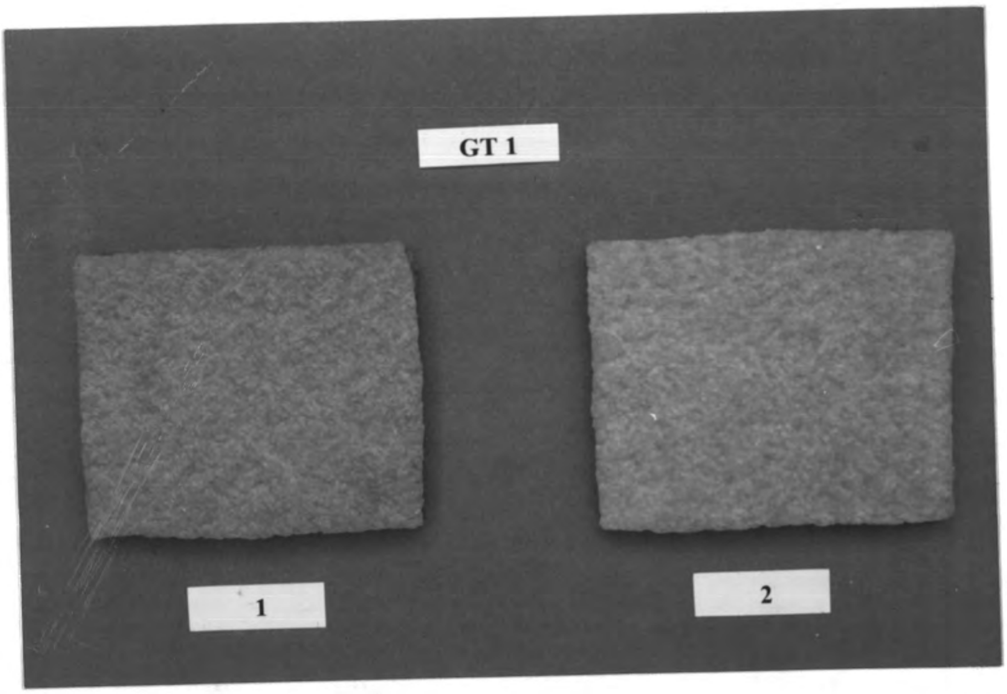
Figure 4.9 Raw rubber properties of CV-DPNR and its control produced from field latex from three different clones

a) Nitrogen content (n=3)
b) Dirt content (n=3)
c) Ash content (n=3)
d) Volatile matter (n=3)
e) Initial plasticity index (n=3)
f) Plasticity retention index (n=3)
g) Mooney viscosity (n=3)
h) Color (n=3)

a)



b)



c)

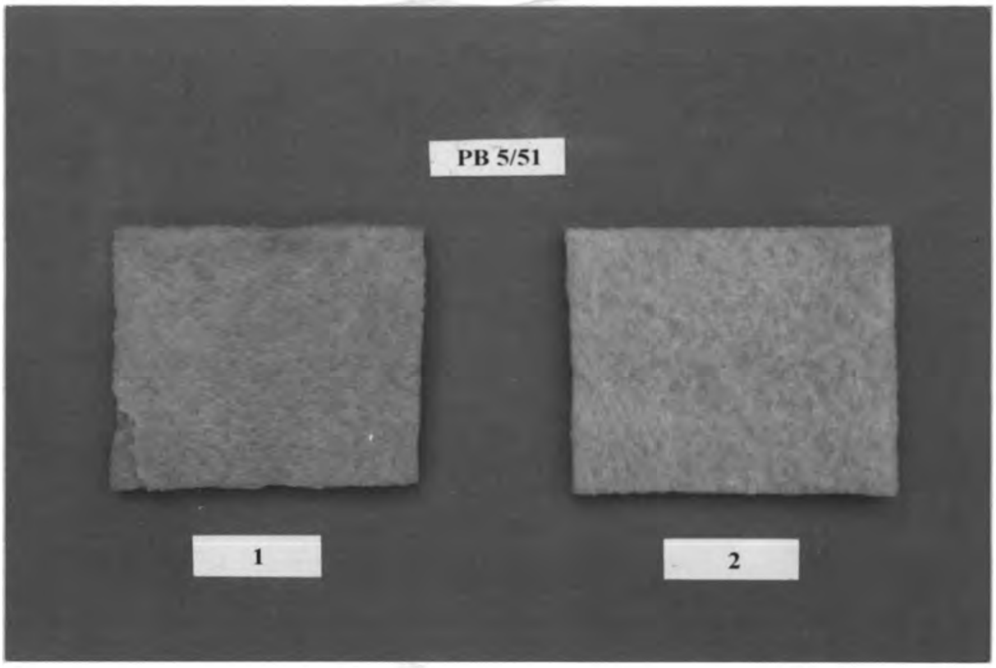


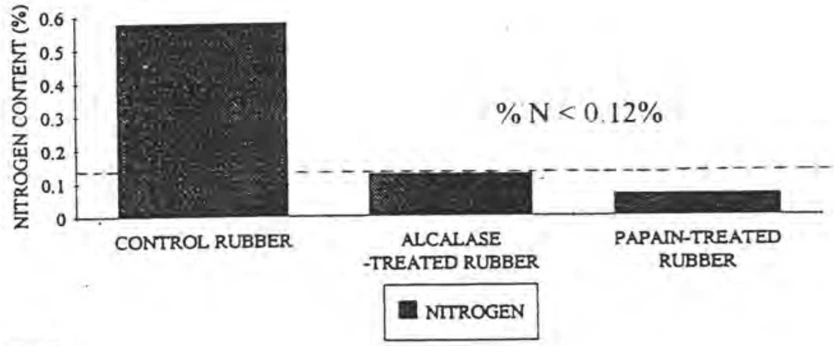
Figure 4.10 Comparison of color of raw rubber between the CV-DPNR with the control produced from different rubber clones.

a) From fresh latex clone RRIM 600
   1) Non-treated rubber
   2) Papain-treated rubber

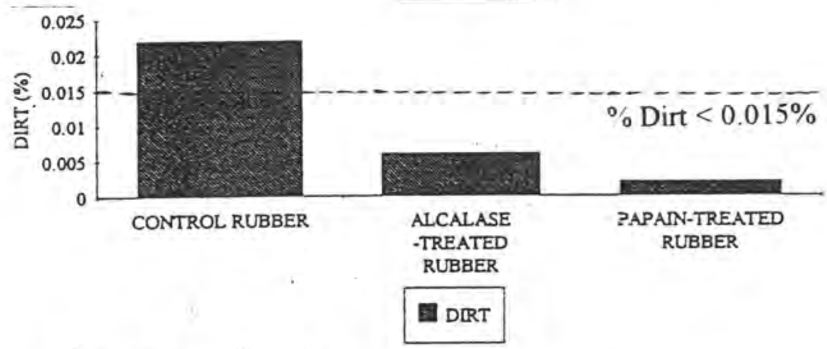
b) From fresh latex clone GT 1
   1) Non-treated rubber
   2) Papain-treated rubber

c) From fresh latex clone PB 5/51
   1) Non-treated rubber
   2) Papain-treated rubber

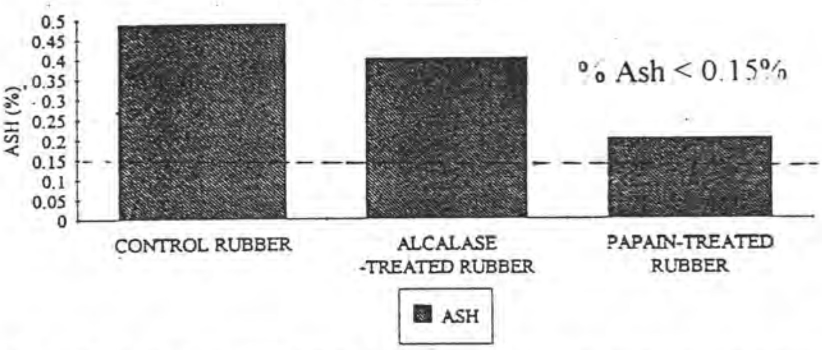
a)


NITROGEN CONTENT (%)
0.6
0.5
0.4
0.3
0.2
0.1
0
% N < 0.12%
CONTROL RUBBER
ALCALASE -TREATED RUBBER
PAPAIN-TREATED RUBBER
NITROGEN

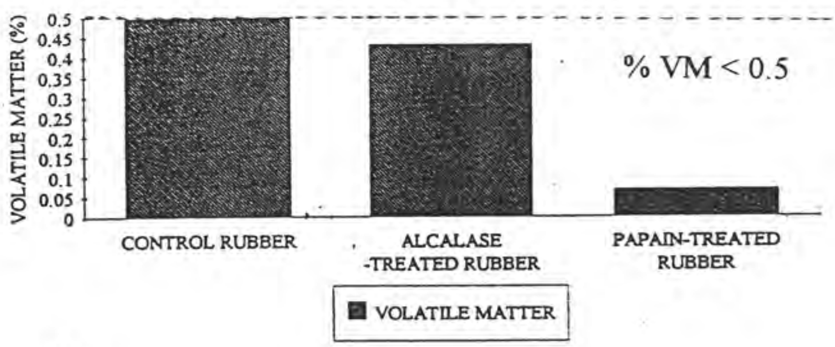
b)


DIRT (%)
0.025
0.02
0.015
0.01
0.005
0
% Dirt < 0.015%
CONTROL RUBBER
ALCALASE -TREATED RUBBER
PAPAIN-TREATED RUBBER
DIRT

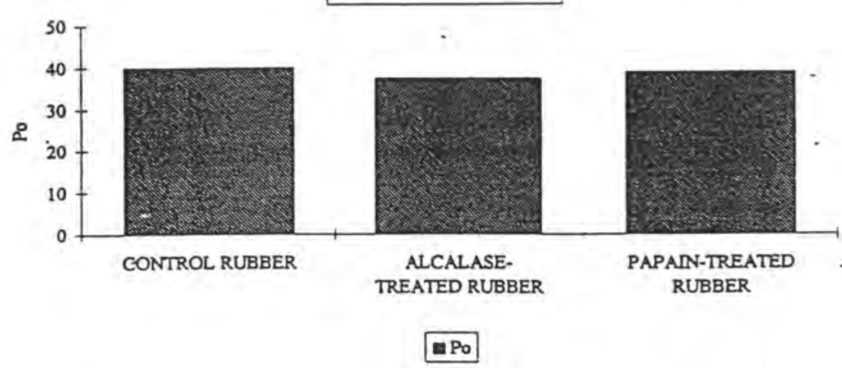
c)


ASH (%)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
% Ash < 0.15%
CONTROL RUBBER
ALCALASE -TREATED RUBBER
PAPAIN-TREATED RUBBER
ASH

d)


VOLATILE MATTER (%)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
% VM < 0.5
CONTROL RUBBER
ALCALASE -TREATED RUBBER
PAPAIN-TREATED RUBBER
VOLATILE MATTER

e)


Po
50
40
30
20
10
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
Po

f)
g)
h)

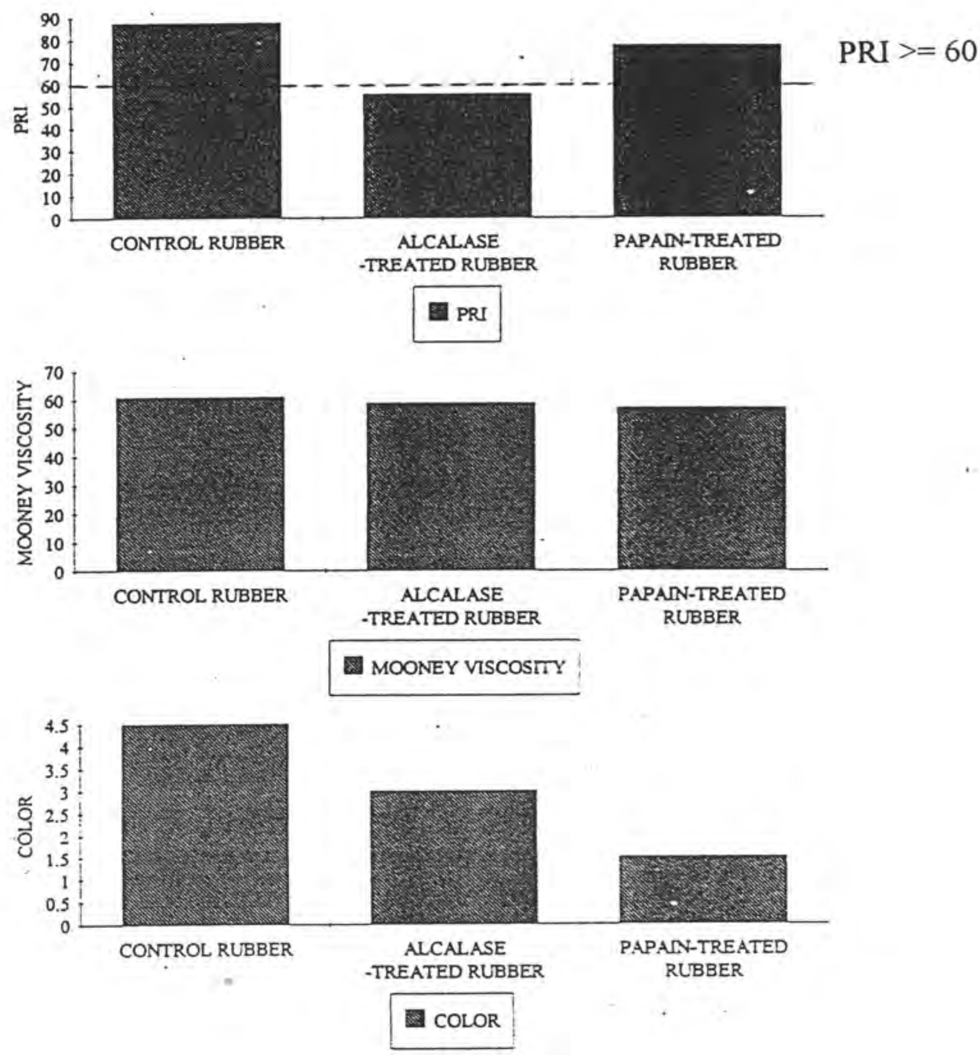


Figure 4.11 Raw rubber properties of CV-DPNR and its control produced from RRIM 600 clone by Alcalase and Papain

a) Nitrogen content (n=3) b) Dirt content (n=3)

c) Ash content (n=3) d) Volatile matter (n=3)

e) Initial plasticity index (n=3) f) Plasticity retention index (n=3)

g) Mooney viscosity (n=3) h) Color (n=3)

a)

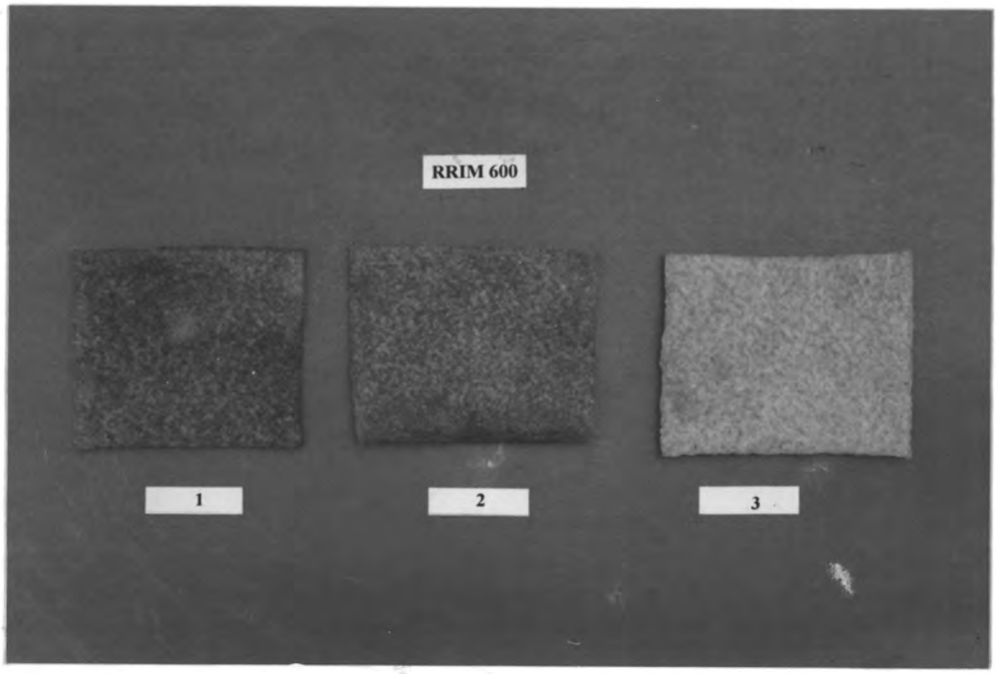
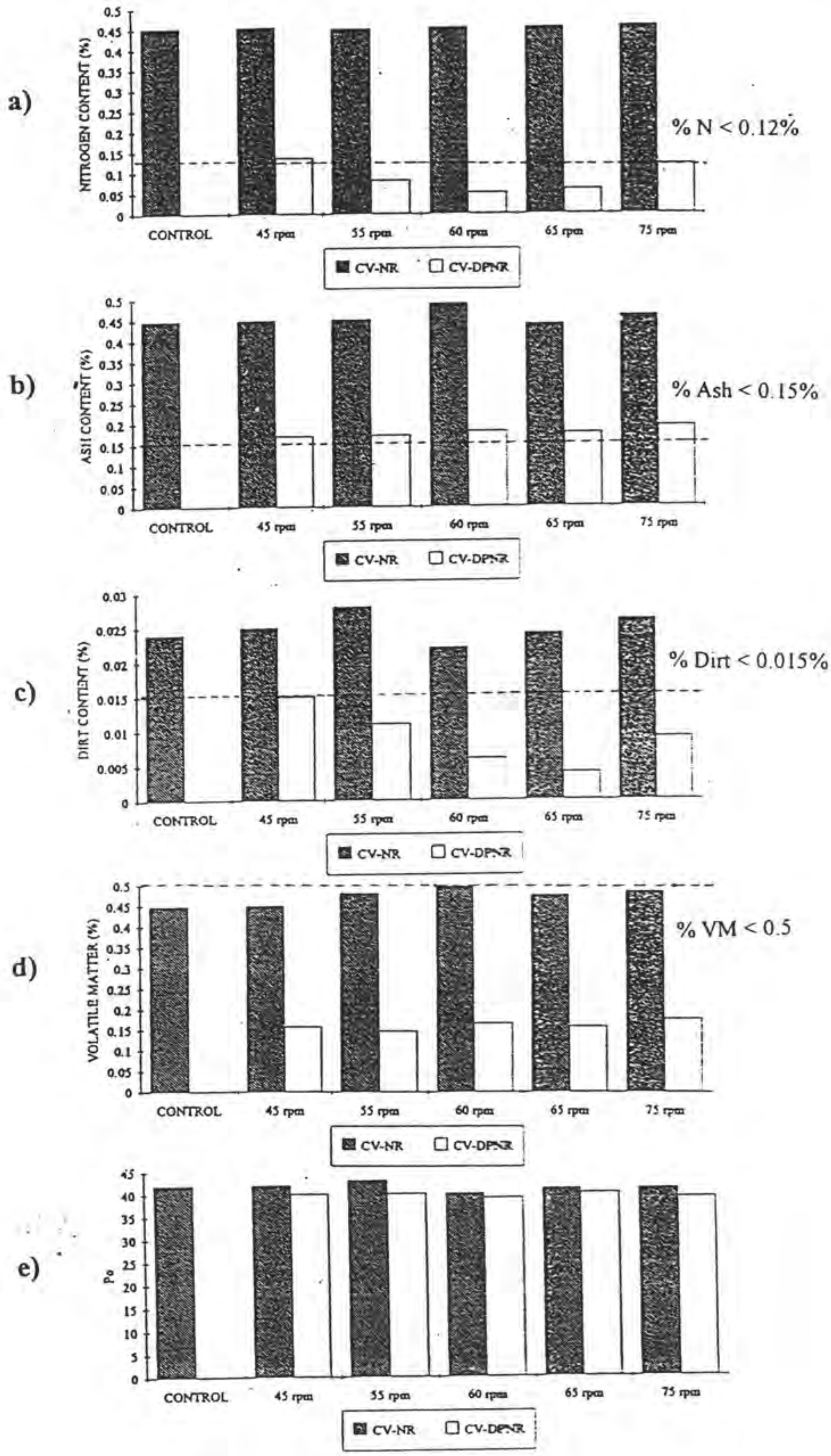


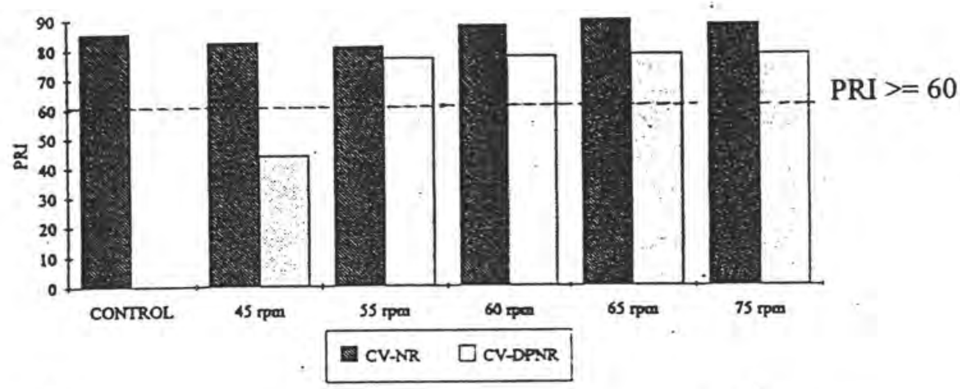
Figure 4.12 Comparison of color of raw rubber between the CV-DPNR with the control produced from RRIM 600 rubber clone by Alcalase and Papain.

a) From fresh latex clone RRIM 600

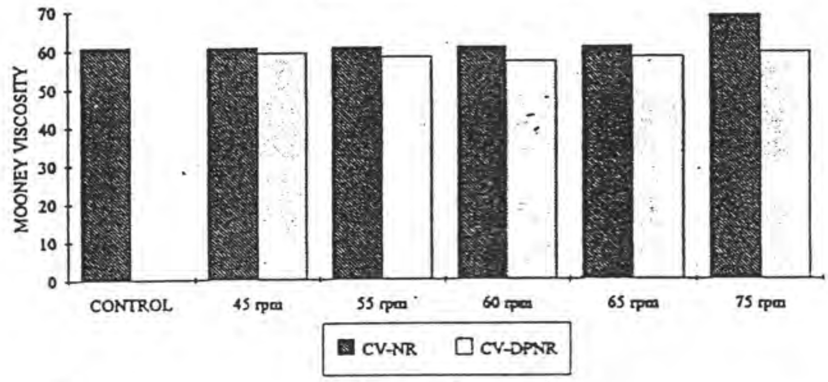
1) Non-treated rubber
2) Papain-treated rubber
3) Alcalase-treated rubber


a)
NITROGEN CONTENT (%)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
CV-NR
CV-DPNR
% N < 0.12%
b)
ASH CONTENT (%)
% Ash < 0.15%
c)
DIRT CONTENT (%)
0.03
0.025
0.02
0.015
0.01
0.005
% Dirt < 0.015%
d)
VOLATILE MATTER (%)
% VM < 0.5
e)
Po
45
40
35
30
25
20
15
10
5

f)



g)



h)

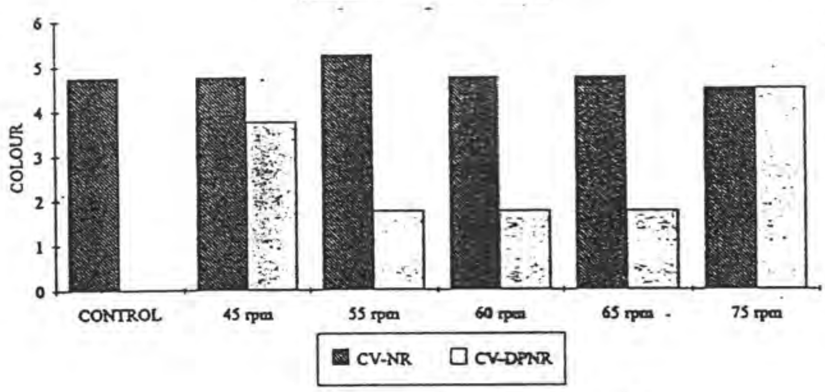


Figure 4.13 Raw rubber properties of CV-DPNR and its control produced from RRIM 600 clone at various agitation speed.

