ABSTRACT

In bright-leaf tobacco curing the midrib, primarily because of its thickness, requires one to two days of drying after the leaf lamina is dry. Although the amount of moisture in the midrib is relatively small as compared to the moisture originally in the total leaf, heat requirements are large because of losses from the barn at the high temperatures necessary to drive the moisture from the midrib.

Crushing of midribs by passing leaves, just prior to curing, between rollers spaced 3 mm to 5 mm apart reduced curing fuel requirements by about 15% and curing time by 9 to 11 hours. Cured weight yield, sugar and alkaloids contents were not adversely affected. Crop value in on-farm upper stalk tests was not affected but other observations suggested a decrease in value of about four cents per kilogram which may have been due to soft rot which developed when curing some of the lower primings.

Although midribs were often broken into parallel strands by the crushing, there were no significant problems in removing the midrib from the leaf with conventional leaf threshing-separating equipment. There was a slight increase in finer particles and a decrease in total midrib indicating that some of the thinner strands passed as lamina.

Mechanical Harvesting of Flue-Cured Tobacco Part 12:
Pre-Curing Crushing of Midribs

Charles W. Suggs

INTRODUCTION

The curing process which produces bright-leaf tobacco (also called Virginia or flue-cured) is characterized by an initial low temperature (38°C) phase of about two or three days which allows the yellow color to develop and desirable chemical changes to occur. During the second phase of the process the temperature is gradually increased to about 60°C and the barn is ventilated to accelerate drying of the leaf. In the third phase the temperature is increased to around 75°C in order to provide sufficient diffusion potential to remove moisture from the leaf midribs which may be over one and one-half cm thick. The total process takes about 6 days, approximately two days in each phase.

In both stick and bulk curing of flue-cured tobacco the midrib (stem) is the last part of the leaf to dry. Typically, 24 to 48 hours of midrib drying are required after the leaf lamina is dry. The stem drys slowly because of its relative great thickness. High drying temperatures are used during stem drying to increase the drying gradient and thereby reduce drying time.

Redundant

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The energy required during midrib drying is less than during leaf drying because less moisture is involved. However, due to the heat losses associated with the high temperatures used and the need to exhaust enough air to maintain a low humidity, relatively large amounts of energy are required. Heat is lost by radiation, conduction and convection (air leakage). In fact most barns have enough leakage to provide the moist air exhaust and fresh air intake required for stem drying.

Midrib crushing offers potential for reducing both the time and energy requirement for drying the midrib. Crushing flattens and splits the midrib thus reducing the distances moisture must diffuse. It also ruptures cell walls so that moisture may move easier. While diffusion distances are reduced by flattening and splitting of the midrib, the diffusion coefficient may also actually be reduced by rupturing the cell walls.

Redundant

~~OBJECTIVES~~

~~It was~~ The objectives of the work reported in this paper were to determine the curing time, energy reductions, leaf quality and other effects associated with midrib crushing and to develop a means for achieving the degree of crushing desired.

LEAF CHARACTERISTICS

Tobacco leaf size is approximately 52 cm long by 31 cm wide (Suggs and Splinter, 1959). A more recent study (Suggs, 1978) gives 57 x 28 cm as the length and width of flue-cured tobacco leaves. The midrib at the large end is approximately .99 cm thick by 1.64 cm

wide (Suggs, 1978). The cross section is shaped like a semicircle plus a rectangle, Figure 1, with the upper side of the leaf lamina flush with the flat side of the midrib. The midrib serves as a tapered cantilever structural member to support the leaf. It is largest at its attachment to the stalk, tapering to almost nothing at the tip of the leaf. A force of about 80 newtons per centimeter of length (44 lb/in) is required to crush the large end of the midrib (Suggs and Howell, 1972).

About 38% of the uncured leaf weight is in the midrib. Moisture content of midrib material was about 89% as compared to 78% for lamina (Suggs, 1975). That is, dry matter was about 11% for midribs versus 22% for lamina. From these values it can be determined that the midrib contains about 41% of the moisture in the leaf. Shimizu (1970) stated that the midrib contains about 1/3 of moisture in the whole leaf. Most (65%) of the midrib weight and moisture is in the first 15 cm of length and over 90% is in the first 30 cm of a 52 cm long leaf (Suggs, 1975). Thus, it would be sufficient to crush the large end of the midrib down about one-half to two-thirds of the leaf length as most of the moisture is contained in this end and the midrib in the leaf tip is small enough to dry about as fast as the leaf itself.

Johnson

PROCEDURE

more

Crushed Midribs

Midribs of intact leaves were crushed by passing them over a conveyor belt and between a pair of steel- smooth rollers spaced about 3 mm to 5 mm (1/8" to 3/16") apart, Figure 2. The clearance was selected to clear

the lamina but crush the large end of the midrib to a point about half way down the leaf. The midrib in the tip end of the leaf is small and usually presents no drying problem. During crushing, sap is forced out of the midrib. Treatments were imposed on the leaves immediately after priming except in an auxiliary set of experiments where midrib crushing was scheduled at priming, when half yellow and when full yellow. In another set of experiments treatments were imposed immediately after priming on green, ripe and over-ripe leaves.

no data

data

The experiments extended over several years and after a mechanical harvester became available leaf midribs were crushed as harvested by two pairs of rollers located in the upper ends of the mechanical harvester elevators. Elevators were run at maximum speed to reduce the numbers of leaves lying on top of other leaves as lamina bruising occurred when a midrib is crushed against another leaf. Between roller clearance could be adjusted to crush midribs or ~~opened~~ to allow leaves to pass uncrushed for check plots and other experiments.

All of the crops were grown in accordance with accepted practices on the Central Crops Research Station near Clayton, N.C. During the first two years of the experiment, 1972, 73, the leaves were hand primed and run through the crusher shown in Figure 2. In 1972 all of the tobacco, five primings, was cured on sticks in small barns. In 1973 racks (57 Kg capacity, uncured leaf) and sticks were used. Small stick barns and small bulk barns were used for curing the material in 1973.

Farmer Tests

2 method of crushing { machine / Test stand } overlap — operating speed

Evolution of curing

A mechanical harvester which became available in the spring of 1974 was used to harvest the tobacco for the rest of the tests. Stick curing was discontinued and container (box) curing was started. In 1973 and 74 five primings of four 57 Kg racks were harvested at each priming, two crushed and two uncrushed. These were placed, one crushed and one uncrushed rack in each of two small plot size bulk curing barns.

A relatively large quantity of leaf with crushed midribs was cured in 1974 in large containers (maxiracks) in a modified commercial bulk curing barn. This tobacco, consisting of approximately four primings from a 1 ha field, was sold on the market to determine the acceptability of leaf with crushed midribs.

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In 1976 the plot size rack curing barns were converted to container curing after which no more crushed vs uncrushed material was cured in stick or rack barns. Gas meters were placed on the barns in 1974 so that curing efficiency could be measured. All cured leaf, uncured sticks and uncured racks were weighed on a platform scale. Containers of uncured leaf were weighed on the harvester by means of a hydraulic pressure system.

A sample of the cured leaf was removed for chemical analyses after ~~which~~ it was graded by a government tobacco grader. Value was determined from market average for each grade.

Several hundred pounds of crushed midrib leaf plus comparative samples of normal or check material were threshed and separated into leaf strips (lamina) and stems (midribs) at two tobacco processing plants.

No of observation
add this data in table.

The lamina was passed over a set of screens to determine the size distribution of the lamina. Samples of lamina were inspected to determine how much midrib material was left in the lamina.

RESULTS AND DISCUSSION

A condensed tabulation of the main results from 1972 through 1979 is given in Table 1 along with the mean values for the eight years of observations.

Fuel Consumption

There was a consistent fuel savings of about 15% associated with curing leaves with crushed midribs. Since crushing does not decrease the amount of water to be evaporated, the reduced fuel (heat energy) requirement is attributed to a decrease in the distance water has to diffuse to get out of the midrib, a decrease in the resistance to diffusion because of ruptured cell membranes and a decrease in curing time.

Reducing the time the barn must be held at high temperature decreases the energy loss from the structure by conduction, radiation, convection and exfiltration of air. Energy requirements to actually evaporate water would not be changed as no appreciable amount of stem moisture is lost during crushing. Because of the current trend toward higher fuel costs, barn design and curing procedures which save fuel are becoming increasingly important.

Cured Weight Yield

Cured weight yield, the weight of cured material divided by the original uncured weight of the same material expressed as a percentage,

was not affected by midrib crushing. The expected increase in cured weight yield for leaves from the mid and upper stalk was observed and the results for 1976 are reported in Table 1.

~~Crop Value~~

Crop value in terms of dollars per kilogram averaged over eight years of data was four cents per kilogram less for leaves cured with crushed midribs. This difference is not very large and appears to have been due to a problem with soft rot which developed when curing some of the lower primings.

Three farmers, involved in on-farm tests in 1975, one each from Lenoir, Bertie and Caswell Counties, judged the crushed midrib tobacco equal in quality to uncrushed tobacco. One farmer who had enough to sell separately indicated that it sold as well as the uncrushed. All reported faster drying and reductions in total curing time.

~~Chemistry~~

Sugar and total alkaloids content of the cured leaf were not affected by midrib crushing. There were, however, some year to year variations and stalk position variations.

Curing Time

Curing time was consistently less for crushed midrib leaf, 149 hours versus 138 hours. Although considerable moisture was forced out of the midrib during crushing most of it was deposited on the leaf. A series of measurements showed that moisture loss during crushing was less than two percent of the total uncured leaf weight. The moisture deposited on the leaf during midrib crushing was usually

removed by drying during leaf yellowing. Most of the crushed midribs dried during the leaf drying phase. Otani (1970) in an experiment to evaluate nitrogen movement between variously treated midribs and lamina reported that crushed midribs dried faster than other midrib treatments.

intro

Reductions in curing time relate to heat and electricity usuage. A shorter curing time is also important because it increases barn throughput by reducing the time each batch must be cured. Fixed costs for barn ownership have been estimated to be about $30 to $36 per day (Suggs, 1979) or about $11 to $13 for the nine hours reduction in curing time found in this study. It is felt that an optimization of air flow, humidity and curing schedule will allow appreciable additional reduction in curing time. Curing time reductions of one to two days have been observed.

Loading Density

Midrib crushing destroys most of the rigidity of the leaves so that they tend to pack too closely in racks or boxes. Care must be taken when loading this material into barns to insure that it is loaded uniformly and that a reasonable density is maintained. Observations indicated that midrib crushing increased box capacity by 20 to 25%. This is a sizeable increase which, if not properly managed and controlled could result in overloading the barn curing system.

Midrib Removal

Threshing-separating tests, Table 2, indicated that the check material yielded slightly more large lamina particles than the crushed

Table 2. Threshing and Separating Characteristics of Tobacco With Midribs Crushed Before Curing.

	% Retained on Screen Mesh Size, Cm			Midribs in Leaf, %	Midrib Left in Lamina, %
	2.5 cm (1")	1.3 cm (½")	.6 cm (¼")		
Check	62.0	24.6	9.4	17.63	0.8
Crushed	48.4	36.3	10.7	15.86	0.3

	Mesh Size, Cm				
	1.9 cm (3/4")	1.3 cm (½")	.9 cm (3/8")		
Check	64.0	19.1	7.5	—	1.2
Crushed	58.4	20.3	8.6	—	3.9

ABSTRACT

In bright-leaf tobacco curing the midrib, primarily because of its thickness, requires one to two days of drying after the leaf lamina is dry. Although the amount of moisture in the midrib is relatively small as compared to the moisture originally in the total leaf, heat requirements are large because of losses from the barn at the high temperatures necessary to drive the moisture from the midrib.

Crushing of midribs by passing leaves, just prior to curing, between rollers spaced 3 mm to 5 mm apart reduced curing fuel requirements by about 15% and curing time by 11 hours. Cured weight yield, sugar and alkaloids contents were not adversely affected. Crop value in on-farm upper stalk tests was not affected but other observations suggested a decrease in value of about four cents per kilogram which may have been due to soft rot which developed when curing some of the lower primings.

Although midribs were often broken into parallel strands by the crushing, there were no significant problems in removing the midrib from the leaf with conventional leaf threshing- separating equipment. There was a slight increase in finer particles and a decrease in total midrib indicating that some of the thinner strands passed as lamina.

midrib material. Fine particles are undesirable as they are difficult to use. The measured midrib content of the crushed leaf was less than for uncrushed leaf. Since the leaves were from the same source the actual midrib content should have been the same. Therefore, it is evident that crushing midribs produces slivers of material thin enough to pass through the separating equipment as lamina. Such slivers can be found in a visual inspection of the material, Figure 3. In the tests at one processing plant less midrib material was left in the processed lamina of the crushed material than in the check material. These results were reversed at the second processing plant.

Pile of lamina

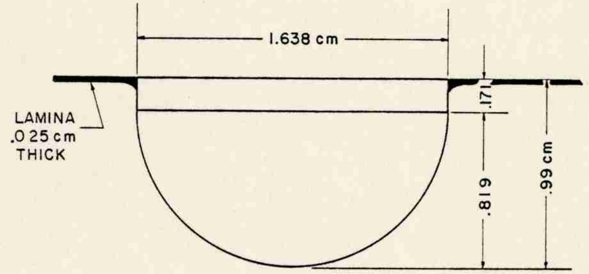

Fig. 1. Diagram of midrib cross section for average butt end dimensions.

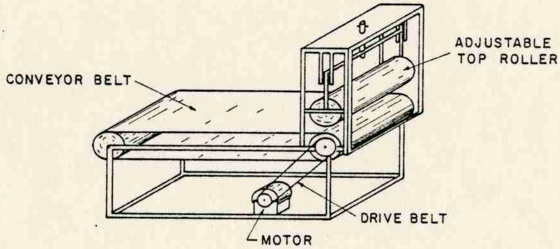

Figure 2. Midrib crushing equipment.

LITERATURE CITED

Suggs, C.W. and W.E. Splinter. Physical Properties of Green Virginia-Type Tobacco Leaves. Part 1. Leaf Dimensions, Weight and Midrib Strength. Tob. Sci. 3:121-124. 1959.

Otani, K. Curing Characteristics of Midrib Treated Burley Tobacco Leaves. Morioko, Japanese Tobacco Exp. Sta. Bull,, (5):25-42, March, 1970.

Shimizu, Yukio. Effects of Moisture Content in Midrib of Tobacco Leaves During Curing. Japanese Society of Agricultural Machinery Journal, 31(4):303-308, March 1970.

Suggs, C.W. and E.L. Howell. Mechanical Harvesting of Flue-Cured Tobacco. Part 3: Lamina Bruising and Midrib Crushing Characteristics. Tob. Sci. 15:150-153, 1972.

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco. Part 6: Weight Distribution and Cured Weight Yield of Midrib and Lamina. Tob. Sci. 19:83-85, 1975.

Walton, L.R., Z.A. Henry, and W.H. Henson, Jr. Moisture Diffusion in Cured Burley Tobacco Leaf. Trans. of ASAE. 19(4):796-800, 1976.

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco. Part 8. Relationships Between Leaf Shear Resistance and Other Leaf Properties. Tob. Sci. 22:134-137, 1978.

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco Part 10: Optimization of Curing Capacity and Bulk Barn Parameters. Tob. Sci. 23:126-130, 1979.

II. Graduate Students: Bryan W. Maw - Ph.D.
Gary T. Roberson - M.S.

III. Post-Doctoral Fellows - None

IV. Publications:

Suggs, C.W. Development of a Transplanter with Multiple Loading Stations. Trans. of ASAE 22(2):260-263, 1979.

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco. Part 9: Developments in Container (Box) Bulk Curing. Tob. Sci. 23:1-6, 1979.

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco. Optimization of Curing Capacity and Bulk Barn Parameters. Tob. Sci. 23:126-130, 1979.

V. Manuscripts Accepted for Publication

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco. Part 11: Harvesting System Selection and Capacity Optimization. Accepted by Tob. Sci.

VI. Manuscripts in Review

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco. Part 12: Pre-Curing Crushing of Midribs.

VII. Papers Presented at Professional Meetings

At 28th Tobacco Workers Conf., Orlando, Fla., Jan. 15-18, 1979.

(1) Powered Dolly for Lifting and Moving Curing Containers

(2) Removal and Destruction of Lower Leaves: Effect of Schedule on Yield and Quality

(3) Air Flow Control in Curing Containers

VIII. Graduate Student Thesis - None

gas.

Table 1. Effect of Midrib Crushing on Leaf Curing, 1972-79 Summary.

crushing method

Year	Treatment		Fuel, m^3/Kg	Cured Wt. Yield, %	Price $/Kg	Sugar %	Total Alkaloids %	Curing Time Hours
1972	Stick Cured,							
	Check			17.2	1.78	10.2	3.4	
	Crushed			18.0	1.63	9.4	3.2	
1973	Stick Cured,							
	Check			17.5	1.91	16.7	1.8	
	Crushed			17.2	1.94	18.2	2.1	
	Rack Cured,							
	Check			18.4	1.91	15.8	2.14	
	Crushed			18.9	1.88	16.4	1.77	
1974	Rack Cured,							
	Check		.740	15.7	-	18.6	2.33	
	Crushed		.514	16.8	-	16.1	2.31	
	Box Cured,							
	Check				2.02	17.0	3.04	
	Crushed				1.91	16.6	2.68	
1975	Rack Cured,							
	Check		.378	17.4	2.21			139.5
	Crushed		.275	18.1	2.31			131
	Box Cured,							
	Check				2.31	19.4	3.37	
	Crushed				2.18	18.0	2.89	
	Rack Cured, Farm Scale							
	Check				2.23			
	Crushed				2.08			
1976	Barn Cured,							
	Check	Bottom	.556	13.2	2.11	7.4	1.42	140
	Crushed	Stalk	.546	11.7	1.96	6.8	1.63	139.6
	Check	Middle	.316	17.0	2.62	6.2	2.90	148
	Crushed	Stalk	.281	17.6	2.62	5.2	3.15	132
	Check	Top	.312	19.5	2.49	5.7	3.70	130.2
	Crushed	Stalk	.312	18.5	2.49	7.7	3.78	109.7
1977	Box Cured,							
	Check		.382	16.3	2.46	10.0	3.84	150.3
	Crushed		.332	16.3	2.51	8.9	4.23	140.2
1978	Box Cured,							
	Check		.296	22.1	2.82	14.9	2.99	162.5
	Crushed		.268	19.1	2.77	14.6	2.68	153.8
1979	Box Cured,							
	Check		.315	19.1	3.04	14.6	3.02	170.2
	Crushed		.277	18.5	3.12	13.6	2.62	161.3
Means	Check		.412	17.6	2.30	12.8	2.88	149
	Crushed		.350	17.3	2.26	12.4	2.79	138

omit — Comment in Text.

Paired Data Analyses

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It was the objective of the work reported in this paper to determine the curing time, energy reductions, leaf quality and other effects associated with midrib crushing and to develop a means for achieving the degree of crushing desired.

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Tobacco leaf size is approximately 52 cm long by 31 cm wide (Suggs and Splinter, 1959). A more recent study (Suggs, 1978) gives 57 x 28 cm as the length and width of flue-cured tobacco leaves. The midrib at the large end is approximately .99 cm thick by 1.64 cm

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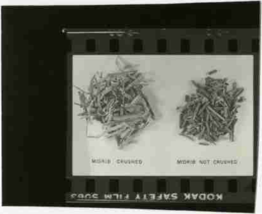
Midrib Removal

Threshing-separating tests, Table 2, indicated that the check material yielded slightly more large lamina particles than the crushed

midrib material. Fine particles are undesirable as they are difficult to use. The measured midrib content of the crushed leaf was less than for uncrushed leaf. Since the leaves were from the same source the actual midrib content should have been the same. Therefore, it is evident that crushing midribs produces slivers of material thin enough to pass through the separating equipment as lamina. Such slivers can be found in a visual inspection of the material, Figure 3. In the tests at one processing plant less midrib material was left in the processed lamina of the crushed material than in the check material. These results were reversed at the second processing plant.

$$\frac{\$\,50.\ \text{saved}}{2000\#\ \text{tob}} = 2.5\text{¢}/\#\ \text{diff.}$$


MIDRIB CRUSHED
MIDRIB NOT CRUSHED
KODAK SAFETY FILM 5063

LITERATURE CITED

Suggs, C.W. and W.E. Splinter. Physical Properties of Green Virginia-Type Tobacco Leaves. Part 1. Leaf Dimensions, Weight and Midrib Strength. Tob. Sci. 3:121-124. 1959.

Otani, K. Curing Characteristics of Midrib Treated Burley Tobacco Leaves. Morioko, Japanese Tobacco Exp. Sta. Bull., (5):25-42, March, 1970.

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Table 1. Effect of Midrib Crushing on Leaf Curing, 1972-79 Summary.

Year	Treatment		Fuel, m^3/Kg	Cured Wt. Yield, %	Price $/Kg	Sugar %	Total Alkaloids %	Curing Time Hours
1972	Stick Cured,							
	Check			17.2	1.78	10.2	3.4	
	Crushed			18.0	1.63	9.4	3.2	
1973	Stick Cured,							
	Check			17.5	1.91	16.7	1.8	
	Crushed			17.2	1.94	18.2	2.1	
	Rack Cured,							
	Check			18.4	1.91	15.8	2.14	
	Crushed			18.9	1.88	16.4	1.77	
1974	Rack Cured,							
	Check		.740	15.7	-	18.6	2.33	
	Crushed		.514	16.8	-	16.1	2.31	
	Box Cured,							
	Check				2.02	17.0	3.04	
	Crushed				1.91	16.6	2.68	
1975	Rack Cured,							
	Check		.378	17.4	2.21			139.5
	Crushed		.275	18.1	2.31			131
	Box Cured,							
	Check				2.31	19.4	3.37	
	Crushed				2.18	18.0	2.89	
	Rack Cured, Farm Scale							
	Check				2.23			
	Crushed				2.08			
1976	Barn Cured,							
	Check	Bottom	.556	13.2	2.11	7.4	1.42	140
	Crushed	Stalk	.546	11.7	1.96	6.8	1.63	139.6
	Check	Middle	.316	17.0	2.62	6.2	2.90	148
	Crushed	Stalk	.281	17.6	2.62	5.2	3.15	132
	Check	Top	.312	19.5	2.49	5.7	3.70	130.2
	Crushed	Stalk	.312	18.5	2.49	7.7	3.78	109.7
1977	Box Cured,							
	Check		.382	16.3	2.46	10.0	3.84	150.3
	Crushed		.332	16.3	2.51	8.9	4.23	140.2
1978	Box Cured,							
	Check		.296	22.1	2.82	14.9	2.99	162.5
	Crushed		.268	19.1	2.77	14.6	2.68	153.8
1979	Box Cured,							
	Check		.315	19.1	3.04	14.6	3.02	170.2
	Crushed		.277	18.5	3.12	13.6	2.62	161.3
Means	Check		.412	17.6	2.30	12.8	2.88	149
	Crushed		.350	17.3	2.26	12.4	2.79	138

Table 2. Threshing and Separating Characteristics of Tobacco With Midribs Crushed Before Curing. As tested by two Tobacco Companies

Company "A"	% Retained on Screen Mesh Size, Cm 2.5 cm (1")	1.3 cm (½")	.6 cm (¼")	Midribs in Leaf, %	Midrib Left in Lamina, %
Check	62.0	24.6	9.4	17.63	0.8
Crushed	48.4	36.3	10.7	15.86	0.3

Company "B"	Mesh Size, Cm 1.9 cm (3/4")	1.3 cm (½")	.9 cm (3/8")		
Check	64.0	19.1	7.5		1.2
Crushed	58.4	20.3	8.6		3.9

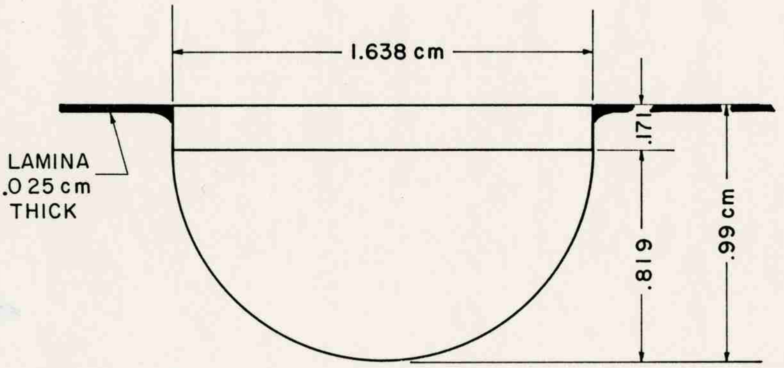

Fig. 1. Diagram of midrib cross section for average butt end dimensions.

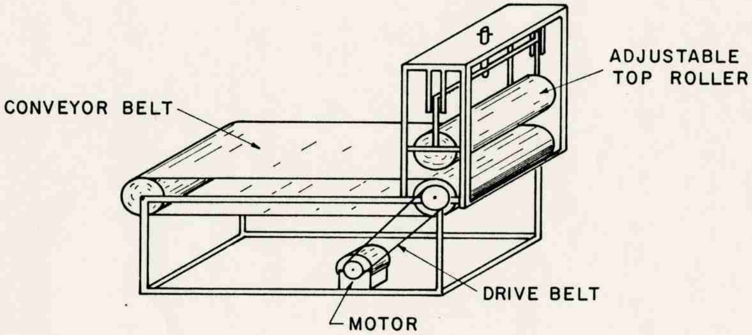

Figure 2. Midrib crushing equipment.

ABSTRACT

In bright-leaf tobacco curing the midrib, primarily because of its thickness, requires one to two days of drying after the leaf lamina is dry. Although the amount of moisture in the midrib is relatively small as compared to the moisture originally in the total leaf, heat requirements are large because of losses from the barn at the high temperatures necessary to drive the moisture from the midrib.

Crushing of midribs by passing leaves, just prior to curing, between rollers spaced 3 mm to 5 mm apart reduced curing fuel requirements by about 15% and curing time by 11 hours. Cured weight yield, sugar and alkaloids contents were not adversely affected. Crop value in on-farm upper stalk tests was not affected but other observations suggested a decrease in value of about four cents per kilogram which may have been due to soft rot which developed when curing some of the lower primings.

Although midribs were often broken into parallel strands by the crushing, there were no significant problems in removing the midrib from the leaf with conventional leaf threshing-separating equipment. There was a slight increase in finer particles and a decrease in total midrib indicating that some of the thinner strands passed as lamina.

