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BIOCHEMICAL CHANGES IN TOBACCO DURING FLUE CURING
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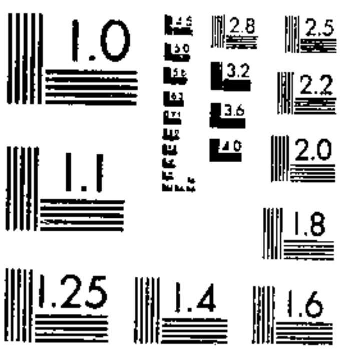

MICROCOPY RESOLUTION TEST CHART
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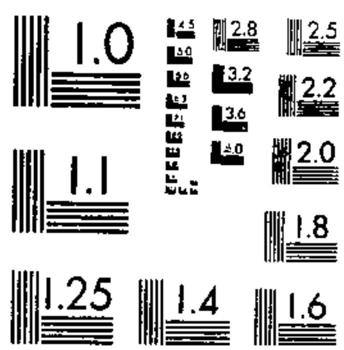

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Biochemical Changes in Tobacco During Flue Curing [1, 2]

By C. W. BACON, *senior physiologist*, RAYMOND WENGER, formerly *associate biochemist*, and JAMES F. BULLOCK, *agronomist, Division of Tobacco, Medicinal, and Special Crops, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration* [3]

United States Department of Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering, in cooperation with the South Carolina Agricultural Experiment Station [4]

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[4] The preliminary work on the different flue-cured types was carried out on samples of tobacco from North Carolina and Georgia Agricultural Experiment Stations, as well as those from the South Carolina station.

INTRODUCTION

FLUE-CURED, or bright, tobacco comprises at present about 62 percent (*26*)[5] of the annual tobacco production of the United States. The agronomic and other aspects of flue-cured tobacco have been studied extensively. Despite its great importance, however, less attention has been given to the biochemistry of its special curing processes than to that of the air-cured tobaccos.

The flue-curing process, requiring only about 5 days for its completion, radically departs from the older process of air curing in certain conditions. The long-used air-curing process, requiring 1 to 2 months for its completion, is carried out in curing barns under the prevailing weather condition, with certain exceptions, and the only control possible is obtained by regulating ventilation. Small fires are at present in general use for the curing of cigar-wrapper tobacco and to a limited extent are used for the curing of burley tobacco. The resulting brown-colored cured tobacco may well be considered as a natural product. In the flue-curing process artificial heat is employed, and its regulation, together with changes in ventilation, permits a controlled curing operation that results in the production of an entirely different, yellow-colored product in about 5 days. The cured tobacco produced is very different in composition from the product obtained by air curing and is essentially an artificial product.

The name of the curing method and of the tobacco itself was taken from the sheet-iron flues that were originally used to distribute the heat. The flues, running from an outside furnace, were located near the floor of the barn and terminated in a smoke pipe outside the barn, thus removing the furnace gases from the various fuels used from contact with the tobacco. However, heating systems without flues are now in common use. They employ different fuels, as kerosene, fuel oils, and the compressed gases propane and butane, in which all the products of combustion are liberated inside the barn.

REVIEW OF LITERATURE

The origin of the flue-curing process and its subsequent modifications, as well as the agricultural and economic situations arising from its widespread use, are interestingly told by Tilley (*25*).

The biochemical changes taking place in a considerable number of the constituents of tobacco during air curing were early studied by Garner, Bacon, and Foubert (*13*). Somewhat later Garner, Bacon, and Bowling (*12*) reported on the relationship of production conditions to the chemical and physical characteristics of cigarette tobaccos (flue-cured and other types) and of cigar tobaccos. They discussed the contrasts in methods of production, curing, chemical composition, physical characteristics, and commercial uses of these tobaccos, but did not consider the changes accompanying their different curing processes. In a series of four extensive studies on flue-cured tobacco, Darkis with Dixon and coworkers (*6, 7, 8, 9*) gave the most complete data on the chemical composition of this class of tobacco yet found. The large number of tobacco samples analyzed was obtained in work covering many aspects of flue-cured tobacco production. The studies covered work on types, seasonal differences, aging, stalk position,

[5] Italic numbers in parentheses refer to Literature Cited, p. 36.

and a limited consideration of fertilizer treatment. All the tobacco examined, however, had been subjected to the flue-curing process, and changes in composition resulting from this treatment were not studied.

In the studies on the flue curing of tobacco by Garner (*10*), Cooper, Delamar, and Smith (*5*), and Moss and Teter (*16*), brief consideration was given to the physiological processes involved. No quantitative data on the changes that take place in the chemical constituents of the tobacco leaf during the flue-curing process, however, were given. Garner (*11*), in his recent book on The Production of Tobacco, considered flue curing briefly and indicated some of the chemical changes occurring during curing, although detailed biochemical analyses of tobacco before and after flue curing were not given.

Ward (*27*) was the first to study some of the physiological changes taking place in tobacco during the flue-curing process. He studied the changes in the carbohydrates and the hemicellulose in flue-cured tobacco. The carbohydrates determined included starch, dextrose, levulose, sucrose, and dextrin. Beginning at harvesttime the changes in percentage composition of these constituents in the curing tobacco leaf were determined at 12-hour intervals throughout the curing process. While many analyses of the composition of flue-cured tobacco itself had been made, this study was the first one in which the initial composition and the subsequent progressive changes during the process of curing were compared.

The work of Ward was carried out on the White Mammoth variety of flue-cured tobacco grown at Ottawa, Canada. The fertilizer applied was 1,000 pounds per acre of a 2-10-8 mixture.