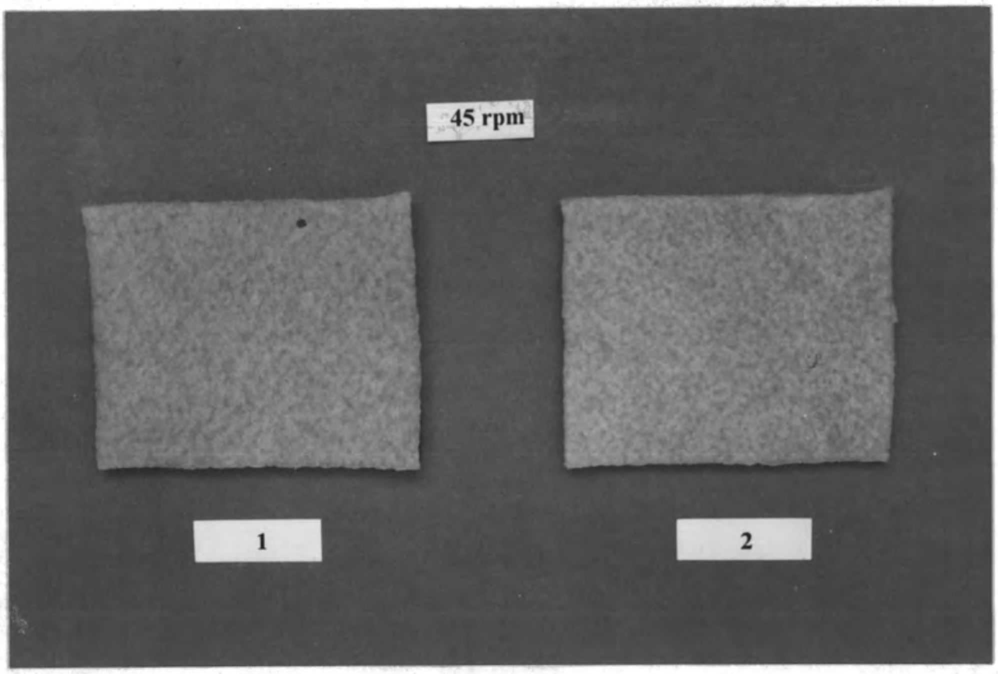
a) Nitrogen content (n=3) b) Dirt content (n=3)

c) Ash content (n=3) d) Volatile matter (n=3)

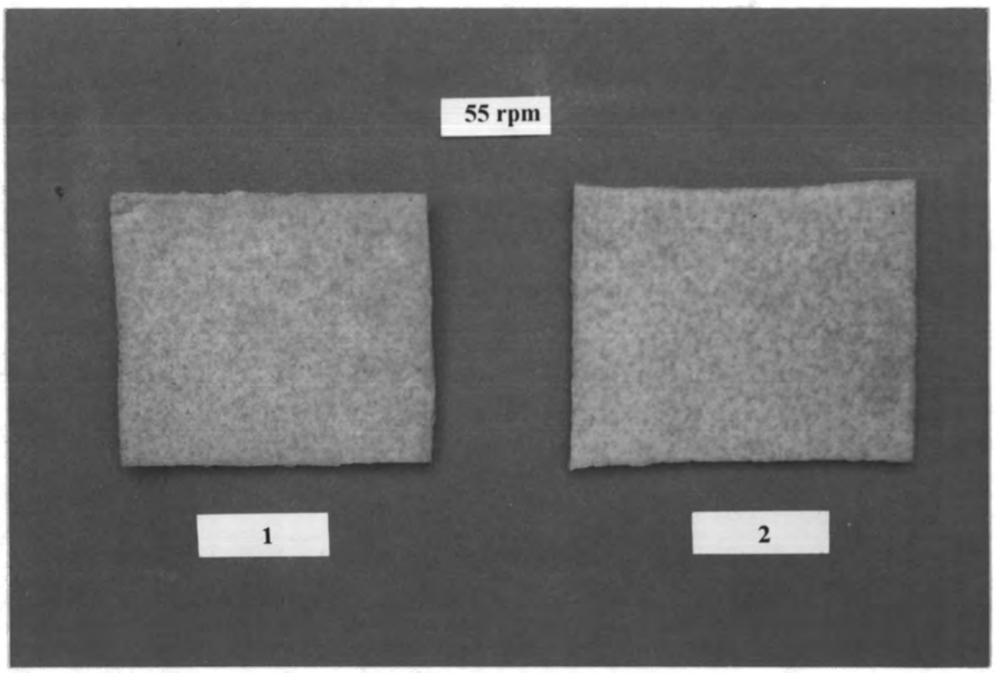
e) Initial plasticity index (n=3) f) Plasticity retention index (n=3)

g) Mooney viscosity (n=3) h) Color (n=3)

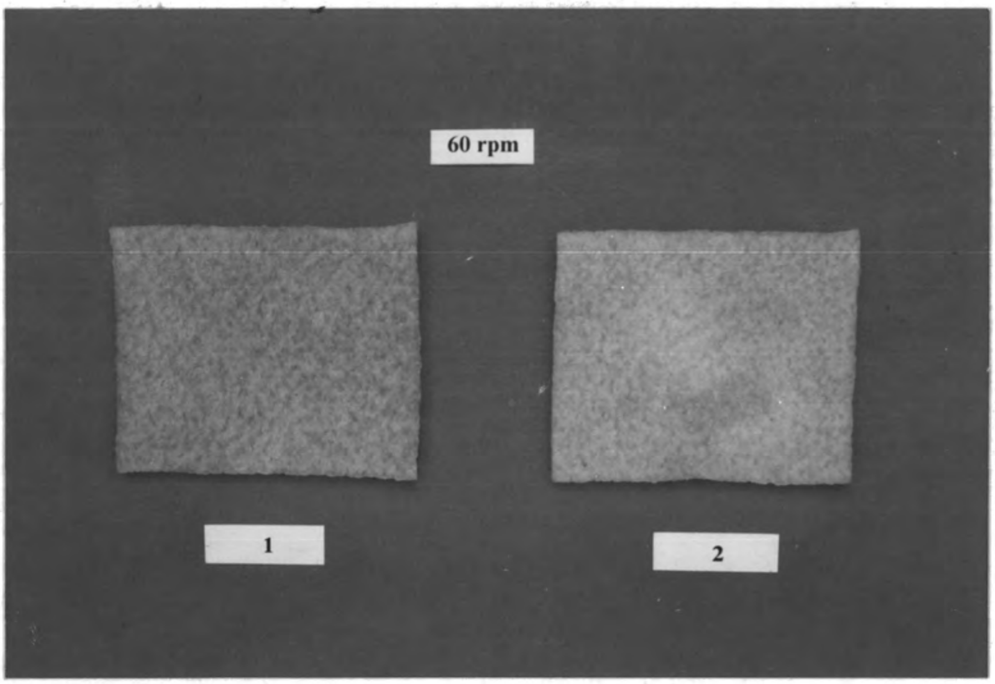
a)



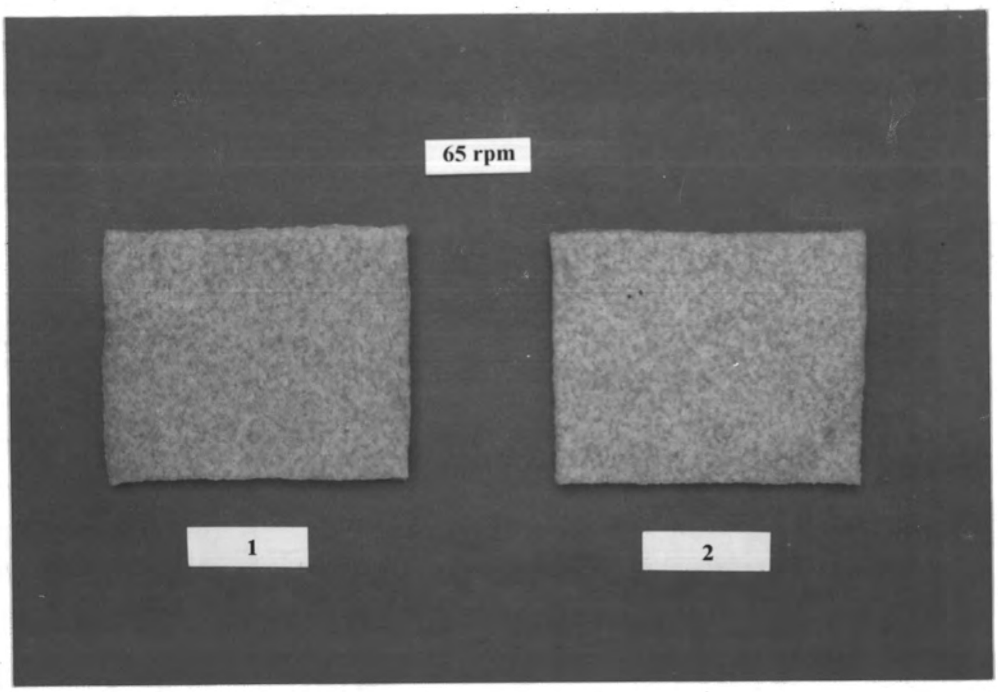
b)



c)



d)



e)

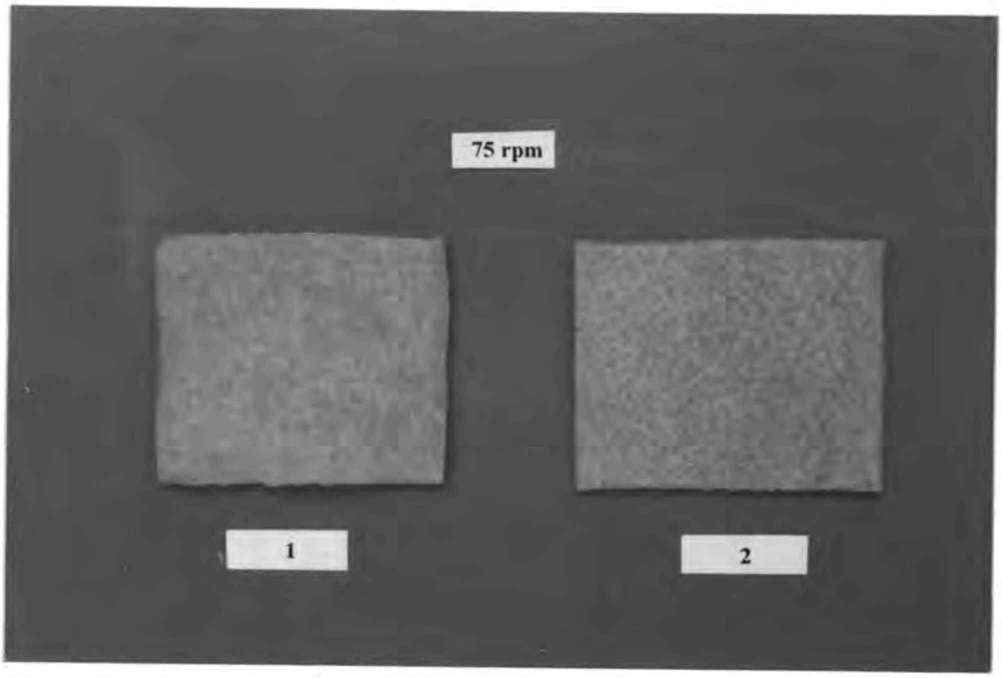


Figure 4.14 Comparison of color of raw rubber between the CV-DPNR with the control produced from RRIM 600 clone at various agitation speed.

a) At agitation speed 45 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

b) At agitation speed 55 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

c) At agitation speed 60 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

d) At agitation speed 65 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

e) At agitation speed 75 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

2. Cure characteristics

Raw rubber samples were tested for cure characteristic by using a Rheometer as shown in Figure 4.15-4.17. Compound formulations for all rubber is the same in this study.

Effect of rubber clone

Comparison between the cure characteristics of CV-DPNR and CV-NR of 3 rubber clones: RRIM 600, GT 1 and PB 5/51 (Figure 4.15 (a)-(f)) show that the CV-DPNR has longer scorch time than its control. The cure rate and cure time of CV-DPNR are longer than its control except for RRIM 600. The minimum torque of all the CV-DPNR are lower than the control CV-NR, but the torque rise of CV-DPNR are higher than its control except clone GT 1, therefore the maximum torque of CV-DPNR from clone RRIM 600 and PB 5/51 are higher than GT 1 and higher than their control CV-NR.

In general removal of protein improve cure characteristic, because the scorch time of CV-DPNR is longer than its control, and the minimum torque is lower which lead to good mixing. It is noted that RRIM 600 is the only fast cure clone with highest crosslink density.

Effect of enzyme

The torque rise of CV-DPNR are higher than its control except clone GT 1, therefore the maximum torque of CV-DPNR from clone RRIM 600 and PB 5/51 are higher than GT 1 and higher than their control CV-NR. The cure time and cure rate of CV-DPNR are decrease for GT1 and PB 5/51. The scorch time of CV-DPNR is longer than its control.

Comparison between CV-DPNR and its control CV-NR from RRIM 600 clone shows that the scorch time, cure time and cure rate of Alcalase-treated rubber are longer than its control and Papain-treated rubber, but the minimum and maximum torque and torque rise of CV-DPNR from Alcalase-treated rubber are lower than Papain-treated rubber indicating that the sulfur-crosslink density is higher in Papain-treated rubber.

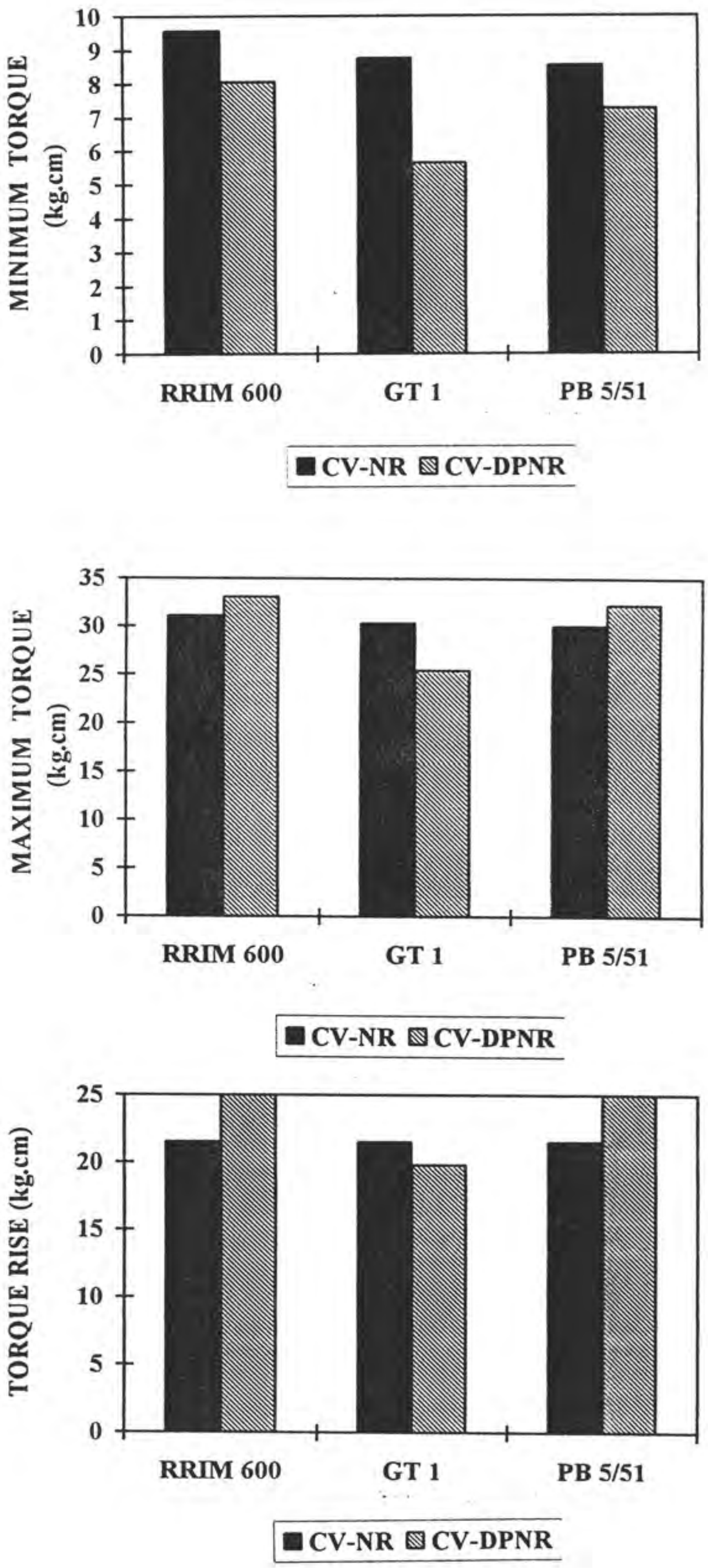
Effect of agitation speed

Comparison between the cure characteristics of CV-DPNR at various agitation speeds and its control CV-NR of clone RRIM 600 show that the cure time and cure rate of CV-NR at various speeds are longer than control but torque rise and scorch time decrease except for CV-NR at 45 rpm. For CV-DPNR, increasing agitation speed has no effect on the scorch time, cure time and cure rate, comparing to agitation speed 0 rpm, but the torque rise and maximum torque were lowest at agitation speed 60-65 rpm, where the crosslink density due to protein were minimized by Papain.

a)

b)

c)


10
9
8
7
6
5
4
3
2
1
0
MINIMUM TORQUE (kg.cm)
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR
35
30
25
20
15
10
5
0
MAXIMUM TORQUE (kg.cm)
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR
25
20
15
10
5
0
TORQUE RISE (kg.cm)
RRIM 600
GT 1
PB 5/51
CV-NR
CV-DPNR

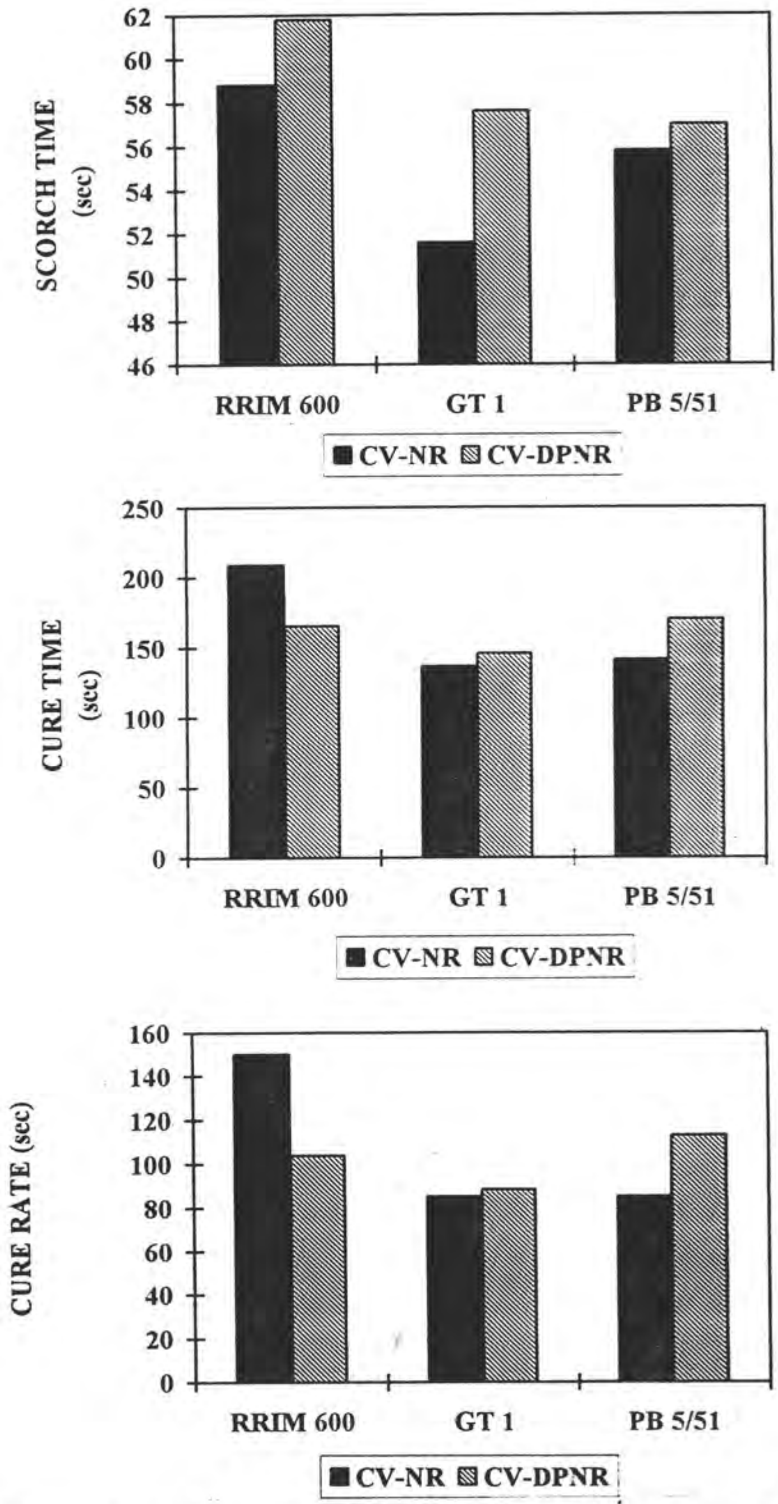


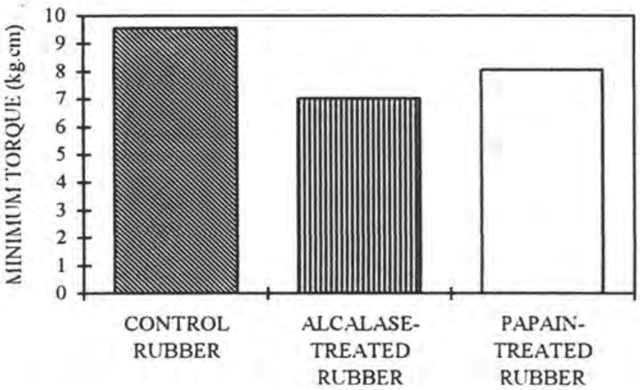
Figure 4.15 Comparison of cure characteristic between CV-DPNR and its control produced from field latex from three different clones

a) Minimum torque (n=3) b) Maximum torque (n=3)