Mechanical Harvesting of Flue-Cured Tobacco Part 12: Pre-Curing Crushing of Midribs

Charles W. Suggs

INTRODUCTION

The curing process which produces bright-leaf tobacco (also called Virginia or flue-cured) is characterized by an initial low temperature (38°C) phase of about two or three days which allows the yellow color to develop and desirable chemical changes to occur. During the second phase of the process the temperature is gradually increased to about 60°C and the barn is ventilated to accelerate drying of the leaf. In the third phase the temperature is increased to around 75°C in order to provide sufficient diffusion potential to remove moisture from the leaf midribs which may be over one and one-half cm thick. The total process takes about 6 days, approximately two days in each phase.

In both stick and bulk curing of flue-cured tobacco the midrib (stem) is the last part of the leaf to dry. Typically, 24 to 48 hours of midrib drying are required after the leaf lamina is dry. The stem drys slowly because of its relative great thickness. High drying temperatures are used during stem drying to increase the drying gradient and thereby reduce drying time.

Repetition to first ¶

Paper No. _______ of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, N.C. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned.

The energy required during midrib drying is less than during leaf drying because less moisture is involved. However, due to the heat losses associated with the high temperatures used and the need to exhaust enough air to maintain a low humidity, relatively large amounts of energy are required. Heat is lost by radiation, conduction and convection (air leakage). In fact most barns have enough leakage to provide the moist air exhaust and fresh air intake required for stem drying. 1

Midrib crushing offers potential for reducing both the time and energy requirement for drying the midrib. Crushing flattens and splits the midrib thus reducing the distances moisture must diffuse. It also ruptures cell walls so that diffusion resistance is reduced. ~~moisture may move easier. While diffusion distances are reduced by flattening and splitting of the midrib, the diffusion coefficient~~ may also ~~actually be reduced by~~ rupturing ~~the cell walls.~~ omit

~~OBJECTIVES~~

Continue under introduc.

~~It was the~~ An objective, of the work reported in this paper were to determine the curing time, energy reductions, leaf quality and other effects associated with midrib crushing and to develop a means for achieving the degree of crushing desired.

LEAF CHARACTERISTICS

Tobacco leaf size is approximately 52 cm long by 31 cm wide (Suggs and Splinter, 1959). A more recent study (Suggs, 1978) gives 57 x 28 cm as the length and width of flue-cured tobacco leaves. The midrib at the large end is approximately .99 cm thick by 1.64 cm

wide (Suggs, 1978). The cross section is shaped like a semicircle plus a rectangle, Figure 1, with the upper side of the leaf lamina flush with the flat side of the midrib. The midrib serves as a tapered cantilever structural member to support the leaf. It is largest at its attachment to the stalk, tapering to almost nothing at the tip of the leaf. A force of about 80 newtons per centimeter of length (44 lb/in) is required to crush the large end of the midrib (Suggs and Howell, 1972).

About 38% of the uncured leaf weight is in the midrib. Moisture content of midrib material was about 89% as compared to 78% for lamina (Suggs, 1975). That is, dry matter was about 11% for midribs versus 22% for lamina. From these values it can be determined that the midrib contains about 41% of the moisture in the leaf. Shimizu (1970) stated that the midrib contains about 1/3 of moisture in the whole leaf. Most (65%) of the midrib weight and moisture is in the first 15 cm of length and over 90% is in the first 30 cm of a 52 cm long leaf (Suggs, 1975). Thus, it would be sufficient to crush the large end of the midrib down about one-half to two-thirds of the leaf length as most of the moisture is contained in this end and the midrib in the leaf tip is small enough to dry about as fast as the leaf itself.

Chang & Johnson paper may be a better reference

PROCEDURE

Crushed Midribs

Midribs of intact leaves were crushed by passing them over a conveyor belt and between a pair of rollers spaced about 3 mm to 5 mm (1/8" to 3/16") apart, Figure 2. The clearance was selected to clear

the lamina but crush the large end of the midrib to a point about half way down the leaf. The midrib in the tip end of the leaf is small and usually presents no drying problem. During crushing, sap is forced out of the midrib. Treatments were imposed on the leaves immediately after priming except in an auxiliary set of experiments where midrib crushing was scheduled at priming, when half yellow and when full yellow. In another set of experiments treatments were imposed immediately after priming on green, ripe and over-ripe leaves.

The experiments extended over several years and after a mechanical harvester became available leaf midribs were crushed as harvested by two pairs of rollers located in the upper ends of the mechanical harvester elevators. Elevators were run at maximum speed to reduce the numbers of leaves lying on top of other leaves as lamina bruising occurred when a midrib is crushed against another leaf. Between roller clearance could be adjusted to crush midribs or opened to allow leaves to pass uncrushed for check plots and other experiments.

All of the crops were grown in accordance with accepted practices on the Central Crops Research Station near Clayton, N.C. During the first two years of the experiment, 1972, 73, the leaves were hand primed and run through the crusher shown in Figure 2. In 1972 all of the tobacco, five primings, was cured on sticks in small barns. In 1973 racks (57 Kg capacity, uncured leaf) and sticks were used. Small stick barns and small bulk barns were used for curing the material in 1973.

A mechanical harvester which became available in the spring of 1974 was used to harvest the tobacco for the rest of the tests. Stick curing was discontinued and container (box) curing was started. In 1973 and 74 five primings of four 57 Kg racks were harvested at each priming, two crushed and two uncrushed. These were placed, one crushed and one uncrushed rack in each of two small plot size bulk curing barns.

A relatively large quantity of leaf with crushed midribs was cured in 1974 in large containers (maxiracks) in a modified commercial bulk curing barn. This tobacco, consisting of approximately four primings from a 1 ha field, was sold on the market to determine the acceptability of leaf with crushed midribs.

In 1976 the plot size rack curing barns were converted to container curing after which no more crushed vs uncrushed material was cured in stick or rack barns. Gas meters were placed on the barns in 1974 so that curing efficiency could be measured. All cured leaf, uncured sticks and uncured racks were weighed on a platform scale. Containers of uncured leaf were weighed on the harvester by means of a hydraulic pressure system.

A sample of the cured leaf was removed for chemical analyses after which it was graded by a government tobacco grader. Value was determined from market average for each grade.

Several hundred pounds of crushed midrib leaf plus comparative samples of normal or check material were threshed and separated into leaf strips (lamina) and stems (midribs) at two tobacco processing plants.

The lamina was passed over a set of screens to determine the size distribution of the lamina. Samples of lamina were inspected to determine how much midrib material was left in the lamina.

RESULTS AND DISCUSSION

A condensed tabulation of the main results from 1972 through 1979 is given in Table 1 along with the mean values for the eight years of observations.

Fuel Consumption

There was a consistent fuel savings of about 15% associated with curing leaves with crushed midribs. Since crushing does not decrease the amount of water to be evaporated, the reduced fuel (heat energy) requirement is attributed to a decrease in the distance water has to diffuse to get out of the midrib, a decrease in the resistance to diffusion because of ruptured cell membranes and a decrease in curing time.

Reducing the time the barn must be held at high temperature decreases the energy loss from the structure by conduction, radiation, convection and exfiltration of air. Energy requirements to actually evaporate water would not be changed as no appreciable amount of stem moisture is lost during crushing. Because of the current trend toward higher fuel costs, barn design and curing procedures which save fuel are becoming increasingly important.

Cured Weight Yield

Cured weight yield, the weight of cured material divided by the original uncured weight of the same material expressed as a percentage,

was not affected by midrib crushing. The expected increase in cured weight yield for leaves from the mid and upper stalk was observed and the results for 1976 are reported in Table 1.

Crop Value

Crop value in terms of dollars per kilogram averaged over eight years of data was four cents per kilogram less for leaves cured with crushed midribs. This difference is not very large and appears to have been due to a problem with soft rot which developed when curing some of the lower primings.

Three farmers, involved in on-farm tests in 1975, one each from Lenoir, Bertie and Caswell Counties, judged the crushed midrib tobacco equal in quality to uncrushed tobacco. One farmer who had enough to sell separately indicated that it sold as well as the uncrushed. All reported faster drying and reductions in total curing time.

Chemistry

Sugar and total alkaloids content of the cured leaf were not affected by midrib crushing. There were, however, some year to year variations and stalk position variations.

Curing Time

Curing time was consistently less for crushed midrib leaf, 149 hours versus 138 hours. Although considerable moisture was forced out of the midrib during crushing most of it was deposited on the leaf. A series of measurements showed that moisture loss during crushing was less than two percent of the total uncured leaf weight. The moisture deposited on the leaf during midrib crushing was usually

removed by drying during leaf yellowing. Most of the crushed midribs dried during the leaf drying phase. Otani (1970) in an experiment to evaluate nitrogen movement between variously treated midribs and lamina reported that crushed midribs dried faster than other midrib treatments.

Reductions in curing time relate to heat and electricity us~~u~~age. A shorter curing time is also important because it increases barn throughput by reducing the time each batch must be cured. Fixed costs for barn ownership have been estimated to be about \$30 to \$36 per day (Suggs, 1979) or about \$11 to \$13 for the nine hours reduction in curing time found in this study. It is felt that an optimization of air flow, humidity and curing schedule will allow appreciable additional reduction in curing time. Curing time reductions of one to two days have been observed.

Loading Density

Midrib crushing destroys most of the rigidity of the leaves so that they tend to pack too closely in racks or boxes. Care must be taken when loading this material into barns to insure that it is loaded uniformly and that a reasonable density is maintained. Observations indicated that midrib crushing increased box capacity by 20 to 25%. This is a sizeable increase which, if not properly managed and controlled could result in overloading the barn curing system.

Midrib Removal

Threshing-separating tests, Table 2, indicated that the check material yielded slightly more large lamina particles than the crushed

midrib material. Fine particles are undesirable as they are difficult to use. The measured midrib content of the crushed leaf was less than for uncrushed leaf. Since the leaves were from the same source the actual midrib content should have been the same. Therefore, it is evident that crushing midribs produces slivers of material thin enough to pass through the separating equipment as lamina. Such slivers can be found in a visual inspection of the material, Figure 3. In the tests at one processing plant less midrib material was left in the processed lamina of the crushed material than in the check material. These results were reversed at the second processing plant.

LITERATURE CITED

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	Check			17.5	1.91	16.7	1.8	
	Crushed			17.2	1.94	18.2	2.1	
	Rack Cured,							
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	Check				2.02	17.0	3.04	
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	Check				2.31	19.4	3.37	
	Crushed				2.18	18.0	2.89	
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	Check				2.23			
	Crushed				2.08			
1976	Barn Cured,							
	Check	Bottom	.556	13.2	2.11	7.4	1.42	140
	Crushed	Stalk	.546	11.7	1.96	6.8	1.63	139.6
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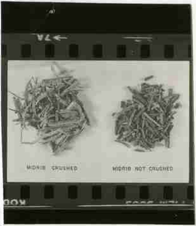
MIDRIB CRUSHED
MIDRIB NOT CRUSHED

Table 2. Threshing and Separating Characteristics of Tobacco With Midribs Crushed Before Curing.

	% Retained on Screen Mesh Size, Cm			Midribs in Leaf, %	Midrib Left in Lamina, %
	2.5 cm (1")	1.3 cm (½")	.6 cm (¼")		
Check	62.0	24.6	9.4	17.63	0.8
Crushed	48.4	36.3	10.7	15.86	0.3

	Mesh Size, Cm				
	1.9 cm (3/4")	1.3 cm (½")	.9 cm (3/8")		
Check	64.0	19.1	7.5		1.2
Crushed	58.4	20.3	8.6		3.9

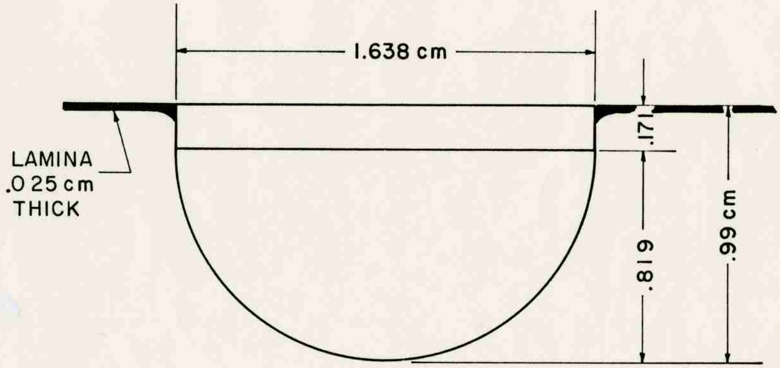

Fig. 1. Diagram of midrib cross section for average butt end dimensions.

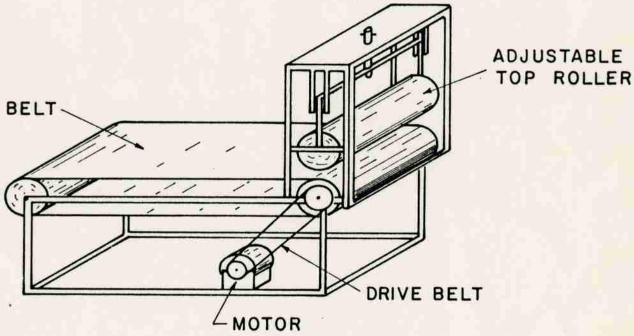

Figure 2. Midrib crushing equipment.

ABSTRACT

In bright-leaf tobacco curing the midrib, primarily because of its thickness, requires one to two days of drying after the leaf lamina is dry. Although the amount of moisture in the midrib is relatively small as compared to the moisture originally in the total leaf, heat requirements are large because of losses from the barn at the high temperatures necessary to drive the moisture from the midrib.

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MECHANICAL HARVESTING OF FLUE-CURED TOBACCO: PART 8
RELATIONSHIPS BETWEEN LEAF SHEAR RESISTANCE AND OTHER LEAF PROPERTIES[1]

By C.W. SUGGS[2]

The force to shear 15 grams samples of butt, central and tip portion of ripe uncured tabacco leaves in a Kramer shear press was measured along with leaf removal force, moisture content, midrib thickness and length, leaf width and length and leaf weight. Total shearing force was also used to determine force per unit of cross section sheared and the force to shear an average midrib. Shearing energy was determined from the area under the force x displacement recorder curves.

Leaf shearing force of 20 varieties at four priming levels did not correlate well with leaf removal force. Therefore, shear resistance would not be a good measure of mechanical harvestibility. Shear resistance did not change appreciably with respect to variety but increase with priming and decrease as moisture content increased. Correlations between shear and the other leaf measurements were poor. The force to shear an average midrib was 14.8 kg or 6.02 kg/cm². The energy to shear an average midrib was 13.16 kg-cm as compared to 13.8 kg-cm to remove the leaf from the stalk by impact.

INTRODUCTION

At the present time approximately 25% ofU.S. flue-cured tobacco is mechanically primed. The percentage is increasing and is expected to reach as much as 80% during the 1980's. Mechanical harvesting has also been introduced into foreign countries.

Although plant breeders would like to select plant characteristics which would increase machine harvesting efficiency and reduce machine damage, they do not have quantified correlations between measurable physical properties and harvestability. It was the objective of this work to determine leaf shear resistance and to correlate this value with measured leaf removal force and other leaf properties. The correlation between leaf shear and removal force was of interest because we have observed that leaves which are easily and quickly removed by the mechanical defoliator are less likely to be lost or damaged by the harvester.

MATERIALS AND METHODS

Plant material was made available[3] from the official variety test at the North Carolina Agricultural Experiment Station's Central Crops Research Station near Clayton, N.C. Twenty varieties were sampled in the 1973 tests but the number varied in 1974, 75 and 76 as some entries were dropped from the tests. Samples were taken and measurements were made on the leaves, as they ripened, for four primings, representing the four quarters of the plant; bottom, second, third and top. The varieties used are listed along the left hand side of **Table 1.**

The followwing measurements were made on five leaves of each variety for each priming:

(1) Force, slowly applied vertically downward to midrib two inches from stalk, required to remove leaf,
(2) Leaf length and maximum width,
(3) Width and thickness of butt end of midrib,
(4) Whole leaf weight, fresh and after oven drying to allow moisture content to be determined,
(5) Force required to shear through 15 gram samples of material taken from the leaf butt, mid portion and tip in a Kramer Shear Press, **Figures 1** and **2.**

Only "normal" leaves were selected and each of the five leaves at a given stalk position were from different plants. Force was measured

Table 1. Influence of Variety and Priming on Various Physical Properties.

Varieties	Shear Force kg	Removal Force kg	Moisture % Wet Basis	Midrib Width cm	Midrib Thickness cm	Leaf Length cm	Leaf Width cm	Leaf Weight gm
NC 2326	255	1.10	78.5	1.57	1.04	59.3	26.6	54.2
NC 95	259	1.02	79.7	1.58	.99	54.0	28.2	52.6
NC 88	273	1.18	80.0	1.83	1.13	58.1	29.8	58.0
Coker 254	272	.90	80.3	1.64	1.02	57.9	29.8	55.3
Coker 298	271	.91	79.1	1.52	.93	57.8	32.5	56.8
Coker 319	276	1.01	78.2	1.66	1.00	58.8	26.9	56.0
Coker 347	269	1.00	78.4	1.70	.96	58.5	26.4	51.0
Coker 354	265	1.08	77.2	1.65	.96	61.0	24.4	47.0
Coker 411	283	.85	78.0	1.59	.94	58.9	26.6	55.5
McNair 133	294	.99	77.6	1.52	.94	54.8	30.9	48.9
McNair 135	275	.91	78.7	1.72	1.04	59.2	27.0	47.4
McNair 944	276	.89	72.7	1.45	.94	53.2	26.5	50.1
SG 72	284	.93	76.0	1.62	.93	56.1	27.9	49.6
Speight G 15	257	1.08	80.9	1.84	1.10	52.9	26.4	51.3
Speight G 28	263	.95	79.6	1.68	1.01	57.8	27.8	58.9
Speight G 33	260	.94	79.3	1.70	1.01	56.7	25.8	51.7
Speight G 41	282	.80	77.5	1.65	.97	57.9	26.4	54.0
Speight G 140	284	1.02	77.9	1.55	.95	60.0	30.9	57.4
Va 080	253	.94	80.6	1.80	1.01	52.3	26.7	43.8
Va 115	283	1.06	76.4	1.57	.98	57.3	26.1	53.1
High	294	1.18	80.9	1.84	1.13	61.0	32.5	58.9
Low	253	.80	72.7	1.45	.93	52.3	24.4	43.8
Difference	41	.38	8.2	.39	.20	8.7	8.1	5.1
Std. Dev.	49	.34	4.7	.29	.20	5.5	4.6	11.4
Std. Error of Mean	8.1	.055	.78	.048	.033	.91	.76	1.88
Mean	271	.98	78.4	1.64	.99	57.4	28.0	53.5
From Literature	--	.85[a]	82.7[b]	1.02[c]	.76[c]	51.7[a]	30.8[a]	52.8[a]
By Primings								
1	232	1.10	82.1	1.76	1.05	55.4	31.1	57.0
2	269	.97	80.0	1.72	1.04	59.5	30.5	56.2
3	293	.91	77.3	1.59	.98	60.1	26.9	53.2
4	289	.93	74.3	1.48	.89	54.4	23.7	47.7
Std. Dev.	41	.34	4.6	.28	.19	5.6	4.0	11.7
Std. Error of Mean	3.0	.025	.33	.020	.014	.41	.29	.85
By Leaf Parts								
1 (Butt)	282							
2 (Mid)	280							
3 (Tip)	254							
Std. Dev.	48							

(a) Suggs & Splinter, 1959
(b) Suggs, 1975
(c) Splinter, Suggs and Beeman, 1962

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1)Approved for publication as paper number 5617 in the journal series of the North Carolina Agricultural Experiment Station. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Experiment Station of the products mentioned nor criticism of similar ones not mentioned.

2)Proffesor, Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, N.C.

3)Courtesy of Dr. John Rice of N.C. State University.

Contribution received May 5, 1978. Tob. Sci. XXII: 134-137, 1978.

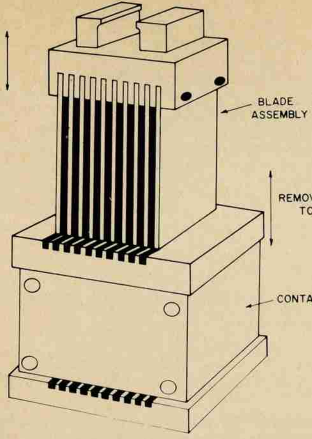

Fig. 1a. Kramer shear press showing sample container at the bottom and shear blades at the top ready to be driven down through the sample.

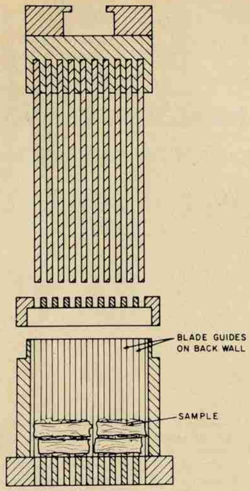

Fig. 1b. Cross section of shear press.

with a small spring scale and leaf dimensions were measured with a steel tape. Midrib dimensions were measured with a vernier caliper or with a steel rule. Samples were weighed on a Mettler P11 electronic balance. In a few instances for leaves weighing less than 45 grams it was necessary to use similar material from another leaf to make up the three samples. For leaves weighing over 45 grams the excess was cut from the leaf mid portion and discarded.

The Kramer Shear Press container, **Figure 1,** which was used for measuring shearing force consisted of a metal box 6.54 cm wide by 6.67 cm long by 6.35 cm deep fitted with a top and bottom through which 10 slots 0.32 cm wide had been cut (manufactured by Food Technology Corporation). An upper element consisting of 10 shear blades 0.32 cm thick separated by a 0.32 cm wide space all connected to a mounting plate and of the proper size to be driven through the slots in the sample box completed the apparatus. In operation, the sample is placed in the box, the top is replaced and then the parallel shear blades are driven down through the slots in the box top to compress and shear the sample and force the material in front of the blades out through the slots in the box bottom. Shear blades are cut square across the ends so that the test material is sheared on each edge, Kramer, *et al.* 1951. They are mounted with a small amount of lateral flexibility to allow them to follow the grooves in the case, (Bourne, 1975).

An Instron Universal Testing Machine was used to drive the shear blade element because it could provide a constant speed, a measure of the shearing force and a permanent record of both force and displacement. Fifteen gram samples were taken from the butt, central and tip portions of the leaf and sheared at a shearing speed of 100mm/min. Material was spread as uniformly as possible over the bottom of the container and midrib sections were always placed perpendicular to the shear blades. Recorder response was set at 500 kg full scale and the speed of the strip chart was set at 200 mm/min. Shear forces were measured as soon as practical after leaves were harvested. Care was taken to prevent leaves from wilting before measurements were made.

Shearing energy for some of the samples was determined by measuring the area under the force-displacement curve, **Fig. 2,** with a planimeter. The vertical axis of this curve is in units of force (kilograms) and the horizontal axis is in units of displacement (centimeters) so that the area is energy in terms of kilogram-centimeters to shear the 15 gram sample.

In order to make comparisons with some related values in the literature, overall sample values were expressed in terms of the force and energy required to shear one cm^2 of the material. This was done by determining the average depth of the sample in the shear box from the weight and density so that the total cross section sheared by each shearing edge could be calculated.

RESULTS

Parameter Values: Although the values of the various physical properties vary with variety, **Table 1,** the differences are not generally statistically significant as the standard deviations are of about the same size as the differences between the high and low values. These values are in general agreement with data available from the literature. Removal force was 0.98 kg compared to 0.85 kg reported by Suggs and Splinter (1959). Moisture content was 78.4% versus 82.7% reported by Suggs (1975). Midrib width and thickness were 1.64 cm and 0.99 cm which is somewhat larger than the 1.02 cm and 0.76 cm reported by Splinter *et al.* in 1959. Leaf length, width and weight were 57.4 cm, 28.0 cm and 53.5 gm or about the same as the 51.7 cm, 30.8 cm, and 52.8 gm reported by Suggs and Splinter in 1959. No shear values for fresh tobacco were found in the literature.

With the exception of leaf length there were consistent changes in the measured physical properties with respect to priming. Shear force increased for the upper primings which may simply be a reflection of the decrease in moisture content, that is, the leaf contained less moisture and more shear resisting dry matter. Midrib width, midrib thickness, leaf width and leaf weight, that is, properties which are positively associated with leaf size, decreased for the upper primings.

Shear Forces: The shear sample of 15 grams would have a volume of 15 cm^3 if the density is assumed to be one, a value which is realistic in view of the high water content of the uncured leaf. If uniformly distributed, this would fill the 6.54 cm x 6.67 cm sample box to a depth of 0.344 cm ($15cm^3/6.54$ cm x 6.67 cm = 0.344 cm). The sample is sheared 20 times; once on each side of the 10 blades which are forced down through the sample. Mean per unit shearing force is the total average shearing force divided by the total sheared area; 271 kg/.344 cm x 20 = 6.02 kg/cm^2. For midribs only, the shearing force is 282 kg so the per unit value is 6.27 kg/cm^2.

If midrib cross section can be determined it could be used to calculate the force required to shear one midrib. Midrib width and thickness measured at the butt end are availablefrom **Table 1,** 1.64 cm x 0.99 cm thick. **Figure 3** approximates the midrib cross sectionas a half circle plus a rectangle. For the average values of this study the area is 2.387 cm^2. The force to shear one midrib is then 6.27 kg/cm^2 x 2.387 cm^2 or 14.8 kg. Forces to remove (prime) leaves from stalks averaged only 0.98 kg. This order of magnitude difference suggests that the mode of failure was different. One difference is the possible presence of an abscission layer which sometimes weakens the midrib sufficiently for the leaf weight to cause the midrib to fail. The second difference is that in leaf removal the midrib is used as a lever to bend the leaf either downward or to the side until the midrib fails, usually on the tension side. It will be seen later that shear values do not correlate well, statistically, with leaf removal forces.

Shear Energy: Measurement of the area under the force-displacement curves gives values which can be converted to energy by application of the appropriate constant. Shearing energy measured from the midrib section of the leaf shear data was about 248 kg-cm for a 15 gram sample sheared 20 times or 12.4 kg-cm per shear. Dividing by the sample cross section of 2.25 cm^2 the energy per unit is found to be 5.51 kg-cm/cm^2. This value is several times larger than the value of 1.22 kg-cm/cm^2 for string beans and 0.86 kg-cm/cm^2 for carrots which were determined from data given by Szczesnick, *et al.* (1970). These differences may be due, at least partially, to the fact that vegetable varieties are selected for tenderness, whereas, there are some advantages for toughness in tobacco leaves.

