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The Evaluation of the Banana Tree as a Source of Papermaking Fiber

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"THE EVALUATION OF THE BANANA TREE AS A SOURCE OF PAPERMAKING FIBER"

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ABSTRACT

This investigation is conducted under four broad categories - effect of various cooking methods, blending with softwood, CEHD bleaching and fiber microscopy.

It is found that the leaves are unpulpable but the stalks and stems give fibers comparable to hardwoods.

Banana pulps are uneconomical to bleach due to high Kappa nubers and acid pretreatment requirement.

The individual fibers are long, slender and stiff similar to bamboo and rice fibers. Peculiar hairlike structures are dominant.

Banana pulp can be substituted for hardwood pulp in the manufacture of bags and wrapping paper and especially advantageous for liner board due to its high stiffness.

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INTRODUCTION

In recent years, due to shortage of wood fibers, attention has been diverted towards various potential fibers such as bagasse, kenaf, and hemp.

Although the banana tree has great potential for papermaking in South America, the West Indies, and Africa, very little work has been done on its fibers. The banana tree, grown mainly in the tropics produces only one bunch of bananas after which it is felled and let to rot on the ground. The life span is about one year.

Before any investigation should be made, economical considerations must be taken into account (1).

1. The supply of papermaking material should be adequate all the year round, or if the supply is seasonal, the stock should last at least for a year, without undergoing deterioration on storing.
2. The cost of collection and transport should be low. This warrants the collection in small concentrated areas. The industrial possibilities of a raw material will not only depend on its technical suitability, but also on its ready availability, in sufficient quantity, at a reasonable price.

The banana tree satisfies all these conditions in Uganda. Being a staple food crop, it is grown widespread by both small scale farmers and huge plantation owners.

LITERATURE REVIEW

It has been reported (2) that several truck gardeners and agricultural experiment stations were induced to experiment with the crushed stalks as a mulch and soil builder. This material was found useful, particularly with tomatoes and cucumbers grown under glass and also has been used out of doors. Fertilization is not a serious problem in the rich volcanic soils in East Africa and hence the banana stalks and leaves could be applied to a more profitable project and eventually supply the lone paper mill at Jinja, Uganda with pulp for the manufacture of bags and wrapping paper for the local sugar, coffee and tea industries. This will greatly alleviate the tremendous expense incurred in importing pulp from India. The banana fibre may also be blended with the Kraft pulp which could be a major savings.

Experiments with locally grown banana fibre in the manufacture of grain bags are being carried out in Rhodesia (3). Bags have been made containing up to 30% banana fibre and 50% sisal and banana fibre combined. The bags appeared under physical and laboratory tests to be as strong as normal bags made from 100% jute, says the report. The bags are, however, slightly coarser in appearance but it is believed that when a technique for batching and carding the fibres has been perfected the resultant product will be indistinguishable from jute. The factory is buying dried "ribbons" of banana stalks from growers in the Umtali district and across the Portuguese border.

Although the yield of fibre per acre cannot be stated accurately, it is thought that the yield will be between one and 1 1/2 tons of dried "ribbons" to the acre. Only the stock is used as it has been found difficult to obtain a clean fiber from the leaves.

Arturo A. Pablo (4), produced wrapping paper from banana leaf sheaths by the sulfate process. He states that banana leaf sheaths showed a high cellulose and ash content when put in hot water and 1% NaOH only, but a comparatively low lignin content. The extremely long fibers with high slenderness ratios gave brown paper with a high tear strength. A suitable portion of short fiber pulps could be blended to give a sufficient supply for producing wrapping paper on a commercial scale.

The United Fruit Company, Research Laboratory (5), performed a few tests on the banana fibre. The yield was found to be poor, completely reiterating the work done by Pablo. The fruit stem, "stalk", produced 3% fresh weight basis and the pseudostem, "trunk" only 1-2% fresh weight basis fibres.

The fiber quality was contradictory to Pablo's work. They were found to be coarse and become brittle on aging.

In 1963, two shipments of banana fibers were sent to their laboratories in the United States for evaluation. These fibers were from Lacatan, Gros Michel, Cocos and Valery varieties and were obtained from banana fruit stalks. The following conclusions were deduced:

1. Fibers are so short and variable and so weak and brittle that fiber tests are impractical.
2. These banana fibers seem to be darker in color, dirtier, shorter and more variable and weaker than any other fiber of this type seen in the past.
3. The fibers were poorly cleaned and the method of extracting appeared drastic.
4. These fibers could not be processed over hard fiber preparation equipment but could have to be, if processed at all, carded followed by running over jute type equipment. A test was run but not well. The card output of Gros Michel-Cocos lot just held together. Valery-Lacatan did better, but again there was appreciable reduction in fiber length.

The banana stalks were analyzed for their chemical composition. The fresh banana stalks contain about 92% moisture. The 8% solids were broken down as follows:

Crude Fiber	39%
Sugars	15%
Necturs	16%
Ash	28%
Organic Matter	2%

A more detailed analysis of the dry material contained in banana stalks followed:

Express as percent oven dry solids:

Crude Fiber	38.94%
Total Carbohydrates other than crude fiber	15.00
Total Sugars	4.34
Furfural, Pentosans and Pentoses expressed as furfural	7.10
Tannins	0.13
Pectin as Calcium Pectate	13.02
Profopectin as Calcium Pectate	3.02
Ash	28.16

The fiber pectin and ash appeared to offer possibilities. It seemed at one time that the fiber might prove valuable for use as an ingredient of paperboard stocks to give added strength and hardness. Unfortunately manufacturers pursued this project no further when they found out that the total tonnage that could ever be available would be inadequate for even one good size paperboard mill. The economics of importing stalks offered additional difficulties.

Due to considerable similarities between banana and bagasse and bamboo, modern technology in pulping of the latter may be applied successfully to pulping of the banana tree.

N.S. Rao and K.M. Chandran (6), obtained a 55% yield from bagasse using the conventional Kraft cook with prehydrolysis at 140°C for 15 minutes in a bath ratio of 1:5 and using 10% active alkali as Na_2O and a sulphidity of 21%. It was cooked at a maximum temperature of 160°C for 10 minutes.