Askew and Blick (*1*) working in New Zealand studied the changes at frequent intervals that occurred in glucose, fructose, and sucrose during flue curing.

PLAN OF THE TESTS

Two series of special tests of flue-cured tobacco were made in the present study. In the first test tobacco of cigarette grade of three of the important types was used: Type 11(b) from Oxford, N. C.; type 13 from Florence, S. C.; type 14 from Tifton, Ga. The carbohydrates in these tobaccos were determined at the end of the curing process and after they had been subsequently processed in bulks in the pack house of the grower in the usual manner prior to marketing. Also, limited consideration was given to the effect of the commercial redrying process on the sugar changes. Special attention was given to the composition of the free reducing sugars and to the changes in sucrose content of the leaf.

In the second series of tests, conducted at Florence, S. C., changes taking place in the carbohydrates and 12 other constituents of tobacco during the flue-curing process were determined. Samples of the tobacco, as harvested, at the end of the yellowing stage, and at the completion of the curing process, were analyzed. In addition, limited analyses were made of tobacco that had been cured in the normal way and of similar tobacco cured by procedures differing considerably at certain stages of the process. Special attention was given the yellowing stage, the leaf-drying stage, and the final temperature used for the stem drying.

CARBOHYDRATES IN FLUE-CURED TOBACCO OF DIFFERENT TYPES AND CHANGES ASSOCIATED WITH THE BULKING PROCESS

METHODS OF SAMPLING AND ANALYSIS

The leaves were selected from plants in the field in order to obtain material of uniform ripeness and composition. In some cases a pair of similar leaves were selected from each of 50 plants and, alternating the upper and lower leaves of each pair, were made into two lots and used for comparative tests. In other tests three uniform lots were prepared by picking three similar leaves from each plant. The middle leaf of the three picked was put into one lot and the other two leaves were used to prepare two additional lots as outlined above. The selected lots of leaves were cured in the regular curing barns at the several locations where experimental work of the Division was being carried on.

In the curing barn the treatment of all samples of a series was the same and like that of other tobacco being cured at the same time. However, as soon as the curing was complete and firing of the barn had ceased, the samples representing the cured tobacco were removed while the barn was still hot and immediately put in airtight containers. Samples that were to be placed directly in the pack house were allowed to remain in the barn and after taking up sufficient moisture were placed with other tobacco to be subjected to the bulking process. Other samples were allowed to take up moisture, redried [6] at a commercial plant, and subjected to the bulking process with other samples.

In conducting the analyses, the free reducing sugars were extracted by the official method (*2, p. 358*) for grain and cattle feed and the determination was carried out by the Quisumbing and Thomas method (*2, p. 138*). The reducing sugar solution was inverted according to the official method (*2, p. 139, sec. 48 (b) 2*) by the use of a preparation of invertase (Wallerstein), and the sucrose was calculated from the increase in reducing sugars. The Jackson-Mathews modification (*2, p. 504*) of Nyns selective method for levulose was used. The dextrose values were obtained as the difference between the free reducing sugars and the levulose.

CARBOHYDRATES IN TOBACCO BEFORE AND AFTER BULKING

Flue-cured tobacco is customarily removed from the curing barn as soon as the dry leaf has taken up sufficient moisture from the air to permit handling without loss from breakage. The tobacco is then packed in a special manner in large piles, or bulks, in a pack house for different periods of time, depending on the type, grade, and other factors, until it is prepared for marketing. The moisture content of the tobacco when removed from the barn and when held in the pack house, may vary greatly with weather conditions. It

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[6] In the redrying operation the tobacco was passed through the machine in about 1 hour. During that time the leaf had been almost completely freed from its moisture at an elevated temperature, approximating 170° F., cooled to 100° to 110°, and reordered to a moisture content of about 12 percent by the use of steam.

may be (1) relatively dry and contain only about 10 percent moisture; (2) in good handling condition, with about 20 percent moisture; or (3) so soft that spoilage takes place. The color of the leaf becomes more uniform, and any moderate amount of green color that remains in the viens of the leaf at the end of the curing is usually removed. These changes, especially the removal of green color, add considerably to the value of the tobacco when marketed.

The quantities of sugars found in the different types of leaf immediately after they had been cured and after they had been kept in bulks are shown in tables 1 and 2. Free reducing sugars in the cured leaves ranged from about 8.5 to 17 percent, values that are on the low side for these tobaccos. The tobaccos were selected to represent cigarette grades that, as a rule, show higher values (*6*). When the free reducing sugars were inverted, however, there was a very considerable increase in total reducing sugars, which then ranged from about 16 to 31 percent. The average increase on inversion, which was carried out by means of invertase, was 9.26 percent, which is the equivalent of 8.80 percent sucrose. The values for the total reducing sugars were in agreement with the values usually given for these types (*6*). The increase in reducing sugars upon acid hydrolysis is usually given as only about 1 or 2 percent. In the samples that had been bulked (with the exception of one that had been in the pack house for only 17 days) the observed increase in reducing sugars on inversion, calculated as sucrose, averaged about 2.5 percent. The large increase found in the samples that were cured only is probably the result of the fact that the material was analyzed in the condition that it was in at the time the curing was completed and before it had been held in a pack house in bulks.