Table 2. Relationship Between Leaf Shear Resistance and Other Leaf Properties.

	Shear	Removal Force	Moisture	Midrib Thickness	Midrib Width	Leaf Length	Leaf Width	Leaf Weight	Priming
Leaf Part	-.2325 - Correlation coefficient 300.1 - Regression intercept -14.09 - Slope .0001 - Intercept probability .0001 - Slope probability								
Removal Force	.0088 270.8 1.263 .0001 .8093								
Moisture	-.3275 466.8 -2.572 .0001 .0001	.2668 -.1864 .0141 .2793 .0001							
Midrib Thickness	-.0435 283.6 -7.145 .0001 .2326	.5311 -.0219 .6107 .7053 .0001	.3779 64.78 8.767 .0001 .0001						
Midrib Width	-.0352 280.4 -8.469 .0001 .3334	.5075 .1295 .8544 .0140 .0001	.3686 67.63 11.33 .0001 .0001	.7305 .5744 1.070 .0001 .0001					
Leaf Length	.1664 192.8 1.273 .0001 .0001	.2104 .2982 .0109 .0174 .0001	.1565 69.49 .1523 .0001 .0003	.3098 .7872 .0130 .0001 .0001	.4664 .0084 .0148 .2031 .0001				
Leaf Width	-.1011 292.2 -.9549 .0001 .0192	.4805 .0245 .0304 .2694 .0001	.3942 65.13 .4707 .0001 .0001	.5529 .7408 .0285 .0001 .0001	.5575 .3321 .0217 .0001 .0001	.4506 41.88 .5528 .0001 .0001			
Leaf Weight	.0506 255.5 .1923 .0001 .2426	.3764 .4035 .0097 .0001 .0001	.2224 72.45 .1080 .0001 .0001	.4470 1.033 .0094 .0001 .0001	.5615 .4613 .0089 .0001. .0001	.5109 43.65 .2549 .0001 .0001	.5677 15.48 .2308 .0001 .0001		
Priming	.4439 221.6 19.55 .0001 .0001	-.1877 1.122 -.0573 .0001 .0001	-.4880 84.84 -2.582 .0001 .0001	-.3594 1.877 -.0955 .0001 .0001	-.2936 1.126 -.0532 .0001 .0001	-.1458 57.87 -.2489 .0001 .2875	-.5801 34.37 -2.571 .0001 .0001	-0.2821 61.16 -3.075 .0001 .0001	

Multiplying the per unit shear energy value (5.51 kg-cm/cm^2) by the average midrib cross section of 2.387 cm^2, the energy required to shear a midrib is found to be 13.16 kg-cm. Splinter, *et al.*, (1962) reported a value of 1.002 lb-ft or 13.8 kg-cm for leaf removal by impact. These two values are remarkably similar, especially since different crop years, varieties, and measuring methods were used. Splinter's value contains the energy to accelerate the end of the leaf in contact with the impact device. At the reported impact speeds of 251 cm/sec, 2 kg-cm would be sufficient to accelerate an entire average leaf of about 50 to 65 gm to the impact velocities. Since only the butt end is impacted and accelerated, probably less than 1 kg-cm is actually required for leaf acceleration.

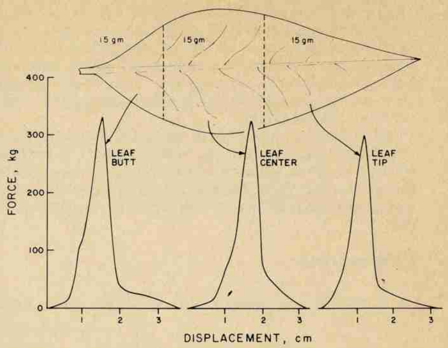

Fig. 2. Typical force-deformation curves of three 15 gram samples of ripe uncured tobacco leaf subjected to shear in a press having 10 blades (20 shearing edges).

Correlations, Shear: The shear resistance of a 15 gram sample of tobacco leaf did not correlate well with any of the physical properies measured, **Table 2.** Although none of the correlation coefficients are close to unity most of the regression slopes and intercepts are statistically significant, many of them at the .0001 level. Because the correlation coefficients are so low the regressions will not be useful for prediction purposes. The best correlations were with priming ($r = .44$) and moisture ($r = -.33$). These two correlations are related because primings 3 and 4 have a lower moisture content than primings 1 and 2. The decrease in shear force with respect to moisture level was expected because fixed weight samples with higher moisture content contain less shear resisting dry matter. Upper primings appear to be more fibrous than leaves from the bottom of the stalk. Backinger (1957) reported a positive correlation between shear energy and fibrousness in asparagus.

Parameters related to leaf size, midrib width and thickness, leaf width and length and leaf weight, were very poorly correlated with shear. This suggests that, physically, the material in a large leaf is similar to that in a small leaf and that using a fixed weight sample effectively normalized leaf size. There was a slight correlation between leaf part and shearing force with the midrib end being the hardest to shear. Leaf removal force was virtually unrelated to shearing force, or energy with correlation coefficients of 0.0088 and -0.0358.

Other Correlations: Removal force was, however, better correlated with midrib thickness and width and with leaf width, length and weight. The relationship indicated that larger leaves are harder to remove from the stalk. Leaf removal force was not normalized with respect to leaf weight as was the shear data. Removal force was poorly correlated with leaf moisture content and priming.

Moisture content showed some correlation (r = .38, .36, .39) with midrib thickness and width and leaf width. It has been shown (Suggs, 1975) that midribs contain a higher moisture content than lamina, therefore, leaves with larger midribs would tend to have higher moisture contents as corroborated here. There is also a negative correlation between moisture content and priming which was referred to earlier in the shear data.

Midrib thickness, midrib width, leaf length, leaf width and leaf weight are all positively correlated with each other with coefficients ranging from .79 to .31 indicating that all of these parameters tend to measure leaf size. These leaf measures are all negatively correlated with priming due to the trend toward smaller leaves at the top of the plant.

LITERATURE CITED

1. Backinger, G.T., A. Kramer, R.W. Decker and A.R. Sidwell. Application of Work Measurement to the Determination of Fibrousness in Asparagus. **Food Technol.** 11:583-585. 1957.

2. Bourne, M.C. **Texture Measurements in Vegetables.** Pages 131-162, in C. Rha, ed. Theory, Determination and Control of Physical Properties of Food Materials. D. Reidel Publishing Co., Boston, Mass. 1975.

3. Kramer, A., G.J. Burkhardt and H.P. Rogers. The Shear Press; A Device for Measuring Food Quality. Canner 112:34-36, 40. 1951.

4. Splinter, W.E., C.W. Suggs and J.F. Beeman. Physical Properties of Green Virginia-Type Tobacco Leaves Part IV. Kinetic Energy Absorption and Force Relationships During Separation from the Stalk. **Tob. Sci.** 6:62-70. 1962.

5. Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco Part 6: Weight Distribution and Cured Weight Yield of Midrib and Lamina. **Tob. Sci.** 19:83-85. 1975.

6. Suggs, C.W. and W.E. Splinter. Physical Properties of Green Virginia-Type Tobacco Leaves Part I. Leaf Dimensions, Weight and Midrib Strength. **Tob. Sci.** 3:121-124. 1959.

7. Szczesnick, A.S., P.R. Hombaugh and H.W. Block. Behavior of Different Foods in the Standard Shear Compression Cell of the Shear Press and the Effect of Sample Weight on Peak Area and Maximum Force. **J. Texture Studies** 1:356-378. 1970.

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TA # 2180, 1971
TA # 821, 2297, 1972

Shimizu, Yukio
Effects of moisture content in midribs of tobacco leaves during curing.
Nogyo Kikai Gakkai-Shi 31(4):303-308, March 1970.
[Society of Agricultural Machinery, Japan. Journal]

Translated by Y.Y. Tsai, N.C. State University, Ralegh

I. INTRODUCTION

It was known that water content was much more in midrib tissue than in blade tissue and is not easy to be dried. Since the curing process is a procedure physically controlling the leaf temperature and water content, whether the water in midrib moves directly from midrib epidermis or part of the water moves to leaf blade cell and dried from blade epidermis becomes an important characteristics of curing.

II. MATERIAL

Harvest the leaves 1/3 from bottom of Nicotiana tabacum L. var. Bright Yellow. For measuring the osmotic pressure of midrib and blade, the leaves 1/2 from bottom of N. tabacum L. var. Burley were used.

III. Water in midrib

Five leaves were cut into midrib and blade, dimensions and water content were measured. For blade, dimensions were measured by copying the blade on section paper. Midribs were measured as cylinder. Volumes were calculated from weight and suppose the density of blade is 1.14 and that of midrib is 1/05. Results were shown in table II. About 90% of water in midrib is in cortex. There is little in vascular bundle, so the water movement is related to cortex.

IV. Water movement from midrib to blade

Exp. 1: Change in water content of midrib and blade during drying. Method: Sample 8-10 leaves. Separate blade and midrib with razor blade. Measure the weight. Dry in 80°C and find out the dry weight.

$$\text{water content} = \frac{W - Wo}{Wo} \times 100\ [\%]$$

W = wet weight

Wo = dry weight

W - Wo = water weight

Result: relationship between water content and time of midrib and blade were shown in Fig. 2. The results show that during curing (yellowing), water content in blade has no change around 45%, while in midrib, water content changed from 94% to 80%. During color fixing period both show not much change in water content, but at this time, most of the water in blade is dried while still some remained in midrib. During midrib drying period drying is mainly on midrib.

Exp. 2: Water movement velocity in midrib and blade. Method: Proceed under 40°C relative humidity 79%.

blade = 10 × 10 cm exclude large veins

midrib : include 5 mm wide blade

Result: decrease of water content in midrib is less than that of in blade. Means part of water in midrib move to blade and then dry from blade. Drying velocity can be shown by the results indicated with unit dimension. As shown in Fig. 4 it shows faster drying velocity in blade than in midrib, but dimension of midrib is 1/10 that of blade. So the obsolute value of water movement from blade is large. So a lot of water being moved from midrib to blade.

Exp. 3: Water disappearance from drying and the recovery by absorption of water. Since water movement from midrib to blade is due to osmotic pressure of the cell, the water content of tobacco leaf has to be in the range for physiological activity. To make sure this point, dried tobacco leaves were observed their recovery by absorption of water. Method: weigh original weight of tobacco leaves, put in 40° C, relative humidity 80%. Weigh again after certain period of drying, then put into beaker with water for 2 hours. Weigh again.

Result: water content after drying and after absorption were shown in Fig. 6. The results show that the drop of absorption ability will be around 300-400% water content and from leaf tip to leaf margin. At 250-300% water content, the water can not come back to leaf margin.

V. Osmotic pressure of midrib and blade fluid during drying

Method: Use osmometer measure osmotic pressure of midrib and blade fluid. Sampling the leaves at harvest and during drying. Separate midrib and blade homogenize. Centrifuge at 10,000 C_T for 10 minutes. Measure the osmotic pressure of supernatent.

Result: $\Delta = 0.00186\,x \ldots . (1)$

$Tv = 12.06\Delta - 0.021\Delta^2 \ldots . (2)$

Δ : freezing point lowered (C°)

x ; reading of osmometer

Tv : atm.

At harvest, osmotic pressure in midrib is higher than that of the pressure in blade. As drying proceeded, osmotic pressure in blade became higher than in midrib. From microscopic study of leaf section, it was shown that starch grains decreased after curing (yellowing).

SUMMARY

The effects of the moisture content in midribs during the drying process of tobacco leaves while curing were studied.

1) Surface areas, moisture contents, and such other factors which are necessary to describe the drying process were determined for separated midribs and laminae respectively.

The moisture in midribs represents about a third of the moisture in the whole leaf. The amount of moisture per unit surface area is about ten times larger in midribs than that in laminae. Within the midribs, over 90% of the total moisture is concentrated in the cortex tissues.

2) In the early stage of curing, the moisture content of laminae was almost unchanged although the moisture content of midribs decreased considerably.

When midribs or laminae were separately subjected to curing, the water loss from the midribs was not so large, whereas the moisture content of laminae decreased markedly. Those results suggest that, in the early stage of curing, some of the water in the midribs is transferred into the laminae, where it is vaporized into the free air. In one of the experiments, leaves were subjected to curing to some extent and the leaves were then examined on their ability of water reabsorption. The results showed that, both in laminae and midrib, the majority of the cells maintained their water transfer activity during the curing.

3) To see whether the osmotic action participates in the generation of the driving force or not, the osmotic pressures of the cell sap obtained from midribs or laminae during curing were determined. Throughout the experiment, the osmotic pressure of laminae was always higher than that of midribs, indicating that the osmose had an important role in the movement of water within the leaves. The most probable reason for the higher osmotic value in the laminae seems to come from the saccharization of starch

during curing. This conception was supported by a microscopic observation of leaf segments, where starch granules were gradually reduced both in number and size.

HARVESTING AND CURING

See also # 2276, 2300

DUNCAN, G. A.; BUNN, J. M.
Forced ventilation curing and a new burley tobacco barn design. Ass. S. Agr. Workers Proc. 65th Annu. Conv. Feb. 5-6, 1968, Louisville, Ky. :36-7.
The scarcity and rising cost of labor for harvesting burley tobacco is becoming more critical for the producer each year. Although only 45 to 60 man-hours out of the 315 to 350 man-hours to produce 1 acre are required for harvesting and housing, this work is very laborious, timely and objectionable due to the large crew size and difficult barning operation. Research has been under way since 1960 by University of Kentucky Agricultural Engineering Department and USDA, ARS personnel to develop an automatic stalk-cut harvester, a portable frame and tractor forklift handling and housing method, and to conduct extensive laboratory studies defining curing conditions and systems compatible with mechanical harvesting and housing. To help solve immediate problems of the farmer and provide a transition between conventional and possibly highly mechanized systems, an alternate approach to the housing and curing problem has been the development of a 2-tier forced ventilation method. Cost of this structure complete with forced ventilation system is about the same as an equivalent size conventional barn. This new barn, however, has versatility for converting to other farm uses. Two demonstrational facilities were built by farmer-cooperators in 1967. These facilities worked successfully as adjudged by the general operation, curing results, and data taken. Further evaluation and development will be made with these and other farmer-cooperators before officially releasing blueprints for public distribution. (From abstract) 2462

FURST, H.
Development of the Styrian quality tobacco culture in the last six years. Tabakpflanzer Osterr. 21(60): 7-9, June 1970. illus., table. (Ger.)
Includes stringing and drying mechanization. 2463

OTANI, K.
Curing characteristic of midrib treated burley tobacco leaves. Morioka, Jap. Tob. Exp. Sta. Bull. (5): 25-42, Mar. 1970. graphs, illus., ref., tables. (Jap.)
In order to shorten the curing period, the curing tests were carried out on four types of treated midrib leaves: The intact leaves, the mesophyll and the midrib were separately cured after separating the leaf into individual parts, the leaves cut in pieces of 5 cm breadth after crushing the midrib (crushed piece), the mesophyll cut in pieces of 5 cm breadth after separating the leaf into the mesophyll and the midrib (laminated piece), under 35°C . 85% condition. The results obtained were as follows: Drying rate of the separated leaves was larger than that of the intact leaves, so that the curing period of the separated leaves was shorter by 100-140 hr than that of the intact leaves. In the curing process, insoluble nitrogen content decreased but soluble nitrogen and total volatile basis contents increased with time. The major parts of the changes of chemical components were completed in the yellowing stage. While curing the separated mesophyll they were found to have slightly larger chemical components than do the intact mesophyll. In the case of the midrib, chemical components of the intact are clearly increased but the separated showed little change. From the result, the author has discussed the possibility of translocation of chemical components between the mesophyll and the midrib during the curing. Color changes of leaves of the laminated piece and the crushed piece were quicker than that of the separated leaves. The water of the midrib of the crushed piece decreased to about 15% (D. B) in four days. Drying rate of the crushed piece was faster than that of the other methods, so that unfavorably cured leaves were easily produced in a low humidity condition. Leaf quality of the separated leaves was the higher, and the crushed piece was the lower. (English summary) 2464

YODER, E. E.
Power requirements for total plant harvesting of burley using portable frames. Tabakpflanzer Osterr. 21(60): 4-7, June 1970. illus., tables. (Ger.) 2465

Physical Properties of Green Virginia-Type Tobacco Leaves

Part I. Leaf Dimensions, Weight and Midrib Strength[1]

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Introduction

Since the production of tobacco, especially the handling of the leaves on the farm, has been almost entirely by hand the need for a knowledge of physical properties of the leaf has not been critical. Because the human hand and the judgment of the individual can accommodate a wide range of properties, the physical properties most generally considered are those, such as moisture content, which are most applicable to curing and manufacturing. However, with the attention which mechanization of the leaf handling operations is receiving, it is felt that the physical properties of the leaf will need to be known with increasingly greater accuracy.

The development of mechanical devices for handling and sorting tobacco leaves is dependent on the leaf possessing certain physical properties which the machine is designed to recognize. Distinctiveness of physical property and a high probability that it will occur to approximately the same degree in every leaf in a particular group is of primary importance to the success of handling and sorting devices. In addition, the physical properties of the plant as a whole exert a marked influence on size and configuration of field machines.

Manufacturers of agricultural machinery will be interested in the physical properties of green tobacco leaves as an aid in the development of new machines for tobacco production.

Jones and Collins and Moore have made measurements of the dimensions of green tobacco leaves as an aid in establishing plant characteristics for plant breeding work. Because the leaves they measured were needed for yield trials, only non-destructive measurements were made. Their data, while quite sufficient to characterize the plants for a breeding program, do not contain measurements of weight or midrib strength.

It was the objective of this work to determine certain of the dimensions, weight and the midrib strength of green tobacco leaves and to tabulate the results in a manner which would have engineering utility.

Methods

Tobacco plants selected for measurements were grown on the Border Belt Tobacco Research Station, Whiteville, N. C. and on the Upper Coastal Plain Research Station, Rocky Mount, N. C. Measurements were made of several varieties at each of these locations. Plants were mature when measured and representative of the respective varieties. Plants were selected at random, subjectively inspected, and excluded from the sample if found to be defective, stunted or growing under special circumstances such as at the end of the row. All of the measurements except the unit area leaf weights were made in the field. Although effort was made to take the measurements under approximately the same soil moisture, temperature and other environmental conditions, part of the variability of the data is probably due to the range of environmental conditions encountered. Leaf angle and weight would be especially sensitive to the environment.

The measurements of the distance between nodes, leaf length and width, and location of the center of gravity with respect to the midrib were made to the nearest quarter inch. The angle between the leaf and the stalk was measured with an adjustable bevel square and a protractor to the nearest degree.

Two angle measurements were made for each leaf. The first (α_1) was the angle between the stalk and a line drawn tangent to a point measured along the midrib 2″ from the stalk. The second (α_2) was a similar measurement made with the tangent line touching the midrib 6″ from the stalk. The difference in these two measurements ($\alpha_2 - \alpha_1$) can be used to find the curvature of the midrib in the interval between 2″ and 6″ from the stalk. The radius of curvature was calculated in the following manner:

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[1] *Approved by the Director of Research of the North Carolina Agricultural Experiment Station as Paper No. 998 of the Journal Series.*

Table 1. Physical Properties of Green Tobacco Leaves

Variety	Node Spacing, In. Mean	Node Spacing, In. Range	Weight, Gm. Mean	Weight, Gm. Range	Length, In. Mean	Length, In. Range	Width, In. Mean	Width, In. Range	Inches to Center of Gravity Mean	Inches to Center of Gravity Range
Va. Gold	1.83	1.5-2.5	60.00	35-95	21.06	16.0-24.0	12.85	10.5-15.5	8.52	6.5-9.5
DB 101	2.12	1.0-3.5	47.81	30-70	18.89	16.0-23.0	11.84	9.0-15.0	8.23	6.5-8.8
DB 28	1.69	1.4-2.0	67.67	45-90	21.77	18.0-25.0	13.65	12.0 16.0	8.38	6.5-10.0
2041	1.98	1.5-2.5	49.17	30-60	19.12	14.0-23.0	12.04	9.5-15.0	7.71	6.0-9.0
DB 244	1.88	1.0-2.5	55.00	30-75	19.96	17.7-23.0	12.89	10.0-15.2	7.81	6.8-9.0
OX 1-181	1.64	0.8-2.2	50.62	40-70	21.09	16.5-25.0	10.72	9.3-13.0	8.61	7.0-10.2
3549	2.66	1.5-4.0	57.50	30-90	21.19	18.0-25.0	13.41	10.5-16.0	8.53	7.5-10.0
White Gold	1.71	1.3-2.2	45.00	20-70	20.92	18.0-24.0	10.83	10.0-13.0	8.71	7.2-10.0
3006	1.59	1.1-2.0	42.08	30-65	19.25	16.5-23.0	10.96	9.0-13.5	8.10	7.0-9.5
Grand Mean	1.90	0.8-4.0	52.76	20-95	20.36	14.0-25.0	12.13	9.0-16	8.29	6.0-10.2
L.S.D. (.05)	0.38		10.61		1.83		1.15		0.76	
(.01)	0.51		14.04		2.40		1.52		1.01	
C.V. (%)	25		25		11	52cm	12	31	11	

$$S = r\Theta$$

where S = arc length,
r = radius of curvature and
Θ = angle in radians.

Solving for the radius of curvature:

$$r = \frac{S}{\Theta}$$

In this application S = 4″

$$\Theta = (\alpha_2 - \alpha_1)\,\frac{\pi}{180^\circ}.$$

The force necessary to remove the leaves was measured in pounds with a spring scale. Approximately half of the leaves were removed by application of a downward force to the midrib two inches from the stalk. The remainder of the leaves were removed by a horizontal force applied perpendicular to the midrib and two inches from the stalk, providing a twisting action around the stalk.

Due to the concavity of the leaf its true center of gravity lies outside the leaf surface. The distance along the midrib to a point directly above this center of gravity was determined. The distance of this point above the true center of gravity was not measured. Center of gravity with respect to the midrib was located by suspending the leaf by any point along one side. Because of the symmetry of the leaf a vertical line dropped from the point of suspension crosses the midrib at the center of gravity.

Results and Discussion

Table 1 gives mean node spacing, leaf weight, center of gravity, and length and width of leaves for nine varieties or lines of flue-cured tobacco. **Table 2** gives mean leaf angle, force required to remove leaves and radius of leaf curvature for the same plants as Table 1. Each of the means was calculated from twelve or more individual measurements. The maximum and minimum measurements contained in each average are given in the column labeled "range". A statement of statistical significance is included at the bottom of each column of means.

Mean node spacing varied with variety from 1.59 inches for line #3006 to 2.66 inches for line #3549. Thus a 48-inch length of stalk of line #3006 would contain 30 leaves whereas line #3549 would contain only 18 leaves. The mean node spacings of the commercial varieties were distributed between these two extremes. The range of internode lengths was quite wide within each variety. This was due primarily to the increase in internode length from the bottom to the top of the stalk. The greatest range observed was 1.0 to 3.5 inches for D.B. 101.

Mean leaf weight varied from 42.08 grams for 3006 to 67.67 grams for D.B. 28. The mean leaf weights of other varieties were distributed

Table 2. Physical Properties of Green Tobacco Leaves

Variety	Angle between Leaf & Stalk, Degrees: 2" Location Mean	2" Location Range	6" Location Mean	6" Location Range	Force Required to Remove Leaf, Lbs.: Downward Mean	Downward Range	Horizontal Mean	Horizontal Range	Radius of Curvature Inches Mean	Radius of Curvature Inches Range
Va. Gold	42.53	25-58	67.92	33-100	1.72	1.0-2.2	2.56	1.5-3.8	11.58	4.68-28.65
DB 101	69.44	40-98	94.88	52-119	1.34	1.5-2.0	1.91	1.2-2.8	10.34	5.21-20.83
DB 28	49.73	24-86	84.60	40-139	1.75	1.2-2.5	3.60	1.5-6.8	7.51	4.32-16.37
2041	56.67	26-94	85.58	51-135	1.38	0.5-2.0	1.96	1.2-3.0	12.46	4.88-38.20
DB 244	56.50	35-79	81.00	50-101	1.69	0.8-3.0	2.58	1.5-3.5	11.05	5.59-22.92
OX 1-181	56.19	30-80	83.38	56-116	1.17	0.8-1.5	1.64	0.8-2.5	9.56	5.88-20.83
3549	40.62	30-61	60.88	38-95	1.55	0.8-2.8	2.12	1.0-4.0	14.23	6.55-28.65
White Gold	43.75	30-60	63.33	40-70	1.75	1.2-2.5	2.46	1.5-4.2	12.54	8.81-22.92
3006	55.42	39-75	84.75	55-108	1.00	0.8-1.8	1.71	0.8-3.0	9.82	4.49-22.92
Grand Mean	52.32	24-98	78.48	33-139	1.48	0.5-3.0	2.28	0.8-6.8	11.01	4.32-38.20
L.S.D. (.05)	11.97		15.30		N.S.		0.93		N.S.	
(.01)	15.84		20.25		N.S.		1.24		N.S.	
C.V. (%)	28		24		40		37		54	

Table 3. Weight of Green Tobacco Leaf Lamina

(Weight in grams per square inch of leaf lamina)

Nitrogen Level	Variety	Priming 1	2	3	4	5	6	7	8	9	10	11	Mean
Normal	Coker 139	.203	.163	.143	.136	.133	.137	.126	.130	.140	.141	.143	.145
	Hicks	.201	.162	.152	.142	.130	.137	.125	.138	.146	.153	.156	.149
4X Normal	Coker 139	.220	.164	.141	.136	.129	.130	.130	.132	.132	.124	.143	.144
	Hicks	.199	.172	.156	.146	.128	.134	.131	.140	.140	.138	.142	.148
Priming Mean		.209	.165	.148	.140	.130	.134	.128	.135	.140	.139	.146	.147
Priming X Variety Means	Coker 139	.212	.164	.142	.136	.131	.133	.128	.131	.136	.133	.143	.144
	Hicks	.200	.167	.154	.144	.129	.136	.128	.139	.143	.146	.149	.148
Priming X Nitrogen Level Means	Normal	.202	.163	.148	.139	.131	.137	.126	.134	.143	.147	.150	.147
	4X Normal	.210	.138	.148	.141	.129	.132	.130	.136	.136	.131	.142	.146

Nitrogen Level L. S. D. (.05) = N.S.
Variety L. S. D. (.05) = .0033
Priming L. S. D. (.05) = .0051
(.01) = .0067
Priming X Variety and Priming X Nitrogen Level L. S. D. (.05) = .0071
(.01) = .0094

C. V. = 9%

fairly evenly within this interval. The range of leaf weights within a variety was larger than the spread of the mean leaf weights between varieties. This indicates that regardless of the variety, large and small leaves will result. The range was wide, for one variety the largest leaf was 3½ times as heavy as the lightest one. This ratio appears to be dependent on topping height.