N.R. Jangalgi and N.S. Jaspal (7), state that high yield Kraft pulps in the yield range of 52-63 percent were obtained from Bambusa arundinacea by applying chemical treatment to the chips at higher temperature and pressure, followed by gentle refining in the Sprout Waldron refiner. Different pulp yields were obtained by varying the active alkali charges, while other conditions were maintained constant. By reduced alkali charges the increase in pulp yield was due to the retention of greater amount of ash, extractives, lignin and holocellulose. Beyond the yield of 59 percent, the increase in pulp yield was solely due to the increase in lignin content.

Therefore using the above technology a very satisfactory pulp may be obtained from the banana tree for the manufacture of liner board, paper bags and wrapping paper.

EXPERIMENT DESIGN

Materials Used

1. Banana fiber - Banana stalks, stems and leaves supplied by United Fruit Company, Boston, Massachussetts.
2. Hardwood Pulp - Standard unbleached Kraft pulp.
3. Softwood Pulp - Standard unbleached Kraft pulp.

Chemicals

A. Cooking

1. Sodium hydroxide, NaOH
2. Sodium Sulfide, Na_2S
3. Sodium Sulfite, Na_2SO_3
4. Sodium Carbonate, Na_2CO_3
5. Alum - analytical grade $Al_2\ (SO_4)_3$, $14H_2O$

B. Bleaching

1. Chlorine gas, Cl_2
2. Chlorine dioxide ClO_2
3. Sodium hydroxide NaOH
4. Sodium carbonate Na_2CO_3
5. Sodium hypochlorite - clorox
6. Hydrochloric acid, HCl

PROCEDURE

PART I COOKING

1. Moisture content of banana stems, stalks and leaves was determined.

2. Batches of 200 gm OD chips were weighed out.

3. These batches were cooked under the following conditions.

Cook Type	Part of Tree	Time Minutes	Temperature °C	Active Alkali as Na_2O 5:1 $NaOH:Na_2S$	NaOH gm/100 gm Fiber	Na_2S gm/100 gm Fiber	Na_2SO_3 gm/100 gm Fiber	Na_2CO_3 gm/100 gm Fiber
KRAFT	Stems	45	170	20%	14.1	5.9	-	-
KRAFT	Stalks	65	170	20%	14.1	5.9	-	-
KRAFT	Leaves	35	170	20%	14.1	5.9	-	-
NSSC	Stalks	35	170	-	-	-	12	6
	Stalks	35	170	-	-	-	12	-
COLD SODA	Stalks	300	24	-	5	-	-	-

The cooking was performed in vessels which are single bombs made from 9.5 in lengths of 2" ID stainless steel pipe. They were heated in an oil bath. A detailed description of this equipment is given by John R. Peckham (8). The cold soda cook was performed in a porcelain ball mill.

4. The fibers were washed thoroughly with hot water and disintegrated in the Standard Tappi disintegrator.
5. After disintegration, the fibers were beaten in the Valley Beater to a freeness of 300 using distilled water and 5000 gm weight on the bed plate.
6. A fraction of the stock was refined in the Mead Refiner for 30 seconds.
7. 4.4 gm handsheets were made in the Noble and Wood handsheet machine after the pH of the stock was adjusted to pH 7 using alum.
8. The handsheets were conditioned for 48 hours and the following tests run on the samples.
   - A. Tear - Elmendorf tear tester.
   - B. Mullen
   - C. Tensile - Instron
   - D. Stretch - Instron
   - E. Zero-span tensile - Instron
   - F. Stiffness - Gurley Stiffness tester.
   - G. Specific volume
   - H. Brightness - GET brightness tester.

PART II BLENDS WITH UNBLEACHED SOFTWOOD KRAFT

1. Softwood pulp was disintegrated in the British Refiner and beaten in the Valley Beater to 400 CSF with 5000 gm weight on the bed plate at 2% consistency.
2. Hardwood pulp was prepared similarly except it was beaten to 300 CSF.
3. The pulp from the banana stems were blended with softwood pulp to make 0, 25, 50, 75, 100 percent blends.
4. Control blends were made by substituting hardwood pulp for the banana pulp.

PART III BLEACHING SCHEDULE

1. Twenty four grams of OD Kraft stems pulp were bleached with the CEHD sequence using amounts of chemicals for a standard Kraft pulp of Kappa number between 14-25.

Stage	Time (Hours)	Temperature °C	Consistency %	pH	Amount Chemical
Chlorination	1	26	3.5	2.5	10% Cl_2
Caustic Extraction	2	70	3.5	11.2	4% NaOH
Hypochlorite	1	40	3.5	9.7	1% Available Chlorine
Chlorine Dioxide	2 1/2	60	3.5	3.4	1% ClO_2

2. After thoroughly washing, the moisture content of the pulp was determined and the bleach loss calculated.
3. Determination of Kappa Number according to Tappi Standard T 236 M-60.
4. 4.4 gm handsheets were made in the Noble and Wood handsheets machine with pH adjusted to pH 7 with alum.
5. The tests run on the unbleached stock were repeated on the above handsheets.

PART IV FIBER ANALYSIS

1. The fiber length was determined by the projection method (9).
2. The fibers were stained with C stain and viewed under a high power microscope.

DISCUSSION ON EXPERIMENTAL DESIGN

This experiment is designed to undertake, as comprehensive as possible, a study on the manufacture of an economical pulp from the banana tree particularly for bag and wrapping paper.

The leaves, stalks and stems were pulped separately to determine each potential and for comparison purposes. Apart from different cooking procedures the fibers were treated under similar conditions. They were disintegrated in the Tappi disintegrator for exactly 15 minutes, then beaten in the Valley Beater at 2% consistency to 300 CSF with 5000 grams weight on the bedplate. The refining in the Mead refiner was performed for 30 seconds.

The standard Kraft, neutral sulfite, sodium sulfite and cold soda cooks were made to compare the products to commercial grades of pulp. The purpose of the diversity of cooks was to cover the broad spectrum of present day pulping processes.

The banana pulp was blended with softwood to increase the strength of pure banana paper and to determine whether banana fibers could be substituted for hardwood pulp to produce a cheaper pulp having the same characteristics as a standard softwood and hardwood blend.

A wide range of physical tests were run on the handsheets for a complete coverage of all aspects of paper properties with special emphasis on tests performed in the bag and wrapping paper industry.

The bleaching schedule was a four stage CEHD bleach. The amounts of chemicals used were for a pulp of Kappa number between 14-25. The reason was both economy and to determine the increase in brightness as compared to a commercial softwood or hardwood Kraft pulp.