Confirmation of the large increase in reducing sugars found on hydrolysis is given by Ward (*27*), who reported increases, calculated as sucrose, averaging about 10 percent. In that work the material was analyzed at the end of the curing process proper and any changes in sugar relations due to the process of bulking were eliminated. A similar large increase of sugars from hydrolysis was reported also by Noguti, Oka, and Ôtuka (*17*). Although only limited data were recorded, increases in value of reducing sugar content of 4 to 8 percent were reported. The Yellow Orinoco variety of tobacco was used, and the leaf crop was subjected to flue curing.

While the leaf remained in the bulks for periods ranging from 17 to 158 days, there was an average increase of free reducing sugars content of 6.12 percent (table 2). This increase apparently was obtained at the expense of the sucrose, which showed an average decrease of 6.54 percent at the same time. This decrease would account for the formation of somewhat more reducing sugar than was found by analysis. The figures show that in addition to physical changes occurring during the bulking process, chemical changes of considerable magnitude were also taking place. The increase in reducing sugar could result in somewhat of an increase in the hygroscopic property of the tobacco, since levulose is much more hygroscopic than sucrose.

In two of the series of samples the effect of redrying the tobacco in a commercial plant before putting it in the pack house was studied. Losses of sucrose were found to take place in very much the same

TABLE 1.—*Sugars in flue-cured tobacco of several types at the end of the curing process and after storage in bulks in a pack house for different lengths of time*

[Water-free basis]

Type, location at which grown, and treatment	Sample No.	Free reducing sugars [1]	Total sugars after invertase inversion [1]	Sucrose	Free reducing sugars: Levulose	Free reducing sugars: Dextrose	Levulose in free reducing sugars
Type 11 (b), Oxford, N. C.:		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cured only	34-1	9. 01	15. 84	6. 49	5. 21	3. 80	57. 8
Cured only	36-1	17. 15	30. 64	12. 82	7. 68	9. 47	44. 8
Cured, bulked 84 days	36-2	23. 42	28. 64	4. 96	12. 22	11. 20	52. 2
Cured, bulked 158 days	36-3	25. 10	28. 91	3. 62	12. 62	12. 48	50. 3
Cured only	37-A	8. 44	15. 92	7. 11	4. 22	4. 22	50. 0
Cured, redried, and bulked 116 days	37-B	11. 71	14. 57	2. 72	6. 78	4. 93	57. 9
Cured, bulked 118 days	37-C	14. 39	15. 04	. 62	8. 15	6. 24	56. 6
Cured only	39-1	10. 82	21. 03	9. 70	6. 27	4. 55	57. 9
Cured, redried, and bulked 120 days	39-2	18. 19	20. 22	1. 93	10. 30	7. 89	56. 6
Cured, bulked 120 days	39-3	17. 25	19. 58	2. 21	9. 64	7. 61	55. 9
Original green leaf	37-D	. 63	1. 78	1. 09			
Cured only	37-E	15. 18	22. 76	7. 20	7. 70	7. 48	50. 7
Air-cured 42 days	37-F	. 08	. 35	. 26			
Type 13, Florence, S. C.:							
Cured only	36-1	12. 77	22. 96	9. 68	6. 28	6. 49	49. 2
Cured, bulked 17 days	36-2	16. 76	24. 89	7. 72	8. 80	7. 96	52. 5
Cured only	39-2	16. 14	24. 77	8. 20	8. 07	8. 07	50. 0
Cured, bulked 40 days	39-1	22. 87	24. 45	1. 50	11. 34	11. 53	49. 6
Cured only	39-4	14. 98	23. 91	8. 48	7. 65	7. 33	51. 1
Cured, bulked 38 days	39-3	21. 49	23. 33	1. 75	11. 05	10. 44	51. 4
Type 14, Tifton, Ga.:							
Cured only	37-1	17. 01	26. 99	9. 48	8. 61	8. 40	50. 6
Cured, bulked 26 days	37-2	23. 69	26. 51	2. 68	12. 04	11. 65	50. 8
Average							52. 4

[1] Calculated as invert sugar.

TABLE 2.—*Changes in sugars taking place in flue-cured tobacco of different types during storage in a pack house for different lengths of time*

[Water-free basis]

Type, location at which grown, and treatment	Sample No.	Free reducing sugars [1]	Increase in free reducing sugars [1]	Sucrose	Decrease in sucrose
Type 11 (b), Oxford, N. C.:		*Percent*	*Percent*	*Percent*	*Percent*
Cured, bulked 84 days	36-2	23. 42	--------	4. 96	--------
Cured only	36-1	17. 15	6. 27	12. 82	7. 86
Cured, bulked 158 days	36-3	25. 10	--------	3. 62	--------
Cured only	36-1	17. 15	7. 95	12. 82	9. 20
Cured, bulked 118 days	37-C	14. 39	--------	. 62	--------
Cured only	37-A	8. 44	5. 95	7. 11	6. 49
Cured, redried, bulked 116 days	37-B	11. 71	--------	2. 72	--------
Cured only	37-A	8. 44	3. 27	7. 11	4. 39
Cured, bulked 120 days	39-3	17. 25	--------	2. 21	--------
Cured only	39-1	10. 82	6. 43	9. 70	7. 49
Cured, redried, bulked 120 days	39-2	18. 19	--------	1. 93	--------
Cured only	39-1	10. 82	7. 37	9. 70	7. 77
Type 13, Florence, S. C.:					
Cured, bulked 17 days	36-2	16. 76	--------	7. 72	--------
Cured only	36-1	12. 77	3. 99	9. 68	1. 96
Cured, bulked 40 days	39-1	22. 87	--------	1. 50	--------
Cured only	39-2	16. 14	6. 73	8. 20	6. 70
Cured, bulked 38 days	39-3	21. 49	--------	1. 75	--------
Cured only	39-4	14. 98	6. 51	8. 48	6. 73
Type 14, Tifton, Ga.:					
Cured, bulked 26 days	37-2	23. 69	--------	2. 68	--------
Cured only	37-1	17. 01	6. 68	9. 48	6. 80
Average	--------	--------	6. 12	--------	6. 54

[1] Calculated as invert sugar.

amounts as in the tobacco that had not been redried. Although the number of tests were small, they appear to show that the inversion of sucrose is not changed materially by the drying treatment.