Leaf weight in grams per square inch of surface area is given in **Table 3**[2]. The values given are for turgid, ripe, uncured leaf lamina exclusive of any midrib. Two varieties, Hicks and Coker 139, were investigated at two levels of nitrogen fertility. The two levels were (1) normal nitrogen and (2) four times normal nitrogen. Nitrogen fertility level did not significantly affect leaf weight per unit area. Variety and priming differences were, however, present. Leaf lamina of Coker 139 was lighter than lamina of Hicks. This difference was small but nevertheless significant. In general leaf lamina from the middle of the stalk was lightest and from the bottom of the stalk heaviest. There were some priming x variety and priming x fertility interactions which were due to slight differences in variety and fertility response over primings. The interactions were not due to reversal of trends. The mean weight in grams per square inch was .1467 and the range was .1254 — .2203.

Leaf length and width are not as variant as many other physical properties. Mean variety leaf lengths varied only from 18.89 to 21.77 inches. The shortest leaf in the sample was 14 inches and the longest one was 25 inches. Mean variety leaf widths varied from 10.72 to 13.65 inches with the narrowest leaf being 9.0 inches and the widest one being 16.0. Thus the ratio of longest leaf to shortest leaf (1.79:1.0) in the sample was approximately equal to the ratio of the widest to the narrowest (1.72:1.0).

The midrib of the tobacco leaf in its normal position on the stalk acts as a tapered cantilever beam in supporting the leaf lamina and itself. The upper fibers of the midrib are in tension and the lower fibers are in compression. The taper of the midrib tends to produce a beam of uniform fiber stress throughout its entire length. Young leaves have a midrib which is essentially straight and inclined upward from the stalk. However, as the leaf grows the midrib bends downward into a curve.

Table 2 lists the angle between the leaf and the stalk at two inches and six inches distance along the midrib. Almost all of the midrib angles at two inches from the stalk were acute indicating an upward direction. In every case the angle at six inches was larger than at two inches due to the downward curve of the leaf. Mean values at two inches vary from 40.26 to 69.44 degrees with least significant difference of 11.97 degrees at the 95% confidence level. This indicates that differences between varieties do exist. Values measured at six inches from the stalk exhibit the same pattern except that the angles are larger. It is felt that the wide range between the smallest and largest angle measured at both two inches and six inches is due partly to the effect of suckers in the leaf axil.

The radius of curvature was calculated for each leaf according to the formula given under Methods. The variety means are listed in **Table 2.** These values were spread over a wide range and difference between varieties were not significant.

It was felt that the radius of curvature of the midrib was related to leaf weight. In order to determine if this were true regressions were made of leaf weight on midrib curvature for the variety means and for individual measurements within five of the varieties. The analysis for the mean data resulted in a regression coefficient which was non-significant. Regression coefficients for the five varieties analyzed were not consistent. White Gold and D.B. 244 had non-significant coefficients; D.B. 101 and Virginia Gold had significant negative coefficients of —.202 and —.227 respectively. Analysis of the data for D.B. 28 gave a significant positive coefficient of .091. A nega-

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[2] *Data taken from observations (unpublished) of W. S. Thompson and O. B. Morgan, formerly graduate students in Agricultural Engineering, N. C. State College.*

tive coefficient indicates a decrease in radius of curvature (or an increase in curvature) with leaf weight. Because of the non-significance of the variety means and the inconsistency of the within variety analyses it is felt that in general leaf weight and radius of curvature are not related.

The force required to break the midrib and remove the leaf from the stalk was less if the force were applied vertically downward than if applied horizontally. Vertical forces of approximately 1½ pounds applied to the midrib two inches from the stalk were usually sufficient to remove the leaf from the stalk. Mean horizontal forces from approximately 1½ to 3½ pounds were required to break the midrib. Individual measurements ranged from 0.75 to 6.75 pounds for horizontal forces. The rather large range of individual values appeared to be due to the location of the leaf on the stalk and the presence of sucker growth in the leaf axil. In almost every case the midrib broke immediately adjacent to the stalk.

Summary and Conclusions

Leaf dimensions, weight and midrib strength were determined for six varieties and three breeding lines of flue-cured tobacco. The measurements were made on normal, healthy, mature leaves growing at two locations in the tobacco producing area of North Carolina. The plants had been grown according to prevalent cultural practices.

Leaf dimension measurements consisted of node spacing, leaf length and width, angle between leaf and stalk, radius of curvature and location of center of gravity with respect to midrib. Midrib strength was determined by stressing the midrib as a cantilever beam and measuring the force at the time of failure. The midribs failed by breaking at the point of attachment to the stalk. Vertical and horizontal measurements of midrib strength were made.

Individual measurements of any given characteristic were distributed over a fairly wide range. It was not uncommon for the largest of 15 measurements to be two or three times the size of the smallest. The mean values and ranges taken over varieties and breeding lines are as follows:

Node spacing—1.90 inches, 0.8-4.0 inches

Weight per leaf—52.76 grams; 20-95 grams

Lamina weight per sq. inch[3]—.1467 grams; .1254-.2203 grams

Length—20.36 inches; 14-25 inches

Width—12.13 inches; 9.0-16 inches

Center of gravity—8.29 inches from stem butt; 6.0-10.2 inches

Leaf angle—52.23° at 2 inches from stalk; 24-98°

Leaf angle—78.48° at 6 inches from stalk; 33-139°

Force to break midrib — 1.48 pounds downward; 0.5-3.0 pounds

Force to break midrib — 2.28 pounds horizontal; 0.8-6.8 pounds

Radius of curvature—11.01 inches; 4.32-38.2 inches

A regression of variety leaf weight on radius of curvature resulted in a non-significant slope value, indicating that varieties with larger leaves do not necessarily have greater curvature in the midrib. Similar regressions within the varieties did not give consistent results. For example, the regression for Virginia Gold was significant and showed that radius of curvature decreased as leaf weight increased while for D.B. 28 the opposite relation was found.

Literature Cited

Jones, Guy L., and W. K. Collins, "Measured Crop Performance." Research Report No. 9, November 1957. Department of Field Crops, North Carolina State College.

Moore, E. L., unpublished Progress Report, 1957.

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[3] *Hicks and Coker 139 only.*

"Reprinted from TOBACCO *New York, Vol. 149, No. 7, pps. 20-23 (Tobacco Science Vol. 3, pps. 121-124) August 14, 1959"*

cured 100:1 Lamina 0.00305 cm thick
Midribs 30 to .45 cm thick

Moisture Diffusion in the Cured Burley Tobacco Leaf

Linus R. Walton, Zachary A. Henry, W. H. Henson, Jr.

INTRODUCTION

THE processing, handling, and storage of biological materials usually involve the basic problem of controlling the exchange of moisture between the material and its ambient environment. When the vapor pressure of the moisture within a material and the vapor pressure of the surrounding air are unequal, moisture diffuses in the direction of the lower vapor pressure. Thus, the moisture exchange may be either a drying or wetting process or a combination of alternate drying and wetting.

Historically, agricultural crops have been dried to prevent spoilage (Hall 1957, Henderson and Perry 1955, Young and Whitaker 1971). However, many problems do arise after drying, especially in such hygroscopic materials as tobacco, wheat, and cotton (Young 1964, Young and Nelson 1967, Henry 1939). Physical properties such as elastic moduli are generally functions of moisture content (Artho 1955) and must often be closely controlled during processing, both on and off the farm. Specific moisture levels are often required for a given phase of processing and, thus, require knowledge of wetting as well as drying phenomena.

Moisture relationships in cured burley tobacco are important since different moisture levels are required for handling, storage, and manufacturing. To be handled, the tobacco must be in order, i.e., its moisture level must be high enough that it will be soft and pliable. Tobacco readily absorbs moisture from the atmosphere, and tobacco producers depend upon natural moisture levels in the air to order the tobacco on the farm. Control of burley leaf ordering would be a natural extension of the trend toward more environmental control in curing facilities. The mechanization of stripping and grading will probably require more stringent control of moisture content. Before we can control the environment to provide a specific moisture level in cured leaves, we must know the response of the tobacco to a given environment. The objectives of this study were:

1 To analytically develop mathematical models for the moisture content of the cured tobacco lamina and midrib during sorption and desorption.

2 To experimentally determine the applicability of the mathematical models to actual sorption and desorption of cured burley leaves.

MATHEMATICAL ANALYSIS

Our problem was to develop mathematical models that define the sorption and desorption of the cured burley leaf caused by a sudden change in the ambient environment. Young (1964) used dimensional analysis to develop a mathematical model for the sorption of whole burley leaves detached from the stalk. Walton and Henson (1970) used the thin layer exponential equation to model sorption of whole detached leaves. Neither of the models were based on the geometry of the leaf. The thickness and shape of the lamina differ greatly from those of the midrib. Therefore, one can expect the moisture transfer rates of the two components to differ. Thus, models are needed for both the lamina and midrib.

We developed the problem mathematically as a boundary value problem by applying basic mass transfer theory to the geometry to the leaf. Our first step in this approach was to determine the geometric models that best represent the lamina and midrib.

The lamina and midrib are the two primary components of the burley leaf. The lamina is the thin broad portion of the leaf with a very small thickness-to-surface-area ratio. Therefore, we chose the infinite thin sheet as the geometric model to represent the lamina.

The midrib, central vein of the leaf, has a diameter of about 0.30 to 0.45 cm near the stalk, and is tapered toward the tip. The cross section has a V-shaped notch in the top. Because of the very high length to diameter ratio of the midrib and its nearly circular cross section, we chose the infinitely long circular cylinder as its geometric model.

Several assumptions were made:

1 We assumed that the moisture transfer between stalk and midrib is negligible to permit use of the infinitely long circular cylinder as the geometric model for the midrib, and, thereby, to reduce the problem to one dimension.

2 We assumed that each component is a homogeneous material.

3 We assumed that the moisture content of the tobacco (between 8 and 32 percent) is a linear function of leaf temperature and of vapor concentration in the pore spaces.

4 We assumed that the diffusion coefficient is a constant for a given environmental condition.

5 We assumed that moisture in the pore space of the leaf was in the vapor phase.

Other necessary information was

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Certain phases of the investigation were conducted while the first author was a graduate student at the University of Tennessee. The paper is published with the approval of the Director of the Agricultural Experiment Station, Institute of Agriculture, University of Tennessee.

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determined by preliminary experiments (Walton 1974):

1 The transfer of moisture directly between midrib and lamina during sorption and desorption is negligible.

2 The transient thermal period of the lamina and midrib is negligible as compared with the transient moisture period.

3 For airflows used in sorption and desorption tests, the external resistance to moisture movement is negligible compared to the internal resistance.

The governing equation was the vapor diffusion equation (Walton 1974), which, by use of assumption 3, reduced to:

$$D \ \nabla^2 \Theta = \frac{\partial \Theta}{\partial t} \ \ldots\ldots\ldots\ldots\ [1]$$

where

D = diffusion coefficient based on the mass of water per unit mass of solid, cm²/sec

$$\Theta = \frac{M - M_e}{M_o - M_e}$$

t = time, sec

M = moisture content at time t, dry basis, percent

M_e = equilibrium moisture content, percent

M_o = initial moisture content, percent

The results of the preliminary experiments (Walton 1974) greatly simplified the boundary conditions. The mathematical consequence of the negligibility of external resistance to moisture flow as compared with internal resistance was that the convective mass transfer coefficient was considered to be infinite. Our physical interpretation was that the surface of the tobacco leaf instantaneously reached equilibrium with its environment. Therefore, our problem was reduced to the solution of the diffusion equation for the infinite thin sheet and for the infinitely long circular cylinder, with a boundary condition that the leaf surface instantaneously reaches equilibrium with its environment. The initial condition was that midrib and lamina were initially at a uniform moisture content, M_o. We followed the methods of Crank (1964) to determine the corresponding solutions for the lamina and midrib.

Lamina Model

The mathematical model for the average moisture content of the lamina as a function of time is:

$$\Theta\,(t) = \sum_{n=0}^{\infty} \frac{2}{(\lambda_n\, L)^2}\, e^{-D\,\lambda_n^{\,2}\, t},\ \ldots\ [2]$$

where

$$\lambda_n = \frac{(2n + 1)\pi}{2L}$$

n = 0, 1, 2....

L = half thickness of the lamina, cm

Midrib Model

The mathematical model for the average moisture content of the midrib as a function of time is:

$$\Theta\,(t) = \sum_{n=1}^{\infty} \frac{2}{(\beta_n R)^2}\, e^{-D\,\beta_n^{\,2}\, t},\ \ldots\ [3]$$

where

β_n = nth positive root of $J_o(\beta_n R) = 0$

$J_o(\beta_n R)$ = Bessel function of order zero

R = Radius of midrib, cm

The exponential equation was used as the standard of comparison in evaluating the validity of equations [2] and [3]:

$$\Theta(t) = e^{-kt},\ \ldots\ldots\ldots\ldots\ldots\ [4]$$

where

k = an absorption constant, hr⁻¹

EXPERIMENTAL PROCEDURE

We developed experimental techniques to determine sorption and desorption of the lamina and midrib without separating the components. In the procedure, we

1 Determined the sorption and desorption data for whole burley leaves.

2 Determined the sorption and desorption data for the lamina, only, of these same leaves.

3 Subtracted the lamina data from the whole-leaf data to obtain sorption and desorption data for the midrib.

4 Then "fitted" the mathematical models (equations [2] and [3]) to the data by determining the value of the diffusion coefficient, D, that minimized the difference between predicted and observed values of Θ (t).

The following levels of variables were chosen:

Temperature (sorption and desorption)	13, 18.5, and 24 °C
Sorption relative humidities	75, 84-88, 97-98
Desorption relative humidity	44 percent
Components	lamina, midrib
Direction of moisture flow	sorption, desorption
Number of replications	four

The test units consisted of 12 single tobacco plants of Burley variety 21.

The whole leaf tests were made with the leaves on the stalk. To accomplish these tests, we coated the stalk with paraffin. The split in the base of the stalk (made at harvest in placing the stalks on a stick for handling and curing) was covered completely with masking tape, and the tape was covered with paraffin.

After we completed the whole leaf tests, we removed the leaves from the stalk, coated the midribs with paraffin, and positioned the leaves on a wire for the lamina tests at about the same spacing as they had been on the plant. Removal of the leaves from the stalk was necessary because the coating process necessitated that the leaves, when attached to the stalk, be moved and bent, a procedure which caused cracks in the paraffin. When the leaves were removed from the stalk, easy access was afforded to both sides of the midrib. The paraffin coating was applied heavily to both sides, not only to provide a moisture barrier, but also to provide structural rigidity to prevent the paraffin from cracking.

A sketch of the well-insulated chamber built for the sorption tests is shown in Fig. 1. The dry bulb temperature was controlled to within ± 0.6 °C. A small fan provided continuous air flow over the tobacco and the salt pans. A constant air velocity was maintained throughout the tests since results of preliminary experiments showed that sorption

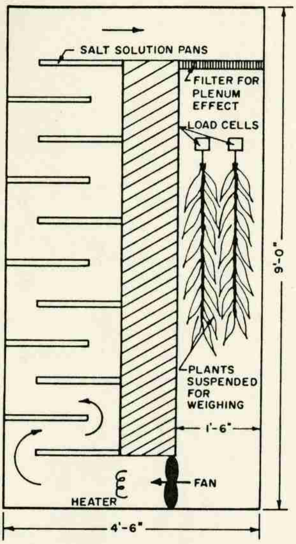

FIG. 1 Schematic of chamber built for sorption tests.

rates were not affected by variation in air flow rates. We placed about 19 l of salt solution in 11 pans so that 2.3 m² of liquid surface would be exposed to the circulating air. The surface area of the solution during all tests was adequate to replace sorbed moisture as monitored by wet bulb thermocouples above and below the test section of the sorption chamber. The salts used were sodium chloride, potassium chloride and potassium sulphate which provided relative humidities of 75, 84-88, and 97-98 percent, respectively. The equilibrium moisture contents used in calculations for the sorption and desorption tests (Walton 1974) are shown in Table 1.

We used four 454 g load cells to monitor specimen weight in the sorption chamber. The combined sensitivity of the load cells and digital recording system was 17 counts/g. The combined accuracy of the system was ±1 count.

A second chamber was constructed for the desorption experiments. The operation of the desorption chamber was similar to that of the sorption chamber, with the exception of the airflow system. We placed a smaller fan in the desorption chamber to provide continuous air circulation to facilitate moisture transfer to the salt solution.

The test plants were always stored in a dry environment (40-45 percent relative humidity) when they were not being tested or prepared for a test. Twenty-four hours before a test was to begin, four test plants were moved to the desorption chamber for conditioning to a uniform initial moisture content at the test temperature. After we placed the plants in the sorption chamber, we took weight readings at 10-min intervals during the first hour, at 15-min intervals for about 8 hr, and at irregular intervals for the next 4 to 6 hr. We took a final reading about 24 hr after the test began. The tobacco was then transferred from the sorption chamber to the desorption chamber which was maintained at the same temperature as the sorption chamber. Desorption values were recorded at 10-min intervals the first hour, at 15-min intervals the second hour, and at 30-min intervals thereafter until weight loss was so small that longer irregular intervals were used.

The half thickness of the lamina and the midrib radius were determined after completion of the tests. We removed the paraffin and conditioned the tobacco at 24 °C, 75 percent. The half thickness of the lamina varied very little, therefore, we used the average of 0.00305 cm for all plants. We measured the midrib radius of each leaf at approximately 13 cm from the point of attachment to the stalk and calculated an average radius for each plant.

We fitted equations [2] and [3] to the sorption and desorption data using the method (Marquardt 1966) of minimizing the sum of squares of the differences between observed and predicted values of moisture ratio, Θ (t), through an iterative process. The computed parameter was the mass diffusion coefficient that gave the best fit of equations [2] and [3] to the experimental data. The mass diffusion coefficient of the lamina and midrib is analogous to the vapor diffusion coefficient of packed flue-cured leaves determined by Stinson et al. 1974.

RESULTS AND DISCUSSION

The mass diffusion coefficients, D, computed by fitting equations [2] and [3] to the sorption and desorption data are shown in Table 2. The values were averaged over replications (plants). The corresponding standard errors of estimate for regression, averaged over replications, are shown in Table 3.

The corresponding average k-values computed in fitting the exponential equation (equation [4]) to the sorption and desorption data are shown in Table 4. The average standard error for the exponential equation is shown in Table 5.

A comparison of the data as shown in Tables 3 and 5, showed that the mathematical models derived for the lamina and midrib were far superior to the exponential equa-

TABLE 1. EQUILIBRIUM MOISTURE CONTENTS (DRY BASIS) USED IN CALCULATIONS FOR THE DESORPTION AND SORPTION TESTS

Temperature, °C	Relative humidity, percent			
	Desorption	Sorption		
	44	75	84-88	97-98
	Equilibrium moisture content (d.b.), percent			
13	8.6	24.9	46.8	79.0
18.5	8.0	22.8	38.5	70.0
24	7.4	20.7	30.2	62.0

TABLE 2. MASS DIFFUSION COEFFICIENT (AVERAGE OF FOUR REPLICATIONS) AS A FUNCTION OF TEMPERATURE AND RELATIVE HUMIDITY

Environmental conditions*		Mass diffusion coefficient (cm^2/sec) x 10^{11}			
Temp, °C	Relative humidity, percent	Lamina sorption	Midrib sorption	Lamina desorption	Midrib desorption
13	75	2.449	1365	19.75	8506
18.5	75	3.569	2299	47.10	12805
24	75	6.601	2986	51.29	21447
13	88	0.769	372	13.89	8438
18.5	86	2.003	809	28.19	14240
24	84	3.920	2875	37.09	21316
13	98	0.717	303	10.25	8230
18.5	98	1.099	507	20.30	20495
24	97	1.695	1038	30.19	18263

*Refer to footnote of Table 3.

~~.0000455999~~

.0705 - 10 hr lamina

.2546 - 10 hr stem

.0648 20 hr stem

.074 - 19 hr stem

.0055 - 38 hr stem

.0497 20 hr lamina

Using the K values from Table 4 it is seen that it takes about 2 times as long to dry midrib as lamina - Assumes that material is already cured - Compares batch of lamina vs batch of stem -

1 Stitt	Syrflot ✓
2 Young	→ ~~Harrison~~
3 Abrams	Ai ✓
4 Roberts	→ Hansson
5 Mishoe	
6 Cundiff	→ Harrison ✓
7 Bright	Alvi ✓
Saran ✓	woob ✓
Robeson	
Maw	

TABLE 3. AVERAGE STANDARD ERROR IN PERCENTAGE OF MOISTURE CONTENT OF LAMINA AND MIDRIB MODELS (EQUATIONS 2 AND 3, RESPECTIVELY) AT VARIOUS TEMPERATURES AND RELATIVE HUMIDITIES

Environmental conditions*		Standard error (percent moisture content)			
Temp, °C	Relative humidity, percent	Lamina sorption	Midrib sorption	Lamina desorption	Midrib desorption
13	75	0.30	0.25	0.17	0.22
18.5	75	0.32	0.47	0.16	0.18
24	75	0.35	0.24	0.14	0.21
13	88	0.39	0.45	0.39	0.31
18.5	86	0.51	0.27	0.35	0.49
24	84	0.49	0.74	0.52	0.75
13	98	0.56	1.07	0.65	0.55
18.5	98	0.51	0.69	0.57	1.28
24	97	0.86	0.49	0.76	1.24

*Relative humidities are those for sorption only. For desorption, these values represent the relative humidities from which the tobacco came before it was placed in the 44-percent-relative humidity desorption environment.

TABLE 4. AVERAGE VALUE OF PARAMETER k IN EXPONENTIAL EQUATION (EQUATION 4) AS A FUNCTION OF TEMPERATURE AND RELATIVE HUMIDITY

Environmental conditions*		k-value (hr^{-1})			
Temp, °C	Relative humidity, percent	Lamina sorption	Midrib sorption	Lamina desorption	Midrib desorption
13	75	0.0487	0.0372	0.2652	0.1368
18.5	75	0.0647	0.0478	0.5348	0.1704
24	75	0.1141	0.0656	0.6555	0.2174
13	88	0.0259	0.0177	0.1873	0.1225
18.5	86	0.0464	0.0276	0.3580	0.1802
24	84	0.0691	0.0543	0.4686	0.2310
13	98	0.0240	0.0166	0.1366	0.1470
18.5	98	0.0517	0.0244	0.2646	0.2480
24	97	0.0480	0.0291	0.3469	0.2440

*Refer to footnote of Table 3.

tion as mathematical predictors of burley sorption. The superiority extended to all environmental conditions for both lamina and midrib sorption; the standard error of equations [2] and [3] was about one-third that of the exponential equation.

Examples of the lamina sorption and desorption data along with the prediction curves from the lamina and exponential models, are shown in Figs. 2 and 3, respectively. The lamina diffusion model generally over-estimated moisture content during the initial portion of the sorption curve and underestimated moisture content during the latter portion of that curve. The exponential equation typically underestimated moisture content during the initial portion of the sorption curve and badly overestimated in the extreme latter portion of the curve. The lamina model typically underestimated moisture content during the initial portion of the desorption curve, but overestimated during the latter portion. In contrast, the exponential model overestimated moisture content during the initial portion of the desorption curve, but underestimated moisture content during the latter portion. A comparison of the magnitude of the k-values for lamina and midrib in Table 4 shows that the moisture content of the midrib changes more slowly than that of the lamina.

The standard errors of the diffusion models for lamina and midrib were of the same order of magnitude for both sorption and desorption as shown in Table 3. The exponential equation showed a great difference between the standard errors for sorption and those for desorption (Table 5). The standard errors were much lower for desorption than for sorption. The difference was so great that the exponential equation (Table 5) showed lower errors for desorption than did the diffusion models (Table 3) for most of the nine environmental conditions. Thus, for accuracy in the fitting of experimental data, the results showed that the exponential equation was slightly superior to the diffusion models for lamina and midrib desorption.

A comparison of the standard error for desorption in Tables 3 and 5 showed that the exponential equation was superior to the lamina and midrib models at high humidity, whereas the reverse was true at low humidity. The relative humidity within the chamber increased slightly (a maximum of 5 percent) upon introduction of the moist tobacco into the chamber, and then decreased to 44 percent over a 3-hr period.

TABLE 5. AVERAGE STANDARD ERROR IN PERCENTAGE OF MOISTURE CONTENT OF EXPONENTIAL EQUATION (EQUATION 4) AT VARIOUS TEMPERATURES AND RELATIVE HUMIDITIES

Environmental conditions*		Standard error (percent moisture content)			
Temp, °C	Relative humidity, percent	Lamina sorption	Midrib sorption	Lamina desorption	Midrib desorption
13	75	1.00	0.77	0.28	0.22
18.5	75	0.92	1.01	0.32	0.32
24	75	0.40	0.49	0.28	0.46
13	88	1.35	1.21	0.28	0.32
18.5	86	1.67	1.19	0.31	0.40
24	84	1.58	1.13	0.15	0.44
13	98	2.37	1.67	0.57	0.49
18.5	98	2.47	2.00	0.51	0.67
24	97	3.02	2.47	0.39	0.53

*Refer to footnote of Table 3.

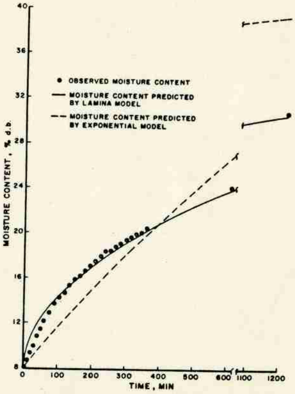

FIG. 2 Observed moisture content and that predicted by the lamina model (equation [2]) and the exponential model (equation [4]) for sorption of the lamina at a temperature of 18.5 °C and a relative humidity of 97 percent.