Fiber microscopy analyzed the constituent of the pulp in terms of fiber characteristics such as fiber length, C stain color and identifications.

The design of this investigation may lead to a satisfactory understanding of the pulping of the banana tree.

DATA

The results of the experiments are presented in Tables I-V. The results in Table III are plotted in Figures I-VII.

TABLE I

PHYSICAL CHARACTERISTICS OF COOKING METHODS

Cook	Part of Tree	Refining	Yield %	Tear Factor (gm)	Burst Factor (psi)	Tensile (kg)	Zero Span Tensile
KRAFT	Leaves	NO FIBER DETECTED FORMED A PASTE					
KRAFT	Stems	Valley	67	80	73	21.5	-
KRAFT	Stalks	Valley	55	61	81	18.3	18.0
KRAFT	Stalks	Valley Mead	55	56	58	17.2	13.5
NSSC	Stalks	Valley	74	80	60	18.9	14.5
NSSC	Stalks	Valley Mead	74	60	53	18.4	12.4
SODIUM SULFITE	Stalks	Valley	77	124	47	17.6	13.0
SODIUM SULFITE	Stalks	Valley Mead	77	50	48	15.2	13.9
COLD SODA	Stalks	Valley	86.5	51.5	30.5	9.8	-

TABLE I
(cont.)

Cook	Part of Tree	Refining	Stiffness Factor	Specific Volume cm^3/gm	Brightness	Percent Stretch	Zero Span Stretch
KRAFT	Leaves	NO FIBER DETECTED FORMED A PASTE					
KRAFT	Stems	Valley	4.4	1.89	15.5	2.5	-
KRAFT	Stalks	Valley	4.15	2.03	14.5	3.8	0.52
KRAFT	Stalks	Valley Mead	2.2	1.68	12.5	3.5	0.35
NSSC	Stalks	Valley	7.2	2.64	28.6	1.9	0.38
NSSC	Stalks	Valley Mead	3.25	2.33	28.5	2.2	0.42
SODIUM SULFITE	Stalks	Valley	9.4	3.04	33.4	1.8	0.25
SODIUM SULFITE	Stalks	Valley Mead	3.9	2.04	33.5	1.8	0.05
COLD SODA	Stalks	Valley	9.3	2.38	30.0	2.3	-

TABLE II

COMPARISON OF BANANA PULPS WITH COMMERCIAL GRADES*

Pulp		Yield %	Burst Factor	Tear Factor	Tensile
COLD SODA	Banana stalks	86.5	30.5	51.5	9.8
	Commercial	89	30	85	11.5
NSSC	Banana stalks	74	60	80	18.9
	Commercial	75	55	81	20.1
KRAFT	Banana stalks	55	81	61	18.3
	Commercial	50	65	90	22.5

* The commercial grades data was obtained from "The Pulping of Wood" by R. G. Macdonald and J. N. Franklin. All commercial grades were made from hardwood pulps.

TABLE III

PHYSICAL TESTS ON BLENDED HANDSHEETS

Percent Softwood Unbleached Kraft	Percent Hardwood Unbleached Kraft	Percent Banana Stalks Unbleached Kraft	Tear Factor	Burst Factor
100	0	0	134	100
75	25	0	126	94
50	50	0	120	83
25	75	0	112	75
0	100	0	96	59
75	0	25	108	85
50	0	50	92	83
25	0	75	78	80
0	0	100	70	62

TABLE III

(cont.)

Tensile	Zero Span Tensile	Stiffness	Specific Volume cm^3/gm	Brightness	Stretch %	Zero Span Stretch
29.5	20.7	3.4	1.42	24.8	3.2	0.65
26.5	23.0	3.6	1.58	28.0	3.15	0.70
23.5	19.5	3.8	1.64	29.2	3.10	0.65
18.5	21.0	4.1	1.69	29.5	3.0	0.6
15.5	17.5	4.3	1.78	29.8	2.9	0.4
26.5	20.0	3.7	1.62	20.1	3.0	0.68
23.1	19.9	4.0	1.76	16.1	2.9	0.65
22.3	18.5	4.65	1.85	15.5	2.7	0.55
18.5	18.0	4.75	1.89	12.9	2.5	0.52

TABLE IV

PROPERTIES OF UNBLEACHED VS. BLEACHED KRAFT BANANA STALK PULP

Fiber	Tear Factor	Burst Factor	Tensile	Brightness	Stretch %	Specific Volume	Stiff-ness
Unbleached	80	73	21.5	15.5	2.5	1.58	4.4
Bleached	98	95	25.0	39.8	3.0	1.89	3.9

TABLE V

SPECIAL CHARACTERISTICS OF BANANA STALK PULP

Property	Value
Unbleached Brightness	15.5
Brightness after CEHD	39.8
Bleach Loss	17%
Kappa Number	32.3
Fiber Length	2.50 mm
C Stained Color	Brownish-yellow