It was found possible to bring about the change of some of the sucrose present in tobacco after curing in the laboratory in much the same manner as in the bulking process itself. A small quantity of powdered flue-cured tobacco was exposed in a desiccator over a saturated solution of sodium nitrate, which maintained a relative humidity of about 72 percent, for a week, and analyses were made before and after the treatment. A reduction in the sucrose content from 8.7 to about 3.7 percent and an accompanying increase in free reducing sugars was found. This indicates that under favorable conditions the process of inversion takes place rapidly.

The difference in composition of tobacco brought about by the method of curing used is shown in a special comparison (table 1). When tobacco was flue-cured the sugar content was about 23 percent, but when air-cured only about 0.4 percent sugar was found. Also, the flue-cured leaves were yellow and the air-cured leaves, brown—the usual colors obtained by these methods of curing.

Nature of the Carbohydrates in Flue-Cured Tobacco

Although carbohydrates are present in large amounts and different forms in flue-cured tobacco, they have never been completely identified. Some of the methods of analysis used in the study of carbohydrates in flue-cured tobacco indicate the presence of sucrose, dextrose, and levulose specifically. The free reducing sugar fractions are usually hydrolyzed by a mineral acid or one of the stronger organic acids, and the increase in reducing sugars is calculated as sucrose. However, their action is more or less general and not limited to any particular compound that would result in the formation of a reducing sugar. The action of the enzyme invertase is specific, and only sucrose is hydrolyzed. Also, the hydrolysis of sucrose results theoretically in the formation of equal parts of dextrose and levulose, and special analysis for the levulose component showed that it made up about 52 percent of the free reducing sugar fraction. Further evidence of the identity of the sucrose was given by a polarimetric test of the reducing sugar from one sample before and after invertase treatment, when more than 10 percent of sucrose was found.

BIOCHEMICAL CHANGES IN FLUE-CURED TOBACCO DURING THE CURING PROCESS

Methods of Conducting Tests

At the Pee Dee Experiment Station Florence, S. C., biochemical changes in the carbohydrates and 12 other constituents of tobacco during the flue-curing process were studied. Material for the tests was supplied by a large planting of the Gold Dollar variety of tobacco. The fertilizer treatment consisted of 1,000 pounds per acre of a 3–8–6 mixture and a top dressing of 30 pounds of nitrate of soda and 100 pounds of sulfate of potash (applied at the first cultivation).

The curing tests were made in a specially constructed barn divided into four completely separate units, each 9 feet by 9 feet by 18 feet, or approximately one-fourth the size of a regular curing barn. The building was of double board-wall construction, with two layers of building paper and rock wool insulation. Each compartment was complete and was provided with its own electric heating system, forced-air heat-distributing system (with return duct), a recording thermometer, and a recording psychrometer. The thermometer bulb was located in the center of the compartment under the first tier pole, and the ventilated psychrometer bulbs were mounted in the center of the compartment at the level of the middle tier pole.

The tobacco samples that were analyzed were cured in one of the units filled with similar leaves of the same priming picked at the same time. Undamaged leaves of average maturity and size were dealt into as many lots of leaves as desired for a study. When lots of 25 leaves each had been selected, a second series was prepared in the same manner. Lots of 50 leaves each were then made by combining the lot of greatest weight from one series with that of least weight from the other series and repeating the operation with the remaining lots.

One of the selected leaf samples in each test was used as a control to represent the original condition of the ripe tobacco when harvested. Control samples were dried in a large forced-air ventilated oven at a temperature of 140° to 149° F. (60° to 65° C.). The midribs were cut away from the tissue, split, and then hung with the leaf tissue in the drying oven. At the end of the curing the fully cured leaves were removed from the barn before the temperature was allowed to fall. As the stems as well as the leaf tissue were thoroughly dry, the material was broken up immediately and placed in preserve jars. Prior to analysis the dry sample was ground in a Wiley mill, then passed through a 40-mesh sieve, and stored in preserve jars.

The analytical data were corrected for the moisture remaining in the dry leaves and also for the small amount of mechanically held sand found in the ash determinations. In addition, since there was a loss in weight of dry matter during the curing, it was necessary to make a correction for this loss and to express all the results on the same original weight basis. Otherwise, the changes occurring during the curing process would not have been correctly shown. The correction factor for the loss in weight during curing can be determined directly from the weight of dry matter found in the leaves when harvested and that present in similar leaves after having been cured. However, as the calcium content of the leaves could not change during the process, it was found more desirable to use the values for this element in the original and cured material as the basis for calculating the correction factor, except in the first two curings on which weight losses were determined from the actual leaf weights.

Methods of Analysis

Starch.—Material previously extracted with 80 percent alcohol for the determination of sugars was used. After drying at room temperature the starch was gelatinized by the official method for grain and stock feeds in the presence of interfering polysaccharides (*2, p. 360*). Hydrolysis was effected by malt amylase (Wallerstein) in the presence of McIlvaine's buffer solution (*14*) having a pH of 5.2. Reducing sugars were then determined by the Phillips method (*18, 19*).