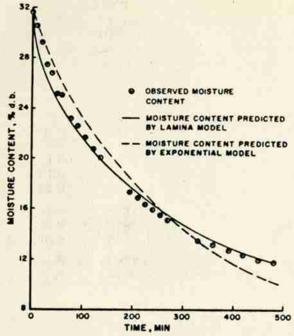

FIG. 3 Observed moisture content and that predicted by the lamina model (equation [2]) and the exponential model (equation [4]) for desorption of the lamina at a temperature of 18.5 °C and a relative humidity of 44 percent after removal from 18.5 °C and a relative humidity of 97 percent.

This error favored the exponential equation, since the moisture content it predicted typically lagged the observed moisture content, whereas the moisture content predicted by the lamina and midrib models led the observed moisture content in the early portion of the curves (Fig. 3).

A comparison of the mass diffusion coefficients of the lamina and midrib during sorption and desorption showed that both components dried considerably faster than they sorbed moisture. This difference was partially attributed to swelling of the tobacco during sorption and shrinkage during desorption. Swelling required energy while shrinkage involved a release of energy. Since more energy is required for a given moisture content change during sorption than during desorption, moisture sorption was retarded and desorption was enhanced.

The superiority of the lamina and midrib models to the exponential equation in describing the physics of the moisture transfer can now be shown. The conductivity of moisture in the midrib was greater than that in the lamina; yet, the characteristic length of path for moisture movement was the radius of the midrib as compared with the half-thickness of the lamina. These factors, combined, caused moisture content to change faster in the lamina than in the midrib. Although the lamina and midrib models showed the effect of both conductivity and path length, the exponential equation showed only the bulk effect of the combination of the two. Therefore, the mathematical models developed for the lamina and midrib describe the physics of moisture transfer better than does the exponential equation.

The mass diffusion coefficients for the desorption and sorption data varied directly with temperature and indirectly with relative humidity. The exponential k-value also varied directly with temperature and indirectly with relative humidity. However, the mass diffusion coefficient was larger in the midrib than in the lamina, whereas the reverse was true for the k-value.

SUMMARY AND CONCLUSIONS

Mathematical models for the diffusion of moisture in the lamina and midrib of the cured burley tobacco leaf were developed. The lamina and midrib were geometrically represented by the infinite thin sheet and the finite circular cylinder, respectively. The models were based on the vapor diffusion equation and expressed the average lamina and midrib moisture content as a function of time in the form of an exponential series.

We developed experimental techniques to determine sorption and desorption of the lamina and midrib without separating the leaf components. We fitted the lamina and midrib models (equations [2] and [3]) to the sorption and desorption data. We also fitted the exponential model (equation [4]) to the experimental data and used it as a standard of comparison.

The results showed that the lamina and midrib models were substantially more accurate than was the exponential model in describing the experimental sorption curves while the exponential model was slightly more accurate than lamina and midrib models in describing the experimental desorption curves. The conclusions formulated during the study were as follows:

1 The lamina and midrib models (equation [2] and [3]) describe the nature of the moisture transfer process better than does the exponential model (equation [4]) in that they include both moisture conductivity and physical dimensions of the leaf, whereas the exponential equation shows only the combined effect of the two.

2 Both the lamina and the midrib dry much faster than they sorb moisture.

3 The diffusion coefficients of the midrib are greater than are the corresponding diffusion coefficients of the lamina.

4 The mass diffusion coefficients of both lamina and midrib vary directly with temperature and indirectly with relative humidity.

References

1 Artho, A. J. 1955. Physical properties of cured tobacco leaves. Vierteljahrsschrift 100:87-113.

2 Crank, J. 1964. The mathematics of diffusion. London: Oxford University Press.

3 Hall, C. W. 1957. Drying farm crops. Agricultural Consulting Associates, Inc. Reynoldsburg, OH. 2nd Ed.

1966 4 Henderson, S. M. and R. L. Perry. ~~1955.~~ Agricultural process engineering. John Wiley and Sons, Inc., New York.

5 Henry, P.S.H. 1939. Diffusion in absorbing media. Proceedings of the Royal Society. Series A, 171:215-241.

6 Marquardt, D. W. 1966. Least squares estimate of nonlinear parameters. Engineering Department, E. I. DuPont DeNemours and Company, Inc., Wilmington, DE.

7 Stinson, J. B., J. H. Young and T. B. Whitaker. 1974. Evaluation of the vapor diffusivity for cured tobacco. Paper No. 74-3036, presented at the annual meeting of the ASAE, Stillwater, OK.

8 Walton, L. R. 1974. Moisture diffusion in the cured burley tobacco leaf. Unpublished Dissertation, University of Tennessee, Knoxville, TN. 112 p.

9 Walton, L. R. and W. H. Henson, Jr. 1970. Moisture sorption of burley tobacco. TRANSACTIONS of the ASAE 13:466-468.

10 Young, J. H. 1964. Development of a relationship between moisture content and time for burley tobacco in a controlled environment. Unpublished M.S. thesis, University of Kentucky, Lexington, KY.

11 Young, J. H. and G. L. Nelson. 1967. Theory of hysteresis between sorption and desorption isotherms in biological materials. TRANSACTIONS of the ASAE 10:260-263.

12 Young, J. H. and G. L. Nelson. 1967. Research of hysteresis between sorption and desorption isotherms of wheat. TRANSACTIONS of the ASAE 10:756-761.

13 Young, J. H. and T. B. Whitaker. 1971. Evaluation of the diffusion equation for describing thin-layer drying of peanuts in the hull. TRANSACTIONS of the ASAE 14(2):309-312.

Physical Properties of Green Virginia-Type Tobacco Leaves

Part V. Critical Radius of Curvature[1]

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Most materials when stressed undergo an elastic deformation. If the stress is increased sufficiently, the limit of elastic deformation will be reached and the material will fail either by fracture, plastic flow or a combination of the two. Tobacco leaf midribs usually fail by fracture although some flow of a semi-plastic nature has been observed. In normal hand or machine handling of tobacco leaves, midribs are more often stressed past their elastic limits because of bending than because of pure tension or compression. Because of this, radius of curvature at the time of failure was measured and will be reported in this paper rather than the related per cent elongation allowable before failure.

The maximum radius of curvature at which a midrib or stalk will break or fracture is defined as its critical radius of curvature. Machines for handling or priming tobacco leaves or which otherwise come in contact with tobacco leaves must be designed with critical curvature values in mind. For example, it is anticipated that leaves with small critical radii will allow more flexible machine design since it will be easier to move them around corners and place into bulk storage with less breakage to midribs.

It was the objective of the work reported here to determine the critical radius of curvature of tobacco leaf midribs and to interpret the results in a form which will have engineering and scientific utility.

Methods and Materials

Critical radius of curvature values were obtained by bending the leaf around the outside surface of a right circular cone and gradually sliding it toward the cone apex, **Figure 1.** In this manner the radius around which the specimen was bent was caused to decrease. The critical radius was taken as the cone radius at the point where fracture occurred. The cone was constructed of galvanized sheet metal and had a maximum radius of nine inches with a slant height of thirty-six inches. Thus it was possible to take one-fourth of a slant distance from any point to the apex

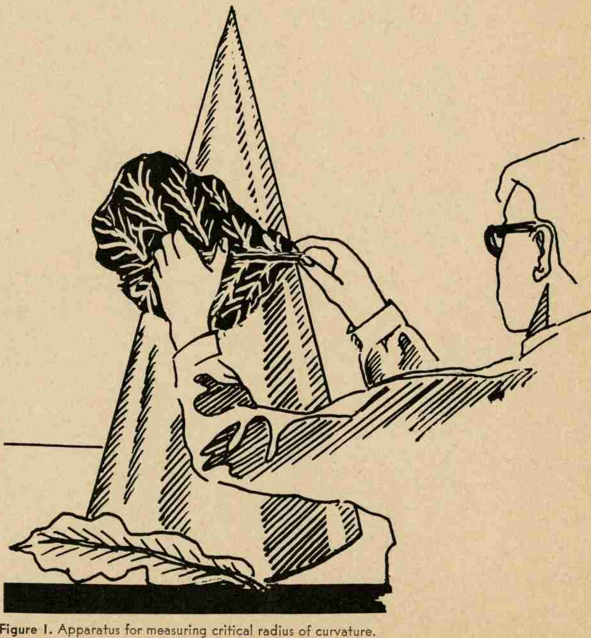

Figure 1. Apparatus for measuring critical radius of curvature.

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[1] *Approved by the Director of Research of the North Carolina Agricultural Experiment Station as Paper No. 1406 of the Journal Series.*

Table 1. Effects of variety, leaf level and orientation on the critical radius of curvature of tobacco leaves. Values in inches. 1960 data.

Variety and Leaf Level	Measured Values Orientation Face Up	Face Down	Mean	Values adjusted for midrib thickness* Orientation Face Up	Face Down	Mean
N. C. 75						
Bottom . . . (B)	1.44	0.89	1.17	1.05	0.48	0.77
Middle . . . (M)	1.14	0.87	1.02	1.04	0.86	0.95
Top . . . . . . (T)	0.22	0.28	0.25	1.04	1.03	1.03
Mean	0.93	0.68	0.81	1.04	0.79	0.92
McNair 121						
Bottom	1.43	1.24	1.34	1.11	0.97	1.04
Middle	1.24	1.05	1.14	0.95	0.73	0.84
Top	0.51	0.48	0.50	1.07	1.09	1.08
Mean	1.06	0.92	0.99	1.04	0.93	0.99
Hicks						
Bottom	1.02	0.97	0.99	0.65	0.71	0.68
Middle	0.78	0.93	0.86	0.42	0.60	0.51
Top	0.30	0.34	0.32	0.84	0.97	0.90
Mean	0.70	0.75	0.72	0.63	0.76	0.70
187 Hicks						
Bottom	1.11	0.88	1.00	0.81	0.54	0.67
Middle	1.45	1.02	1.23	1.09	0.64	0.87
Top	0.39	0.34	0.36	0.85	0.80	0.82
Mean	0.98	0.74	0.86	0.92	0.66	0.79
Overall Means						
Bottom	1.25	1.00	1.13	0.90	0.68	0.79
Middle	1.15	0.97	1.06	0.88	0.71	0.79
Top	0.36	0.36	0.36	0.95	0.97	0.96
Grand Means	0.92	0.78	0.85	0.91	0.78	0.85
C. V.		48%			41%	

LSD'S

	Measured .05	.01	Adjusted .05	.01
Orientation . . (O)	0.10	0.14	0.09	0.12
Variety . . . . . (V)	0.14	0.19	0.13	0.17
Level . . . . (L)	0.12	0.16	0.11	0.14
V x O	N.S.	N.S.	0.19	0.24
L x O	N.S.	N.S.	N.S.	N.S.
V x L	N.S.	N.S.	N.S.	N.S.

**Corrected by equation: Adjusted critical radius of curvature $\tilde{y}_i = y_i - 6.3172\ (X_i - \overline{X})$ where X is the thickness of the midrib.*

as the radius at the given point. The leaf was held in contact with the cone through approximately 180° of arc. Midribs which made zone contact, because they were evaluated with the flat upper side of the midrib against the cone, rather than line contact with the cone, were evaluated to the center line of the contact zone. In some of the experiments midrib width and thickness at the point of fracture were recorded so that covariant analyses could be run.

Samples were taken from the field and evaluated before they had a chance to lose appreciable turgor. Evaluations were made under approximately similar conditions of soil moisture and normal summer ambient environment. Uniform representative samples were selected at random from the appropriate field areas. Moisture content of the midrib was not measured. In fact, the difference in morning and afternoon midrib turgor may account for some of the experimental variability observed. This variability does not affect the validity of the results because it must be remembered that machine design data should reflect the range of conditions over which the machine is to operate. Except for the maturity study, leaves were evaluated at optimum ripeness.

All of the leaves used in this study, except for a few observed on a private farm near Lumberton, N. C., were grown on the Central Crops Research Station, Clayton, N. C. They were from the 1960 and 1961 crops and were grown in accordance with normal cultural practices except for the experimental variables imposed for the evaluations of fertility level effects. The experiments were replicated ten times in 1960 and six times in 1961 by measuring the required number of leaves from each field treatment. Over 800 leaves were tested.

The response was measured over the following variables:

Variety: 1960—N. C. 75, McNair 121, Hicks Broadleaf and Coker 187 Hicks.
1961—Coker 316, Coker 139, N. C. 75 and McNair 121.
Leaf level: 1960 and 1961—bottom, middle and top across the 1960 and 1961 varieties, respectively.
Ripeness: 1960—green (about one week under mature), ripe and over-ripe (about one week over mature) N. C. 75 only.
1961—green, ripe and over-ripe across the 1961 varieties.
Fertilizer rate: 1960—500, 1000, 1500 lb 5-10-15 per acre, N. C. 75 only.

Leaves were evaluated in two orientations; "face up" in which the top side of the leaf was away from the cone and "face down" in which top side of the leaf was placed against the cone. Thus in the face up orientation the leaf was bent in the direction of its normal curvature. Since the test was destructive, replicate leaves as nearly identical as possible, were used for the two measures.

Results and Discussion

Critical radius of curvature was found to vary with both variety and leaf level, **Tables 1 and 2.** Measurements were made during two consecutive years and two of the varieties (N. C. 75 and McNair 121) were common to both years' data. The largest variety value measured during 1960 (.99 inches) was for McNair 121 and the smallest value (.72 inches) was for Hicks Broadleaf. Varietal observations made in 1961 indicated that values for

Table 2. Effect of variety, leaf level, ripeness and direction of bending (orientation) on critical radius of curvature of tobacco leaves. Values in inches, 1961 data.

Variety and Leaf Level	Orientation								
	Face Up				Face Down				Overall Means
	Green	Ripe	Over-Ripe	Mean	Green	Ripe	Over-Ripe	Mean	
Coker 316									
Bottom	2.15	1.95	1.68	1.93	1.27	1.54	1.46	1.42	1.67
Middle	1.89	1.80	1.72	1.80	1.30	1.24	1.48	1.34	1.57
Top	.73	1.18	.75	0.89	.58	.99	.72	0.76	.83
Mean	1.59	1.65	1.39	1.54	1.05	1.25	1.22	1.17	1.36
Coker 139									
Bottom	1.54	1.26	1.47	1.42	1.56	1.17	1.03	1.25	1.34
Middle	.96	1.54	1.00	1.17	.69	1.51	1.24	1.15	1.16
Top	.64	.27	1.18	.70	.41	.36	1.09	0.62	.66
Mean	1.05	1.02	1.22	1.10	.89	1.01	1.12	1.01	1.05
N. C. 75									
Bottom	1.50	1.01	1.37	1.27	1.49	1.09	.96	1.18	1.24
Middle	1.67	.86	.86	1.13	.81	.78	.72	0.77	.95
Top	.00	1.16	1.18	0.78	.58	1.22	1.51	1.10	.95
Mean	1.06	1.01	1.16	1.07	.96	1.03	1.06	1.02	1.05
McNair 121									
Bottom	1.00	1.44	1.12	1.19	.95	.95	1.33	1.08	1.12
Middle	1.17	.74	1.06	0.99	.64	1.12	.86	0.87	.93
Top	.46	1.10	.56	0.71	.33	1.07	.92	0.77	.74
Mean	.88	1.10	.91	0.96	.64	1.04	1.04	0.91	.93
Overall means									
Bottom	1.55	1.42	1.41	1.46	1.32	1.19	1.20	1.23	1.34
Middle	1.42	1.24	1.16	1.27	0.86	1.16	1.08	1.03	1.15
Top	0.46	0.93	0.92	0.77	0.48	0.91	1.06	0.81	0.80
Grand Means	1.14	1.19	1.17	1.17	.88	1.08	1.11	1.03	1.10

	LSD's	
	.05	.01
Variety (V)	.11	.14
Ripeness (R)	.10	N.S.
Level (L)	.10	.12
Orientation (O)	.08	.10
V x R	N.S.	N.S.
V x L	.19	.25
V x O	.15	N.S.
R x L	.11	.22
R x O	N.S.	N.S.
L x O	N.S.	N.S.

Coker 316 were larger than for Coker 139 or N. C. 75, all three of which were larger than for McNair 121, **Table 2.** This is in contrast to the previous year's data in which values for McNair 121 were larger than for N. C. 75, the only other variety common to both year's observations. No explanation other than yearly variations is given for this difference.

There was a slight decrease in midrib critical radius of curvature from the bottom of the stalk to the middle of the stalk and a marked decrease from the middle to the top. This change was present in both year's data although it appeared to be more consistent in 1960. In order to determine if the differences observed were caused by a variation in midrib thickness X and, if so, to what extent, a covariant analysis of midrib thickness and critical radius of curvature was run on the 1960 data. Measured values were adjusted by means of the equation

$$\tilde{y}_i = y_i - 6.3172\ (X_i - \bar{X}). \qquad (1)$$

This equation was derived from the measured values of **Table 1** and was used to adjust the critical radius of curvature values to what they should have been had all midribs had a thickness equal to the observed mean, **Table 1,** columns 4, 5 and 6. The resulting values might be thought of as an index of the brittleness of the midrib. There are some varietal differences with Hicks Broadleaf having the lowest brittleness index, .70, a value which is significantly lower than the index for other varieties. Observed values for top leaves (last two primings) were low but their midribs were also small. Values adjusted to the mean midribs thickness were larger for the top leaves, however, than for middle or lower leaves, indicating that upper leaves are actually more brittle than lower ones.

The presence of a variety by level interaction in the experiment the second year was due largely to the failure of the critical radius for the top leaves of N. C. 75 to be smaller than for the middle leaves.

Leaf maturity (ripeness) caused a rather sharp decrease in allowable radius measured in the face down orientation, as leaf maturity changed from green to ripe to over-ripe, **Table 3.** Leaf orientation, i.e., face up in which the lower side of the leaf is placed against the cone and on the inside of the curve, and face down in which the upper side of the leaf is placed on the inside of the curve, did not have a significant effect on the results in **Table 3** although the value in the face up orientation tended to be larger. There was also a ripeness by position interaction which was due to the failure of a green leaf to respond in the face up orientation in the same manner as did the ripe and over-ripe leaves.

It was felt that this interaction, since it differentiated ripe leaves from green and over-ripe ones, might form the basis of a method for separating ripe leaves from green and over-ripe. In the face up orientation the differences were not only statistically significant but also large absolutely, 1.34 for ripe leaves versus .85 for green leaves and .71 for over-ripe leaves. In order to further investigate this response additional observations were made in 1961 over varieties, leaf level, and ripeness. In this experiment the ripeness by orientation interaction was not significant although there was a slight tendency for ripe leaves to have a larger critical radius of curvature in the face up direction than green or over-ripe leaves, **Table 2.** Ripeness differences were significant with the critical radius in the face down direction increasing for the riper leaves, that is, in the opposite direction from the previous year. In view of the two years data it must be concluded that ripeness effects are not consistent from year to year and that the ripeness by orientation interaction is not stable.

In most of the observations alternate leaves were tested in face up and face down orientations. Although there were isolated cases of reversal the response in the face down direction was smaller than in the face up direction, **Tables 1, 2 and 3.** It was not expected that the leaf midrib would have a smaller critical radius when bent in a direction opposite to its normal curvature. This may be partially explained by observations which indicated, that in the area where failure occurred, the midrib was essentially straight. In some leaves it was even observed to have a slight amount of reverse curvature.

Table 3. Effects of leaf maturity on critical radius of curvature. Values in inches, Variety N. C. 75, 1960 data.

Ripeness	Leaf Orientation Face Up	 Face Down	Mean
Green	.85	1.22	1.03
Ripe	1.34	1.03	1.18
Over-ripe	.71	.59	.65
Mean	.97	.94	.95
C. V.		45%	
LSD's	.05	.01	
Ripeness (R)	.18	.37	
Orientation (O)	N.S.	N.S.	
R x O	.39	N.S.	

Table 4. Effects of fertilizer level on critical radius of curvature, midrib width and thickness of tobacco leaves. Variety N. C. 75, 1960 data.

Fertilizer applied lbs. 5-10-15/A.	Critical radius, inches	Area, sq. in.	Midrib width inches	Midrib thickness inches	Critical radius adjusted to mean midrib width & thickness.
1500	1.51	227.8	.541	.440	1.32
1000	1.03	158.9	.439	.344	1.12
500	1.06	148.4	.441	.343	1.15
Mean		1.20cm	.474	.376	.956cm
C.V.	38%		16%	13%	
LSD's: .05	.42		.068	.044	N.S.
.01	N.S.		.091	.060	N.S.

Adjusted value of $y_i = \tilde{y}_i = y_i - .64667\ (X_{1i} - \bar{X}_1) - 2.2414\ (X_{2i} - \bar{X}_2)$ *where* y *= critical radius of curvature*

X_1 = *width*

X_2 = *thickness*

r_2 *between* X_1 & X_2 = *0.92*

Table 5. Observed and adjusted critical radius of curvature values for very large leaves. Values in inches and square inches, 1960 data.

Variety and sample number	Observed critical radius of curvature	Leaf length	Leaf width	Leaf area*	Midrib thickness**	Adjusted critical radius of curvature***
N.C.75	R	L	W	A	T	R
1	1.75	24.0	16.0	213.2	.419	1.48
2	2.12	27.0	16.0	274.1	.495	1.37
3	2.44	31.2	18.0	256.9	.597	1.04
4	2.25	27.5	15.0	261.7	.479	1.60
5	2.25	27.5	16.5	287.9	.512	1.39
Mean	2.16					1.38
Hicks						
1	4.00	34.0	18.5	399.1	.650	2.27
2	4.25	31.0	17.0	334.4	.569	3.03
3	2.25	27.0	12.5	214.1	.420	1.97
4	2.38	29.0	16.5	303.6	.531	1.40
5	5.50	33.5	18.5	393.2	.642	3.82
6	2.62	31.0	18.5	363.9	.606	1.17
7	2.38	31.5	16.5	329.8	.564	1.19
8	3.25	32.0	17.5	355.3	.594	1.87
9	3.12	32.0	18.5	375.6	.620	1.58
10	2.75	31.0	17.0	344.4	.569	1.53
Mean	3.25					1.98
Grand mean	2.89					1.78

**Calculated by means of equation* $A = .6345LW$ *(Suggs & Splinter, 1960).*

***Calculated by means of equation* $T = .00124\,A + .1547$, $r^2 = .847$.

****Calculated by means of equation* $\tilde{R}_i = R_i - 6.3172\,(T_i - \overline{T})$.

Values are adjusted to a mean thickness, $\overline{T} = .376$.

Fertility level of the soil, as produced by application of 500, 1000 and 1500 lbs. of 5-10-15 per acre, had a significant effect on the critical radius of curvature of tobacco leaf midrib, **Table 4,** column 2. The observed values increased from 1.06 inches and 1.03 at the two lowest fertility levels to 1.51 inches at the highest. In order to determine if the observed differences were due to the differences in the size of the midribs, the data were adjusted to a mean width and thickness by the equation:

$$\tilde{y}_i = y_i - .64667(X_{1i} - \overline{X}_1) - 2.2414(X_{2i} - \overline{X}_2). \qquad (2)$$

where y = critical radius of curvature in inches,
X_1 = midrib width in inches and
X_2 = midrib thickness in inches.

This equation was derived from midrib size measurements taken simultaneously with the curvature values. Adjusted values, last column **Table 4,** indicate that high fertility levels tend to be associated with larger curvature values independently of midrib size, although the differences are not significant at the 5% level.

Equation (2) for adjusting critical radius of curvature values to a constant midrib size indicates that midrib thickness, X_2 with a coefficient of 2.2414, has a greater effect on allowable curvature than does midrib width X_1 with a coefficient of only .64667. From an engineering point of view the tobacco leaf is supported by its midrib acting as a cantilever beam. In fact, it would be expected that the curvature of such a beam at the yield point would be independent of the beam width. The presence of a midrib width coefficient would indicate that midrib width is correlated with thickness or with some other material property such as brittleness which in turn affects the radius of curvature at fracture.

Limited observations were made in two fields of extremely large and heavily fertilized Hicks and N. C. 75 tobacco plants on a farm near Lumberton, N. C. These critical curvature values were considerably larger, 2.89 inches average, than those measured at the Central Crops Research Station near Clayton, N. C., **Table 5.** Unfortunately, midrib thickness measurements were not made of the leaves for which curvature values were determined, however, leaf length and width measurements were made. From this information it was possible to calculate midrib thickness by a two-step process. The first step was to determine leaf area from the equation of Suggs *et al.* (1960),

$$A = .6345LW, \qquad (3)$$

Where L is leaf length and W is leaf width. The second step was to calculate midrib thickness by means of an equation derived from the data summarized in **Table 4.** This equation,

$$T = .00124A + .1547, \qquad (4)$$

with an r^2 of .847 indicates a strong correlation between leaf area and midrib thickness at the butt end. Observed curvature values were adjusted to the same mean thickness as **Table 4** equation (1). The adjusted values for the very highly fertilized large leaves of N. C. 75 were little, if any, larger than for the highly fertilized N. C. 75 leaves of **Table 4,** 1.38 and 1.32 inches, respectively. The adjusted values for the very highly fertilized Hicks leaves were larger than the comparable N. C. 75 leaves.

Although covariant analyses were used in **Tables 1, 4 and 5** to account for critical curvature variations by adjusting to a common midrib thickness, it should be remembered that explaining the variation does not reduce it. Harvesting and leaf handling equipment will be expected to operate over the entire unadjusted range of critical curvature values.

The range of values over which responses were observed as well as the distribution are given in **Figures 2 and 3.** The distribution curves tend to be high in the middle and low on each end but are skewed away from zero because negative values could not occur. Some of the variety curves have more than one peak but it is felt that a larger volume of data would tend to round these curves out.

Some type of edge or end effect was suspected because the midribs

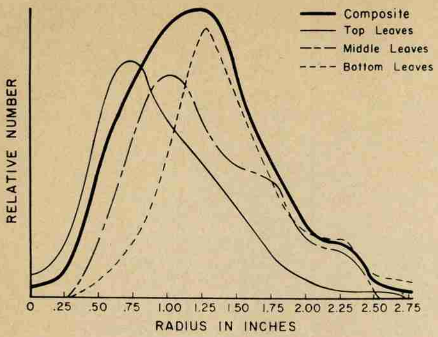

Figure 2. Distribution of critical radius of curvature values over leaf levels.