FIGURE 1 - TEAR FACTOR VS PERCENT SOFTWOOD

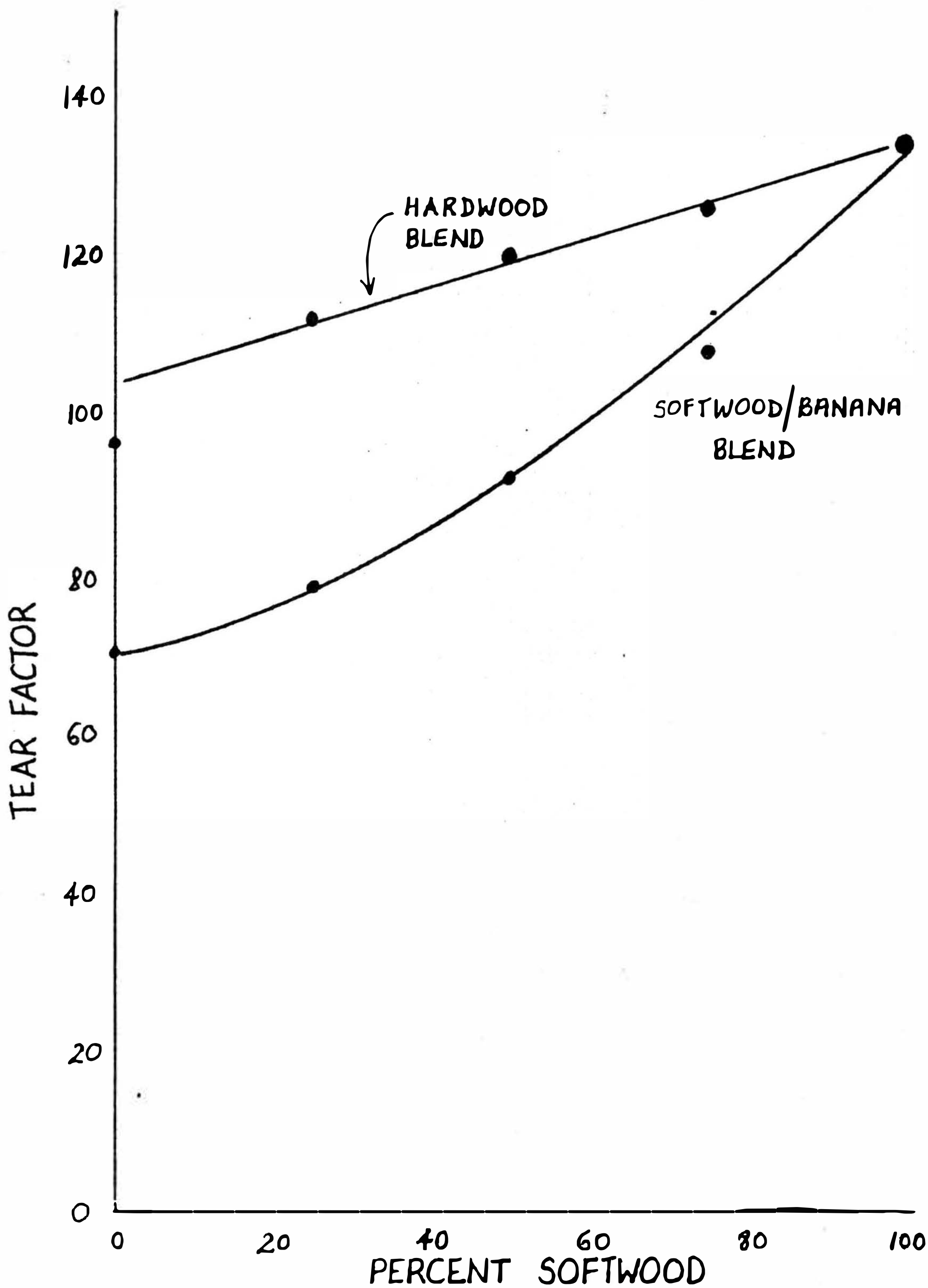
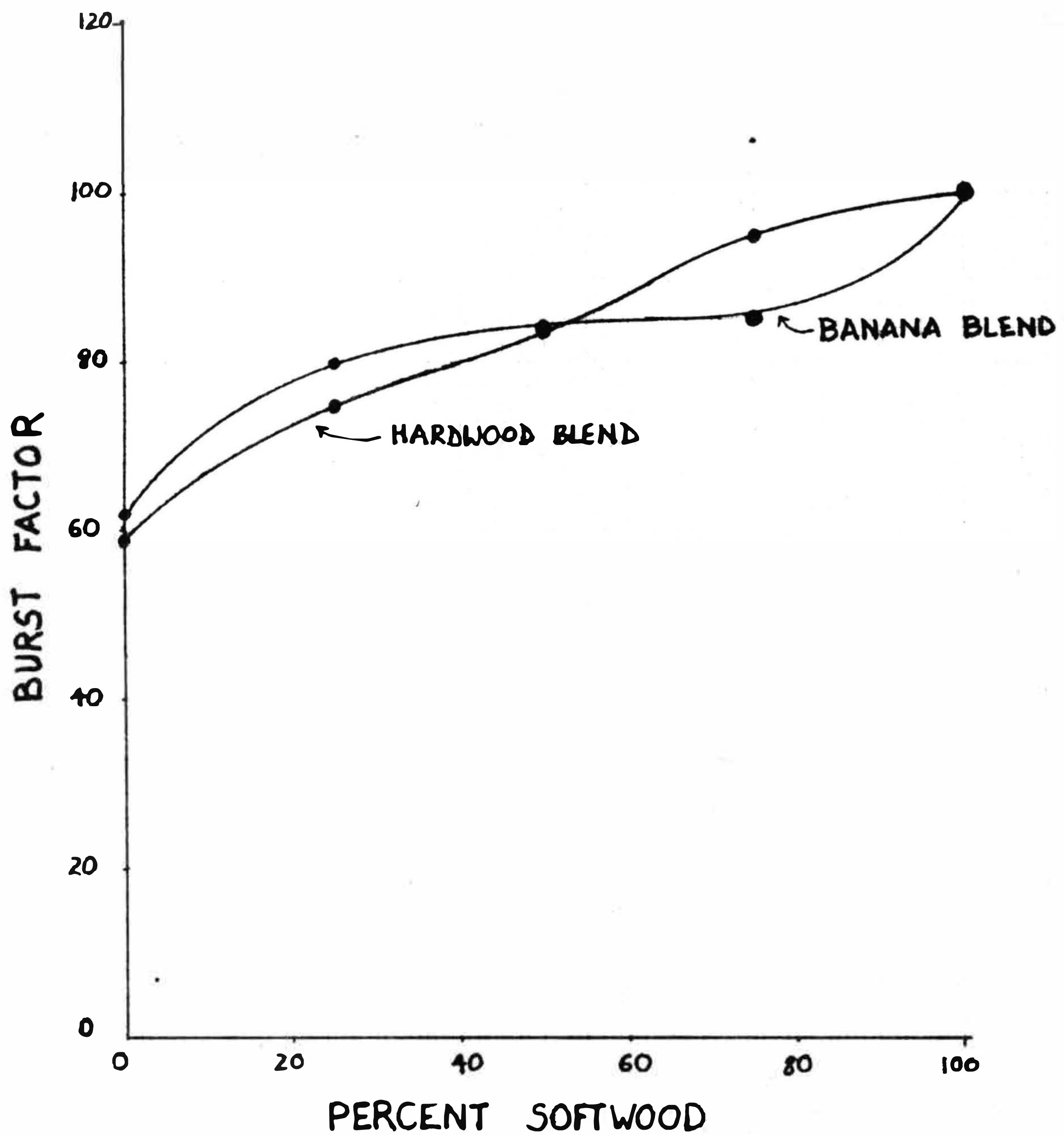