Sugars.—The several sugars were extracted by the official method for sugars in plants (*2, p. 138*). The free reducing sugars present as such and associated with the determinations of levulose and sucrose were determined by the Phillips method (*19*). Levulose was determined after removing dextrose by oxidizing with iodine in potassium iodide solution (J. T. Sullivan,[7] private communication). The inversion of sucrose was carried out with invertase (Wallerstein) by the official method for sucrose in plants (*2, p. 139, sec. 48 (b) 2*).

Crude fiber.—The official method (*2, p. 357*) was used.

Nitrogen.—Total nitrogen determination was made according to the official Kjeldahl method modified to include the nitrogen of nitrates (*2, pp. 26–27*). The protein nitrogen was determined by the Mohr method (*15*) by boiling 2 gm. of the material for 5 minutes with 100 ml. of 0.5 percent acetic acid, filtering when cold, and washing with hot 0.5 percent acetic acid. The nitrogen in the residue was

[7] Physiologist, U. S. Regional Pasture Research Laboratory, State College, Pa.

determined by the official Kjeldahl-Gunning-Arnold method (*2, p. 26*).

Nicotine.—The official silicotungstic acid method for tobacco and tobacco products (*2, p. 64*) was used.

Ash.—The tobacco was ignited in a silica dish in a muffle furnace for 2 hours at 550° C., until light gray in color. The crude ash was then treated with hot water, filtered, and washed. The filter paper and residue were returned to the original dish and ashed until white. The filtrate was added, evaporated on steam bath, and ignited to constant weight. The sand present was determined (*2, p. 125*), and the results calculated as sand-free ash.

Calcium.—The official macro method for plants (*2, p. 127*) was used.

Oxalic, citric, and malic acids.—Extraction of the tobacco after mixing with sulfuric acid and pumice stone was made with ether for 40 hours, using the method of Pucher, Vickery, and Wakeman (*22*). The ether was removed, and the extracted acids taken up in a water solution. For the determination of oxalic acid, the solution was first treated with hydrochloric acid that caused the precipitation of some interfering organic material, which was removed by filtration. A double precipitation of the oxalic acid was then made with calcium chloride. The calcium oxalate was determined by titration with potassium permanganate solution. The citric acid was determined by the pentabromoacetone method of Pucher, Vickery, and Leavenworth (*20*). The malic acid was also determined by the method of Pucher, Vickery, and Wakeman (*21*). This method is based on the formation of a bromine compound volatile with steam that combines with dinitrophenylhydrazine to form an insoluble compound. Solution of the compound in pyridine in the presence of alkali develops a blue color that is measured spectrophotometrically.

Resins.—Determination of the resins was made following the method of Pyriki (*23*) of extracting the tobacco with ethyl alcohol and then washing the resins so obtained. The final purified product weighed contains the total resins and waxes, as well as the ethereal oils with boiling points above that of ethyl alcohol.

Pectins.—The method of Balabuha-Popzova (*3*) for determining pectinic acid by the carbon dioxide formed from the decomposition of the pectin materials was used. The tobacco was first boiled with 75 percent alcohol and then washed on a filter paper with more of the alcohol to remove substances of a nonpectin nature, which liberate carbon dioxide under the conditions of the method. Tobacco and filter paper were then placed in the decomposition flask and hydrochloric acid added, and any carbon dioxide formed by the decomposition of carbonates present was removed by means of a current of carbon dioxide free air. The reaction mixture was heated at 130° C. for 5 hours, and the weight of carbon dioxide evolved, after passing through a purifying train, was determined by absorbing in a sodium hydroxide-asbestos preparation contained in an absorption bulb.

pH value.—The pH value was determined electrometrically by use of a glass electrode. The water extract was prepared according to Brückner (*4*) by shaking 5 gm. of tobacco with 100 ml. of freshly boiled distilled water, allowing it to stand, and filtering.

Moisture.—The powdered tobacco (2 gm.) was dried in aluminum moisture dishes for 4 hours at 100° C.

Changes in Composition During Flue Curing

Curing tests were made on two primings of tobacco each year for 3 years. The third or fourth pickings were used of leaf of the high grade usually employed in cigarette manufacture. Analyses were made of the leaf as harvested, when yellowed, and when the curing was complete.

The differences in composition between the original green tobacco and the yellowed leaf and the differences between original leaf and cured leaf also were determined.

The composition of the material used varied to a certain extent from year to year. Some of the variation in the composition of materials resulted also because of difficulty in selecting strictly comparable samples of plant materials. However, the nature of the changes occurring during the curing process remained the same and, in order to simplify their consideration, the results of the several tests, calculated as averages, are shown in table 3. The results of the 3 years' tests are shown separately in tables 4, 5, and 6. All the values are on a sand- and water-free basis, and the data for the material in the yellow stage and when cured have been corrected to the original dry-weight basis. The average loss of weight, with one exception, was approximately 8.8 percent at the yellowed stage and 13.3 percent when fully cured.