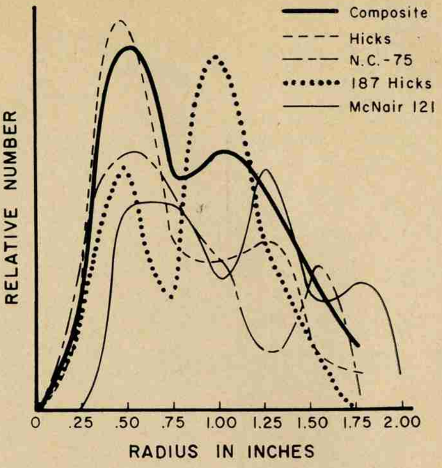

Figure 3. Distribution of critical radius of curvature values over varieties.

did not fracture as near to the large end as was anticipated. Most tests left a stub about two and one half inches in length. The cause of this type of failure was not determined but three possibilities are suggested: (1) Midrib thickness decreased near the butt end, (2) Material at site of fracture permits less extension than elsewhere (3) Lateral slippage of the fibers occurs.

Errors from all sources combined to give coefficients of variation from 38 to 48%. Undoubtedly some of this was due to inaccuracies in making the measurements. Measurements along the cone surface were made to one-eighth of an inch. When converted to radius values this would be equivalent to one-thirty-second of an inch. It is felt that most of the variation was due to differences between replicate samples. Little can be done outside of careful management of the cultural operations and rigorous selection of samples to reduce this variation of biological material. However, by more accurately describing the material in terms of moisture content, size, etc. it may be possible to reduce the variation by statistical techniques.

Theoretical Aspects

When a beam is placed under a bending stress the fibers on the outside of the curve are placed in tension and those on the inside in compression. Somewhere between the outer and inner surface there is a plane in which the fibers are in neither tension nor compression. This is called the neutral plane. For rectangular or circular beams of homogeneous materials, it is located at the center line of the beam provided the material has the same properties in tension as in compression. Because the neutral plane is in neither tension nor compression, distances measured along it are invariant with bending stresses.

Consider a beam, initially straight, of thickness T elastically stressed by bending around a radius r_o, **Figure 4**. Strain Y, defined in terms of the original length S_o and the length after deformation S is

$$\frac{S - S_o}{S_o} = Y. \qquad (5)$$

Because the angle θ, **Figure 4**, is common to all factors and S is equal to $r\theta$ this may be written from **Figure** 4 in terms of the radius r to a given fiber as

$$Y = \frac{r - (r_o + kT)}{r_o + kT} \qquad (6)$$

where kT is the distance from the inside surface of the curved beam to the neutral plane. Because r_o is the radius of curvature of the compres-

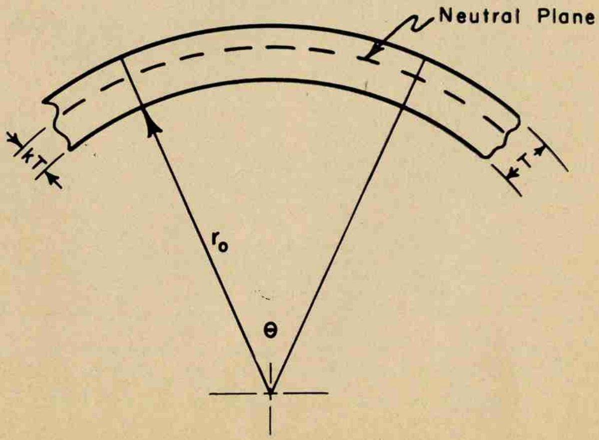

Figure 4. Symbols and diagram used in locating neutral plane.

sion side of the beam, the quantity $r_0 + kT$ locates the neutral plane with respect to the center of curvature.

Although equation (6) is valid for computing the strain at any location across the beam, the most interesting and important case is the one in which failure occurs. In bending, the fibers on the inside and outside of the curve will be subjected to the greatest strains (compression and tension, respectively) and if the beam is homogeneous these fibers, either the ones in tension or the ones in compression will fail first. Furthermore, if the beam material acts the same in tension as in compression and has symmetry about its neutral plane the fibers in tension on one surface of the beam will fail at the same time as the fibers in compression on the other side of the beam. All of these conditions are seldom met completely in even precisely engineered systems. Biological systems probably deviate widely from the simplest mathematical case.

For tobacco leaf midribs it cannot be assumed that the neutral plane lies at the centerline because these structures may not be homogeneous and may have different tension and compression characteristics. In addition, midribs do not have a plane of symmetry about which the bending in these tests could have occurred. However, equation (6) is general and may be used to investigate the bending characteristics of tobacco midribs.

In the observations of this study the outermost fibers on the tension side were the first to fail. The distance from the center of curvature to these fibers is the critical radius of curvature r_0 plus the thickness T of the midrib. Observations of the authors indicate that midrib material fails in tension at strains Y of about .046 inches per inch. Substituting this value of Y, a mean critical radius of .847 inches for r_0 and a midrib thickness of .3227 inches for T from **Table 3** into equation (6) and solving for k, the location of the neutral plane, gives

$$k = \frac{r - r_0 - Yr_0}{YT + T} = .84. \qquad (7)$$

Values for individual midribs varied from .65 for the smallest r_0 value in the 1960 variety observations to .93 for the largest one. The fact that k is so nearly unity indicates that either the midrib material has a larger modulus of elasticity in tension than in compression or that the midrib is structurally inhomogeneous. A number of observations are available in which midribs were bent in opposite directions, **Table 1.** The fact that the means were so nearly identical gave k values in the face up and face down positions of .83 and .85, respectively. This suggests that the midrib is structurally homogeneous and that noncentral location of the neutral plane is due to the difference in modulus of elasticity in tension and compression.

Anatomically the midrib is not homogeneous, there being a line of xylem fibers arranged in a shallow arc with upward concavity located at approximately the center of the midrib. Avery (1933) described the cellular structure and development of this material in the midrib but did not discuss its role in the mechanical support of the leaf. The orientation of this arc of fibers, since they appear to be stronger than the rest of the midrib, might suggest that the leaf would have a smaller critical radius of curvature when bent upward. That the results do not support this may be due to the opposite normal curvature of the leaf.

Summary and Conclusions

Mature, uncured tobacco leaf midribs were placed in mechanical stress by bending around the outside surface of a right circular cone. Samples were moved toward the cone apex until fracture occurred. The critical radius of curvature of the sample was taken as the radius of the cone at the point of sample failure. The measurements were made over six varieties, (N. C. 75, McNair 121, Hicks, Coker 316, 187 Hicks and Coker 139) three levels of leaf ripeness, three fertility levels, three leaf levels and two testing orientations (face up and face down).

The mean critical radius of curvature for midribs was 0.974 inches with a standard error of .41 inches (6 variety mean). It varied somewhat depending on the conditions of the test and each of the experimental variables imposed on the selection of the sample. It was larger for highly fertilized plots, larger for the bottom leaves and larger for Coker 316 than for the other five varieties. It was also larger for the face up position and tended to be larger for ripe leaves than for green or over-ripe leaves but only when tested in the face up position. Although the differences observed were statistically significant, the range was relatively narrow for biological material with most of the values, except for very large and very small leaves, falling between 0.7 and 1.3 inches. There was a significant positive correlation between midrib thickness and critical radius of curvature. By using this correlation to adjust the responses to a common midrib thickness many of the differences either disappeared or were appreciably decreased.

A beam analysis using values of strain at failure indicated that midribs act as homogeneous beams. The midrib material appears to have a higher modulus of elasticity in tension than in compression. The location of the neutral plane was determined and found to lie approximately 84% of the thickness of the midrib toward the tension side of the beam.

Critical radius of curvature of tobacco midribs is affected by variety, soil fertility of the source plot, stalk level from which the leaf was removed, leaf ripeness, midrib thickness and the orientation of the leaf on the testing device. The values are distributed in a skewed manner with values approaching zero on the left, five and one-half inches on the right and with a mean of approximately one inch. Fewer than one per cent of the values measured were greater than three inches. For the conditions encountered in these tests it would appear that a critical radius of curvature value of three inches would be reasonable for machinery design purposes.

Because the imposed variables covered many of the conditions anticipated in machinery operation, the associated responses appear sufficient to characterize allowable leaf curvature for machinery design purposes. Leaf handling systems designed to move leaves around small radii, e.g. with belts and rollers, must be designed to accommodate an acceptably high percentage of the leaf variability anticipated in its operation.

Literature Cited

Avery, G. S., "Structure and development of the tobacco leaf." *Am. J. Botany* 20:565-592 (1933).

Suggs, C. W., J. F. Beeman and W. E. Splinter. "Physical properties of green Virginia-type tobacco leaves. Part III. Relations of leaf length and width to leaf area." *Tobacco Science* 4:194-197 (1960).

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	Fuel cuft/lb	Cured out yield,	Price $/lb.	% Sugar	% T.A.	Curing time hours.
1972 Stick ~~and~~ cured - hand primed						
Check				8.2	3.1	
Bruised				~~4.9~~	~~2.9~~	Chemistry OK
Crushed Midrib				7.4	2.8	
Cut Midrib				~~7.9~~	~~2.8~~	
LSD (05)				~~.86~~	~~.32~~	
Check		17.2	0.81	12.1	3.81	Chemistry, yield
crushed when Primed		18.0	0.74	11.4	3.61	Price OK.
crushed ½ yellowed		~~16.2~~	~~0.80~~	~~11.9~~	~~4.11~~	
crushed Full yellowed		~~18.0~~	~~0.78~~	~~13.1~~	~~3.36~~	
LSD .05		~~.86~~	NS.	NS	NS	
1973 - stick cured						
check		17.5	0.87	16.7	1.8	O.K.
crushed.		17.2	0.88	18.2	2.1	
1973 Bulk cured (Racks)						
Check		18.4	0.866	15.8	2.14	OK - T.A
crushed		18.9	0.855	16.4	1.77	maybe low.
1974 Bulk cured (Racks)						
check small barns	(497 cuft) ~~12.06~~ 11.85	15.7	~~[illegible]~~	18.6	2.33	OK.
crushed	(~~385~~ cuft) ~~8.52~~ 8.23	16.8		16.1	2.31	fuel very good.
1974 Bulk cured (Boxes)						time 1 to 2 days
check	—		0.92 (1.01)	17.0	3.04	less for crushed just OK
crushed	—		0.87 (.945)	16.6.	2.68	
1975 ~~Small Racks~~ Boxes ~~in~~ large barn ~~+ Small barns~~.						
Check	—		1.048	19.4	3.37	just OK
crushed	—		.991	18.0	2.89	
Check) ~~boxes~~ Racks						
Crushed) ~~Racks~~ in small barns	27% < 6.06 4.40	17.4 18.1	1.005 1.048			1395 lbs price very 1311 lbs good.
Check Farm scale - ~~2 + 3~~ rd Mid + last Priming			1.015			OK
crushed watkins -			0.945			

		Fuel cuft/lb.	cured wt yield %	Price ¢/lb.	% Sugar	% T.A.	Curing time Hrs.	stated (1 to 2) days Ethrel
1976.								
Bottom	check	~~13.2~~ 8.91	13.2	.96	7.4	1.42	140	
	crushed	~~11.7~~ 8.74	11.7	~~.72~~ .89	6.8	1.63	139.6	no fuel advantage
Mid	check	5.06	17	1.19	6.2	2.90	~~145~~ ~~146~~	no time advantage
	crushed	~~5.81~~ 4.5	17.6	1.19	5.2	3.15	~~150~~ 132	
Top	check	5.00	19.5	1.13	5.66	3.70	130.3	
	crushed	~~5.32~~ 4.99	18.~~47~~ 57	1.13	7.68	3.78	109.7	
								139.4 135.1
1977								
	Check	6.12 ~~5.84~~	16.3	1.12	10.0	3.84	150.3	some
	Crushed	5.32	16.3	1.14	8.9	4.23	140.2	crush
	Crushed + Ethrel	4.60	~~5.8~~ 18.5	1.18	8.4	4.0	124.1	adv.
	Ethrel	5.14	16.7	1.22			132	
1978	Check	4.74	22.1	1.28	14.9	2.99	162.5	no
	crushed	~~5.26~~ 4.29	19.08	1.26	14.6	2.68	~~168.6~~ 153.75	crush adv.
1979								
	Check	5.04	19.1	1.38	14.6	3.02	170.2	crush
	Crushed	4.43	18.5	1.42	13.6	2.62	161.3	adv.
	Crushed + Ethrel	4.72	19.5	—			137.4	
		n=8	n=11	n=13	n=13	n=13	n=7	
Σx̄	ck	52.78	193.4	1359.4	166.55	37.46	1040.7	
Mean	ck	6.5975	17.58	104.57	12.81	2.88	148.67	
Σx̄	cr	44.9	190.7	1335.9	160.88	36.25	967.55	
Mean	cr	5.6125	17.336	102.75	12.38	2.79	138.22	

~~2~~ Used Rewrote

1973 Tests. Crushed and uncrushed samples from 5 primings of N.C. 2326 were strung on sticks and conventionally cured and 5 primings were bulk cured. Samples were weighed before crushing and again after curing so that cured weight yields could be determined.

For bulk curing, four 57 Kg ~~125 lb~~ racks of tobacco were used at each priming, two crushed and two uncrushed. These were placed, one crushed and one uncrushed rack, in each of two small plot size bulk curing barns. Four sticks, two crushed and two uncrushed, of each priming were used in the conventional curing tests. These were cured in a small plot size barn.

1974 Tests. Additional midrib crushing equipment was constructed and mounted directly on a mechanical tobacco harvester for the 1974 season. Five primings of N.C. 2326 were bulk cured. Each priming consisted of two 57Kg ~~125~~ lb racks of crushed and two 57Kg of uncrushed material. The uncrushed material was also mechanically harvested as it was possible to open the crushing rollers to permit the leaves to pass without crushing the midribs.

small plot barns

no appreciable differences in percent cured weight yield but price of the crushed material was slightly lower because of a tendency for crushed samples to dry before yellowing was complete. Since setting the color green was not a problem in the stick barn it is felt that improvement in the bulk curing humidity control during yellowing might rectify this problem.

Because of the moisture crushed out of the midrib and deposited on the leaf we were concerned that soft rot might become a problem during the low temperature stages of the cure especially in the bulk barn. To reduce this possibility, a lower than usual humidity was maintained during yellowing. This may have contributed to the green coloring of the bulk cured crushed samples. Soft rot problems were encountered, however, in later work. Midrib dry as soon as lamina

Midrib crushing did not have a marked effect on sugar or alkaloid content of the cured leaf. Sugar content for the crushed material, stick and bulk cured, averaged 17.3% compared to 16.2% for the uncrushed. Total alkaloid content for the crushed averaged 1.96% compared to 1.98% for the uncrushed.

There was a savings in curing time of 1 to 2 days. In most cases the midrib was dry as soon as the lamina. This appreciable reduction in curing time can significantly increase the amount of tobacco which can be cured in one barn during the harvest season. This means that the capital investment per acre can be reduced.

There will also be an energy (fuel) savings due to the reduction in heat loss associated with the decreased time the barn is held at high temperatures. Energy requirements to actually evaporate moisture would not be changed as no appreciable amount of stem moisture is lost during crushing.

In 1974 the work was expanded to include curing in large containers holding 700-1200 lb of tobacco, Table 2. This work gave similar results showing only minor differences between the crushed and uncrushed midrib material. Table 2 shows the fuel saving attributable to midrib crushing. The requirements were 497 cuft for the uncrushed as compared to 385 cuft for the crushed midribs or a savings of 22.5%. This savings was measured in a small plot sized barn. In a larger barn the fuel savings could be different. Curing time was reduced by from 1 to 2 days, all of it in the midrib drying phase.

First primings, harvested when wet and crushed were severely affected by soft rot and had to be discarded. Second and third primings subjected to midrib crushing were successfully cured and sold on the warehouse floor for 94.5 cents per pound versus 101 cents per pound for the machine harvested check. Some overloading of the crushed material in the racks may have occurred as these leaves are very limp and tend to pack excessively. Such overpacking could account for the difference in sale price between the crushed and normal samples.

1974

Results

Small Racks. The crushed material appeared to be a little lower in sugar content than the uncrushed material, 16.1% versus 18.6%, Table 2.1. However, total alkaloids were almost identical, 2.31% versus 2.33%. Cured weight yields were appreciably higher for the crushed samples at the lower primings but equalized for the upper primings. Overall,the crushed material yielded 16.8% compared to 15.7% for the uncrushed material. Fuel savings were appreciable. The uncrushed material required 497 cu ft of gas per cure while the crushed material required only 358 cu ft per cure for a fuel saving of about 28%. Each cure contained 250 lb of tobacco at the beginning of the curing cycle. Two plot size curing barns were used and the crushed and uncrushed material was alternated between the barns so that the 1st, 3rd and 5th cures of crushed leaves were placed in one barn and the 2nd and 4th in the other. Curing time was reduced by 1 to 2 days.

Large Racks. The crushed material cured in the large racks appeared to be a little lower in sugar content than similarly cured uncrushed tobacco,

~~in sugar or alkaloid due to the pre-curing crushing treatment.~~

~~Because these results suggested that midrib crushing offered some significant potential for reducing curing time and fuel consumption the work was continued.~~

Procedure

Midribs of intact leaves were crushed by passing them over a conveyor belt and between a pair of steel rollers spaced about 1/8" apart. The clearance was selected to crush the large end of the midrib to a point about half way down the leaf. The midrib in the tip end of the leaf is small and usually presents no drying problem. During crushing sap is forced out of the midrib.

Crushed and uncrushed samples from 5 primings of N.C. 2326 were bulk cured. Samples were weighed green before crushing and after curing so that cured weight yields could be determined. Four 125 lb racks of tobacco were used at each priming, two crushed and two uncrushed. These were placed, two crushed or two uncrushed racks, in each of two small plot size bulk curing barns.

In 1975 ... little diff in sugar & T.A
between the ethrel plus crush & crush only, Table
However the check was higher in both Sugar & T.A. Cured wt. yield

Results, All Treatments

1972

Sugar Content

~~The lamina bruising treatment significantly reduced the sugar content of the cured leaf, Tables 3 and 5. There was also the expected priming effect with the upper primings having a higher sugar content. A priming X treatment interaction due to a reduction in the bruising treatment effect at the upper primings was found, Table~~ 3. Although there was a maturity effect with the over-ripe material being low in sugar. Maturity did not interact with the treatment effects.

Alkaloid Content

~~The~~ midrib ~~cutting,~~ crushing ~~and lamina bruising treatments~~ produced a slight reduction in total alkaloids with the cut midrib treatment being significantly lower than the check, Table 4. ~~There was the expected priming effect characterized by an increase in alkaloids at the upper primings, Table 4 and 5~~. There was also a maturity effect with green material being highest in alkaloids, Table 5. However, maturity did not interact with maturity.

Visual Evaluation

~~Bruised material was discolored and generally degraded in appearance.~~ Material with ~~cut or~~ crushed midribs looked as good as the check.

1972

Results, Midrib Crushing Only

Since the midrib crushing treatment did not appear to adversely affect the cured tobacco several additional evaluations were made to determine if it might be feasible on a farm scale. Unfortunately it was not possible to evaluate drying rate or curing time.

Dry Matter Yield

Crushing of the midrib either at time of priming or during the yellowing of the leaf did not affect the amount of dry cured leaf yield per pound of material in the original uncured sample, Table 6.

Price

Price of the cured leaf was not significantly affected by the midrib crushing treatments, Table 6.

Leaf Chemistry

Total sugar and total alkaloid content was not significantly affected by the midrib crushing treatments, Table 6.

Summary and Conclusions

Although the work has been conducted only one year it can be concluded that severe bruising of uncured tobacco leaves adversely affects leaf sugar content and the general appearance of the leaf. Leaves with midribs cut or crushed before curing were not degraded in sugar or alkaloids content or appearance. In an additional experiment leaves with crushed midribs were not significantly different from the check samples with respect to dry matter yield, or market price.

The work suggests that if appreciable reductions in stem drying time can be realized crushing of the midrib in the uncured leaf could be feasible.

was a little lower for the check plots than for either of the treatments.

In 1976 the earlier harvests were immature and considerable barn yellowing was required and the check plot cured greenish, Table 4. Later in the season drought made it difficult to yellow the non-ethrel plots as excess drying occurred during yellowing, a condition aggravated in the small one-box curing barns used.

Yellowing was not uniform with the butt of the leaf often remaining green after the middle part of the leaf turned yellow while the tip often started turning brown. Attempts to yellow the leaf butts in the barn often resulted in increased browning of the leaf tips. Because considerable barn yellowing was required, curing time savings were not as great as previously experienced, however cures were always one to two days shorter than the untreated cures. The time reduction probably would have been greater if yellowing of the untreated plots had not been terminated by excessive drying.

Except for one questionally high sugar analysis there were no marked differences in sugar, alkaloids, starch or cured weight yield between any of the treatment combinations and the check, Table 4. Differences in sugar are expected if in some samples the starches are more completely converted to sugar. This did not happen in this case as the starch values are consistent across treatments. It does not appear that leaf chemistry is significantly modified by either ethrel, midrib crushing or the combination of both.

1977 - Midrib crushing reduced curing time by 7% & fuel by 9%

1979 Crushing reduces curing time 9 hrs - about 5.2%
Crushing reduces fuel by 11% - pull of water by 19%
Crushing reduces drying time by 0% nothing

1978 - See short tabulation - -

Jan 3-1980

1975 Work

cuft ~~lb.~~

Cure	Fuel cuft. Barn 3	Barn 4	wt Barn 3	Barn 4	time Barn 3	Barn 4	
1	945 un Cr. 9.09	990 Cr. 9.52	(104)	104 X4F	8 days	7 days	
2	990 ½ crushed ½ un 9.80	1100 uncrushed 10.89	127 lb in 84.5 P4F (101)	101 P3F P4F	6 days ~~B~~F	7 days	
3	808 uncrush 6.54	835 uncrush 6.76	123.5 C4F X42V	(123.5)	138 6 days	138 6 days	8-8 3 Pm to 8-14 at 9 Pm ~~[illegible] 8/14 to 9 Am 8/20~~
4	762 uncr. 5.52	745 uncr. 5.40	138 B3F B3L	138 B3F	~~6~~ 141	~~6~~ 141	12 Noon 8/14 to 9 Am 8/20
5	720 crushed 5.22	540 crushed 4.00	138 B5L	135 B4BL	~~6~~ 127 hr	~~6~~ 127 hr	4 Pm 8/22 to 11 Pm 8/27
6	600 crushed 4.32	530 crushed 4.08	139 B5BF	130 B4BF	135 141 ~~129~~	135 141 ~~124~~	Bo delayed Turn off time about 6 hours 8-28 12 noon to 9 Am Sept 3

3-6 (1-6)

Crushed (16.49) (6.16) 4.40 (7.37) 27.4% cured wt yield 18.07 (139.3) 131

uncrushed 6.06 17.4 139.5 hrs. (153)

6 racks -

First cure	Crushed	Crushed	uncrushed
	Barn 1	Barn 2	Barn 3
	960 cuft	749	945
	6 days	7 days	8 days = 186 hr
	854.5		945

Further Studies on Pre-Curing Midrib Crushing of Bulk Cured Tobacco

C.W. Suggs 1975

Previous work has clearly demonstrated the reduction in curing time and fuel realized when leaf midribs are crushed prior to curing. Chemical analyses have indicated that sugars and total alkaloids are not adversely modified.

The present work seeks to further corroborate these results as well as obtain some on-farm evaluations.

Results

Price. Leaf from the Central Crops Research Station with uncrushed midrib averaged $1.048 per pound versus $.991 for the crushed midrib material or almost 6 cents per pound more, Table 2.4. In a three priming on-farm test the first priming crushed midrib treatment was so badly damaged by soft rot in the curing barn that it was discarded. Midstalk tobacco averaged $.985 per pound for the crushed midrib treatment versus $1.02 per pound for the mechanically harvested check and $.99 per pound

1975

for the hand harvested check. Top stalk tobacco averaged $.905 per pound versus $1.01 and 1.03 for the two checks. Three farmers, one each from Lenoir, Bertie and Caswell Counties judged the midrib crushed tobacco as equal to the uncrushed and one who had enough to sell separately indicated that it sold as well as the uncrushed.

Leaf Chemistry. Sugar content of the normal leaf (19.4%) appeared to be slightly higher than for the crushed midrib material (18.0%), Table 2.4. There was a reversal in the trend at the second priming level when the crushed midrib leaves had 2% more sugar than the control. Total alkaloids also appeared to be higher for the control than for the crushed midrib leaf, 3.37% versus 2.89%. The difference between control and crushed was small at the first but increased progressively with stalk level.

Curing Box Capacity. The leaf midrib is the structural member which gives the leaf most of the stiffness which it has. When it is crushed the leaves become very flexible and pack more closely in a curing container. Box capacity was increased from 103.4 lbs for the uncrushed to 127 lb for the crushed material or about 23%. This is a sizeable increase which if not properly managed could result in overloading the barn curing system.

Summary

Midrib crushing yields very attractive reductions in curing fuel (to 28%) and curing time (to 2 days per cure). While sugar and alkaloid content do not appear to be adversely affected even though they appeared to be lowered slightly, slight decreases in market value have been measured. Also, crushing can produce ideal conditions for the growth of soft rot during curing. Additional work both on-farm and on the research station is needed to further evaluate these problems.

The significant reduction in curing time can significantly increase the amount of tobacco which can be cured in one barn during the harvest season. This means that the capital investment per acre can be reduced.

There will also be an energy (fuel) saving due to the reduction in heat loss associated with the decreased time the barn is held at high temperatures. Energy requirements to actually evaporate moisture would not be changed as no appreciable amount of stem moisture is lost during crushing.

Chemical analyses of reducing sugars and total alkaloids did not reveal any differences due to the pre-curing crushing treatment. There were, however, the expected priming trends.

Threshing Tests

In tests of midrib removal (threshing) the crushed samples were found to have only 15.86% midrib as compared to 17.63% for the check. Midrib removal was more complete for the crushed material with only .3% remaining in the lamina sample versus .8% for the check. Although it appears that the crushed midrib material had less midrib the apparent discrepancy is due to some of the crushed midribs slivers being thin enough to pass for lamina.

It is desirable for the lamina to strip off the midrib in relatively large pieces. There were only minor differences in the sieve results with 84.7% of the crushed lamina passing over a 1/2" sieve versus 86.6% for the check. Material passing through a 1/2" and over a 1/4" sieve was 10.7% for crushed and 9.8% for the check. Of the remaining material, 4.6% of the crushed and 4.1% of the check passed through a 1/4" screen.

DISCUSSION

This work has clearly demonstrated that reductions in curing time and fuel requirements are realized when leaf midribs are crushed prior to curing to allow moisture to move more freely out of the midrib. ~~It has also been shown that the~~

use of ethrel reduces curing time as the tobacco is partially to almost fully yellowed before harvesting.