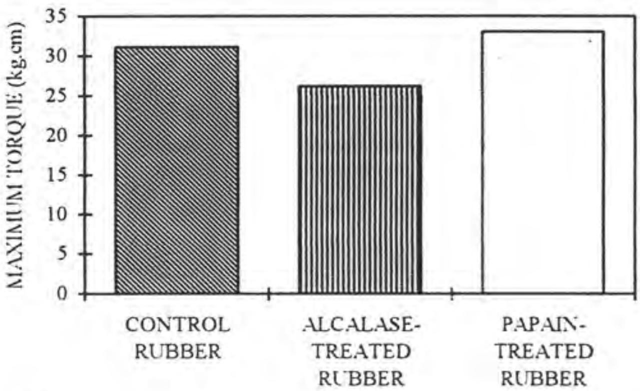
c) Torque rise (n=3) d) Scorch time (n=3)

e) Cure time (n=3) f) Cure rate (n=3)

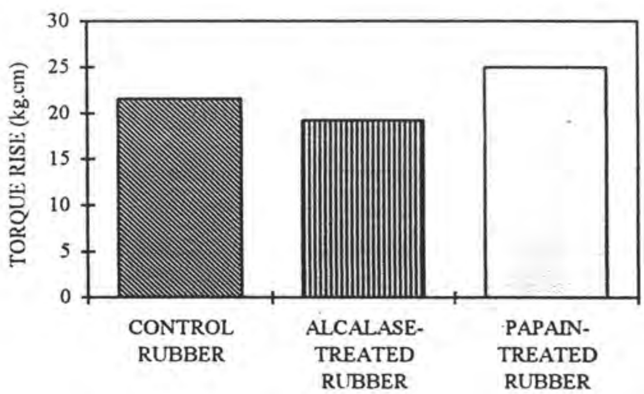
a)


MINIMUM TORQUE (kg.cm)
10
9
8
7
6
5
4
3
2
1
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER

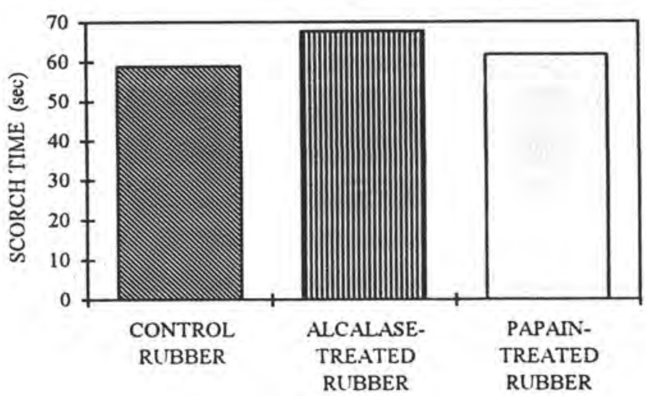
b)


MAXIMUM TORQUE (kg.cm)
35
30
25
20
15
10
5
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER

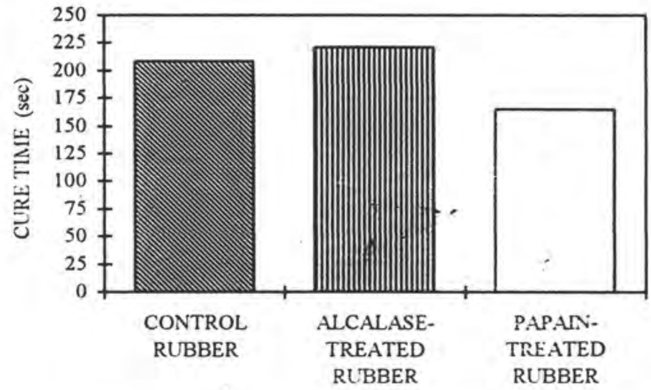
c)


TORQUE RISE (kg.cm)
30
25
20
15
10
5
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER

d)


SCORCH TIME (sec)
70
60
50
40
30
20
10
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER

e)



f)

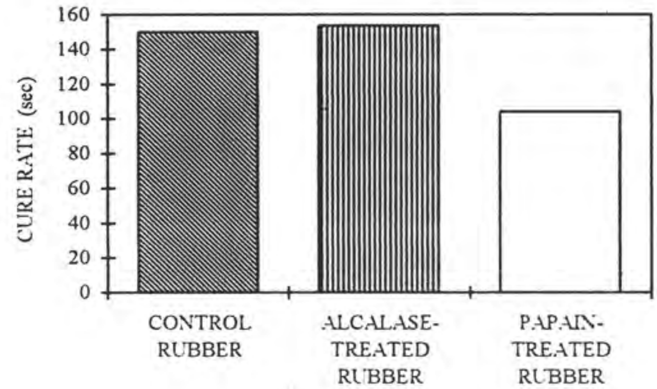


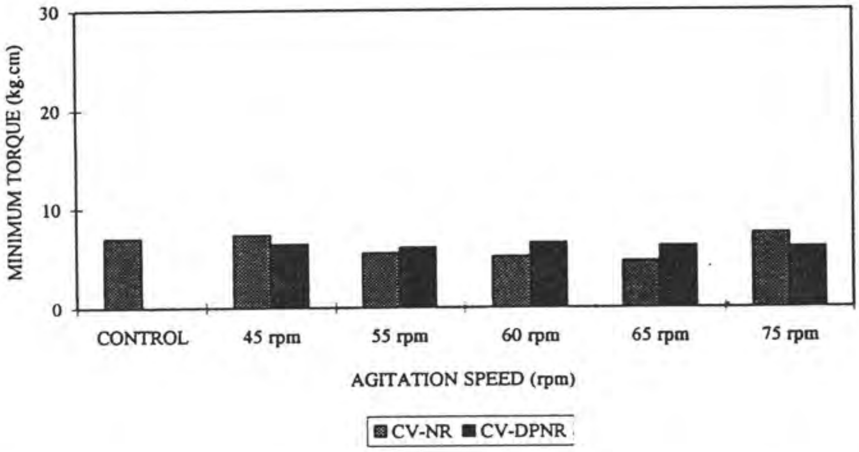
Figure 4.16 Comparison of cure characteristic between CV-DPNR and its control produced from RRIM 600 clone by Alcalase and Papain

a) Minimum torque (n=3) b) Maximum torque (n=3)

c) Torque rise (n=3) d) Scorch time (n=3)

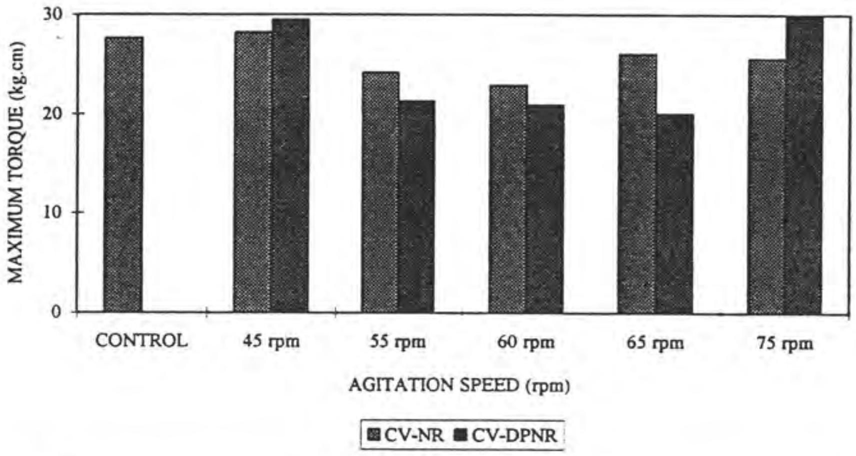
e) Cure time (n=3) f) Cure rate (n=3)

a)



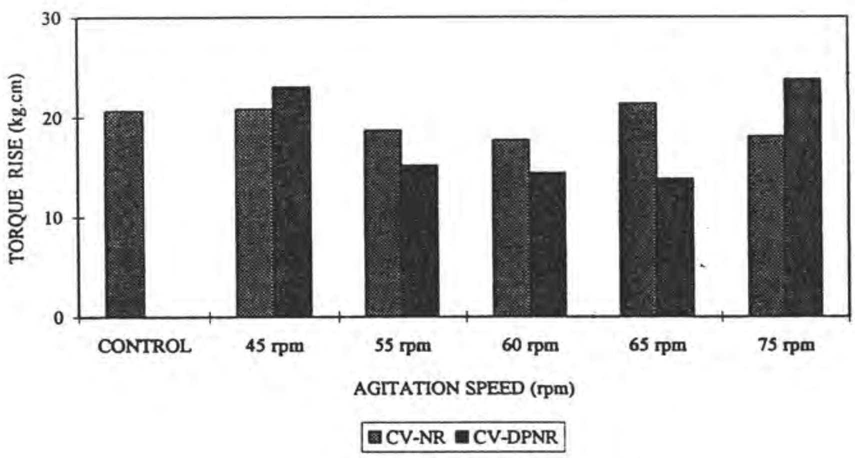
MINIMUM TORQUE (kg.cm)
30
20
10
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

b)



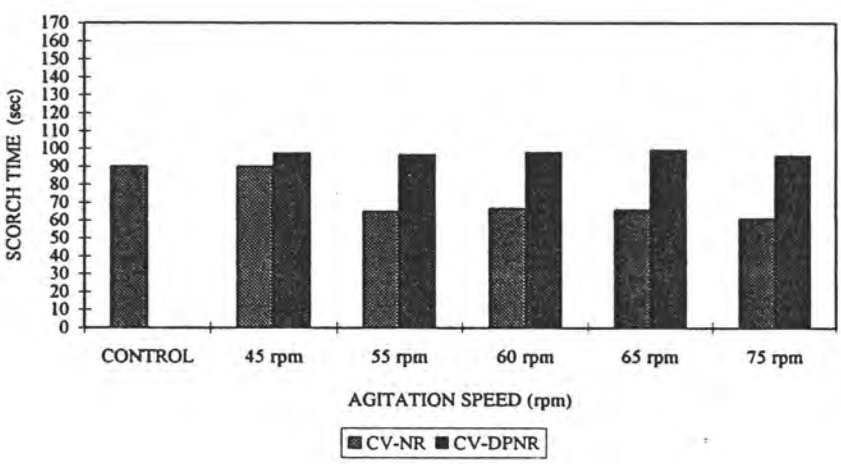
MAXIMUM TORQUE (kg.cm)
30
20
10
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

c)



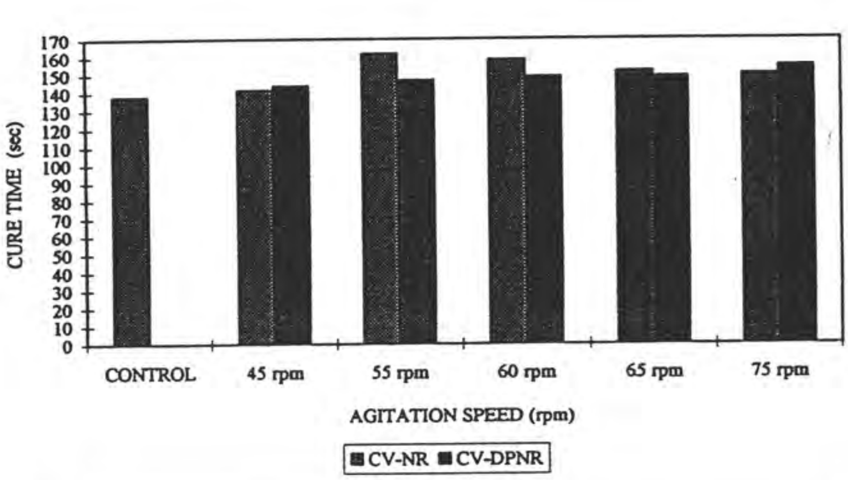
TORQUE RISE (kg.cm)
30
20
10
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

d)



SCORCH TIME (sec)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

e)



f)

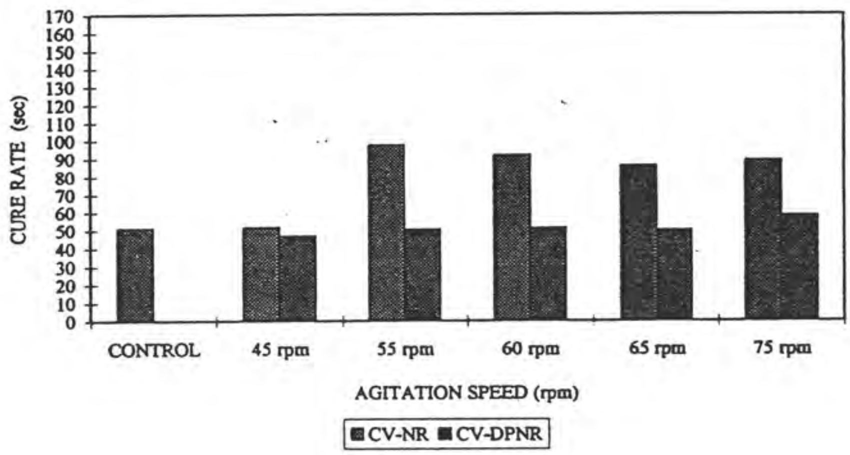


Figure 4.17 Comparison of cure characteristic between CV-DPNR and its control produced from RRIM 600 clone at various agitation speed

a) Minimum torque (n=3) b) Maximum torque (n=3)

c) Torque rise (n=3) d) Scorch time (n=3)

e) Cure time (n=3) f) Cure rate (n=3)

3. Properties of vulcanizates

Effect of rubber clone

Comparison of vulcanizate properties between CV-DPNR with its control prepared from three rubber clones show that tensile strength and % elongation at break of CV-DPNR were increased while 300% modulus and hardness were decreased. PB5/51 has the highest tensile strength, where GT 1 has the highest tear strength and 300% modulus. (Figure 4.18)

Deproteinization leads to better vulcanizate properties in all 3 clones, as evidient by higher tensile strength and % elongation at break, lower 300% modulus and the hardness of CV-DPNR than its control CV-NR.

The color of CV-DPNR vulcanizates are lighter than its control. CV-DPNR vulcanizates from RRIM 600, PB 5/51 are lighter than GT 1 as shown in Figure 4.19.

Effect of enzyme

Using latex from clone RRIM 600, Figure 4.20 shows comparison of the vulcanizate properties between CV-DPNR prepared from Alcalase and Papain with its control. The tensile strength and % elongation at break of Papain-treated rubber have higher values than Alcalase-treated rubber and its control. However, Alcalase-treated rubber has the highest tear strength and 300% modulus of 72.44 and 64.04 respectively. The hardness of Alcalase-treated rubber is higher than Papain-treated rubber but less than its control. Specific gravity of Alcalase-treated rubber and its control are similar. The color of Papain-treated rubber is lighter than Alcalase-treated rubber and its control as shown in Figure 4.21.

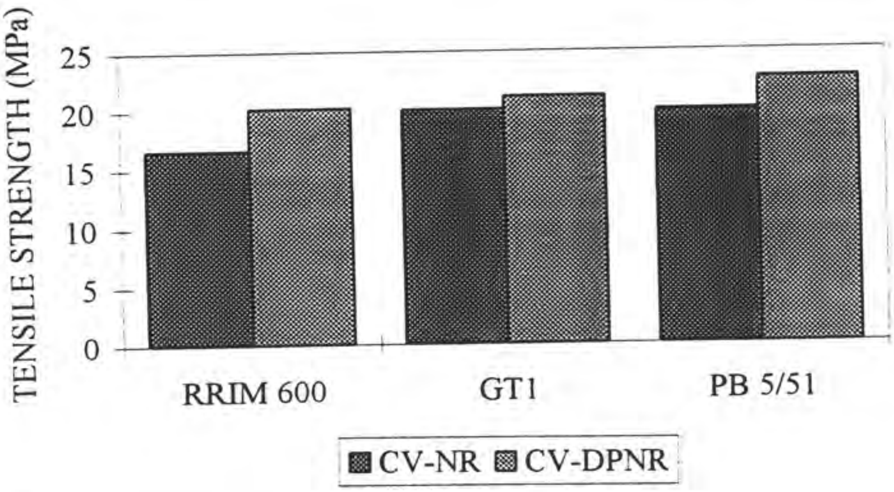
In general the vulcanizate properties of Papain-treated DPNR is better because of its high tensile strength and light color.

Effect of agitation speed

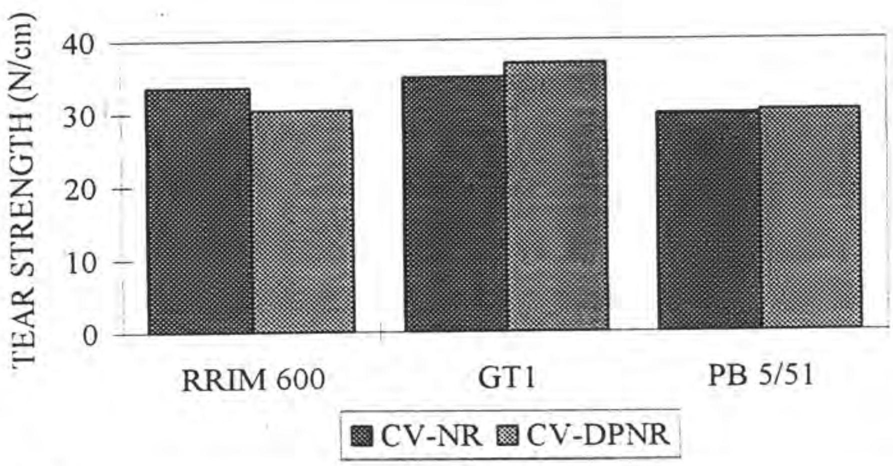
Using clone RRIM 600 as model, the properties vulcanizate of CV-DPNR prepared at various agitation speeds were compared with its control CV-NR as shown in Figure 4.22. The tensile strength of CV-DPNR at various speeds is decreased except for CV-DPNR at 45 - 60 rpm. Tear strength of CV-DPNR at 75 rpm is lowest while CV-DPNR at 45 rpm is highest. CV-DPNR at 45 rpm has the lowest 300% modulus. The elongation at break of CV-DPNR at 45 and 55 rpm is higher than its control. The hardness of CV-DPNR at all agitation speeds is less than its control. Specific gravity of CV-DPNR at various speeds and its control are not different..

For CV-DPNR agitation speed 45-60 rpm improved tensile strength and elongation at break, which are important properties of NR.