Table 3.—*Changes in composition of tobacco during the flue-curing process* [1]

[Averages of 6 curings]

Constituents	Green	Yellowed	Difference, green to yellowed	Cured	Difference, green to cured
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Starch	29.30	12.40	−16.90	5.52	−23.78
Free reducing sugars [2]	6.68	15.02	+9.24	16.47	+9.79
Levulose	2.87	7.06	+4.19	7.06	+4.19
Sucrose	1.73	5.22	+3.49	7.30	+5.57
Crude fiber	7.28	7.16	−.12	7.34	+.06
Total nitrogen	1.08	1.01	−.04	1.05	−.03
Protein nitrogen	.65	.56	−.09	.51	−.14
Nicotine	1.10	1.02	−.08	.97	−.13
Ash	9.23	9.24	+.01	9.25	+.02
Calcium [3]	1.37	1.37	±0	1.37	±0
Oxalic acid	.96	.92	−.04	.85	−.11
Citric acid	.40	.37	−.03	.38	−.02
Malic acid	8.62	9.85	+1.23	8.73	+.11
Resins	7.05	6.53	−.52	6.61	−.44
Pectinic acid	10.99	10.22	−.77	8.48	−2.51
pH value	5.55	5.61		5.55	

[1] Data on water- and sand-free basis. Yellowed and cured samples calculated to original dry-weight basis.

[2] Calculated as dextrose.

[3] Average of 4 curings.

TABLE 4.—*Changes in composition of tobacco occurring during the flue-curing process, 1940* [1]

Constituents	Third priming [2]					Fourth priming [2]				
	40–14, green	40–21, yellowed	Gain or loss	40–22, cured	Gain or loss	40–38, green	40–39, yellowed	Gain or loss	40–31, cured	Gain or loss
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Starch	33. 37	9. 49	−23. 88	5. 61	−27. 76	28. 56	15. 49	−13. 07	4. 48	−24. 08
Free reducing sugars [3]	4. 92	19. 51	+14. 59	19. 12	+14. 20	5. 53	12. 14	+6. 61	12. 35	+6. 82
Levulose	2. 14	8. 83	+6. 69	8. 29	+6. 15	1. 84	4. 93	+3. 09	5. 81	+3. 97
Sucrose	2. 65	7. 57	+4. 92	6. 57	+3. 92	2. 41	5. 87	+3. 46	6. 78	+4. 37
Crude fiber	6. 67	6. 64	−. 03	6. 60	−. 07	7. 68	7. 15	−. 53	7. 59	−. 09
Total nitrogen	1. 05	1. 04	−. 01	1. 05	±0	1. 36	1. 27	−. 09	1. 29	−. 07
Protein nitrogen	. 65	. 47	−. 18	. 48	−. 17	. 65	. 84	+. 19	. 55	−. 10
Nicotine	1. 14	1. 04	−. 10	. 96	−. 18	1. 14	1. 18	+. 04	. 99	−. 15
Ash	9. 54	9. 21	−. 33	9. 36	−. 18	9. 50	8. 61	−. 89	8. 89	−. 61
Oxalic acid	1. 12	1. 03	−. 09	. 95	−. 17	1. 15	1. 12	−. 03	1. 08	−. 07
Citric acid	. 49	. 41	−. 08	. 41	−. 08	. 34	. 31	−. 03	. 32	−. 02
Malic acid	7. 58	9. 60	+2. 02	7. 72	+. 14	8. 36	8. 41	+. 05	7. 24	−1. 12
Resins	7. 69	6. 86	−. 83	6. 23	−1. 46	7. 64	7. 18	−. 46	6. 53	−1. 11
Pectinic acid	16. 88	12. 58	−4. 30	11. 74	−5. 14	11. 32	12. 04	+. 72	11. 02	−. 30
pH value	5. 92	5. 94	------	5. 95	------	5. 48	5. 50	------	5. 38	------

[1] Data on water- and sand-free basis. Yellowed and cured samples calculated to original dry-weight basis.
[2] 40–14, etc., indicate the year and the lot number of the sample.
[3] Calculated as dextrose.

Table 5.—*Changes in composition of tobacco occurring during the flue-curing process, 1941* [1]

Constituents	Third priming [2]					Fourth priming [2]				
	41-15, green	41-21, yellowed	Gain or loss	41-20, cured	Gain or loss	41-23, green	41-27, yellowed	Gain or loss	41-29, cured	Gain or loss
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Starch	33.48	7.47	−26.01	6.35	−27.13	38.61	17.92	−20.69	7.90	−30.71
Free reducing sugars [3]	8.36	17.24	+8.88	19.93	+11.57	7.70	15.60	+7.90	15.23	+7.53
Levulose	3.69	8.07	+4.38	8.57	+4.88	2.79	7.17	+4.38	6.91	+4.12
Sucrose	.49	2.57	+2.08	7.01	+6.52	1.47	4.80	+3.33	7.99	+6.52
Crude fiber	7.76	8.26	+.50	8.59	+.83	7.90	7.65	−.25	7.56	−.34
Total nitrogen	1.01	1.02	+.01	.99	−.02	1.08	1.06	−.02	.98	−.10
Protein nitrogen	.70	.55	−.15	.55	−.15	.74	.58	−.16	.53	−.21
Nicotine	.96	.80	−.16	.72	−.24	.97	.94	−.03	.95	−.02
Ash	11.26	11.45	+.19	11.30	+.04	8.28	8.50	+.22	9.14	+.86
Calcium	1.21	1.21	±0	1.21	±0	.94	.94	±0	.94	±0
Oxalic acid	.92	.89	−.03	.77	−.15	.74	.61	−.13	.48	−.26
Citric acid	.25	.27	+.02	.33	+.08	.25	.27	+.02	.24	−.01
Malic acid	6.36	8.82	+2.46	8.11	+1.75	6.30	7.78	+1.48	6.25	−.05
Resins	6.19	6.06	−.13	7.73	+1.54	6.79	5.71	−1.08	5.09	−1.70
Pectinic acid	10.56	9.85	−.71	9.08	−1.48	11.75	11.46	−.29	8.01	−3.74
pH value	5.40	5.55	-------	5.50	-------	5.60	5.76	-------	5.52	-------

[1] Data on water- and sand-free basis. Yellowed and cured samples calculated to original dry-weight basis.
[2] 41-15, etc., indicate the year and lot number of the sample.
[3] Calculated as dextrose.