These two practices, if used simultaneously, offer additive advantages in the reduction of curing time and fuel requirements. The use of ethrel to reduce the time required to yellow the leaf coupled with precuring crushing of the midrib to shorten the stem drying phase should make it possible to complete a cure in significantly less time. Fuel savings can be interpreted directly as reductions in production costs. Reductions in curing time make it possible to refill a barn more frequently so that fewer barns are needed for a given size crop, a saving that can be related to production costs.

While these savings and advantages are attractive the question of the acceptability of the cured product must be addressed. In this research, sugar, starch and total alkaloids contents of crushed midribs ethrel treated leaf was not found to be markedly different from untreated check material. Also, grade and cured weight yields were not adversely affected. However, cured weight yield, being based on the harvested leaf weight before curing, would not reflect any dry matter loss which might have occurred in the field prior to removal of the leaf from the stalk.

In some instances ethrel may also be used to manipulate or schedule harvest date. A mature field of tobacco can be ripened in about three days by the application of ethrel. Therefore, a grower can treat the proper acreage to fill a barn which he will have empty three days after the application of the ethrel. In this way it is possible to have the tobacco ripen at the rate which will keep the curing barns filled.

1974

16.6% versus 17.0%, Table 2.2. This difference is slightly less than found in the small rack bulk cured tobacco. Total alkaloid content tended to be very slightly more for the uncrushed material, 3.04% versus 2.68%.

1973-74 Comparison. Although there have been some small differences in sugar and alkaloid content, the differences have not been major, Table 2.3. There was a reversal between the 1973 and 1974 data with respect to sugar content with the 1973 crushed material having a higher sugar content than in 1974. No overall reversals in alkaloid content have been detected. Sugar content for the two years averaged 16.4% for the crushed and 17.1% for the uncrushed. Alkaloid content for the crushed was 2.25% versus 2.50% for the uncrushed.

Because of the moisture crushed out of the midrib and deposited on the leaf we were concerned that soft rot might become a problem during the low temperature stages of the cure. To reduce this possibility, a lower than usual humidity was maintained during yellowing. This may have contributed to the green coloring of the crushed samples. Soft rot problems, however, were not encountered.

Discussion

The significant reduction in curing time can significantly increase the amount of tobacco which can be cured in one barn during the harvest season. This means that the capital investment per acre can be reduced.

There will also be an energy (fuel) saving due to the reduction in heat loss associated with the decreased time the barn is held at high temperatures. Energy requirements to actually evaporate moisture would not be changed as no appreciable amount of stem moisture is lost during crushing.

Chemical analyses of reducing sugars and total alkaloids did not reveal any major differences due to the pre-curing crushing treatment. There were, however, the expected priming trends.

Table 2.1. Cured Weight Yield, Curing Fuel, Sugar and Alkaloid Content of Bulk Cured, Crushed Midrib Tobacco.

Clayton, 1974
CWS

125 lb racks

Small Racks
250 lb tob in

		Crushed				Uncrushed			
Cure	Sample	Fuel Cu.Ft.	% Sugar	% TA	Cured Wt. Yield, %	Fuel Cu.Ft.	% Sugar	% TA	Cured Wt. Yield, %
1	1		~~17.9~~	~~1.39~~	~~14.6~~		~~11.9~~	~~1.76~~	~~10.2~~
	2		~~13.7~~	~~1.57~~	~~13.8~~		~~15.3~~	~~1.32~~	~~10.2~~
	Mean	-	~~15.8~~	~~1.48~~	~~14.2~~ ✓	-	~~13.6~~	~~1.54~~	~~10.2~~
2	1		9.6	1.40	13.2		17.4	2.10	12.0
	2		11.6	1.57	13.6		14.3	1.57	11.6
	Mean	224	10.6	1.49	13.4	350	15.8	1.84	11.8
3	1		20.5	2.30	18.4		21.1	2.03	17.2
	2		18.3	2.02	19.2		21.5	2.28	16.8
	Mean	435	19.4	2.16	18.8	640	21.3	2.16	17.0
4	1		19.0	3.04	18.8		22.0	2.76	18.8
	2		16.8	2.88	18.0		21.3	2.81	18.0
	Mean	405	17.9	2.96	18.4	540	21.7	2.78	18.4
5	1		18.6	3.49	19.6		20.9	3.33	21.2
	2		14.5	3.41	18.4		20.2	3.25	18.6
	Mean	370	16.6	3.45	19.0	460	20.6	3.29	19.9
Overall Mean		358 = 8.52 cuft/lb	16.1	2.31	16.8 17.4	497 12.66 cuft/lb	18.6	2.33	~~15.7~~ 16.78

250 lb × 16.8% = 42 lb tob.

250 × 15.7% = 39.25

$\frac{358 \text{ cuft}}{42 \text{ lb}}$ = 8.52 cuft/lb

$\frac{497}{39.25}$ = 12.66 cuft/lb

250 × 17.4 = 43.5

250 × 16.78 = 41.9

$\frac{358}{43.5}$ = 8.23

$\frac{497}{41.9}$ = 11.85

significant increases in fuel consumption. The low temperature stem drying reduced heat loss enough to more than compensate for the increase in drying time so that a small fuel saving resulted.

Ethrel and Midrib Crushing. Ethrel was applied at the recommended rate on several dates in August and September after the leaves from the lower half of the plant had been harvested. After application of the chemical, harvesting was delayed from 1 to several days to allow the leaves to yellow in the field. After two days, leaf abscission becomes a serious problem with approximately 35% of the leaves on the ground by the fourth day. Harvesting before leaf drop starts does not allow the leaves to fully field yellow so that much of the advantage of the treatment is not realized. Ethrel treated tobacco tended to have a high cured weight yield which may have been due to low initial moisture content as many of the leaves picked up from the ground were wilted.

Midrib crushing, severe enough to split the midrib for about 1/2 to 2/3 of its length was imposed in combination and independent of the ethrel treatments. Crushing equipment was harvester mounted so that the midribs were crushed as primed.

The use of ethrel decreased curing time and fuel by 12%. Midrib crushing decreased curing time and fuel by 7% and 9%, respectively, Table 1. The combination treatment decreased curing time by 14% and fuel by 21%.

Economics of Decreased Fuel and Curing Time. In general, a capital expenditure is required to apply the treatments which reduce fuel consumption and curing time, for example, high fan pressure, ethrel and midrib crushing. The treatments which increase fuel consumption and curing time are less expensive than the "standard", for example, low fan pressure and fan cycling.

The value of the increase or decrease in fuel consumption can be easily calculated and compared to the cost of ethrel, midrib crushing equipment or electricity to operate a larger fan. The daily or hourly cost of a curing barn is not so readily determined.

If a bulk curing barn is used only for curing tobacco during a six week curing season then the entire yearly cost of ownership must be charged to that 42 day period. Assume that the barn costs $8500 and that interest, taxes, insurance, up-keep and repairs and depreciation are 8%, 1%, 1%, 5% and 5%, respectively, for a total of 20%. The yearly cost of ownership is found to be $1700 or a little over $40 per day. In selecting the barn-acreage or poundage ratio for a given enterprise, activities which shorten the curing cycle are economically feasible if they cost no more than $40 per day of reduction. Cost of activities which also reduce fuel consumption could be divided between the two benefits. One example is given in the next paragraph.

Ethrel treatment costs are about $60 per acre ($50 for chemical + $10 machine and labor cost to apply) but only about 2 1/2 acres would be required to fill a barn as the upper half of the stalk would be harvested. The treatment cost would, therefore, be $150 per barn. The value of the time saved (18 hr, $40 per day) would be $30, the value of the fuel saved (12% x $230/barn) would be approximately $27: Electricity saving would be (18 hr x 5 Kw x 3¢/Kwh = $2.70 for a total of about $60 per barn. Thus the use of ethrel could not be justified unless the time and fuel savings have been underestimated or there are other benefits which have not been considered such as impending loss of the crop if not harvested on an accelerated schedule.

Box Loading Density. Curing boxes were loaded to a green weight density of 10.5 to 18.8 lb/cuft, Table 2. The standard or reference density used in the various tests was 14 lb/cuft equal to 800 lb in the 4 1/2 x 4 1/4 x 3' (57.4 cuft) curing container. Several boxes were cured with an initial weight of 1000 lb (17.4 lb/cuft) and one at 1080 lb (18.8 lb/cuft).

Output weights ranged from 109 to 150 lb for the 800 lb boxes depending primarily on priming. Barns holding 18 of these boxes would, therefore, hold 1962 to 2700 lb of cured tobacco. Barns with the taller boxes which are standard with several manufacturers would hold more. A disadvantage of taller boxes is that the energy to circulate the required air increases faster than the volume of the container. Glover* has calculated that a barn having a cured leaf capacity of 2500 lb would require 3.9 hp for 4 ft containers, 4.9 hp for 5 ft containers and 6.9 hp for 6 ft containers.

Considerable packing is required in order to get 800 to 1000 lb of uncured tobacco in a 60 to 70 cuft curing container (about 3 x 4 1/2' x 4 1/4' or 5'). Upper leaves, because they tend to be wrinkled require

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*Glover, J.W. "Air Handling in Bulk Tobacco Barns". Paper presented at Energy and Bulk Barn Seminar, Myrtle Beach, S.C., 1977.

Table 1. Effects of Various Leaf Treatments and Curing Conditions on Specific Fuel Consumption and Curing Time. Negative Values Indicate that <u>Less</u> Fuel or <u>Less</u> Time was Required.

Central Crops Research Station, 1977
CWS

Treatment or Condition	Priming	Fuel Consumption More(+) or Less(-)		than	Curing Time "Standard"	
		cuft/lb	%		Hours	%
std		6.36				
High Pressure	2	- .73	- 11		- 6	- 3
(30 mm, 13 to 18 was std)	3	- 1.21	- 19		- 6.4	- 4
	4	+ .38	+ 7		- 2.1	- 2
Low Pressure (9 mm, 13 to 18 was std)	2	+ 2.99	+ 47		+ 63	+ 37
Fan Cycle	2	+ .46	+ 7		+ 39	+ 23
45 min on 15 min off entire cure	3	+ 1.7	+ 27		+ 36.1	+ 24
Low Temp 155° Stem Drying	3	- .59	- 9		+ 18.5	+ 12
Ethrel and Midrib Crushing	std	5.83			152.5h	
Ethrel Only	3,4	- .70	- 12		- 18.3	- 12
Crushed Midribs Only	3,4	- ~~.57~~ .52	- 9		- 10.1	- 7
Ethrel and Crushed Midribs	3,4	- 1.24	- 21		- 21.2	- 14

Table 2. Loading Density and Cured Weight Out. Standard Curing Container was 4 1/2 x 4 1/4 x 3', 57.4 cuft. Tall box was 4 1/2 x 5 x 3'.

Central Crops Research Station, 1977
CWS

Standard Density - 800 lb in 57.4 cuft = 14.0 lb/cuft
Lightly Loaded - 600 lb in 57.4 cuft = 10.5 lb/cuft
Heavy Box - 1000 lb in 57.4 cuft = 17.4 lb/cuft
Very Heavy Box - 1080 lb in 57.4 cuft = 18.8 lb/cuft
Tall Box Max Load - 1170 lb in 67.5 cuft = 17.3 lb/cuft

	Weight In	Weight Out
1st Priming	800 lb	96 to 115 lb
2nd Priming	600	88
	800 lb	109 to 136
	1000 lb	177
3rd and 4th Primings	800 lb	134 - 150
	850 - 950	136 to 181*
	1000 lb	163 to 202*
	1100 lb	202*

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*Ethrel Treated

Mechanical Harvesting and Bulk Curing of Burley, Maryland and Cigar Filler Tobacco

1975

C.W. Suggs

In continuation of previous work, a planting of burley, Maryland and cigar filler tobacco, grown on the Central Crops Research Station, was mechanically primed and bulk cured and compared to similar samples that were hand primed and air cured and samples that were stalk cut and air cured.

Results-Chemistry

Burley. Average sugar content, Table 2.2 of mechanically primed, bulk cured samples, 5.0%, was the same as for hand primed air cured samples, but slightly higher than for the samples air cured on the stalk, 3.4%. Average total alkaloid content of the bulk cured and stalk cut air cured samples were about the same, 2.55% and 2.36% respectively. These values were somewhat lower than for the hand primed air cured samples, 3.65%. Mechanically primed, bulk cured samples subjected to precuring midrib crushing had only 3.9% sugar as compared to 5.0% for the uncrushed material. There was a small decrease in total alkaloids, to 2.24% from the 2.55% of the uncrushed material. While the sugar values are high for burley there were not large differences with respect to curing techniques. Sugar values were larger than for similar material in previous years. Overall, the values for primed bulk curing are not appreciably different from the values for stalk cut air curing.

Table 2.2 Chemical Properties of Burley, Maryland and Cigar Filler Tobaccos After Various Curing Treatments.

Clayton
CWS 1975

Stalk Position	Variety	Primed Bulk Cured % Sugar	Primed Bulk Cured % T.A.	Primed Air Cured % Sugar	Primed Air Cured % T.A.	Stalk Cut Air Cured % Sugar	Stalk Cut Air Cured % T.A.
		Burley					
Bottom	11A Crushed*	3.4	1.91				
	Uncrushed	4.8	1.82			3.7	2.70
	21 Crushed	3.2	1.28				
	Uncrushed	4.3	1.38			3.0	1.60
Middle	11A Crushed	5.0	2.19				
	Uncrushed	5.9	2.56			3.3	2.93
	21 Crushed	4.5	1.09				
	Uncrushed	5.0	1.62			3.2	2.06
Top	11A Crushed	4.1	4.48				
	Uncrushed	5.4	4.80	5.8	4.29	3.8	2.79
	21 Crushed	3.5	2.51				
	Uncrushed	4.6	2.95	4.2	3.01	3.4	2.11
Means	Crushed	3.9	2.24				
	Uncrushed	5.0	2.55	5.0	3.65	3.4	2.36
		Maryland					
Bottom	Md 609 Crushed	6.6	1.87				
	Uncrushed	5.4	2.46	5.5	3.38	4.6	2.81
Middle	Md 609 Crushed	8.4	3.98				
	Uncrushed					4.2	2.68
Top	Md 609 Crushed						
	Uncrushed	5.1	3.49	5.7	4.18	3.6	2.58
Means	Crushed	7.5	2.92				
	Uncrushed	5.2	2.98	5.6	3.78	4.1	2.69
		Cigar Filler					
Bottom	409 Crushed	6.8	3.36				
	Uncrushed	5.7	2.82	8.2	4.60	8.7	3.39
Middle	409 Crushed	5.9	4.90				
	Uncrushed					6.8	3.70
Top	409 Crushed						
	Uncrushed	4.4	4.78	8.2	3.55	5.6	3.36
Means	Crushed	6.4	4.13				
	Uncrushed	5.0	3.8	8.2	4.08	7.0	3.48

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*Midribs

Maryland. Sugar values for machine primed bulk cured, hand primed air cured and stalk cut air cured Maryland were similar at 5.2%, 5.6% and 4.1% respectively. The lowest value for the stalk cut air cured sample, like the burley, was expected because the stalk tends to keep the leaves alive longer so they can respire more of the sugar. Total alkaloid values were 2.98%, 3.78% and 2.69%, respectively for the bulk cured, primed air cured and stalk air cured material. This repeats the pattern for the burley but the reason for the higher value for the primed air cured sample is not known. Crushed midrib samples had more sugar than the uncrushed samples, 7.5% versus 5.2% whereas the crushed midrib burley had less sugar. Total alkaloids were not affected by crushing. As with burley, there were no large changes in the sugar and total alkaloids content of Maryland tobacco attributable to priming and bulk curing.

Cigar Filler. Sugar content was lowest for the bulk cured material, 5.0%, intermediate for the stalk cut air cured samples, 7.0%, and highest for the primed air cured samples, 8.2%. Total alkaloids did not vary appreciably being 3.8% for the bulk cured material, 3.48% for the stalk cut air cured material and 4.08% for the primed air cured samples. There were some small changes due to midrib crushing with sugar increasing to 6.4% from 5.0% and total alkaloids increasing to 4.13% from 3.8% for the uncrushed material. Again the changes in sugar and total alkaloids observed were not large and suggest that cigar filler tobacco as well as burley and Maryland can be successfully primed and bulk cured.

Results-Harvesting

Burley. Existing mechanical priming techniques when properly applied are capable of good leaf removal, Table 2.3. Losses for the entire plant ranged from less than 1% at the bottom of the stalk to about 5% or 6% for the upper leaves. Cured weight yield of machine primed bulk cured burley averaged from 11 to 16.4% being highest at the bottom of the plant. Apparently the bottom priming was already partially dry when harvested as dry weight yields normally are higher at mid to upper stalk positions. Samples of primed air cured burley gave cured weight yields of 18.5%. Whole stalks of air cured burley had cured weight yields of about 6.7% leaf. The presence of the stalk in the original weight but not in the final dried weight accounts for the small value. Harvesting of about 3/4 of the stalk after one priming gave cured weight yields of 8.7%. In harvesting by whole stalk cutting, much of the material handled is waste.

Maryland. Harvesting losses averaged 4.54% and cured weight yields were about 11 to 15.5% for bulk cured samples. Primed air cured samples had almost the same cured weight yield, 15.6%. Stalk cut air cured material gave cured weight yields of 8 and 11.4% for the whole stalk harvest and the 3/4 stalk harvests respectively.

Cigar Filler. Harvesting losses were about the same as for burley and Maryland, 4.26%, and cured weight yield of the bulk cured material was 13 to 16%. Cured weight yield for primed air cured was slightly higher 18% but this may have been due to the chance. Stalk cut air cured material gave cured weight yields of 5.9 and 12.3% for the whole stalk harvest and the 3/4 stalk harvest, respectively.

Table 2.3 Mechanical Priming Losses and Cured Weight Yield of Burley, Maryland and Cigar Filler Tobaccos.

Clayton
CWS 1975

	Bulk Cured, Primed						Air Cured	
	Priming 1		Priming 2		Priming 3			
	Harvesting Losses %	Cured Wt. Yield %	Harvesting Losses %	Cured Wt. Yield %	Harvesting Losses %	Cured Wt. Yield %	Primed Cured Wt. Yield %	Stalk Cured Wt. Yield %
Burley								
11A Crushed [†]	0.80	14.4	5.26	11.0	4.09	14.2		
Uncrushed	1.00	15.2	5.74	11.2	6.26	13.8	18.5	6.5[*],7.9[**]
21 Crushed	0.60	19.2	4.06	11.8	2.96	14.1		
Uncrushed	0.20	17.0	4.30	11.6	2.89	14.4		7.0[*],9.5[**]
Means	0.65	16.4	4.84	11.4	4.05	14.1	18.5	6.7[*],8.7[**]
Maryland								
Crushed	2.67	10.0		15.5				
Uncrushed	6.40	12.1					15.6	8.0[*],11.4[**]
Means	4.54	11.0		15.5			15.6	8.0[*],11.4[**]
Cigar Filler								
Crushed	5.79	12.5		16.2				
Uncrushed	2.73	13.8					18.0	5.9[*],12.3[**]
Means	4.26	13.2		16.2			18.0	5.9[*],13.3[**]

[*] Whole Stalk

[**] 3/4 Stalk

[†] Midribs

Summary

Bulk curing boxes or maxi-racks because they can be mechanically filled on and by mechanical harvesters offer the potential for significantly reducing barning labor. Ultimately a two-man harvesting-barning crew should be possible with outputs of four to eight thousand pounds cured weight per day.

Farmers are moving very rapidly to the adoption of curing boxes and a significant percentage of the 1976 barns will be supplied with boxes instead of racks.

Transplant Storage

Because of the problem of having seedlings arriving at transplant size at the right time, it may be beneficial to harvest them before transplant time and store them for a few days to a week. This would allow farmers to have seedlings ready when transplanting started. It would also spread out labor peaks.

Work during the last two seasons indicated that seedlings could be successfully stored for one or more weeks without serious loss of livability. Our work in 1975 was designed to determine yield effects and learn more about storage.

Results

Although none of the plants stored performed as well with respect to yield, value or livability it was evident that a storage temperature of 50°F was better than 70°F, Table 2.5. Also it appeared that storage in plastic bags caused a decrease in livability as well as yield and value.

Use of Ethrel to Stalk Yellow Tobacco

C.W. Suggs

Several rows of tobacco were treated with ethrel by means of a hand sprayer. The rate used was 150 mg. of ethrel in 30 ml of solution per plant. The sprayer was calibrated to determine the number of seconds required for each plant.

The plants were treated on August 15 when about 1/2 of the leaves were still on the plant. The leaves yellowed well and on August 18 the plants were machine primed and midribs were crushed. Some leaves were left in the tops of the plants. Leaves (5 racks, 125 lb each) were bulk cured on an accelerated schedule. Since little yellowing was required and midrib drying occurred while the leaf was drying the cure was complete in 3 days.

Cured weight yield was 19.04% and the tobacco graded a B4F. Leaf sugar content averaged 17.4% and total alkaloids averaged 2.90%. A second treatment harvested a few days later had 17.5% sugar and 3.75% total alkaloids.

II. Graduate Students: Lincoln Wood. January 75 - December 75.

III. Post-Doctoral Fellows: None

IV. Publications:

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco Part 6: Weight Distribution and Cured Weight Yield of Midrib and Lamina. Tob. Sci. 19:83-85, 1975.

Suggs, C.W. Effect of Yellowing Duration on Leaf Chemistry, Grade, Price and Yield of Flue-Cured Tobacco. Proc. 29th Tob. Chemists Res. Conf., College Park, Md. Oct. 8-10, 1975

V. Manuscripts Accepted for Publication: None

VI. Manuscripts in Review:

Suggs, C.W. Mechanical Harvesting of Flue-Cured Tobacco Part 7: Machine Filling, Handling and Curing in Large Bulk Racks.

VII. Papers Presented at Professional Meetings:

Suggs, C.W. Potential of Midrib Crushing for Reducing Curing Time and Fuel. 26th Tobacco Workers Conf. Charleston, S.C. Jan. 27-30, 1975.

Suggs, C.W. Mechanical Filling and Handling of Large Curing Racks. 26th Tobacco Workers Conf. Charleston, S.C. Jan. 27-30, 1975.

Suggs, C.W. Experiments with Leaf Harvesting and Bulk Curing Burley and Cigar Tobacco. 26th Tobacco Worker's Conf. Charleston, S.C. Jan. 27-30, 1975.

Suggs, C.W. Mechanized Harvesting and Handling of Bulk Tobacco. Curing Barn Workshop, Raleigh, N.C. Sept. 30, 1975.

1972

1973 5 priming, stick cured, hand fed crusher.
-5 priming small racks 125 lb each. 4 racks/priming - 2 barns, 1 crushed & one uncrushed per barn -

1974 Mach mounted crusher built & used - bulk curing -
125 lb/rack. - boxes in big barn - first time. no fuel data on boxes. Fuel data on racks -

1975 ~~Changed small barns to boxes~~ Built shed at Clayton - Heat exchanger in barn 4
Cured ~~boxes~~ racks small in barns 1, 2, 3, & 4 and long barn ~~5~~ - other small barns built later
fuel data available.

1976

1977 Mach harv. Mach crush, box cured fuel consumption measured.

1978 Machine harv., Mach crushed box cured fuel consumption measured

1979 - Machine harvested, Mach. Crushed, box cured - fuel consumption measured.

Leaf thickness is about .01 inches

Lamina weighs about .147 gm/in^2

specific gravity is . .01" x 1" x 1" = ~~.010~~ $.01\ in^3$

$$\xrightarrow{\quad} \frac{.147}{.16387} \; .897$$

1 in = 2.54 cm

$1\ in^3 = 16.387\ cm^3$

$.01\ in^3 = .16387\ cm^3$ — This weighs .147 gm

lamina	4.2% lamina, 2.6% of total leaf	Green	100
Rib -	38.9% of Rib $\frac{45\%}{17.6}$ of total leaf		

would be <u>8 gm for a 53 gm leaf</u>

For a 100 gm leaf — 15 gm would be the weight of the first 3 in of midrib — cross section is $2.38\ cm^2$

Volume is $2.38\ cm^3 \times 3\ in \times 2.54\ cm/in = 18.1356\ cm^3$ assuming constant cross section (poor assumption)

sp. grav. $\frac{8}{18} = .44$ completely unacceptable value

Master

TABULATION OF SOME PHYSICAL PROPERTIES OF THE TOBACCO STALK AND GREEN TOBACCO LEAVES

January, 1961

C. W. Suggs, W. E. Splinter and J. F. Beeman

Although the physical properties of tobacco stalks and leaves may vary widely dependent on variety, cultural practices and environment it is possible to tabulate some mean physical values which indicate the general level of these properties.

Node Spacing

Lower levels - - - - - - - - - - - - - - - - - - 1"
Average - - - - - - - - - - - - - - - - - - 1.9"
Tip levels - - - - - - - - - - - - - - - - - - 3"

Stalk Diameter

1st leaf above ground level - - - - - - - - - - 1 1/4 - 1 1/2"
Tip level - - - - - - - - - - - - - - - - - - 3/8 - 7/8"

Vertical Force to Cause Stalk Failure

Minimum - 10 lbs.
Average - 40
Maximum - 65

Eccentric Loading to Cause Stalk Failure at Tip

Minimum - 6 lb. in.
Average - 18
Maximum - 27

Angle Between Stalk and Leaf Stem

2 inches from stalk - - - - - - - - - - - - - - - - 52.3°
6 inches from stalk - - - - - - - - - - - - - - - - 78.5°

Radius of Curvature

Leaves

Normal - 11.01 inches
Critical (midrib breaks when bent to this radius) .99

Stalks

Normal - ∞
Critical (stalk breaks) - - - - - - - - - - - - - 4.63 inches

Vertical Force to Break Midrib from Stalk - - - - - - - - 1.48 lbs

Increased 40% if MH-30 is used.

Horizontal Force to Break Midrib from Stalk - - - - - - - 2.28 lbs.

Energy to Break Midrib by Impact - - - - - - - 1 ft. lb.

With large sucker nub present - - - - - - - - - - - 3 ft. lb.
Does not appear to be affected by fertilizer level, plant population, leaf size or force required to remove leaves.

Leaf Thickness

Bottom leaves - .008 - .009 in.
Middle leaves - .009 - .010 in.
Tip leaves - .010 - .011 in.