FIGURE II - BURST FACTOR VS PERCENT SOFTWOOD



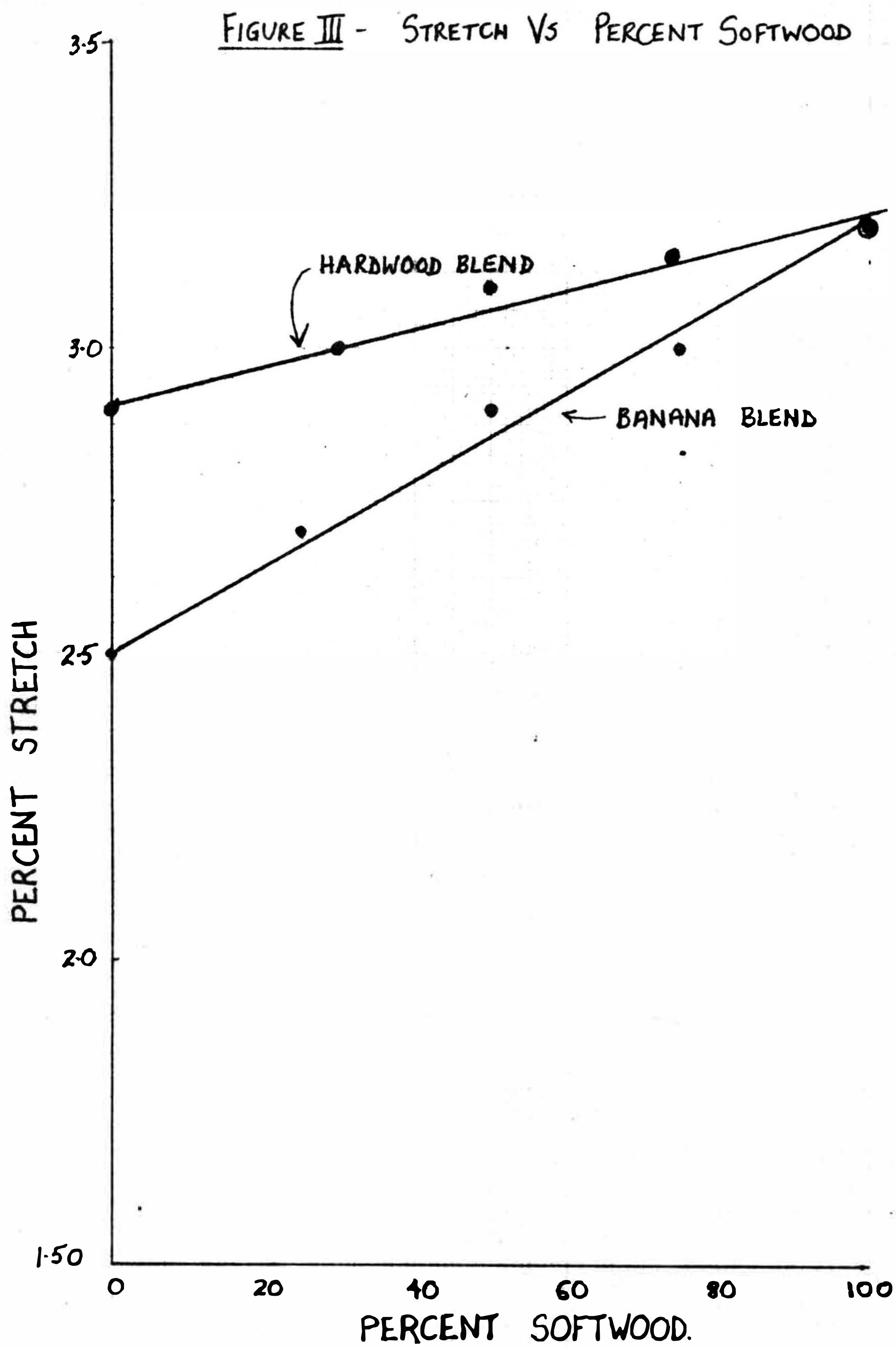


FIGURE III - STRETCH VS PERCENT SOFTWOOD
3.5
3.0
2.5
2.0
1.50
HARDWOOD BLEND
BANANA BLEND
PERCENT STRETCH
0
20
40
60
80
100
PERCENT SOFTWOOD.