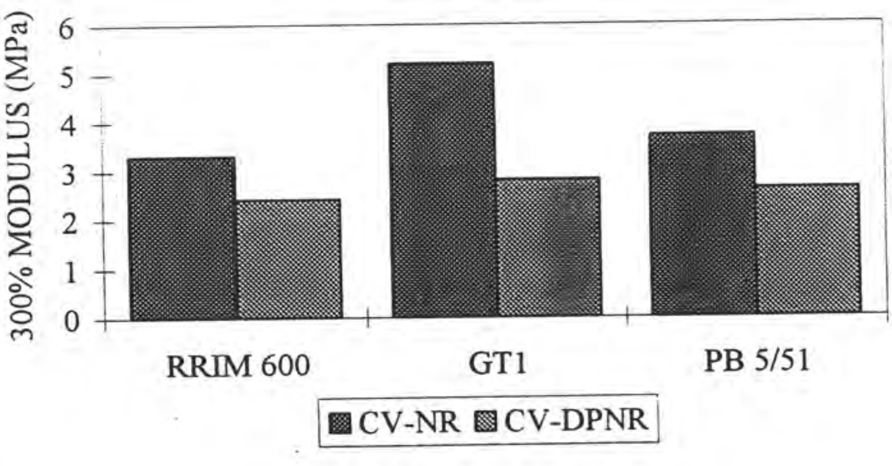
a)


TENSILE STRENGTH (MPa)
25
20
15
10
5
0
RRIM 600
GT1
PB 5/51
CV-NR
CV-DPNR

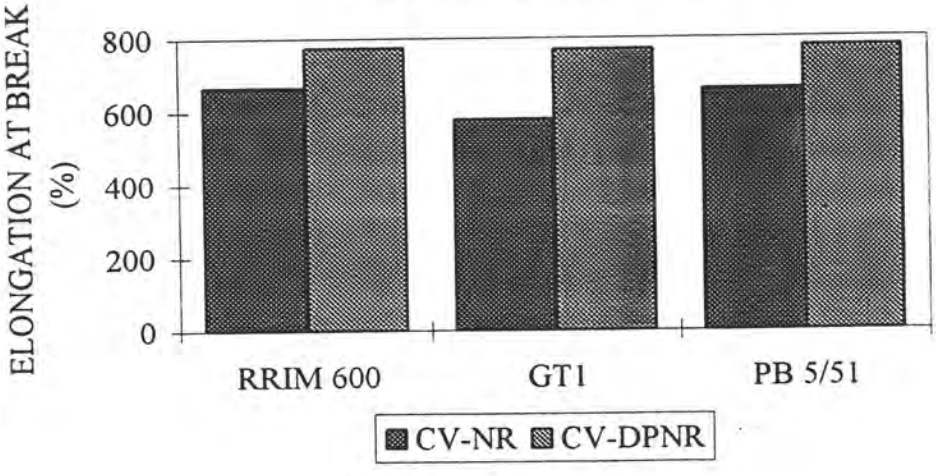
b)


TEAR STRENGTH (N/cm)
40
30
20
10
0
RRIM 600
GT1
PB 5/51
CV-NR
CV-DPNR

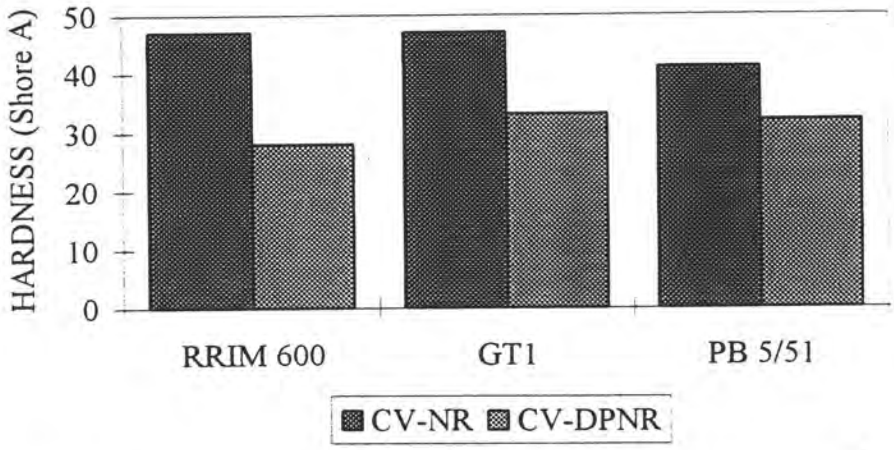
c)


300% MODULUS (MPa)
6
5
4
3
2
1
0
RRIM 600
GT1
PB 5/51
CV-NR
CV-DPNR

d)


ELONGATION AT BREAK (%)
800
600
400
200
0
RRIM 600
GT1
PB 5/51
CV-NR
CV-DPNR

e)



f)

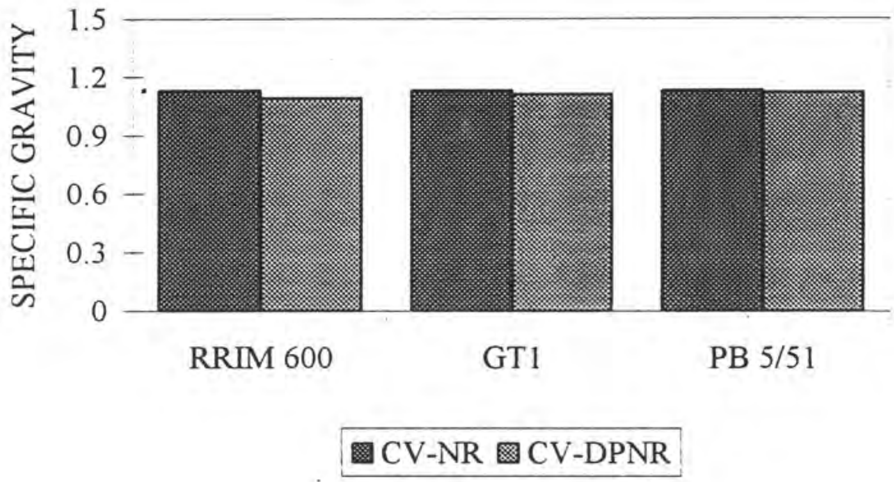
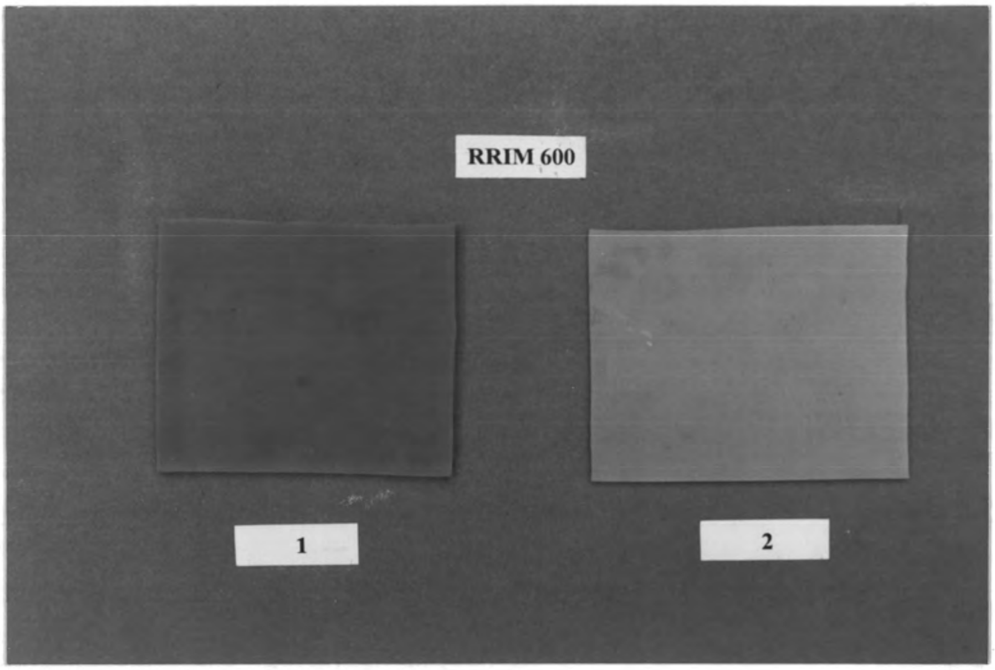


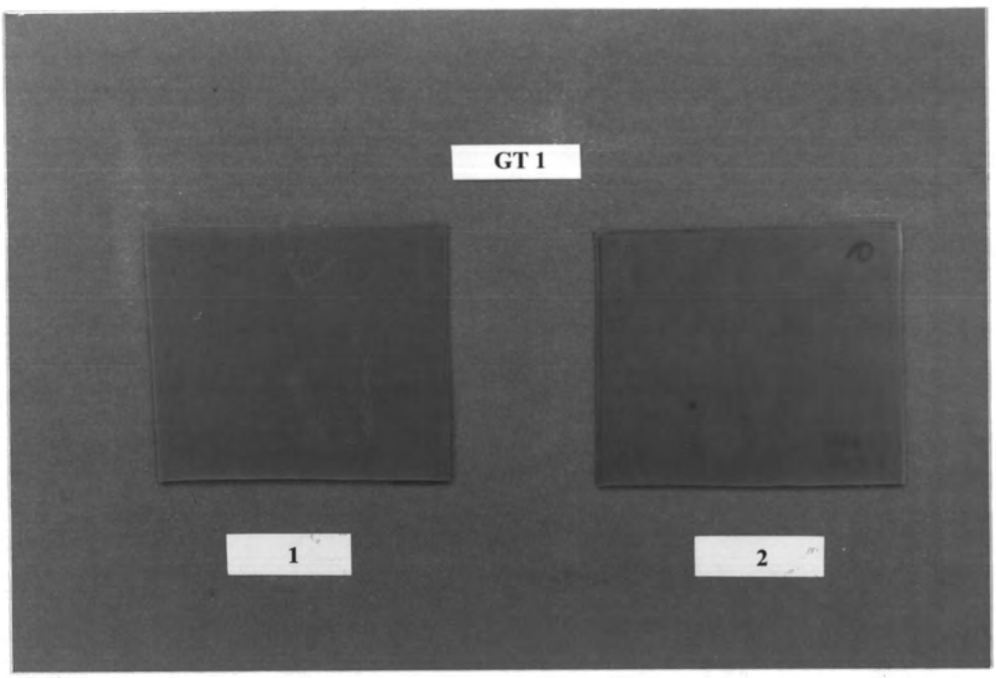
Figure 4.18 Comparison of vulcanizate properties of CV-DPNR and its control produced from field latex from three different clones

a) Tensile strength (n=5)
b) Tear strength (n=5)
c) 300 % Modulus (n=5)
d) Elongation at break (n=5)
e) Hardness (n=3)
f) Specific gravity (n=3)

a)



b)



c)

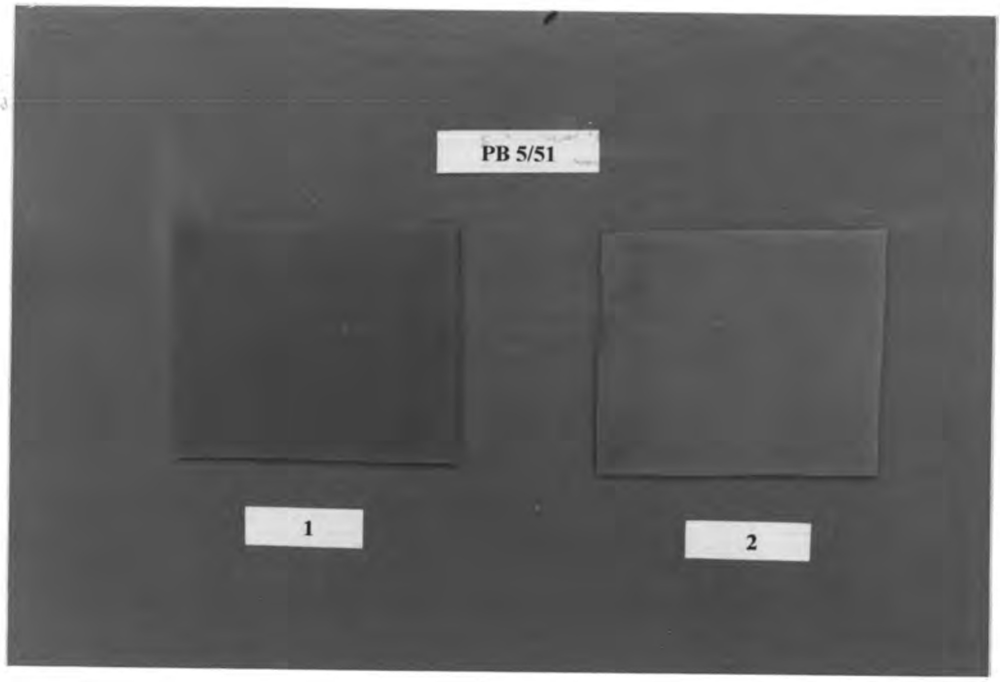


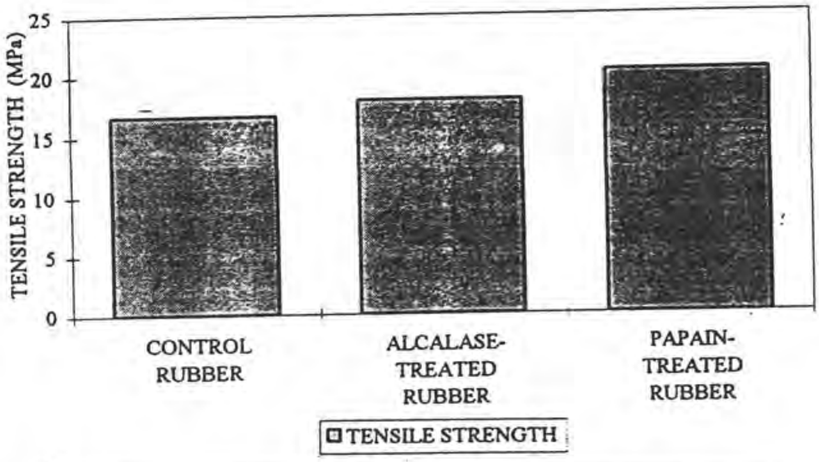
Figure 4.19 Comparison of color of vulcanizate rubber between the CV-DPNR with the control produced from different rubber clones.

a) From fresh latex clone RRIM 600
   1) Non-treated rubber
   2) Papain-treated rubber

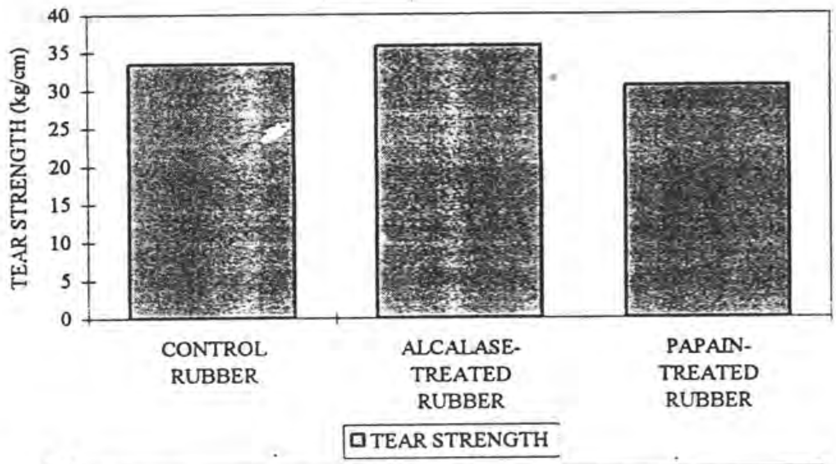
b) From fresh latex clone GT 1
   1) Non-treated rubber
   2) Papain-treated rubber

c) From fresh latex clone PB 5/51
   1) Non-treated rubber
   2) Papain-treated rubber

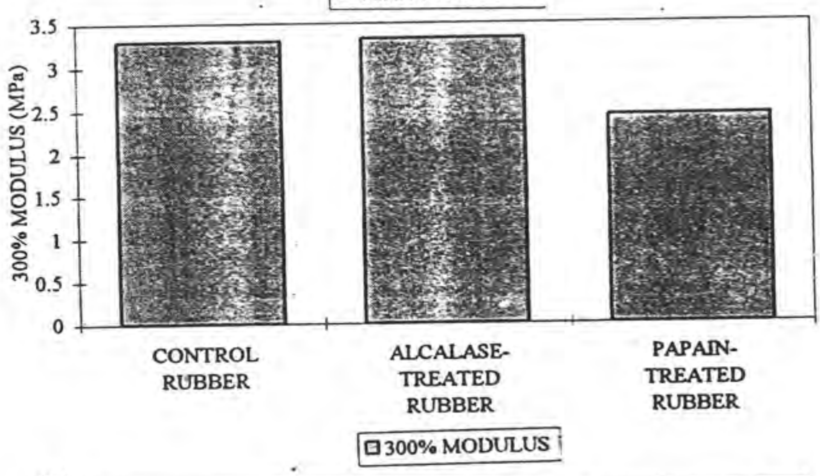
a)


TENSILE STRENGTH (MPa)
0
5
10
15
20
25
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
TENSILE STRENGTH

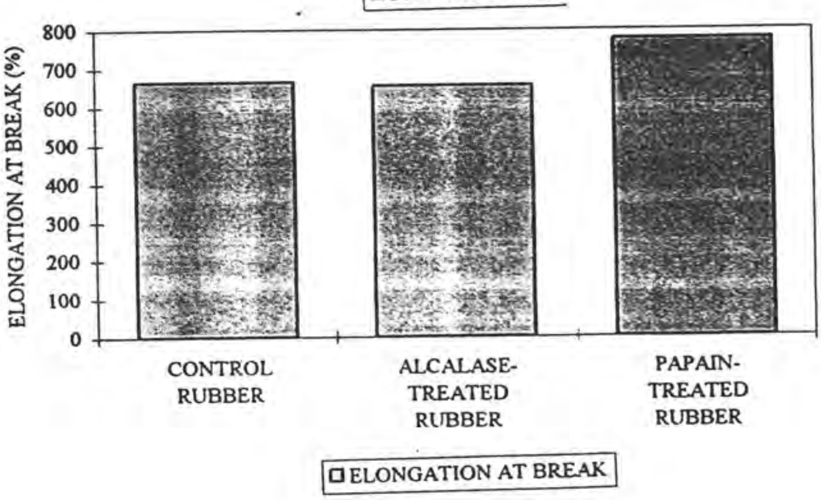
b)


TEAR STRENGTH (kg/cm)
0
5
10
15
20
25
30
35
40
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
TEAR STRENGTH

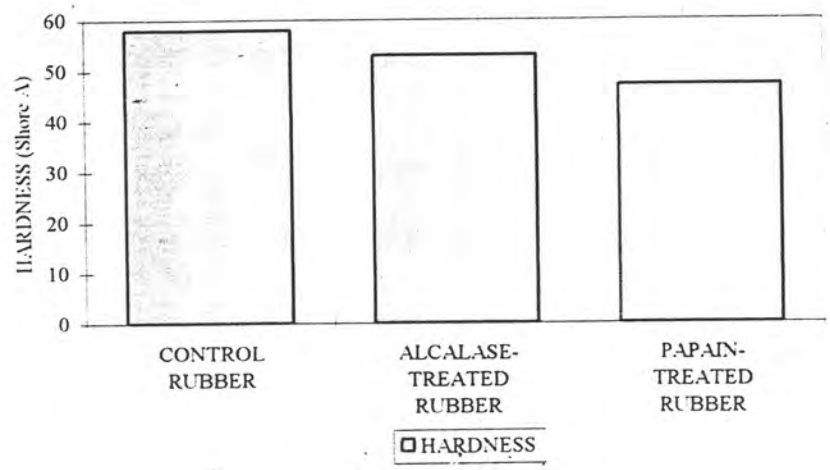
c)


300% MODULUS (MPa)
0
0.5
1
1.5
2
2.5
3
3.5
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
300% MODULUS

d)


ELONGATION AT BREAK (%)
0
100
200
300
400
500
600
700
800
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
ELONGATION AT BREAK

e)



f)

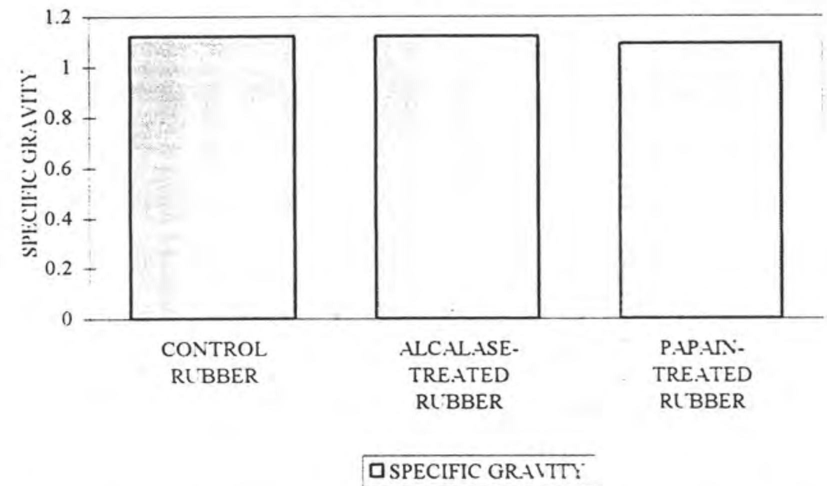


Figure 4.20 Comparison of vulcanizate properties of CV-DPNR and its control produced from RRIM 600 clone by Alcalase and Papain

a) Tensile strength (n=5)
b) Tear strength (n=5)
c) 300 % Modulus (n=5)
d) Elongation at break (n=5)
e) Hardness (n=3)
f) Specific gravity (n=3)

a)

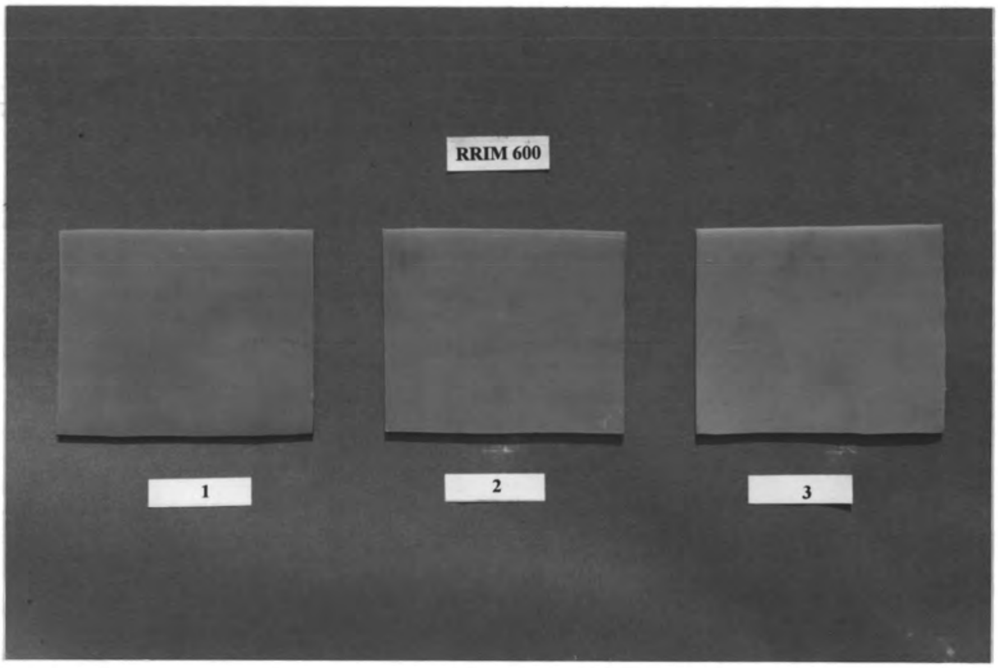
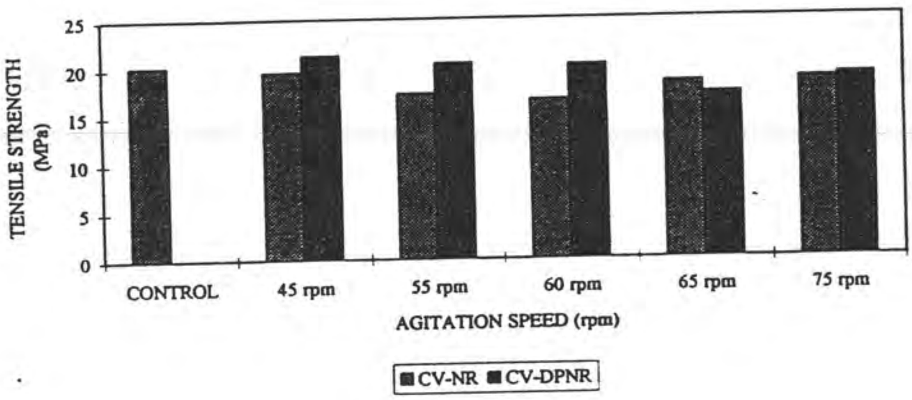


Figure 4.21 Comparison of color of vulcanizate rubber between the CV-DPNR with the control produced from RRIM 600 rubber clone by Alcalase and Papain.