TABLE 6.—*Changes in composition of tobacco occurring during the flue-curing process, 1942* [1]

Constituents	Third priming [2]					Third priming [2]				
	42–14, green	42–yellowed	Gain or loss	42–8, cured	Gain or loss	42–green	42–yellowed	Gain or loss	42–17, cured	Gain or loss
	Percent	*Percent*	*Percent*		*Percent*		*Percent*	*Percent*	*Percent*	*Percent*
Starch	17. 66	12. 50	−5. 16	4. 69	−12. 97	24. 14	11. 52	−12. 62	4. 07	−20. 07
Free reducing sugars [3]	6. 16	16. 61	+10. 45	17. 68	+11. 52	7. 42	14. 45	+7. 03	14. 51	+7. 09
Levulose	3. 88	7. 41	+3. 53	6. 62	+2. 74	2. 87	5. 92	+3. 05	6. 16	+3. 29
Sucrose	1. 88	5. 26	+3. 38	7. 40	+5. 52	1. 45	5. 24	+3. 79	8. 04	+6. 59
Crude fiber	6. 76	6. 67	−. 09	6. 93	+. 17	6. 90	6. 56	−. 34	6. 79	−. 11
Total nitrogen	. 94	. 87	−. 07	. 97	+. 03	1. 04	. 99	−. 05	1. 02	−. 02
Protein nitrogen	. 52	. 46	−. 06	. 47	−. 05	. 65	. 48	−. 17	. 48	−. 17
Nicotine	. 95	. 88	−. 07	. 91	−. 04	1. 41	1. 28	−. 13	1. 27	−. 14
Ash	7. 59	7. 43	−. 16	6. 62	−. 97	9. 23	10. 22	+. 99	10. 22	+. 99
Calcium	1. 71	1. 71	±0	1. 71	±0	1. 63	1. 63	±0	1. 63	±0
Oxalic acid	. 90	. 98	+. 08	. 94	+. 04	. 91	. 90	−. 01	. 89	−. 02
Citric acid	. 52	. 50	−. 02	. 46	−. 06	. 53	. 43	−. 10	. 51	−. 02
Malic acid	12. 36	10. 66	−1. 70	11. 18	−1. 18	10. 73	13. 81	+3. 08	11. 90	+1. 17
Resins	6. 87	6. 64	−. 23	7. 09	+. 22	7. 12	6. 73	−. 39	6. 98	−. 14
Pectinic acids	9. 71	8. 21	−1. 50	6. 56	−3. 15	5. 70	7. 20	+1. 50	4. 48	−1. 22
pH value	5. 52	5. 60	--------	5. 61	--------	5. 52	5. 60	--------	5. 50	--------

[1] Data on water- and sand-free basis. Yellowed and cured samples calculated to original dry-weight basis.
[2] 42-14, etc., indicate the year and lot number of the sample.
[3] Calculated as dextrose.

The outstanding changes in composition of the tobacco during the flue-curing process were in the carbohydrate group. The initial value of approximately 29 percent starch was reduced to about 12 percent when the leaf was yellowed and to about 5.5 percent when the leaf was cured. The total free reducing sugars increased about 10 and levulose about 4 percent. The entire change in these two sugars appeared to take place during the yellowing stage. Sucrose had increased by about 3.5 percent at the end of the yellowing and continued to increase to a final value of about 5.5 percent at the end of the curing. The tobacco in the green condition was low in all three sugar components, and the origin of the increased quantities found was evidently associated with the large loss of starch. The final total sugar content of about 24 percent characterizes good flue-cured tobacco and stands in marked contrast with the sugar content of the air-cured types in which these components are practically absent.

The origin of the increase in sucrose, which averages about 5.5 percent in the cured leaf, is of interest from the standpoint of plant physiology. Although increases in sucrose were accompanied by loss of starch, its derivation from starch is speculative. The amount of sucrose found is also higher than usually reported, since, as previously noted, many of the analyses recorded were made on leaf that had been held for a considerable time in large bulks in a packing house. Under such conditions change of sucrose to reducing sugars readily takes place. The present samples were removed from the curing units when dry and before there had been a drop in the temperature and were not allowed to take up moisture again.

The content of crude fiber, which is essentially cellulose, remained very near the value of 7.25 percent at all stages of curing. A material change in amount present was not indicated at any time, which was to have been expected, considering the very stable properties of cellulose.

Although the sugar content of the tobacco under observation was at a maximum value, the nitrogen-containing compounds were correspondingly low. The leaf was of a light color and thin and of the type generally considered as having a very high carbohydrate and low nitrogen content. Small losses of a few hundredths of a percent of nitrogen were found, and the total quantity present was about 1 percent. Corresponding to the low total nitrogen content the protein nitrogen in the tobacco was also exceedingly low. Although the change in this component was small, a consistent loss of about 0.15 percent was found between the green and cured material. The total amount present was about 0.65 percent, and the loss represents about 20 percent of that originally present. The nicotine content of the samples was also low and averaged about 1.10 percent, and there was an indicated loss of about 0.13 percent during the curing process. Highest temperatures reached in the tests were about 180° F., and, under the curing conditions employed, there was no ammoniacal or similar odor at any stage of the process to indicate the decomposition of nitrogen compounds. When higher temperatures are used, an irritating atmosphere and penetrating odors are developed.