Avery gives value of 235 μ or about .010 inch - A. J. Botany 20:565-592

Allowable Pressure without Bruising - - - - - - - - - - 10 lbs/in^2

Leaf Weight, Green

Whole leaf, average - - - - - - - - - - - - - - - - - .116 lbs. - 52.7 gm
Per square inch of lamina - - - - - - - - - - - - - .0052 oz.

Leaf Area

At maximum growth - - - - - - - - - - - - - - - - - 1500 in^2
or 3 to 5 ft.^{2} of leaf surface per ft.^{2} of soil
Growth Rate, until flowering or until plants become competitive - - - - - - - - - - - - - 16% per day
(Field and plant bed rates about equal)
Formula for determining leaf area
Area of leaf in square inches = .6345 (midrib length)(max. leaf width)

Leaf Temperatures

In sunlight - - - - - - - - - - - - - - - - - - up to 15°F above ambient air temperature

In shade - - - - - - - - - - - - - - - - - - essentially air temperature

Coefficient of Friction

On wood - .99
On canvas (Neoprene impregnated) - - - - - - - - - 1.04
(Untreated) - - - - - - - - - - - - - - 1.75
On galvanized sheet metal - - - - - - - - - - - - - 1.04
On Teflon - 1.60

Deflection of Stalk - - - - - - - - - - - -	Force, lbs	Deflection, inches
(Force applied perpendicular to and at top of stalk)	1/4	1.93
	1	4.82
	4	19.81

Column Strength of Stalk 28.2 lbs.

Vertical Force to Remove Stalk from Ground 111 lbs.

Force to crush outer skin of stalk (crusher jaws 1/2" wide).	124.8 lbs.
Force to shear leaf midrib	26.2 lbs.
Force to cut leaf midrib	12.2 lbs

References

Splinter, W. E. and Suggs, C. W. 1959. Systems engineering of bright leaf tobacco production. Agricultural Engineering Information Circular #14.

PHYSICAL PROPERTIES OF GREEN VIRGINIA-TYPE TOBACCO LEAVES

Suggs, C. W. and Splinter, W. E. 1959. Part I. Leaf dimension, weight and midrib strength. Tobacco Science 3:121-124.

Suggs, C. W. and Splinter, W. E. 1960. Part II. Frictional characteristics. In press. Tobacco Science.

Suggs, C. W. and Splinter, W. E. 1960. Part III. Relation of leaf length and width to leaf area. Tobacco Science 4:194-197.

Splinter, W. E. and Suggs, C. W. 1960. Part IV. Kinetic energy absorption and force relationship during separation from stalk. To be submitted to Tobacco Science.

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April 9, 1974

Mr. R.L. Covington
Quality Control Manager
Universal Leaf Tobacco Company
P.O. Box 25099
Hamilton Street at Broad
Richmond, Virginia 23260

Dear Bob:

Thank you for your candid appraisal of the "crushed midrib" and stem material which you received from us.

While your comments were generally negative they do help us evaluate the problems at an early stage in the research. This is beneficial as we already have developed some ideas for modifying the treatment to make the material more acceptable.

Since we hope to be able to improve the characteristics of crushed midrib tobacco this season it might be too early to show samples as customers might become prejudice. A lot would depend on the attitude of the individual to change. I would defer to your judgment.

Thanks for your evaluation.

Sincerely,

Charles W. Suggs
Professor

CWS/bf

P. O. BOX NO. 25099
HAMILTON STREET AT BROAD

CABLE ADDRESS "ULTOCO"
PHONE: AREA CODE 804 359-9311
TELEX NO. 827438

Universal Leaf Tobacco Co.
INCORPORATED
EXPORTERS AND IMPORTERS
Richmond, Virginia 23260

April 8, 1974

Dr. Charles W. Suggs, Professor
Dept. of Biological and Agricultural Engineering
Box 5906
Raleigh, North Carolina 27607

Dear Charles:

Thank you for affording us the opportunity to evaluate the mibrib and strip products from your experimental efforts to reduce tobacco curing time and cost. A number of our account executives and production personnel have inspected the strips and stems and we offer the following comments:

OBSERVATIONS

We appreciate the fact that all reasonable efforts should be made to reduce production cost so that the farmer can continue to provide tobacco at a competitive price. However, it is also just as important that the end product be of high quality and acceptable to the manufacturer. With these thoughts in mind, most of our people believe that the strips and stems would be unacceptable to many of our customers.

RESIDUAL STEM IN STRIPS

It is our opinion that it would be very difficult to efficiently separate the flat stem particles from the lamina in our threshing and spearating systems. If this assumption is correct, this type of stem would also affect our established quality control definition of the residual stem content of strips. Another point is that this type of residual stem could create fines at the cigarette maker.

Further, when considering our type of business, the strips might appear to contain more stem than the product would actually contain. This would of course affect our customer relations.

Universal Leaf Tobacco Co.
INCORPORATED
Richmond, Virginia

Dr. Charles W. Suggs
Page 2
April 8, 1974

THRESHING

In most threshing systems it is important that the midrib be plyable without breaking so that the stem will slide across and through the thresher basket allowing the lamina to be stripped off the stem. If the stem breaks, the thresher tends to grind the tobacco into fine particles which generates more fine scrap and reduces strip yield. With this in mind, I believe that stems from this product would tend to break-up more than the conventional product and thereby create more scrap.

STEM PRODUCT

The condition of the midrib can also present additional problems for a processors. Just a few years ago, all of our customers wanted long stems. However, some of them now want short stems, others continue to request long stems and some customers want long and short stems. Obviously, this is due to the final usage i.e. whether they are rolled for cigarettes, ground for tobacco sheet and snuff or rolled for pipe tobacco.

It is my opinion that these stems would be acceptable for all products with the possible exception of pipe tobacco. Possibly more stem slivers would be generated from this product which would be objectionable to pipe tobacco manufacturers.

Charlie, I realize that most of these comments are negative, however, I am giving you our candid appraisal. You must realize that it is difficult for us to make a completely fair evaluation since we can only speculate on our ability to successfully thresh this tobacco. Perhaps we could obtain a better appraisal by showing the samples to our customers when they are over here during the forthcoming season. However, I will wait for your approval on this.

Thanks again for sending the samples. With best regards,

Sincerely yours,

R. L. Covington

R. L. Covington
Quality Control Manager

RLC/cgh

Threshing and Separating Characteristics of Tobacco With Midribs Crushed Before Curing

Imperial Tob. - Wilson

C.W. Suggs
N.C. State University
1974

Sample	1st Pass Strip	Other Passes Strip	Stems	% Stems	% Stem in Strip
	75.6% in 1st Pass	24.4%			
1	5122	2971	967	10.67	0.2
2	8718	683	1968	17.31	-
3	9258	1828	1905	14.66	-
4	5511	5398	1357	11.06	-
5	6396	747	1414	16.52	-
6	2066	352	456	15.86	0.3
7	not crushed compare with #6	~~3316~~ (all passes) 1,979	710	17.63	0.8

Sieve Results

	Sample 6 Weight	Sample 6 %		Sample 7 Weight	Sample 7 %	
over 1"	1130	48.4		2055	62.0	
over ½"	845	84.7	(1 & ½ pooled)	815	86.6	(1 & ½ pooled)
over 1/4"	250	10.7		310	9.4	
through 1/4"	108	4.6		135	4.1	
	2333*			3315		

*Does not agree with weight above.

	[illegible]	> 1/4"	> 1/2"	> 1"	% Midribs	~~Stem~~ Midrib in strip
crushed	[illegible]	95.4	84.7	48.4	15.86	0.3
Check	4.1	95.9	86.6	62.0	17.63	0.8

<— % Retained on Screen Mesh

	1"	1/2"	1/4"	% Midribs, %	Midribs left in lamina, %
Crushed	48.4	36.3	10.7	15.86	0.3
Check	62.0	24.6	9.4	17.63	0.8

	3/4	1/2	3/8	
Crushed	58.4	20.3	8.6	3.9
Check	64.0	19.1	7.5	1.2

R.J.Reynolds Tobacco Company
Winston-Salem, N. C. 27102

August 28, 1974

Dr. C. W. Suggs
Department of Biology & Agricultural Engineering
North Carolina State University
Raleigh, North Carolina

Dear Charlie:

I am enclosing data on 1973 samples of crushed midrib tobacco, as we discussed on the phone yesterday.

Sincerely yours,

Ivan

Ivan Neas, Manager
Agricultural Research Department

Enclosures

Reynolds Tob Co.

August 27, 1974

Tobacco with Midribs Crushed Before Curing Compared with Uncrushed Midrib for Leaf Processing and Smoking Flavor

The tobacco was run through the stemming process in three passes which is representative of the commercial process.

Seive analyses were run to determine the percent of lamina in various sizes. The stem was hand picked from some samples to determine the percent of stems in the strip after processing.

Two-454 gram samples from the first and second passes were blended together. The stems were hand picked from the two samples and averaged together to determine the percent of stem that was left in the lamina. The maximum acceptable amount of stem content in lamina is 3% after stemming (Table 1).

The percent of large strips (retained on 3/4") was greater and the percent of small strips (retained on No. 8) was less for the uncrushed stems (Table 2).

On the third pass the concave broke the crushed stem into very small slivers which was very noticeable throughout in the lamina. The 3rd pass, having a noticeably excessive amount of stem, was hand picked from each mesh using two-100 gram samples and averaged together (Table 3).

Smoking Flavor

The crushed sample was prepared for cigarette making with all the stem left in the tobacco leaf. The uncrushed was prepared with the stems removed for cigarette making.

The cigarettes with uncrushed stems had a low to medium flavor and was fairly mild with a fair flue-cured taste and aroma. The cigarettes with crushed stems had a very low flavor, was strong and had a bitter, stemmy, and green immature taste.

Summary

An increase in the percent passing a 3/8" screen (includes % retained on No. 8 screen and fines) is undesirable.

The increase in the percent small strips and the high percent of stems in the strip with the crushed stems would make the strip less desirable for cigarette manufacture. The smoking panel results indicates that removing the stems gives a better smoking cigarette.

Reynolds

TABLE 1

PERCENT LAMINA AND STEMS FOR CRUSHED AND UNCRUSHED STEMS. AVERAGE OF TWO-454 GRAM SAMPLES

stems left in material ½ from 1st pass + ½ from 2nd pass

3% is max allowable.

		% Lamina	% Stem
Hand picked	Uncrushed	98.7	1.2
	Crushed	96.0	3.9

TABLE 2

ROTEX ANALYSIS FOR TOBACCO WITH UNCRUSHED STEMS AND STEMS CRUSHED BEFORE CURING*

C. W. Suggs, N. C. State - 1973

Pass through Stemming Operation		% Retained on Screen Mesh					
		3/4"	1/2"	3/8"	No. 8	Fines	
1	Uncrushed	70.8 x6	15.8 x4	6.4 x6	5.9	1.0	
1	Crushed	69.5	15.2	5.7	7.7	1.8	
2	Uncrushed	51.6 x1	22.6 x1	9.7 x1	12.9	3.2	
2	Crushed	32.2	35.6	13.7	16.1	2.3	
3	Uncrushed	35.3 x1	35.3 x1	11.8 x1	11.8	5.8	
3	Crushed	17.6	35.3	20.6	23.6	2.9	ΣX
X̄	uncr.	63.96	19.09	7.49	7.51	1.88	99.93
	crush.	58.35	20.26	8.56	10.74	2.00	99.91

*Average of two-100 gram samples

TABLE 3

PERCENT STEMS IN STRIP FOR THIRD PASS THROUGH STEMMING OPERATION*

Third pass material

(Average of two-100 gram samples)

	% Retained on Screen Mesh material was			
	3/4"	1/2"	3/8"	No. 8
Lamina				
Uncrushed	97.5	97.5	97.0	93.1
Crushed	93.8	88.0	80.5	65.4
Stems				
Uncrushed	2.5	2.5	3.0	6.9
Crushed	6.2	12.0	19.5	34.6

*Picked out by hand

Table 3. Effects of Cut or Crushed Midribs or Bruised Lamina on the Total Sugar and Alkaloids Content of Cured Tobacco

~~Total Sugar~~ %

Clayton 1972,
CWS

Treatment	Rep 1	Rep 2	Rep 3	Rep 4	Total Sugar ~~Mean~~ %	Total alkaloids ~~Mean~~ %
Priming 1						
Check	4.8	6.3	4.4	5.0	5.1	2.50
~~Bruised~~	~~3.6~~	~~3.2~~	~~3.0~~	~~2.5~~	~~3.1~~	~~2.30~~
Crushed Midribs	4.7	5.1	5.0	4.5	4.8	2.27
Cut Midribs	4.7	4.3	3.7	6.4	4.7	2.14
Mean	4.45	4.7	4.0	4.6	4.45	2.30
Priming 2						
Check	6.2	6.7	7.3	6.7	6.7	2.59
~~Bruised~~	~~3.3~~	~~3.3~~	~~2.8~~	~~2.5~~	~~2.9~~	~~2.23~~
Crushed Midrib	4.1	5.5	7.3	4.8	5.4	2.08
Cut Midrib	7.8	6.5	7.6	6.7	7.1	2.25
Mean	5.35	5.5	6.25	5.18	5.57	2.29
Priming 3						
Check	10.7	12.1	11.7	9.5	11.0	3.40
~~Bruised~~	~~5.0~~	~~4.5~~	~~6.1~~	~~5.4~~	~~5.2~~	~~3.36~~
Crushed Midrib	8.9	7.4	8.1	8.4	8.2	3.43
Cut Midrib	9.9	7.7	11.9	9.9	9.8	3.18
Mean	8.6	7.9	9.45	8.3	8.58	3.34
Priming 4						
Check	10.5	11.3	9.0	9.6	10.1	4.02
~~Bruised~~	~~8.5~~	~~7.8~~	~~8.0~~	~~9.3~~	~~8.4~~	~~3.80~~
Crushed Midrib	11.1	13.0	10.9	8.9	10.9	3.57
Cut Midrib	9.3	10.6	9.7	10.2	9.9	3.49
Mean	9.85	10.7	9.4	9.5	9.86	3.72
Overall Mean	7.0	7.2	7.2	6.9	7.1	2.91
Treatment Means						
Check	8.05	9.1	8.1	7.7	8.2	3.13
~~Bruised~~	~~5.1~~	~~4.7~~	~~5.0~~	~~4.9~~	~~4.9~~	~~2.925~~
Crushed Midrib	7.2	7.75	7.8	6.65	7.35	2.84
Cut Midrib	7.9	7.3	8.2	8.3	7.9	2.77

Differences: % Sugar Primings (.05) = 0.865, Treatments (.05) = 0.865, Priming x Treatments (.05) = 2.180

Differences: % alkaloids Primings (.05) = 0.324, Treatments (.05) = 0.324, Reps x Treatments (.05) = 0.844

Table 6. Properties of Cured Tobacco With Midribs Crushed Before Curing

Clayton 1972
CWS

Treatment	Dry Matter %	Price $/100 lb	Grade	Sugar Content %	Alkaloid Content %
Priming 4					
Not Crushed	17.2	78	B5GL	13.0	3.30
Crushed at Priming	17.9	73	N2	9.9	3.83
Crushed ½ Yellow	16.2	78	B6GL	11.1	4.26
Crushed Full Yellow	17.7	73	N2	14.0	2.74
Mean	17.25	75.5		12.0	3.53
Priming 6					
Not Crushed	17.3	84	B5F	11.2	4.32
Crushed at Priming	18.2	75	B6GF	12.9	3.39
Crushed ½ Yellow	16.3	82	B6F	12.8	3.97
Crushed Full Yellow	18.2	82	B6F	12.3	3.98
Mean	17.50	80.8		12.3	3.91
Treatment Means					
Not Crushed	17.25	81		12.1	3.81
Crushed at Priming	18.05	74		11.4	3.61
Crushed ½ Yellow	16.25	80		11.9	4.11
Crushed Full Yellow	17.95	77.5		13.1	3.36
LSD Differences					
LSD Treatment (.05)	0.86	NS		NS	NS
Priming (.05)	NS	4.77		NS	NS

Table 5. Effect of Maturity x Midrib Cutting, Crushing or Lamina Bruising on Leaf Chemistry.

Clayton 1972, CWS

Treatment	Total Sugar %			Total Alkaloids %		
	~~Priming~~			~~Priming~~		
	1	2	~~Mean~~	1	2	~~Mean~~
Over-Ripe						
~~**Bruised**~~	~~2.0~~	2.0	~~2.0~~	0.48	0.62	~~0.55~~
Crushed Midrib	3.8	5.1	4.45	1.33	2.11	1.72
Cut Midrib	4.9	7.0	5.95	1.08	1.85	1.465
Mean	5.35	7.05	4.13	0.96	1.53	1.245
Ripe						
Bruised	4.4	5.5	~~4.95~~	1.05	1.67	~~1.36~~
Crushed Midrib	16.1	11.4	13.75	1.43	1.87	1.65
Cut Midrib	16.0	11.6	13.8	1.72	1.49	1.605
Mean	12.17	9.5	10.88	1.40	1.68	1.54
Green						
Bruised	6.1	6.5	~~6.3~~	1.54	2.96	~~2.25~~
Crushed Midrib	16.6	6.9	11.75	1.96	3.39	2.675
Cut Midrib	15.7	14.2	14.95	2.16	2.51	2.335
Mean	12.8	9.2	11.00	1.89	2.95	2.42
Overall Mean	9.5	7.8		1.42	2.05	1.73
Treatment Means						
Bruised	4.2	4.7	~~4.4~~	1.02	1.75	~~1.39~~
Crushed Midrib	12.2	7.8	10.0	1.57	2.46	2.015
Cut Midrib	12.2	10.9	11.6	1.66	1.95	1.80

Differences: Maturity (.05) = 4.82 Priming (.05) = 0.465
Treatment (.05) = 4.82 Maturity (.05) = 0.737

Omit

Table 5. Effect of Maturity x Midrib Cutting, Crushing or Lamina Bruising on Leaf Chemistry.

Clayton 1972,
CWS

	Total Sugar %			Total Alkaloids %		
	~~Priming~~			~~Priming~~		
Treatment	1	2	~~Mean~~	1	2	~~Mean~~
Over-Ripe						
~~**Bruised**~~	~~2.0~~	2.0	~~2.0~~	0.48	0.62	~~0.55~~
Crushed Midrib	3.8	5.1	4.45	1.33	2.11	1.72
Cut Midrib	4.9	7.0	5.95	1.08	1.85	1.465
Mean	5.35	7.05	4.13	0.96	1.53	1.245
Ripe						
Bruised	4.4	5.5	~~4.95~~	1.05	1.67	~~1.36~~
Crushed Midrib	16.1	11.4	13.75	1.43	1.87	1.65
Cut Midrib	16.0	11.6	13.8	1.72	1.49	1.605
Mean	12.17	9.5	10.88	1.40	1.68	1.54
Green						
Bruised	6.1	6.5	~~6.3~~	1.54	2.96	~~2.25~~
Crushed Midrib	16.6	6.9	11.75	1.96	3.39	2.675
Cut Midrib	15.7	14.2	14.95	2.16	2.51	2.335
Mean	12.8	9.2	11.00	1.89	2.95	2.42
Overall Mean	9.5	7.8		1.42	2.05	1.73
Treatment Means						
Bruised	4.2	4.7	~~4.4~~	1.02	1.75	~~1.39~~
Crushed Midrib	12.2	7.8	10.0	1.57	2.46	2.015
Cut Midrib	12.2	10.9	11.6	1.65	1.95	1.80

Differences: Maturity (.05) = 4.82
Treatment (.05) = 4.82

Priming (.05) = 0.465
Maturity (.05) = 0.737

Omit

RESULTS AND DISCUSSION

Crushed Midribs

73

For the stick cured samples there were no appreciable differences in price or percent cured weight yields, Table 1. For the bulk cured samples there were

Table 1. Effects of Midrib Crushing on Cured Weight Yield, Price, and Leaf Chemistry (1973 data).

	Stick Cured				Bulk Cured			
Priming	Cured Wt. Yield, %	Price ¢/lb	% Sugar	% Alkaloids	Cured Wt. Yield, %	Price ¢/lb	% Sugar	% Alkaloids
1								
Crushed	–	86	17.8	2.32	12.3	86	12.6	1.38
Uncrushed	–	84	14.1	1.64	13.0	86	11.4	1.66
2								
Crushed	14.6	88	17.6	2.04	14.2	85	22.0	1.67
Uncrushed	14.4	–	16.1	1.56	12.8	88	19.8	1.80
3								
Crushed	14.2	–	17.6	2.04	19.8	86	15.4	1.79
Uncrushed	14.2	88	16.1	1.56	19.2	88	15.6	2.04
4								
Crushed	18.0	88	21.6	2.22	23.2	84	15.6	2.23
Uncrushed	18.8	88	22.2	1.66	23.2	84	16.2	3.08
5								
Crushed	22.1	88	16.6	2.09	25.0	86	–	–
Uncrushed	22.7	88	15.0	2.64	23.8	86	–	–
Means								
Crushed	17.2	88	18.2	2.14	18.9	85.5	16.4	1.77
Uncrushed	17.5	87	16.7	1.81	18.4	86.6	15.8	2.14

Table 2.3. Effect of Pre-Curing Midrib Crushing on Leaf Chemistry, Summary

	Crushed		Uncrushed	
Year	% Sugar	% TA	% Sugar	% TA
1973 (Plots)	16.4	1.77	15.8	2.14
1974 (Plots)	16.1	2.31	18.6	2.33
1974 (Field)	16.6	2.68	17.0	3.04
Mean	16.4	2.25	17.1	2.50

Table 2. Cured Weight Yield, Curing Fuel and Sugar and Alkaloid Content of Bulk Cured, Crushed Midrib Tobacco, (1974 data).

	Crushed				Uncrushed			
Cure	Cured Weight Yield, %	Fuel Cuft	% Sugar	% TA	Cured Weight Yield, %	Fuel Cuft	% Sugar	% TA
			Small Racks 125 lbs in.					
1	14.2	-	15.8	1.48	10.2	-	13.6	1.54
2	13.4	224	10.6	1.49	11.8	350	15.8	1.84
3	18.8	435	19.4	2.16	17.0	640	21.3	2.16
4	18.4	405	17.9	2.96	18.4	540	21.7	2.78
5	19.0	370	16.6	3.45	19.9	460	20.6	3.29
Mean	~~16.8~~ 17.4 ?	385	16.1	2.31	~~15.7~~ 16.8 ?	497	18.6	2.33
		cuft/lb	Large Racks (Curing Containers)					
1		8.52	9.4	1.76		12.66 cuft/lb	17.5	2.11
2			14.8	2.82			20.1	2.70
3			17.8	2.88			15.0	3.68
4			16.5	3.27			15.4	3.65
Mean			16.6	2.68			17.0	3.04

Table 3. Effect of Ethrel and Midrib Crushing on Flue Cured Tobacco
1975 Data

Treatment	% Sugar	% T.A.	Cured Wt. Yield
Ethrel plus crushing	17.0	3.33	19.8
Crushing only	17.5	3.20	19.6
Check	19.6	3.69	18.9

Table 2.4 Bulk Curing Box Capacity, Midrib Treatment, Grade and Price

Clayton
C.W. Suggs 1975

Priming	Rack	Wt. Out lb.	Midrib	Grade	Price	% Sugar	% TA
1	1	96	Uncrushed	P3F	.92	16.1	2.53
	2	119.5	Crushed	P4F	.88	21.6	2.05
	3	115	Crushed	P4F	.88	15.2	2.56
	4	94	Crushed	P5F	.88	7.8	2.24
$\bar{x}$ Uncrushed		97			.92	16.1	2.53
$\bar{x}$ Crushed		117.8			.88	14.9	2.28
2	1	102.5	Uncrushed	X3L	1.10	19.5	2.69
	2	97	Uncrushed	X3L	1.10	21.1	3.01
	3	100	Uncrushed	X3F	1.07	17.6	2.98
	4	115	Crushed	X3F	1.07	22.0	2.85
	5	129.2	Crushed	C5F	1.08	20.5	2.71
	6	115.5	Crushed	X4FV	1.08	21.7	2.76
$\bar{x}$ Uncrushed		99.8			1.09	19.4	2.89
$\bar{x}$ Crushed		119.9			1.077	21.4	2.77
3	1	123.5	Uncrushed	B3F	1.06	20.2	3.54
	2	114	Uncrushed	B4L	1.10	21.6	3.30
	3	133.5	Uncrushed	B4LV	1.00	14.6	3.34
	4	134.8	Crushed	B5F	.99	17.4	3.20
	5	126	Crushed	C4LV	.98	19.5	2.83
	6	122.5	Crushed	B5F	.99	18.8	3.00
$\bar{x}$ Uncrushed		118.8			1.08	20.9	3.42
$\bar{x}$ Crushed		129			.99	17.6	3.09
4	1	98	Uncrushed	B4F	1.10	21.2	4.63
	2	125	Crushed	B4LV	1.02	18.0	3.11
	3	152	Crushed	B4LV	1.12	14.0	3.58
	4	~~136~~	~~Crushed~~	~~B5FV~~	~~.93~~	~~19.5~~	3.39
	5	152	Crushed	B5LV	1.00	20.6	3.64
$\bar{x}$ Uncrushed		98			1.10	21.2	4.63
$\bar{x}$ Crushed		141.2			1.018	18.0	3.43
Overall							
$\bar{x}$ Uncrushed		103.4			1.048	19.4	3.37
$\bar{x}$ Crushed		127.0			.991	18.0	2.89

Table 4. Effect of Ethrel and Midrib Crushing on Flue Cured Tobacco
1976 Data

Treatment	% Sugar	% T.A.	% Starch	Cured Wt. Yield	Grade
Ethrel plus crushing	4.7	3.74	4.4	19.5	B4F
Check	6.0	2.70	2.1	17.3	B3V
Ethrel plus crushing	7.1	3.71	3.2	18.1	B4F
Check	7.6	3.66	2.7	19.4	B4V
Ethrel plus crushing	2.6	4.03	1.7	18.4	B4F
Crushing only	18.8	4.19	2.9	18.1	B4GK
Check	6.2	4.35	2.6	19.5	B4GK
Ethrel plus crushing	6.5	4.55	2.9	18.5	B5GK
Crushing only	5.9	2.62	2.2	19.5	B4GK
Ethrel only	7.1	4.71	2.8	20.5	B4F
Check	4.6	4.24	2.2	19.2	B5GK
Means					
Ethrel plus crushing	5.2	4.01	3.0	18.6	
Crushing only	12.4	5.40	2.6	18.8	
Ethrel only	7.1	4.70	2.8	20.5	
Check	6.1	3.74	2.4	18.8	