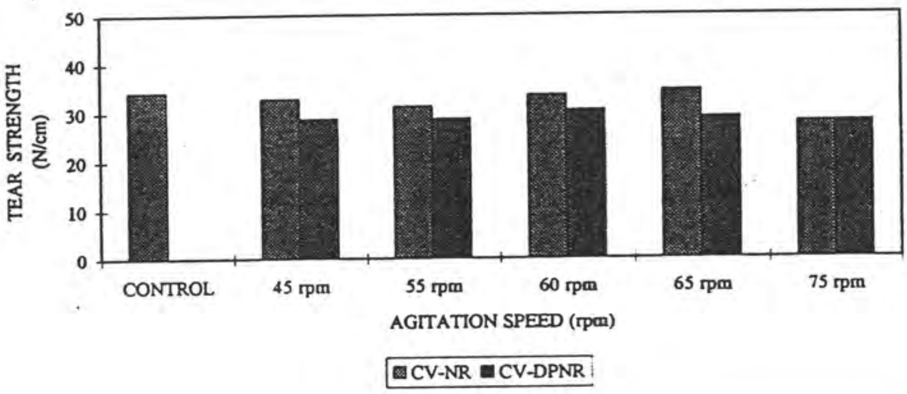
a) From fresh latex clone RRIM 600

1) Non-treated rubber
2) Papain-treated rubber
3) Alcalase-treated rubber

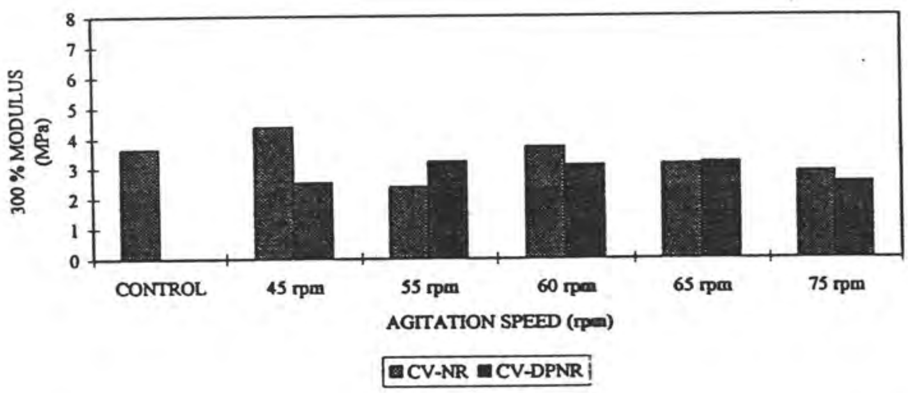
a)


TENSILE STRENGTH (MPa)
25
20
15
10
5
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

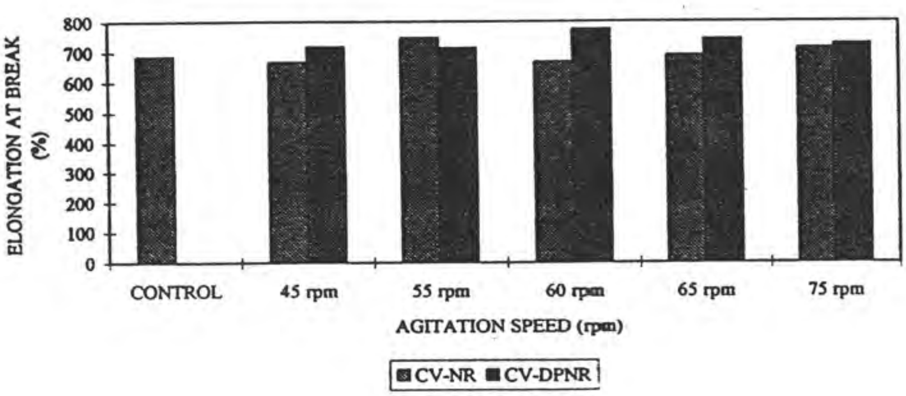
b)


TEAR STRENGTH (N/cm)
50
40
30
20
10
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

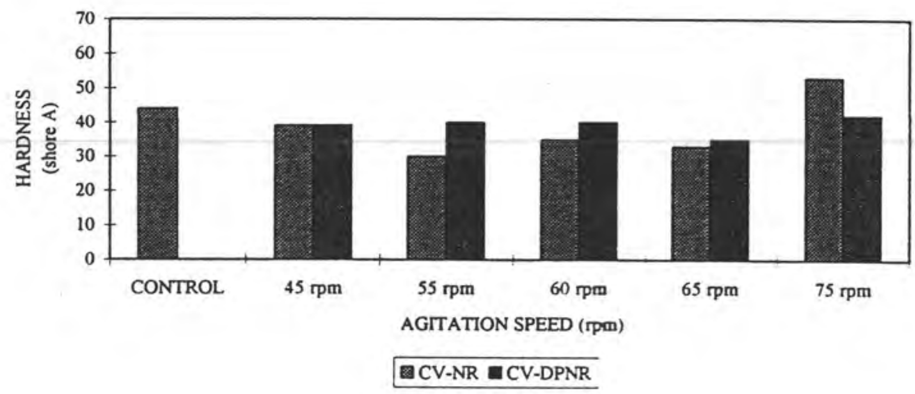
c)


300 % MODULUS (MPa)
8
7
6
5
4
3
2
1
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

d)


ELONGATION AT BREAK (%)
800
700
600
500
400
300
200
100
0
CONTROL
45 rpm
55 rpm
60 rpm
65 rpm
75 rpm
AGITATION SPEED (rpm)
CV-NR
CV-DPNR

e)



f)

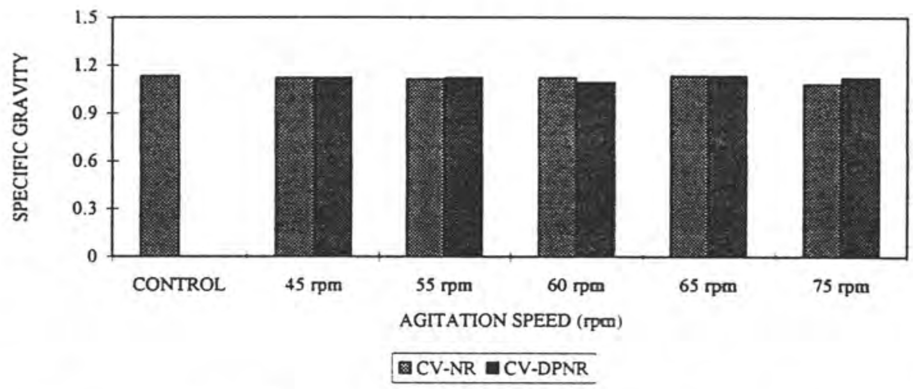
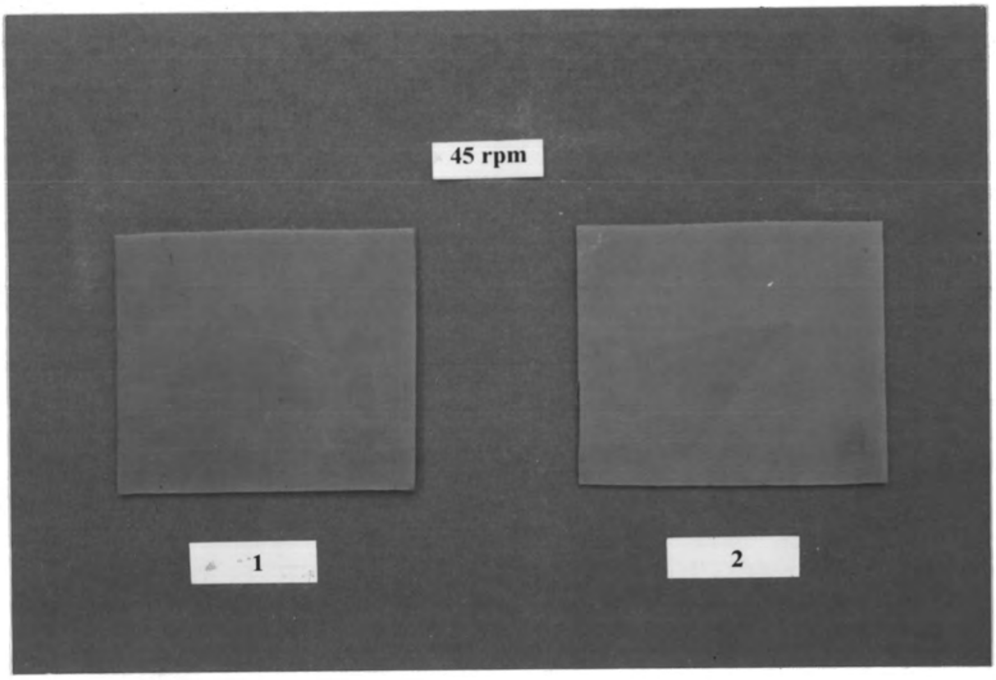


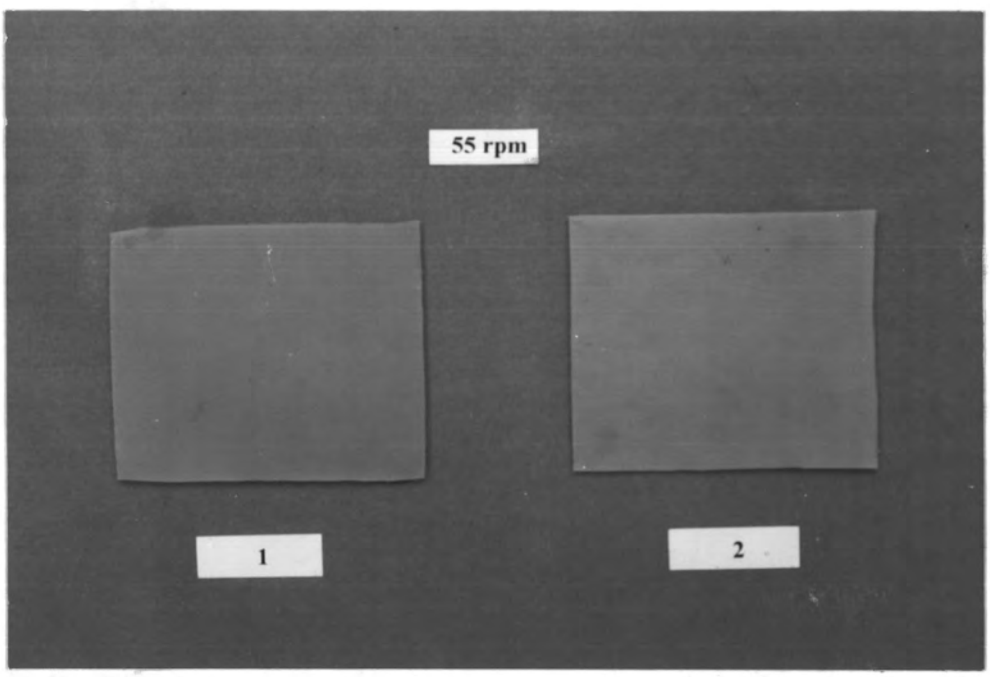
Figure 4.22 Comparison of vulcanizate properties of CV-DPNR and its control produced from RRIM 600 clone at various agitation speed.

a) Tensile strength (n=5)
b) Tear strength (n=5)
c) 300 % Modulus (n=5)
d) Elongation at break (n=5)
e) Hardness (n=3)
f) Specific gravity (n=3)

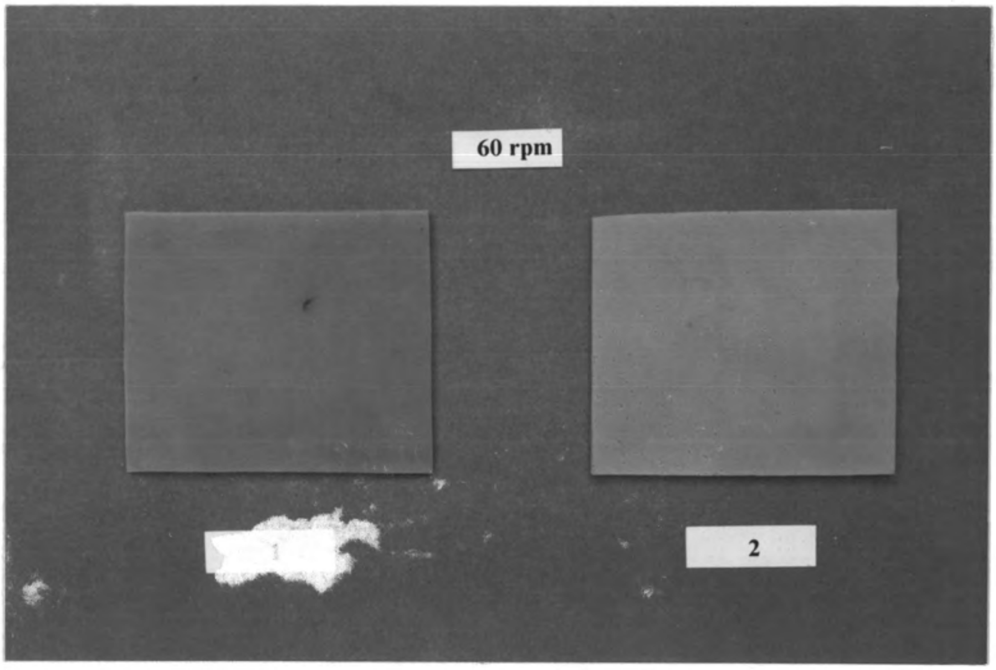
a)



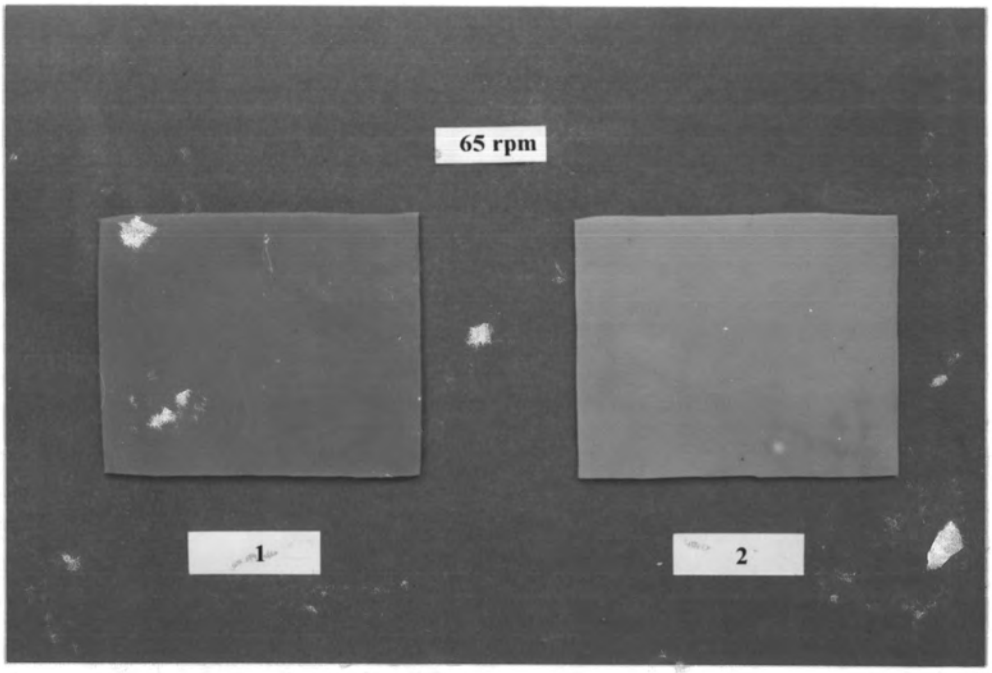
b)



c)



d)



e)

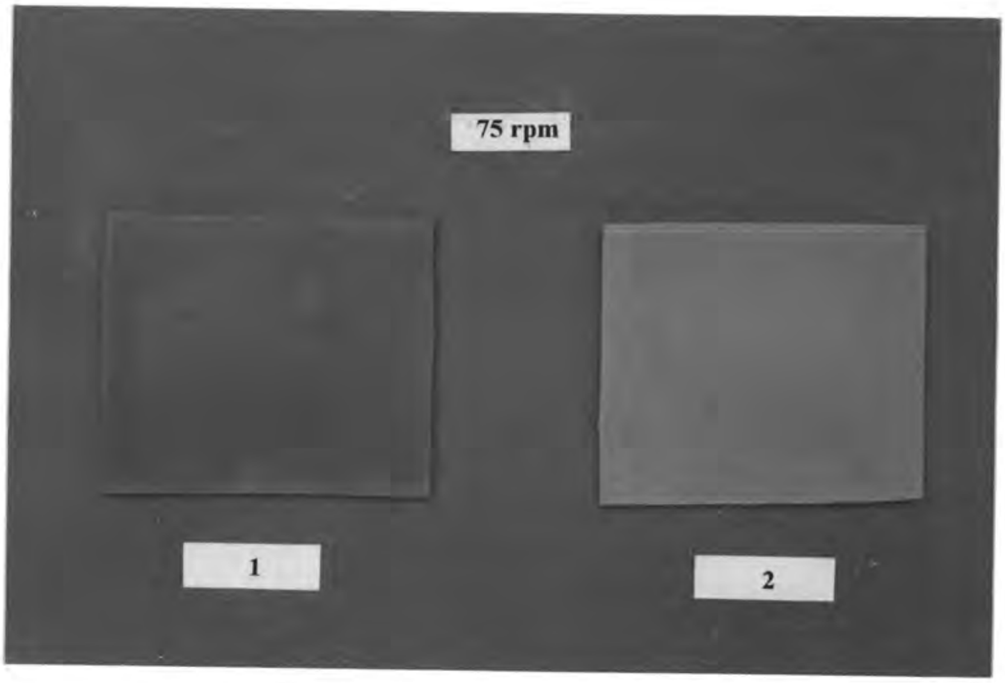


Figure 4.23 Comparison of color of vulcanizate rubber between the CV-DPNR with the control produced from RRIM 600 clone at various agitation speed.

a) At agitation speed 45 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

b) At agitation speed 55 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

c) At agitation speed 60 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

d) At agitation speed 65 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

e) At agitation speed 60 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

4. Effect of ageing on vulcanizate properties of deproteinized rubber

Effect of rubber clone

The effect of ageing on the vulcanizate properties of CV-DPNR and its control CV-NR produced from three different rubber clones shows that tensile strength of CV-NR and CV-DPNR has slightly decreased except RRIM 600. Tear strength, 300% modulus and hardness of all CV-NR and CV-DPNR of all 3 clones increased after ageing. The elongation at break and hardness show increasing trend, but specific gravity did not change after ageing. (Figure 4.24)

There is no different in the color of vulcanizates before and after ageing as shown in Figure 4.25.

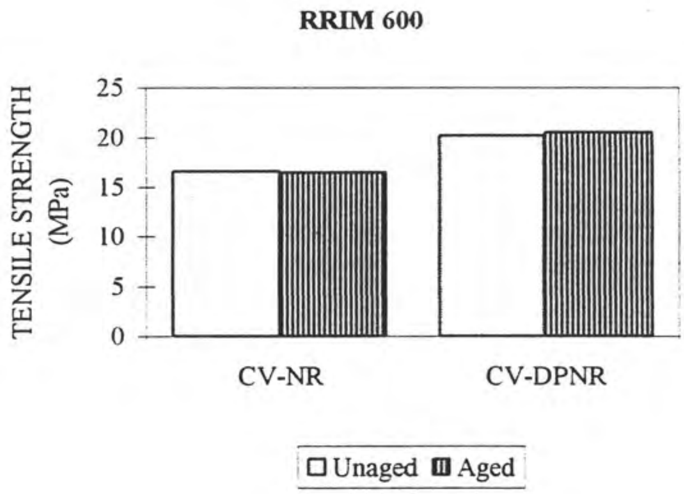
All these results indicate that CV-DPNR can maintain high vulcanizate properties after ageing.

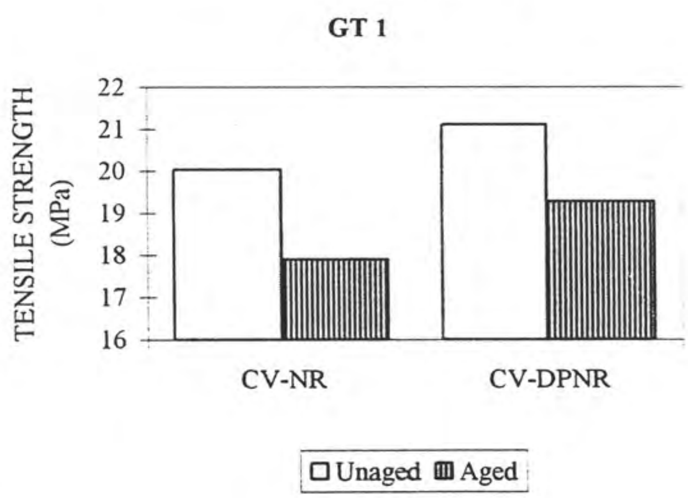
Comparison of the vulcanizate properties between CV-DPNR of rubber clone RRIM 600 produced from Alcalase and Papain with its control before and after ageing shows that tensile strength and tear strength of all samples has slightly increased while 300% modulus and hardness have markly increased. The elongation at break show decreasing trend but specific gravity remains unchanged. (Figure 4.26) After ageing, the color of vulcanizates from CV-DPNR and its control are not different compared with before ageing as shown in Figure 4.27.