FIGURE IV - BULK VS PERCENT SOFTWOOD

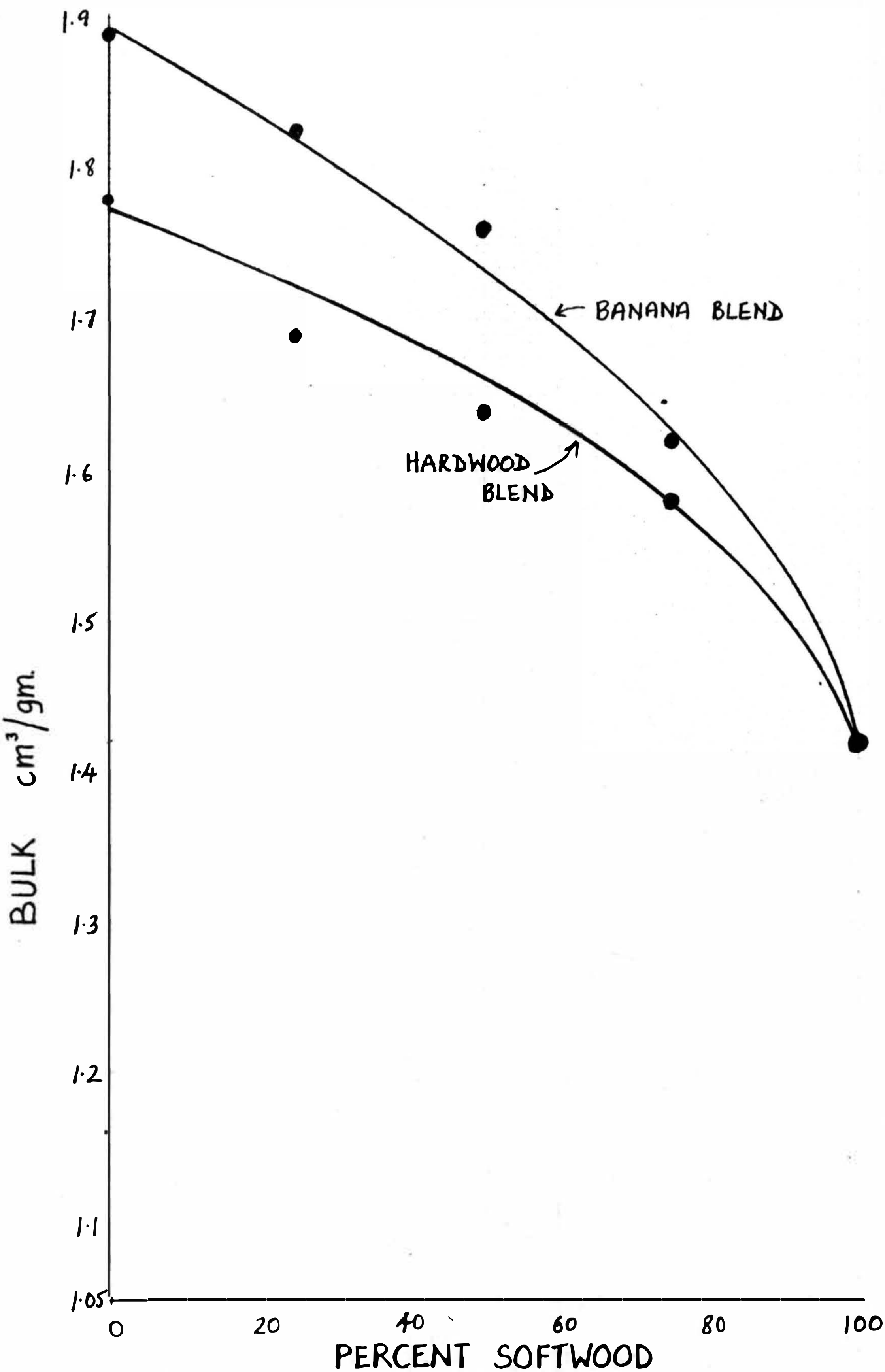


FIGURE V - BRIGHTNESS VS PERCENT SOFTWOOD

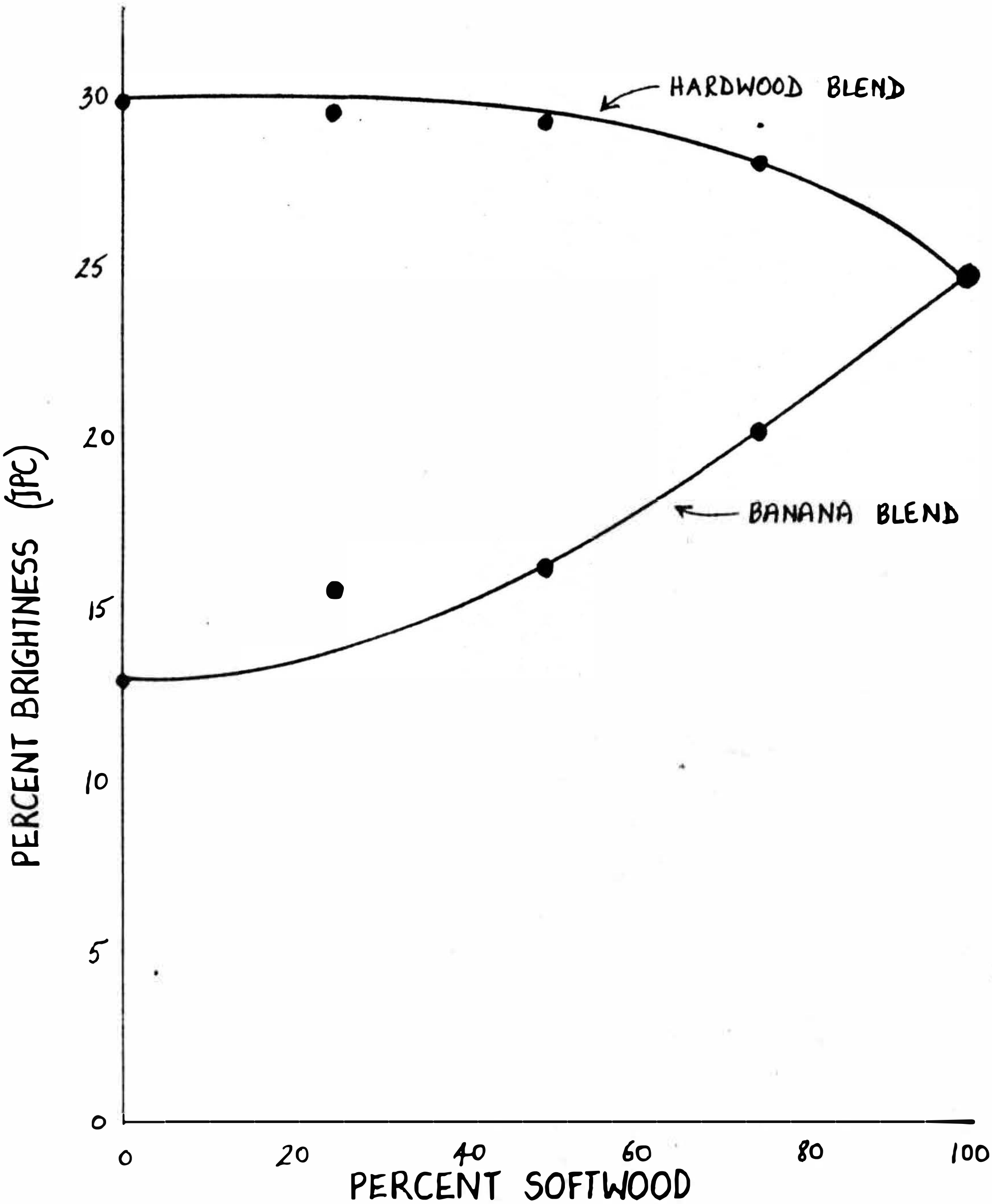