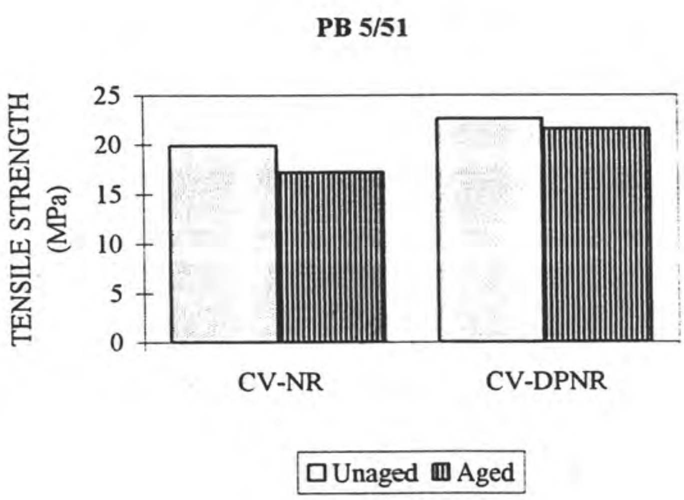
Comparison of the vulcanizate properties of CV-DPNR from clone CV-DPNR at various agitation speeds with its control (speed = 0 rpm) show that agitation speed has no effect on the overall vulcanizate properties of CV-NR but after ageing, tensile strength, tear strength and elongation at break can be highly maintained at speed 45 rpm, where 300% modulus and hardness increased not so much. Specific gravity after ageing has close to before ageing. (Figure 4.28)

Comparing the vulcanizate properties of CV-DPNR from clone RRIM 600 by Papain at various agitation speeds with its control (speed = 0 rpm) show that agitation speed has no effect on the overall vulcanizate properties of CV-DPNR but after ageing, tensile strength, tear strength and elongation at break can be highly maintained at agitation speed 45-60 rpm. . (Figure 4.29) However at agitation speed 45-60 rpm, 300% modulus and hardness increased significantly after ageing. Specific gravity has not changed. The color of vulcanizates of CV-NR and CV-DPNR at various agitation speeds before ageing are similar to those after ageing as shown in Figure 4.30.

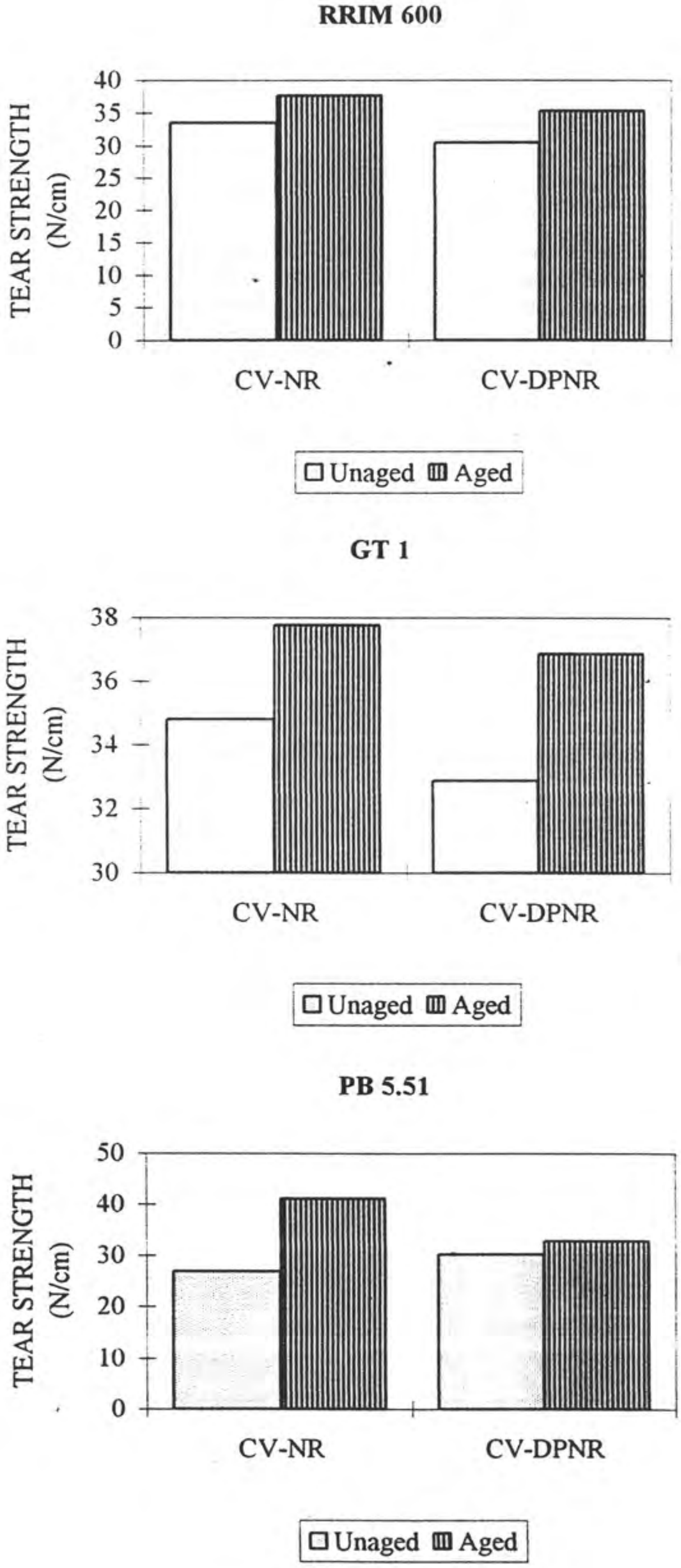
It is concluded that deproteinization improved the overall vulcanizate properties even after ageing and variation of agitation speed 60 rpm yield acceptable quality of vulcanizates.


RRIM 600
TENSILE STRENGTH (MPa)
0
5
10
15
20
25
CV-NR
CV-DPNR
Unaged
Aged

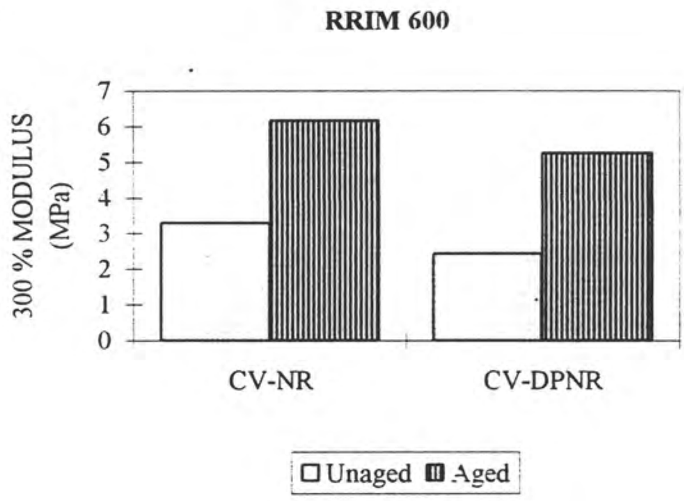

GT 1
TENSILE STRENGTH (MPa)
16
17
18
19
20
21
22
CV-NR
CV-DPNR
Unaged
Aged

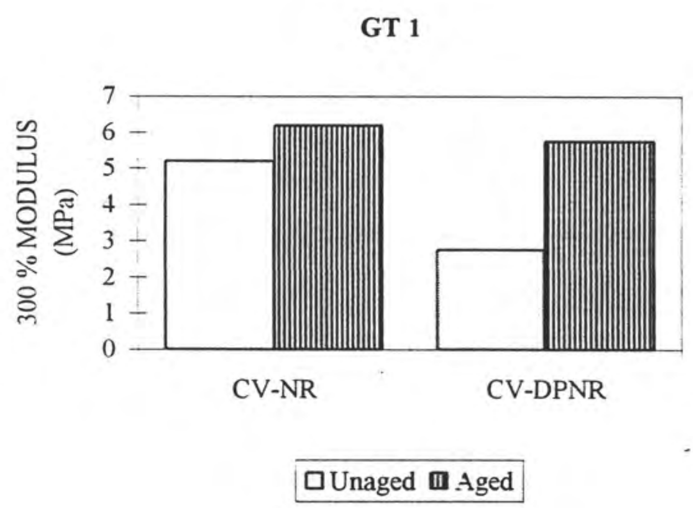

PB 5/51
TENSILE STRENGTH (MPa)
0
5
10
15
20
25
CV-NR
CV-DPNR
Unaged
Aged

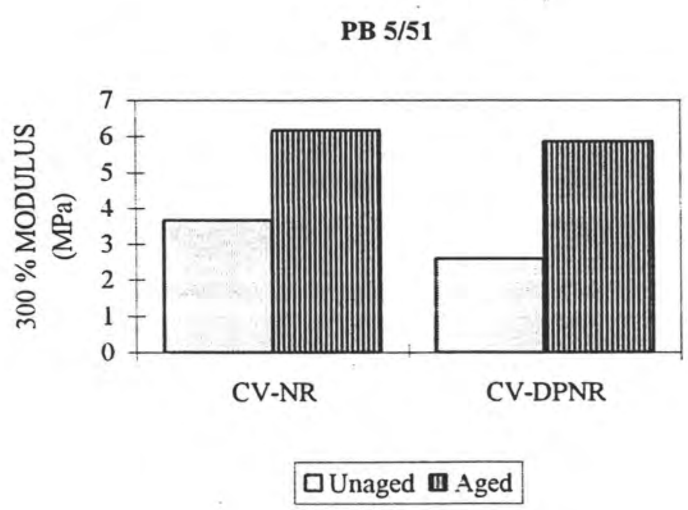
(a)


RRIM 600
TEAR STRENGTH (N/cm)
40
35
30
25
20
15
10
5
0
CV-NR
CV-DPNR
Unaged
Aged
GT 1
TEAR STRENGTH (N/cm)
38
36
34
32
30
CV-NR
CV-DPNR
Unaged
Aged
PB 5.51
TEAR STRENGTH (N/cm)
50
40
30
20
10
0
CV-NR
CV-DPNR
Unaged
Aged

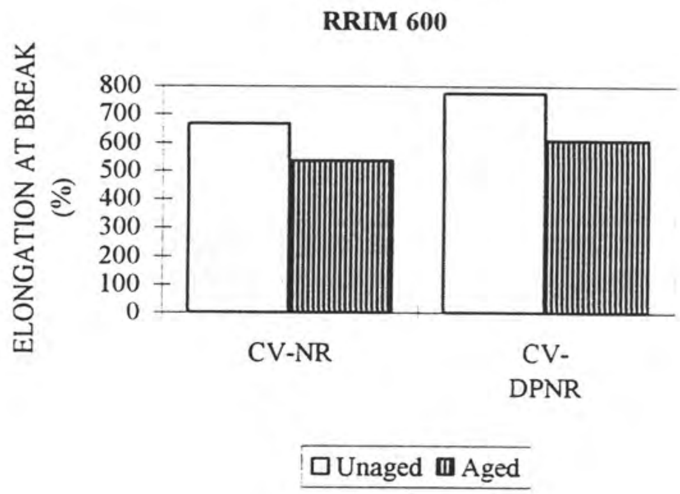
(b)

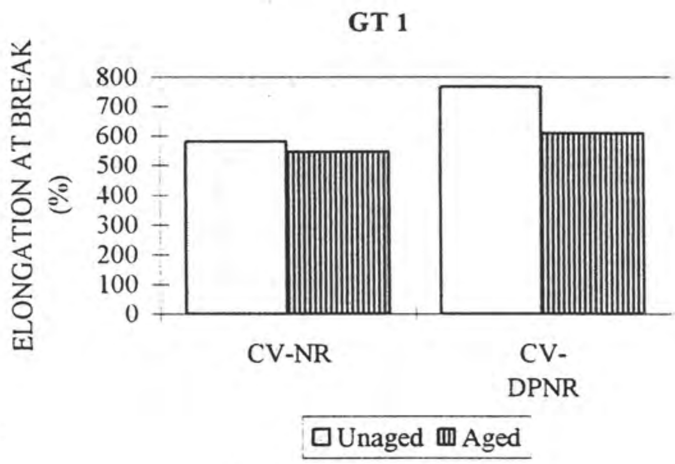

RRIM 600
300 % MODULUS (MPa)
7
6
5
4
3
2
1
0
CV-NR
CV-DPNR
Unaged
Aged

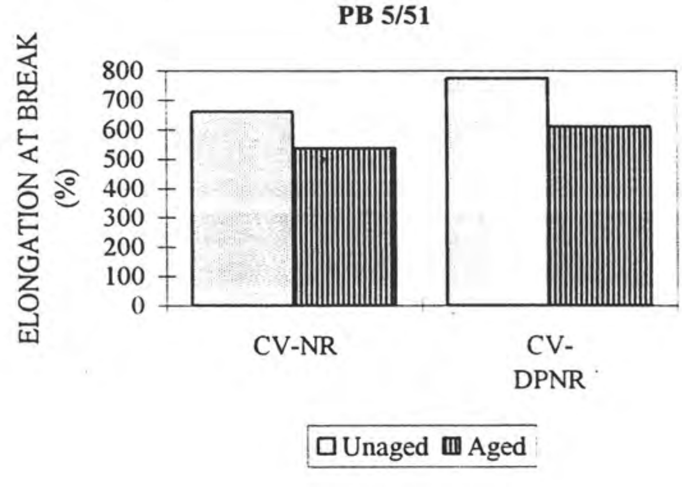

GT 1
300 % MODULUS (MPa)
7
6
5
4
3
2
1
0
CV-NR
CV-DPNR
Unaged
Aged


PB 5/51
300 % MODULUS (MPa)
7
6
5
4
3
2
1
0
CV-NR
CV-DPNR
Unaged
Aged

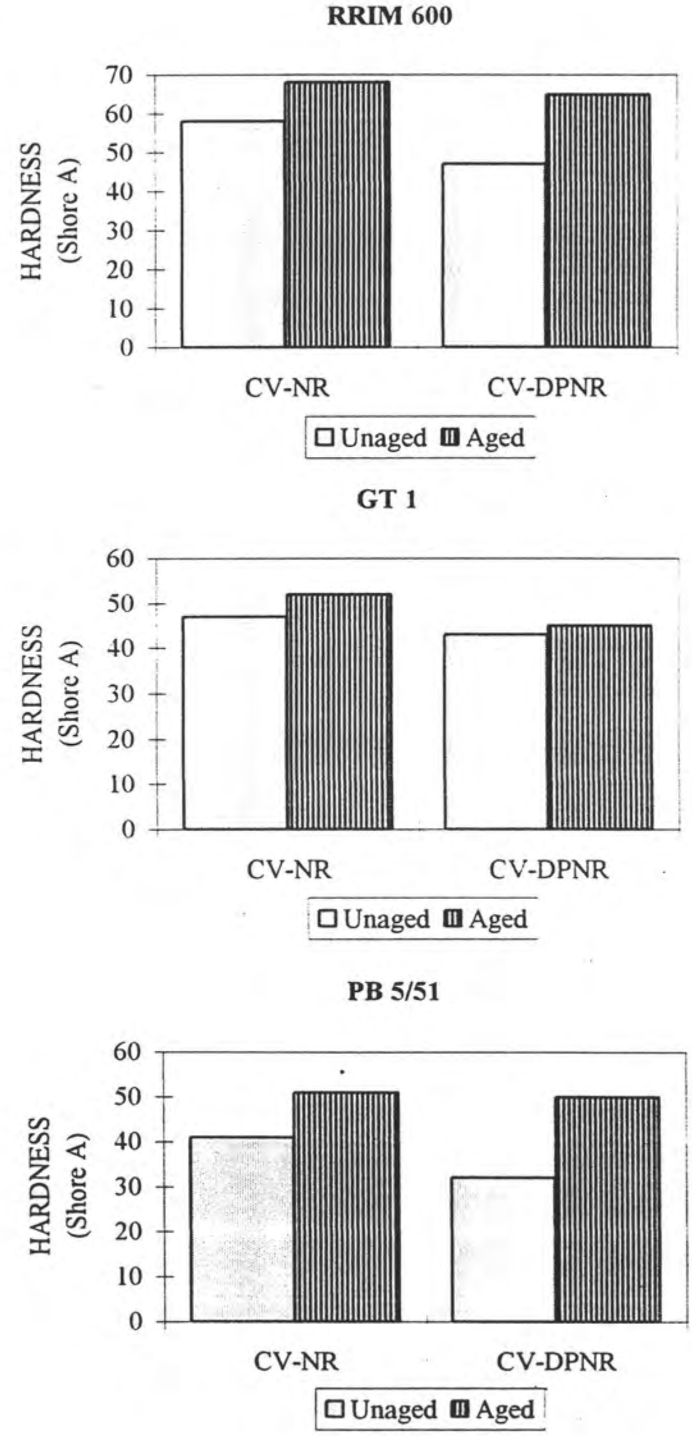
(c)


RRIM 600
ELONGATION AT BREAK (%)
800
700
600
500
400
300
200
100
0
CV-NR
CV-DPNR
Unaged
Aged

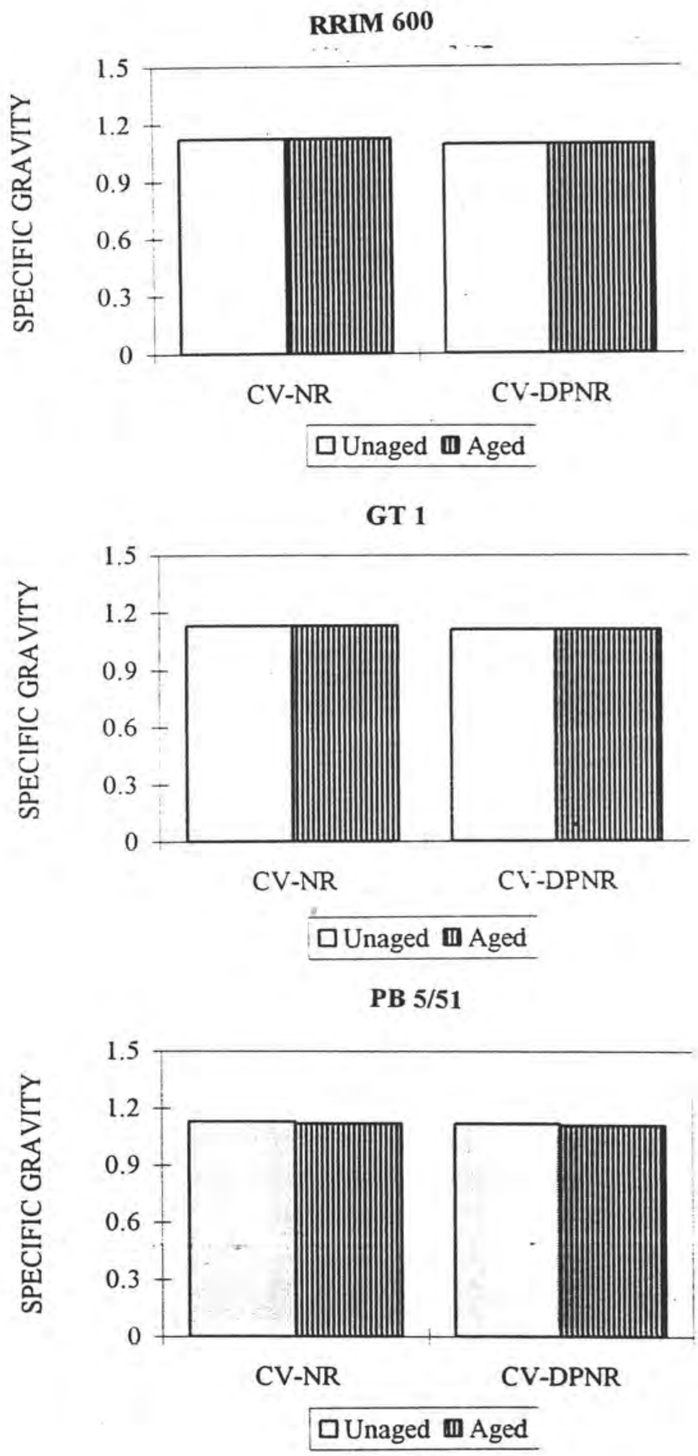

GT 1
ELONGATION AT BREAK (%)
800
700
600
500
400
300
200
100
0
CV-NR
CV-DPNR
Unaged
Aged


PB 5/51
ELONGATION AT BREAK (%)
800
700
600
500
400
300
200
100
0
CV-NR
CV-DPNR
Unaged
Aged

(d)


RRIM 600
HARDNESS (Shore A)
70
60
50
40
30
20
10
0
CV-NR
CV-DPNR
Unaged
Aged
GT 1
HARDNESS (Shore A)
60
50
40
30
20
10
0
CV-NR
CV-DPNR
Unaged
Aged
PB 5/51
HARDNESS (Shore A)
60
50
40
30
20
10
0
CV-NR
CV-DPNR
Unaged
Aged

(e)

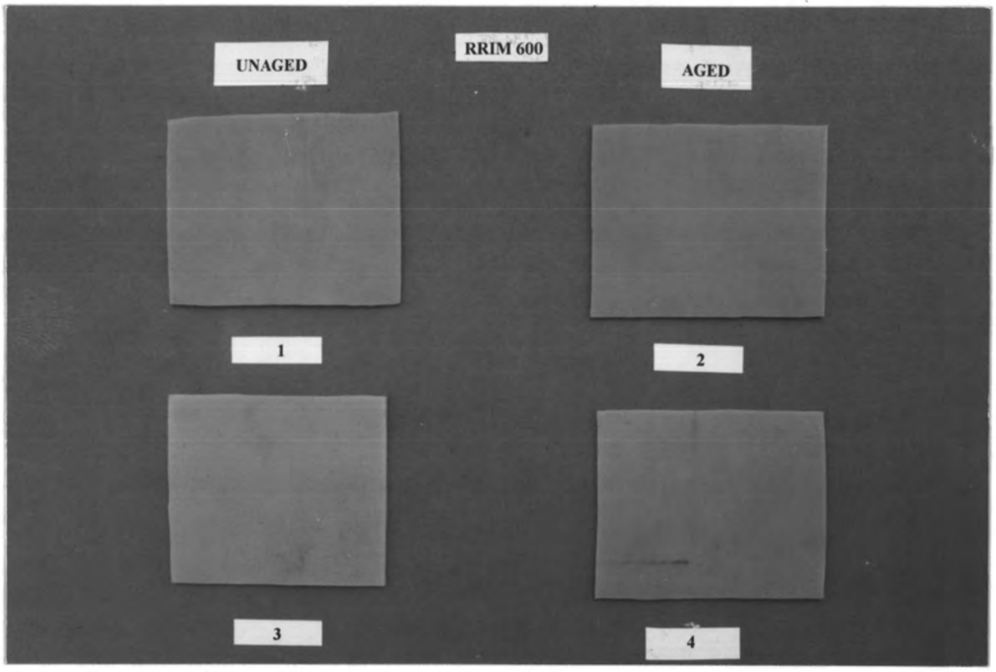


(f)