FIGURE VI - TENSILE VS PERCENT SOFTWOOD

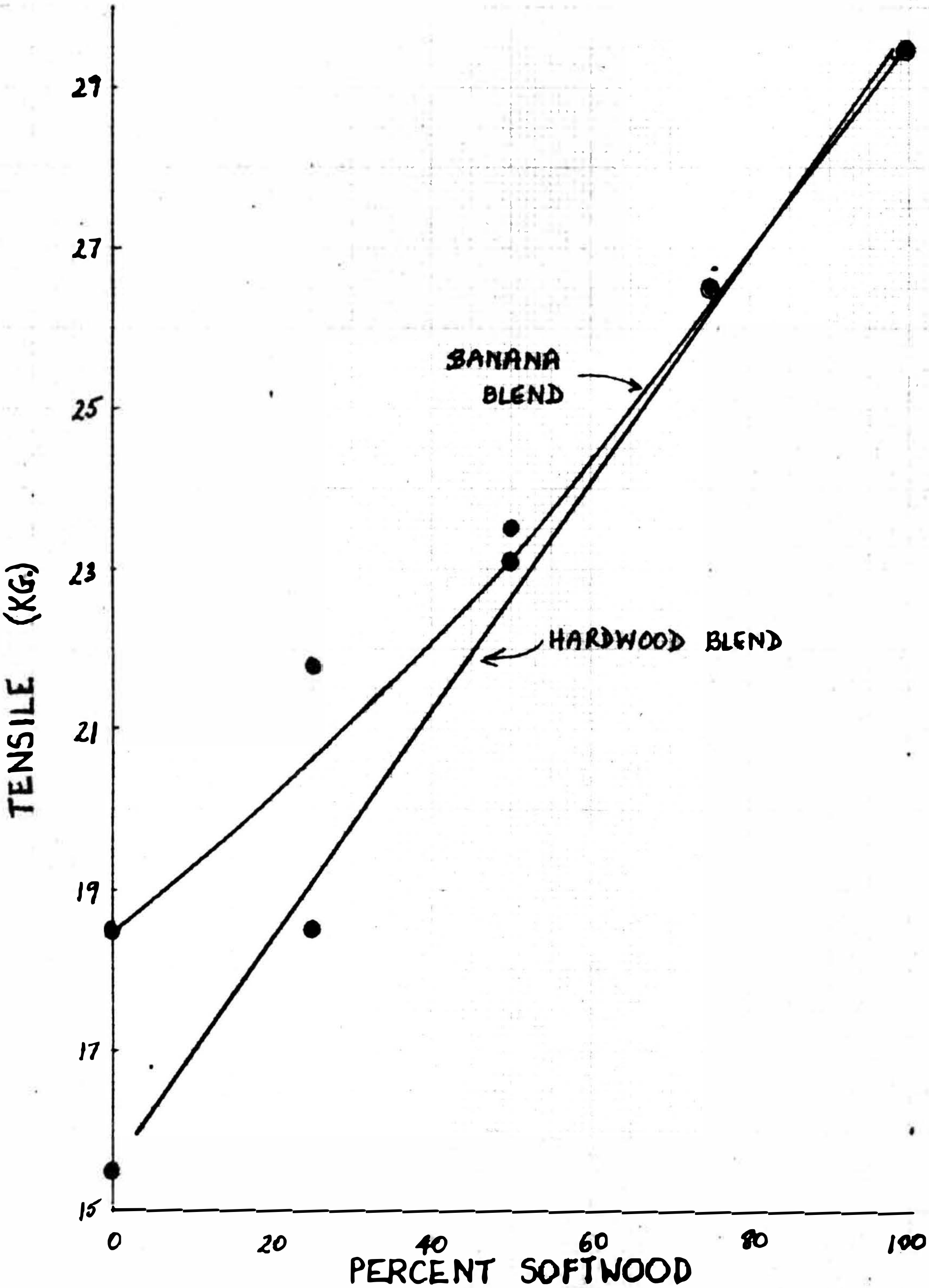
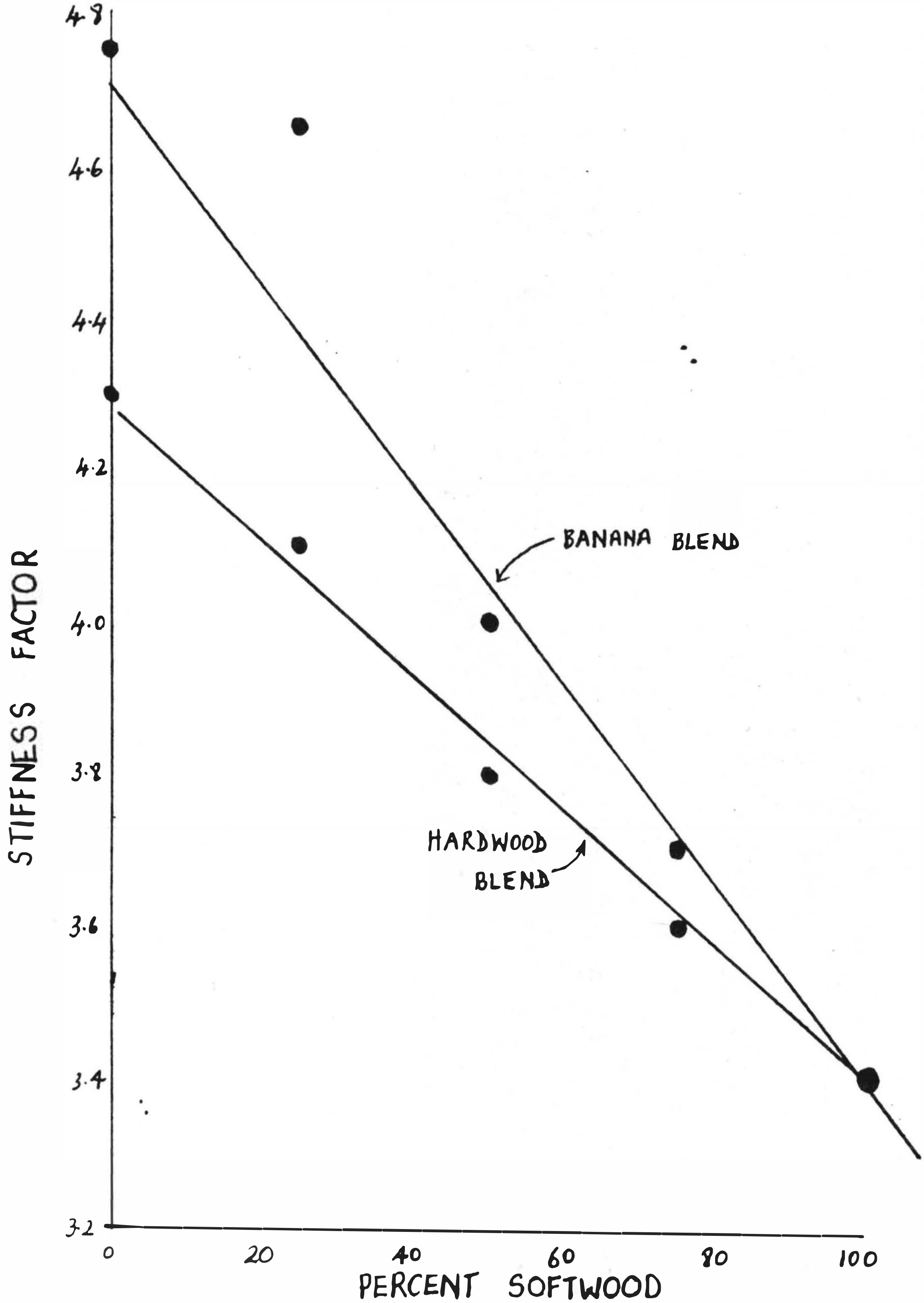


FIGURE VII - STIFFNESS VS PERCENT SOFTWOOD



DISCUSSION OF RESULTS

Comparison of Various Cooking Methods

The cook made from banana leaves, when disintegrated for two minutes produced a thick paste with no indication of fibers which could contribute towards papermaking.

The cold soda cook on banana stalks utilizing 5% sodium hydroxide gave a high, 86.5% yield pulp which demonstrated a poor strength qualities. The tear was low at 51.5, mullen 30.5 and tensile 9.8. This cook gave very coarse fibers with a poor bonding potential. Table II indicates that cold soda banana stalk pulp produces sheets of strengths comparable to commercial pulp.

The neutral sulfite process utilizing sodium sulfite and sodium carbonate at pH 7.0, decreased the yield to 74%. This is due to greater removal of lignin caused by sulphonation and hydrolysis. Also hemicelluloses are degraded to a certain extent. The properties of commercial nominal 26 lb. corrugating boards made from neutral semi-chemical pulps compare favorably with the banana pulp as shown in Table II. There is very close correlation between burst, tear and tensile, thus again verifying that banana pulp can be used successfully as a substitute for hardwood pulps.

More severe action on the banana stalks was involved in the Kraft process. A drastic decrease in yield resulted with an appreciable increase in strength. The sodium sulfide and hydroxide dissolve low molecular weight polysaccharides. Lignin, largely insoluble in their original form are first degraded by the action of the cooking liquor to smaller fragments and then dissolve. The chain length of the cellulose is reduced and about 20% of it is lost through alkaline "peeling". Table II clearly shows that banana Kraft pulp produced sheets as strong as commercial grades.

The Kraft cook on banana stems gave a surprisingly high yield of 67%. The tear and tensile strengths were higher with mullen slightly lower than the stalks.

<u>Comparison Between Softwood/Hardwood and Softwood/Banana Blends</u>

Pulp blends, ranging in banana content from zero to 100 percent (softwood content 100 to zero percent) showed near linearity with respect to all tests performed. This fact is demonstrated in Table III and illustrated in Figures I through VI.

Parallel blends were made using hardwood pulp instead of banana, and these showed a similar linear function with a slightly higher strength at the same concentration as compared to the banana/softwood combinations.

Figure I showing the relationship between tear and percent softwood demonstrates the superiority of the hardwood/softwood blends but the 50/50 banana/softwood blends shows a significant strength. When the burst factor was plotted against percent softwood the two curves were almost superimposed as shown in Figure II.

Referring to Figure IV, the banana/softwood blends tend to form more bulky (i.e. less dense) sheets than its hardwood counterpoint. This indicates that the hardwood pulp formed a considerably more "closed formation" sheet than the banana pulp which follows from the relative bulking properties of the pulps.

Bleaching of Banana Kraft Pulp

The Kraft pulp has an extremely high Kappa number, 32.3.

The bleaching procedure used, which was a standard four stage CEHD bleach for Kraft pulp produced a poor 24.3 points increase in brightness. The bleach cycle resulted in a 17% loss in fiber which consisted mainly of pith since the freeness of the pulp increased appreciably.

Banana stalks consists of approimately 30.7% ash composed of mainly calcium oxide, magnesium and iron oxide together with aluminum, phosphates, carbonates and sulphates. The metallic ions rapidly degrade the bleaching chemicals particularly chlorine and chlorine dioxide, reducing their effectiveness. This is a possible explanation for the low brightness increase. An acid pretreatment with hydrochloric acid followed with washing will remove the metallic ions and increase the bleaching power of chlorine and chlorine dioxide.

Table IV shows the tremendous increase in strengths due to bleaching.

The high Kappa number of banana pulp dictates a much more severe bleaching schedule which makes bleaching of banana pulp very uneconomical and utilization of this pulp for only unbleached grades of paper.

Fiber Characteristics

Fiber microscopy reveals the banana fibers as thin long and slender with minute pores very similar to those in pine. The pores are singly lined along the entire axis of the fiber. A very interesting observation is the presence of hairlike structures which may contribute towards fiber bonding and offset the low flexibility of the fibers.

The average fiber length is 2.54 mm and very comparable to many hardwood fibers.

The zero span tensile strength, Table III, which indicates the average ultimate strength of individual fibers shows that the banana fiber is as strong as hardwood fibers with a much higher stretch. Naturally the softwood fibers are stronger than either of the two.

CONCLUSION

1. It is not feasible to produce a papermaking pulp from banana leaves.
2. Pulp made from banana stalks and stems compare favorably with commercial hardwood pulps demonstrating equal strengths.
3. Pulp blends, ranging from zero to 100 percent softwood show near linearity with respect to all tests performed.
4. Banana pulp has a high Kappa number. Commercial hardwood Kraft bleaching schedules are inadequate and acid pretreatment is required to rid the pulp of metallic ions which degrade the bleaching chemicals.
5. Banana fibers are thin, long and slender and very inflexible. They have a characteristic pore structure. Many hairlike structures are also present. The average length of the fibers is 2.54 mm zero span tensile tests shows that the banana fiber is as strong as hardwood fibers.

The above concludes that banana pulp could be substituted for hardwood pulp in specific grades such as wrapping, sack and box liner papers in combination with softwood pulp.

Since banana fibers have a high stiffness it is especially useful in the corrugating medium layer in boxboards.

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