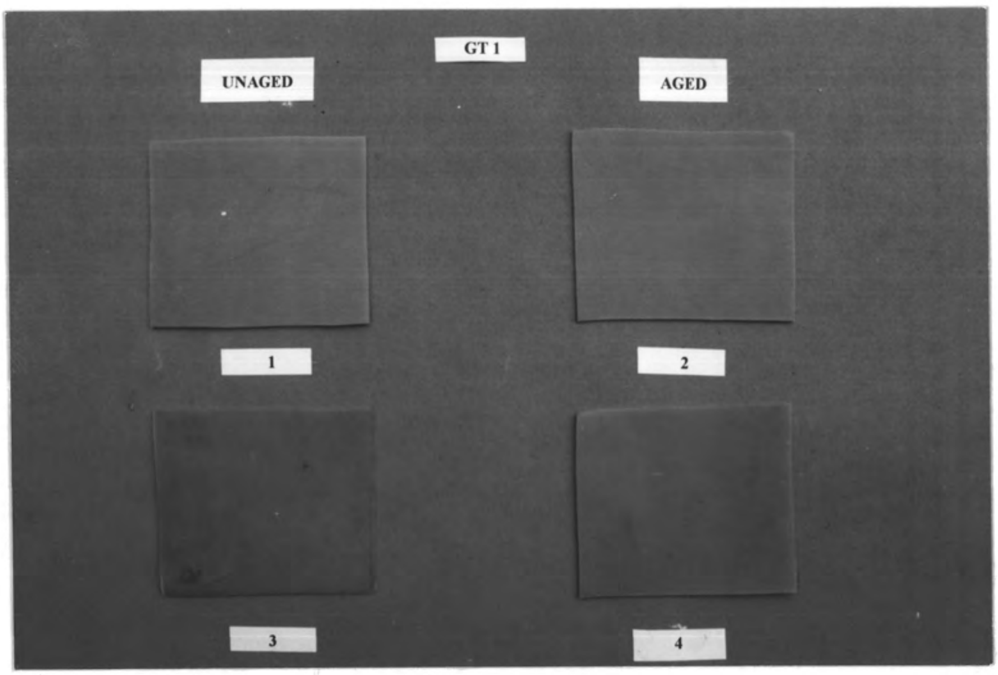
Figure 4.24 Comparison of vulcanizate properties of CV-DPNR and its control produced from field latex from three different clones before and after ageing.

a) Tensile strength (n=5) b) Tear strength (n=5)
c) 300 % Modulus (n=5) d) Elongation at break (n=5)
e) Hardness (n=3) f) Specific gravity (n=3)

a)



b)



c)

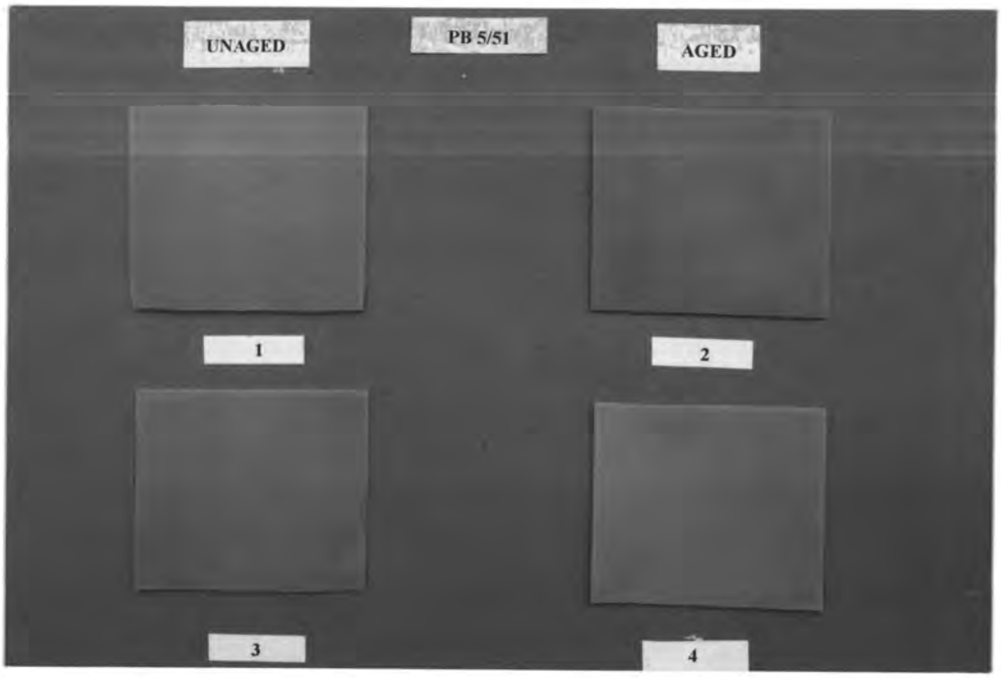


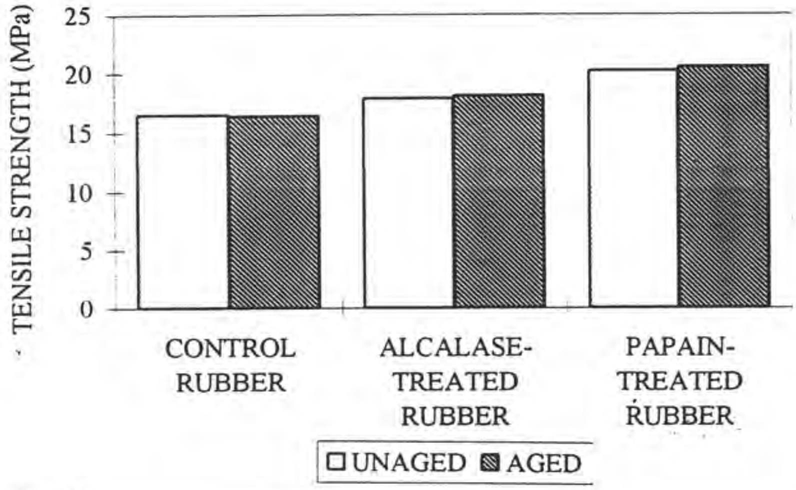
Figure 4.25 Comparison of color of vulcanizate rubber between the CV-DPNR with the control produced from different rubber clones before and after ageing.

a) From fresh latex clone RRIM 600
   1) Non-treated rubber
   2) Papain-treated rubber

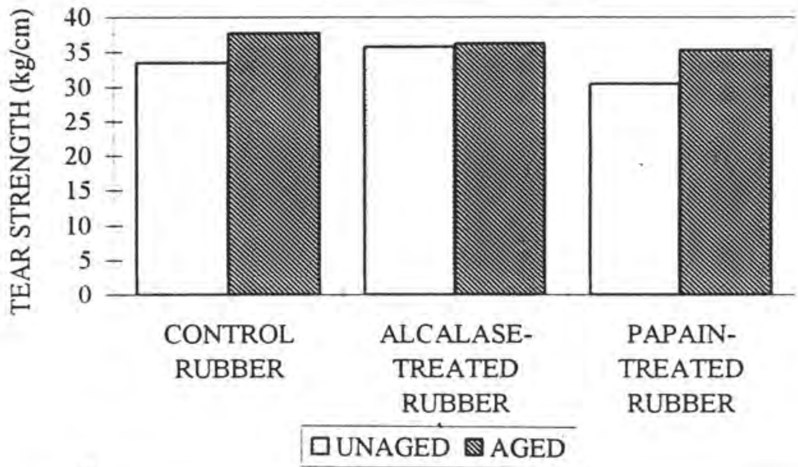
b) From fresh latex clone GT 1
   1) Non-treated rubber
   2) Papain-treated rubber

c) From fresh latex clone PB 5/51
   1) Non-treated rubber
   2) Papain-treated rubber

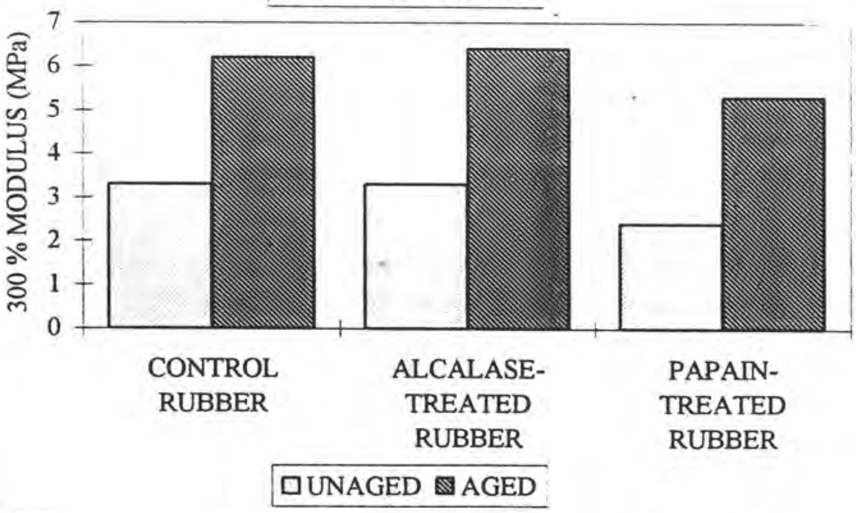
a)


TENSILE STRENGTH (MPa)
25
20
15
10
5
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
UNAGED
AGED

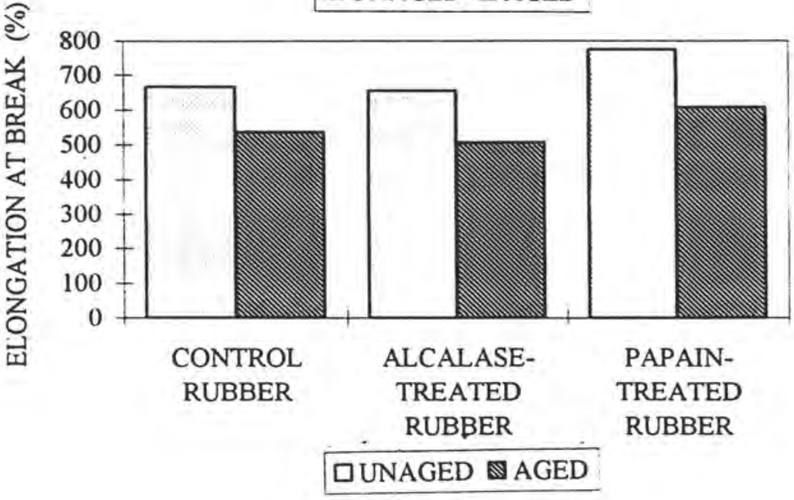
b)


TEAR STRENGTH (kg/cm)
40
35
30
25
20
15
10
5
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
UNAGED
AGED

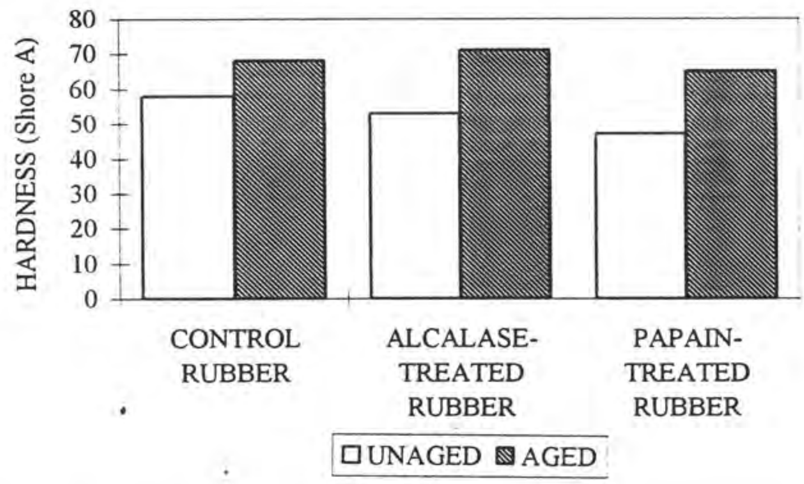
c)


300 % MODULUS (MPa)
7
6
5
4
3
2
1
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
UNAGED
AGED

d)


ELONGATION AT BREAK (%)
800
700
600
500
400
300
200
100
0
CONTROL RUBBER
ALCALASE-TREATED RUBBER
PAPAIN-TREATED RUBBER
UNAGED
AGED

e)



f)

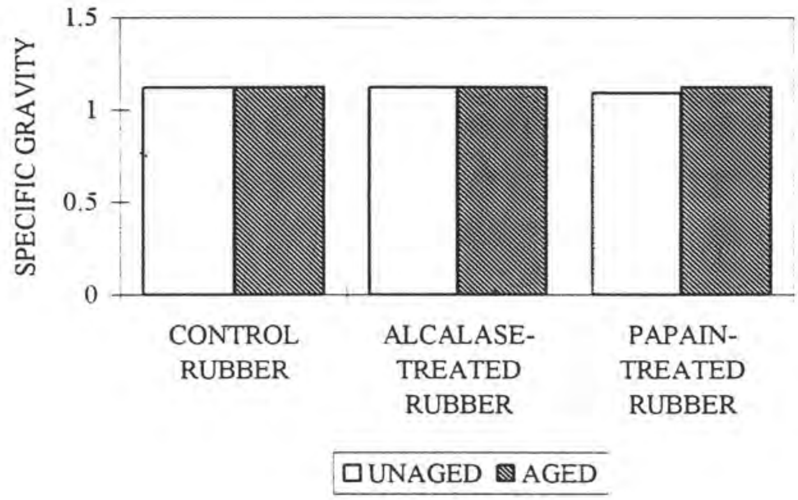


Figure 4.26 Comparison of vulcanizate properties of CV-DPNR and its control produced from RRIM 600 clone by Alcalase and Papain before and after ageing

a) Tensile strength (n=5)
b) Tear strength (n=5)
c) 300 % Modulus (n=5)
d) Elongation at break (n=5)
e) Hardness (n=3)
f) Specific gravity (n=3)

a)

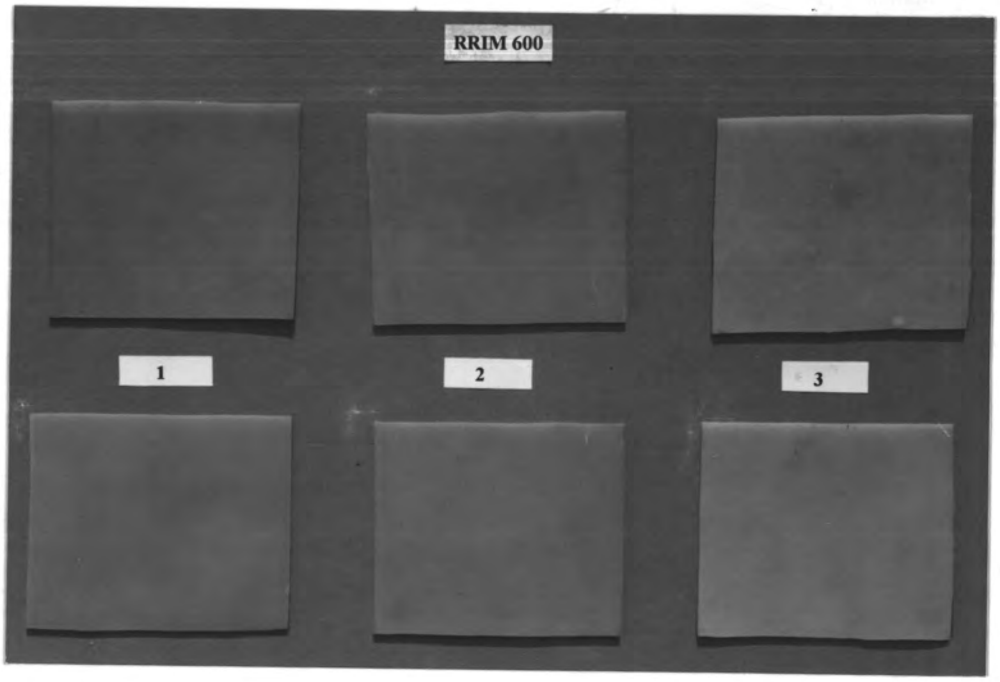
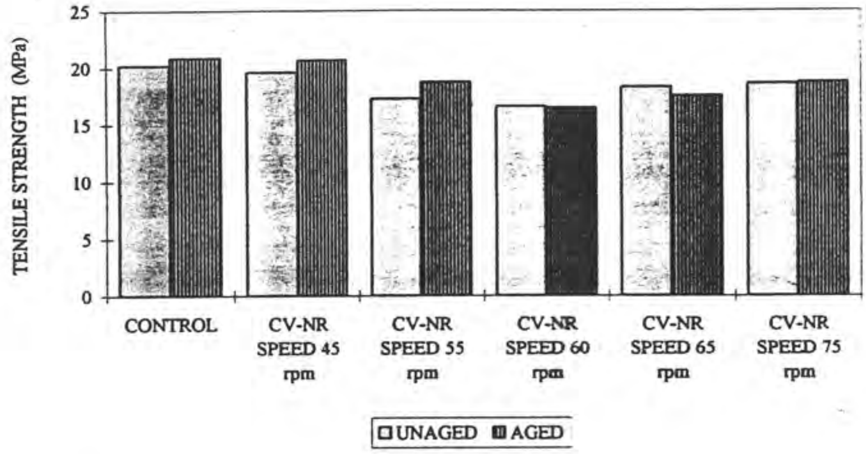


Figure 4.27 Comparison of color of vulcanizate rubber between the CV-DPNR with the control produced from RRIM 600 rubber clone by Alcalase and Papain before and after ageing.

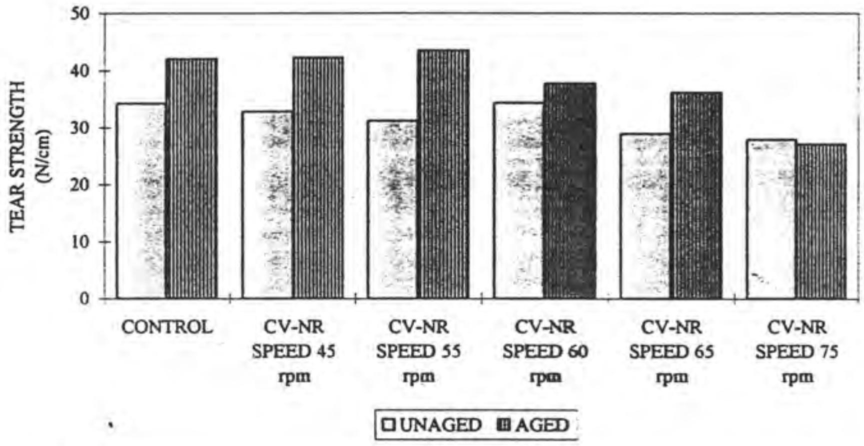
a) From fresh latex clone RRIM 600

1) Non-treated rubber
2) Papain-treated rubber
3) Alcalase-treated rubber

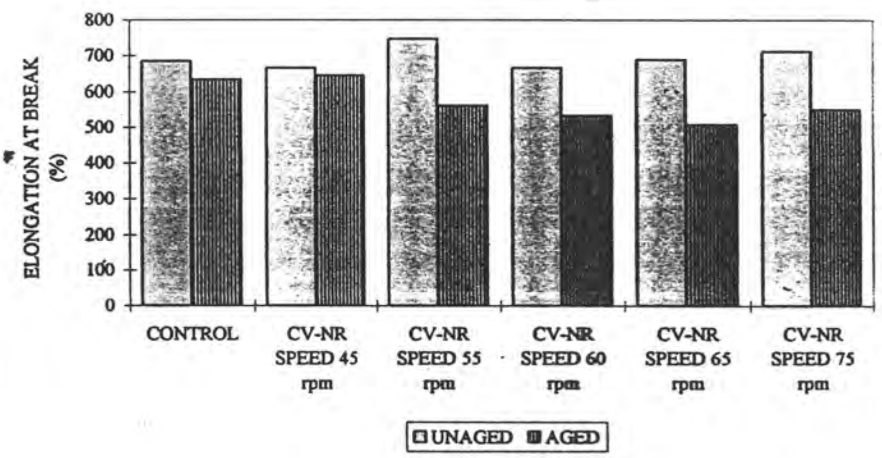
a)


25
20
15
10
5
0
TENSILE STRENGTH (MPa)
CONTROL
CV-NR SPEED 45 rpm
CV-NR SPEED 55 rpm
CV-NR SPEED 60 rpm
CV-NR SPEED 65 rpm
CV-NR SPEED 75 rpm
UNAGED
AGED

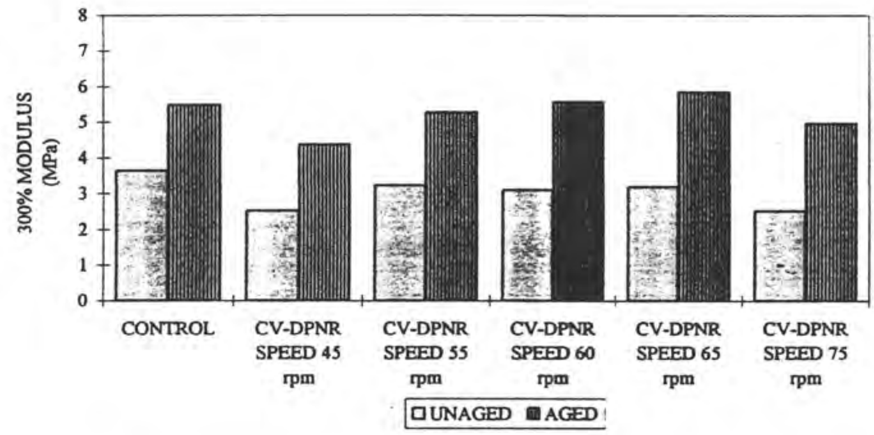
b)


50
40
30
20
10
0
TEAR STRENGTH (N/cm)
CONTROL
CV-NR SPEED 45 rpm
CV-NR SPEED 55 rpm
CV-NR SPEED 60 rpm
CV-NR SPEED 65 rpm
CV-NR SPEED 75 rpm
UNAGED
AGED

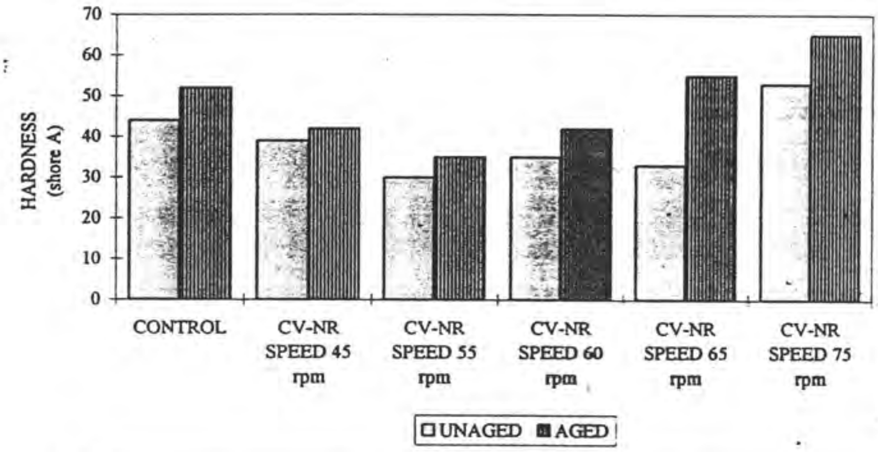
c)


800
700
600
500
400
300
200
100
0
ELONGATION AT BREAK (%)
CONTROL
CV-NR SPEED 45 rpm
CV-NR SPEED 55 rpm
CV-NR SPEED 60 rpm
CV-NR SPEED 65 rpm
CV-NR SPEED 75 rpm
UNAGED
AGED

d)



e)



f)

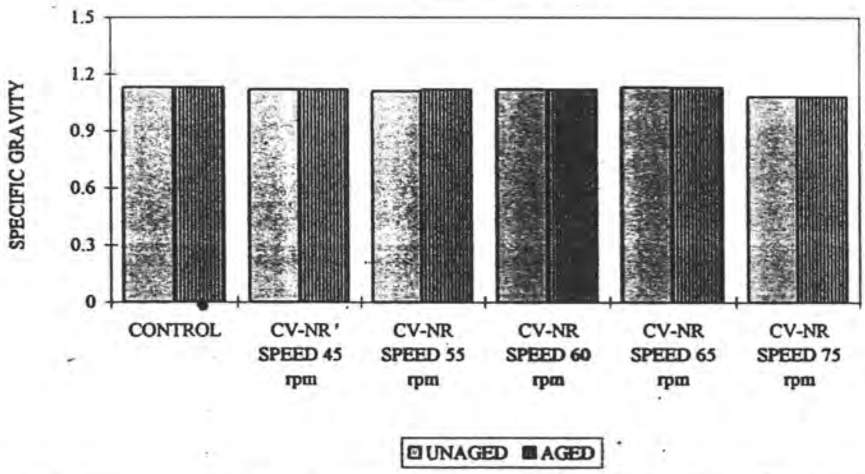
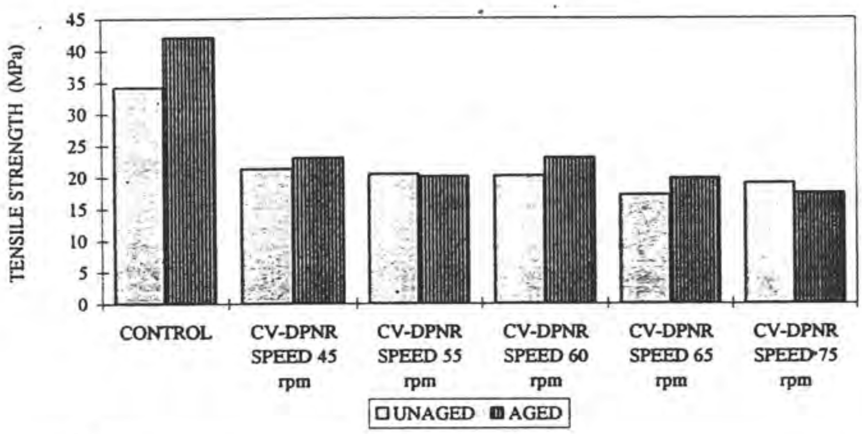


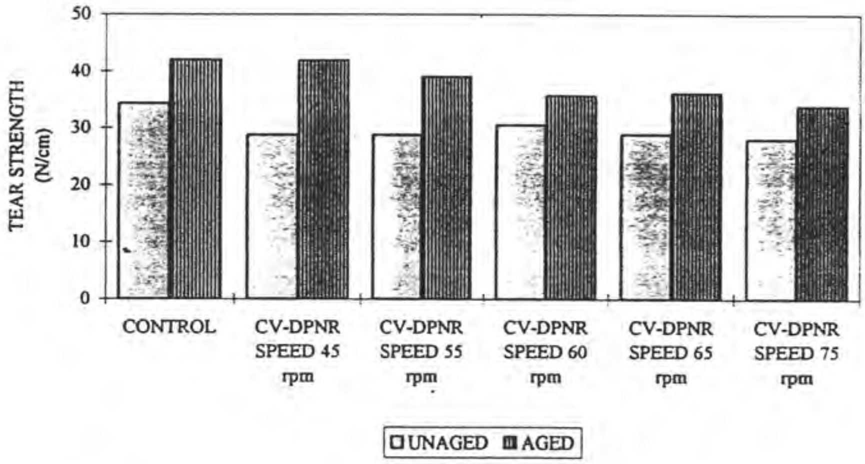
Figure 4.28 Comparison of vulcanizate properties of CV-DPNR and its control produced from RRIM 600 clone at various agitation speed before and after ageing

a) Tensile strength (n=5)
b) Tear strength (n=5)
c) 300 % Modulus (n=5)
d) Elongation at break (n=5)
e) Hardness (n=3)
f) Specific gravity (n=3)

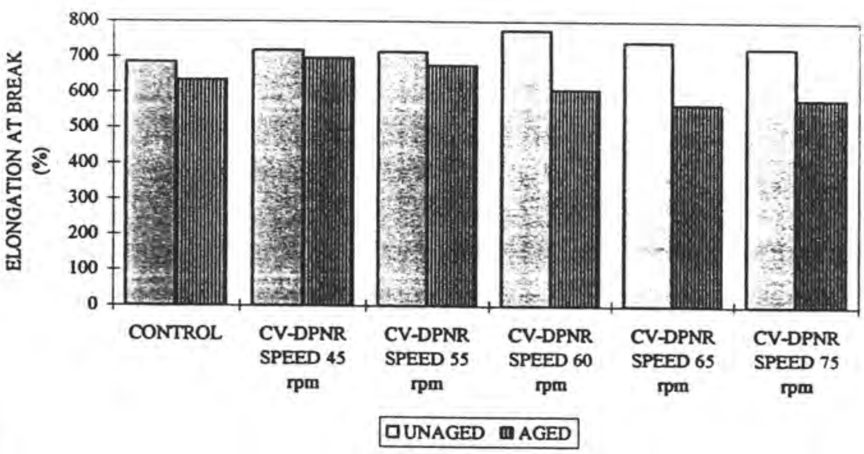
a)


TENSILE STRENGTH (MPa)
45
40
35
30
25
20
15
10
5
0
CONTROL
CV-DPNR SPEED 45 rpm
CV-DPNR SPEED 55 rpm
CV-DPNR SPEED 60 rpm
CV-DPNR SPEED 65 rpm
CV-DPNR SPEED 75 rpm
UNAGED
AGED

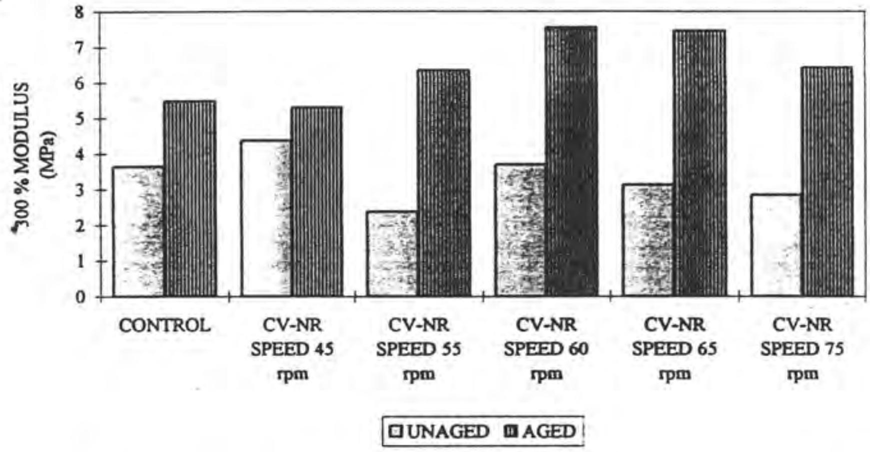
b)


TEAR STRENGTH (N/cm)
50
40
30
20
10
0
CONTROL
CV-DPNR SPEED 45 rpm
CV-DPNR SPEED 55 rpm
CV-DPNR SPEED 60 rpm
CV-DPNR SPEED 65 rpm
CV-DPNR SPEED 75 rpm
UNAGED
AGED

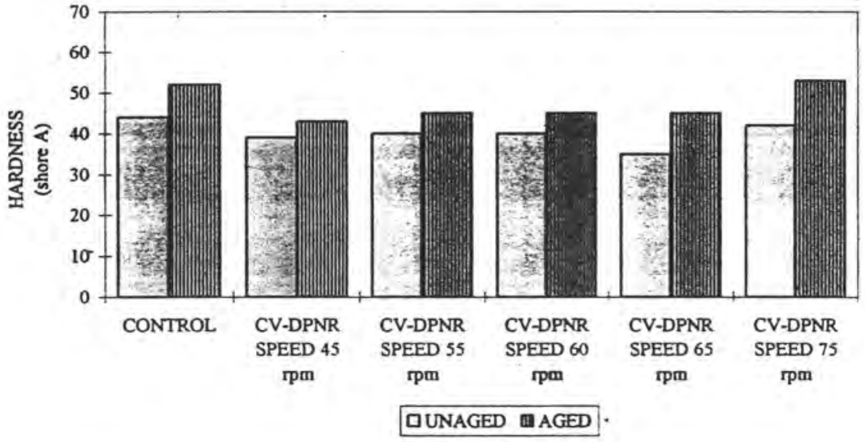
c)


ELONGATION AT BREAK (%)
800
700
600
500
400
300
200
100
0
CONTROL
CV-DPNR SPEED 45 rpm
CV-DPNR SPEED 55 rpm
CV-DPNR SPEED 60 rpm
CV-DPNR SPEED 65 rpm
CV-DPNR SPEED 75 rpm
UNAGED
AGED

d)



c)



f)

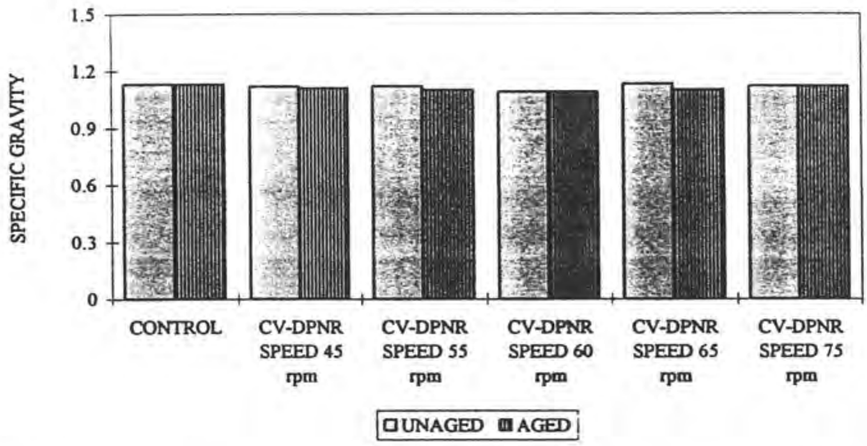
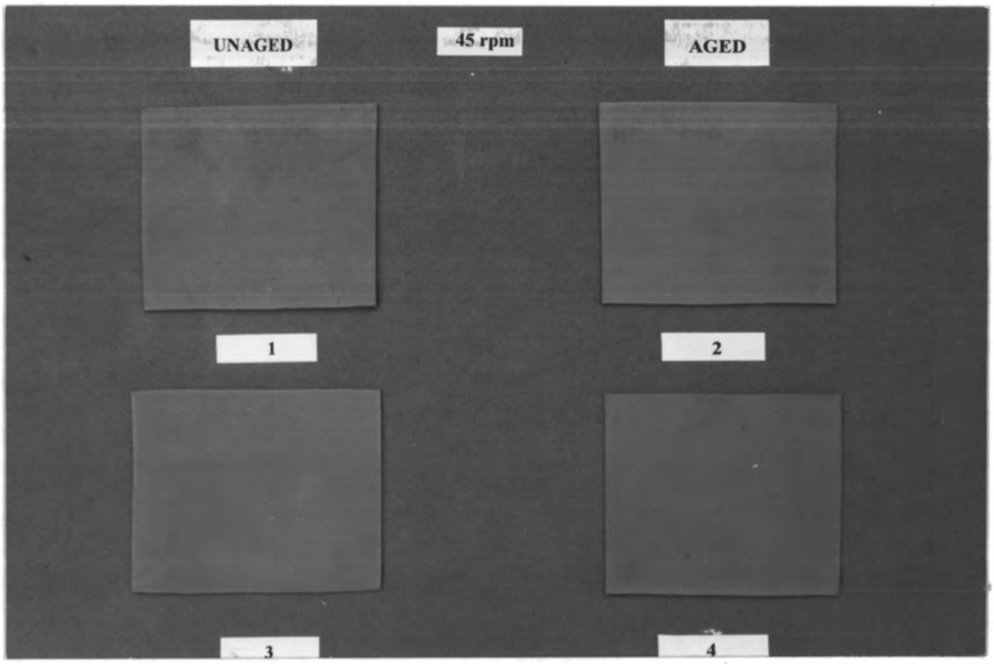


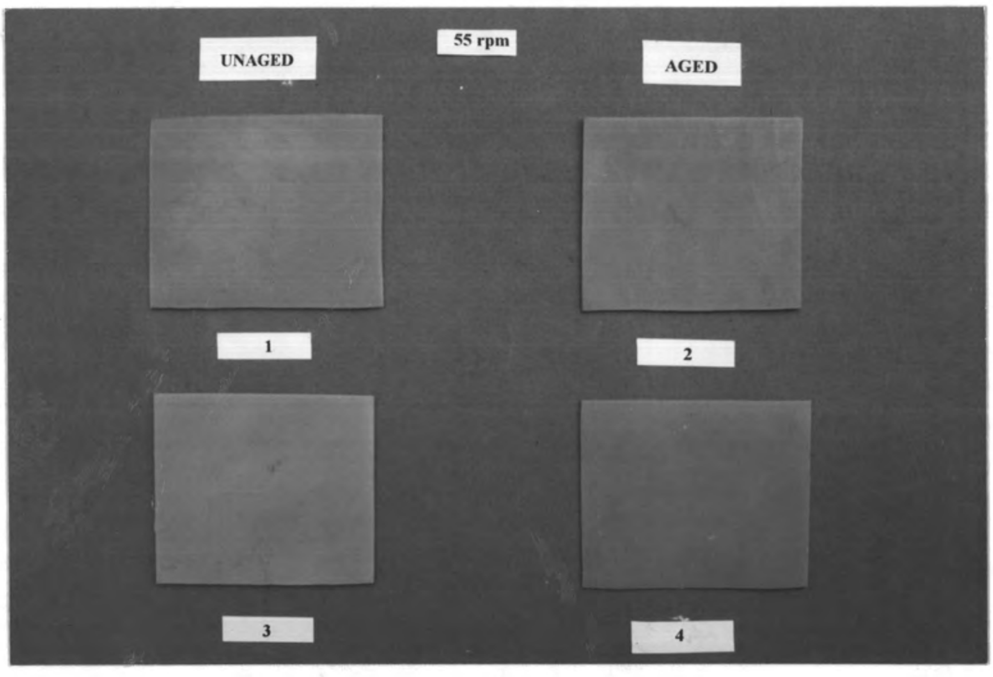
Figure 4.29 Comparison of vulcanizate properties of CV-NR and its control produced from RRIM 600 clone at various agitation speed before and after ageing

a) Tensile strength (n=5) b) Tear strength (n=5)
c) 300 % Modulus (n=5) d) Elongation at break (n=5)
e) Hardness (n=3) f) Specific gravity (n=3)

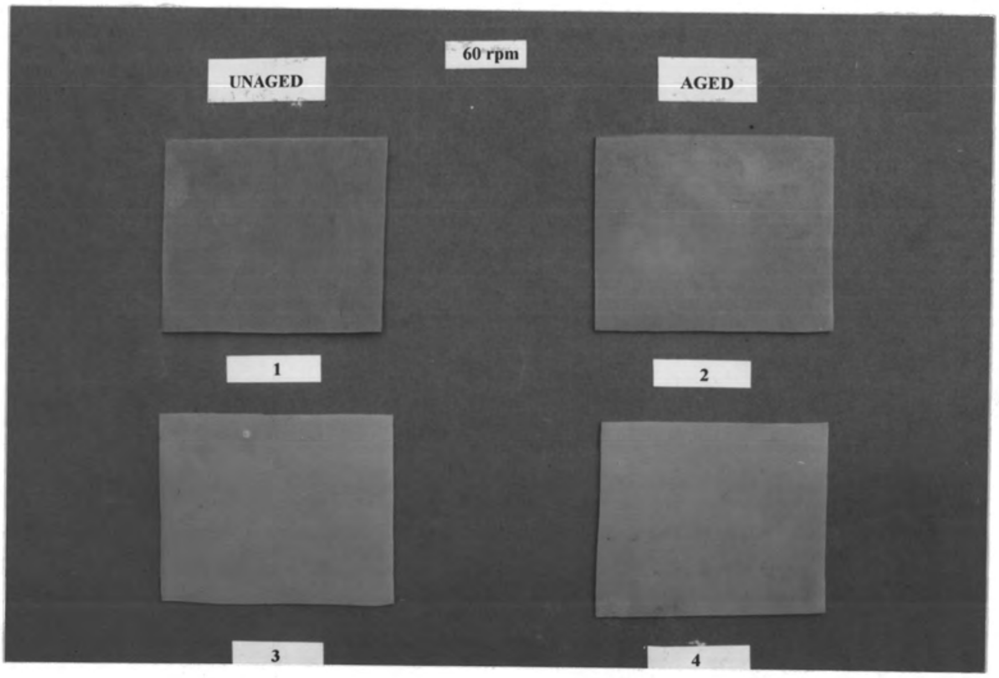
a)



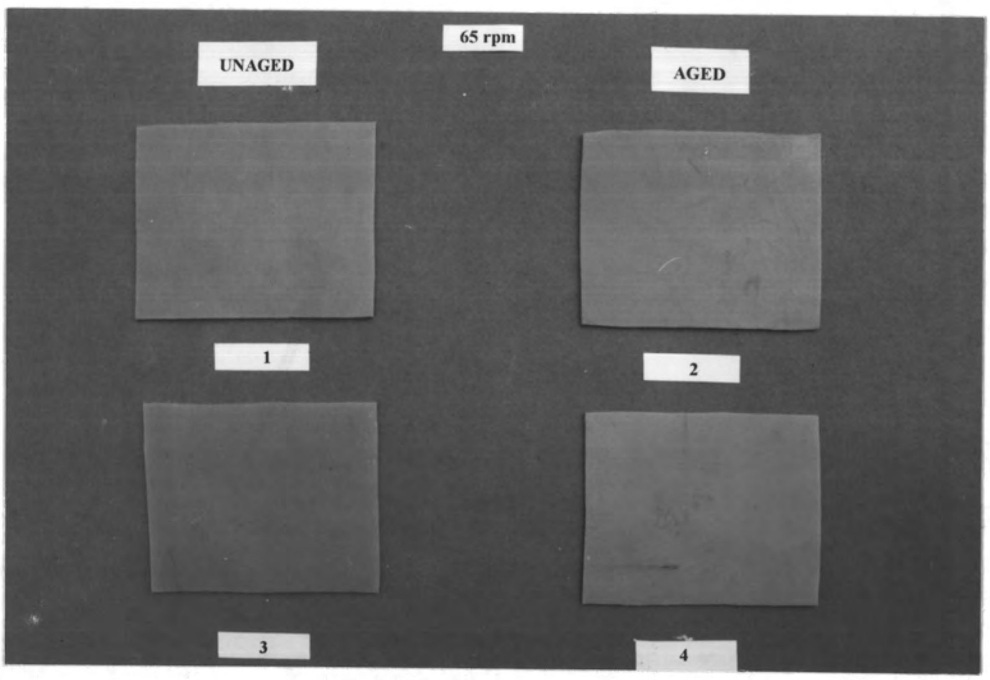
b)



c)



d)



e)

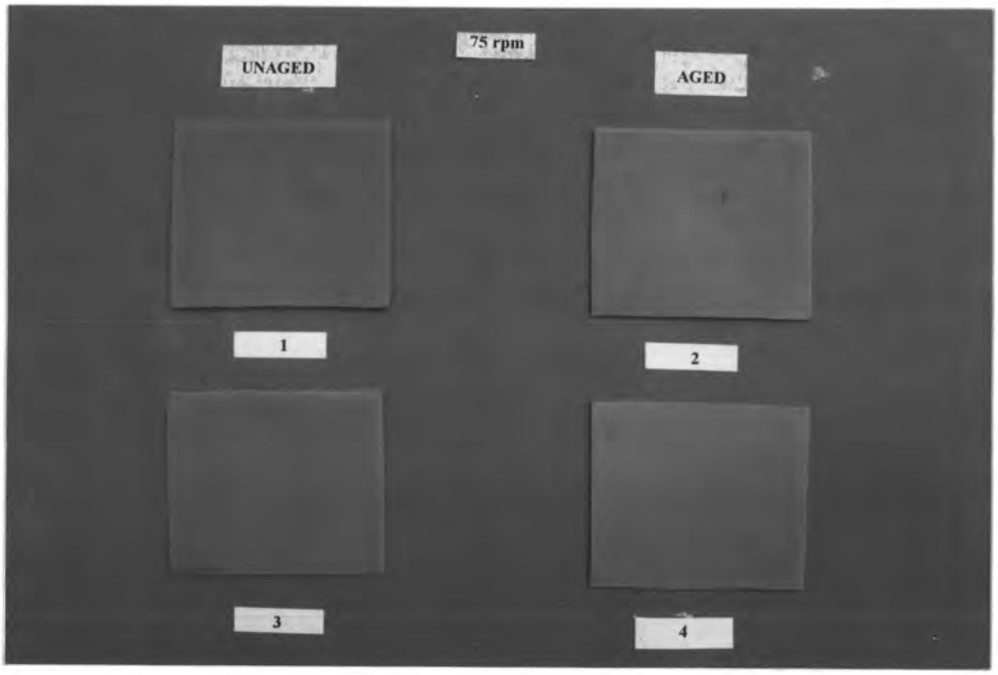


Figure 4.30 Comparison of color of vulcanizate rubber between the CV-DPNR with the control produced from RRIM 600 clone at various agitation speed before and after ageing.

a) At agitation speed 45 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

b) At agitation speed 55 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

c) At agitation speed 60 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

d) At agitation speed 65 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber

e) At agitation speed 60 r.p.m
   1) Non-treated rubber
   2) Papain-treated rubber