The ash constituents of flue-cured tobacco are low when compared with other types—only about 9.25 percent was present in the original material. As the constituents of the ash could not be changed by the conditions of the curing process a real loss or gain could not occur. Although changes in percentage were found for separate tests, when averaged no differences were found in the value for ash. The value for calcium, which could be determined with greater accuracy than that for total ash, was used as the basis for making the correction for the losses in weight occurring during the curing. Obviously on this basis all calcium values in a series would be the same, as well as the value of the original material itself, which averaged about 1.4 percent.

Oxalic, citric, and malic acids, frequently considered together as total organic acids, represented approximately 10 percent of the weight of the original leaf. They are, without doubt, important in determining the character of the tobacco leaf. Greater attention would be given them except for the fact that the method for their extraction (continuous long-time extraction with ether) and the none too satisfactory method for determining malic acid make their study very difficult.

About 1 percent of oxalic acid was found in the green leaf, and there was an indicated loss of about 0.10 percent during the curing. This acid is a constituent of all types of tobacco and is little changed by any method of curing. Only about 0.40 percent citric acid was present, and the changes in percentage during curing were consistently so small that no real change was indicated. The malic acid value was much higher than either oxalic or citric; an average value of 8.6 percent was found in the green tobacco. An indicated average gain of about 1 percent was found during the yellowing and practically no change at the end of the process. Malic acid is known to undergo changes quite readily, but as the changes found varied considerably for the different years and the method of analysis used is not entirely satisfactory, no significance is attached to the indicated change.

The resins include various compounds of the nature of resins, gums, and waxes, and make up about 7 percent of the composition of the green tobacco. A small loss of these compounds occurred, but from the chemical nature of the group it is not considered significant. These compounds are of special interest because of their effect on the aroma of tobacco.

Included in the pectinic acid determination are various compounds contained in the cell-wall structure of the tobacco leaf. The average quantity of this acid found was about 11 percent, with wide variation, and there was an apparent loss of around 2 percent. The materials of the group are considered important in determining the water-holding properties of the tobacco (*3*).

The acidity of the flue-cured type of tobacco is higher than that of any of the other tobacco types and is an important factor in its smoking characteristics. The pH values found were around 5.5 in the tobacco as harvested, and as the greatest differences were only about 0.2 pH no real change was considered as having taken place.

Curing Data of Samples Analyzed and Limiting Conditions

The tobacco analyzed was cured in the special curing units under the direction of experienced persons, in a manner considered desirable for the particular lot of tobacco being tested. The details of the operating conditions actually used are given in table 7. The conditions under which different tobacco "curers" operate differ to a considerable degree although they all result in a good final product. As shown in the table, the tobacco used in the first three cures was left in the compartments overnight unheated while in the last three cures the heating of the compartments was begun shortly after they were filled. Conditions used for the yellowing stage of curing vary more than those used for the other stages, and practices used successfully with one type of flue-cured tobacco cannot be applied successfully to all the others.

Fortunately the tobacco leaf itself affords a good index to experienced persons of the progress of its curing. Otherwise the commercial curing of the enormous production of this type, approximately 1,317,466,000 pounds in 1948 (*26*), could not be accomplished. Certain departures from an indicated normal curing procedure were intentionally made, and the results obtained are considered in a later section. These tests showed that a considerable range of curing conditions can be used without materially changing the cured tobacco obtained.

The successful conduct of the curing depends upon the controlled action of the enzymes of the tobacco plant to bring about the desired biochemical changes. If the temperature that the enzymes can tolerate is exceeded too soon, the transformations are abruptly ended and a less desirable product will result. Also, if the leaf dries to such an extent that the enzymes are unable to function and produce the desired changes in the leaf, the cure will be unsatisfactory.

The highest temperature to which it is safe to subject the tobacco leaf enzymes will vary, and as is true of other enzymes the critical temperature will depend upon such factors as length of time of exposure, moisture conditions, presence of other substances, and acidity. Consequently, it becomes a matter of judgment on the part of the operator to determine the upper limits of temperature to use during the critical yellowing period. Tobacco leaves vary so much in ripeness at the same time that it is only possible to harvest leaves in approximately the same degree of ripeness. Great care is used to keep curing conditions of temperature and drying within safe limits, but the fact that there is always some green color remaining in some leaves probably indicates that for those leaves, at least, the upper limits of the curing operation have been exceeded.

THE FLUE-CURING PROCESS

The production of bright, or flue-cured, tobacco of yellow color is of comparatively recent origin compared to the production of other tobaccos. Following the demand for lighter colored, milder tobacco, successful production of the new type by the use of charcoal burned in small fires under the leaves in the barn was evolved. Subsequently, furnaces placed outside the barn and burning wood were used in conjunction with sheet-iron flues inside the barn (*25, p. 18*). The original flue-curing system was used without major changes for about 100 years; more recently, modern house-heating systems, using oil and coal, have been adapted to the purpose.

It is only recently that investigations of the flue-curing process itself and the use of different fuels for heating the curing barns have

TABLE 7.—*Temperature and humidity in curing compartments during the curing of the tobacco, 1940–42* [1]

Time		1940				1941				1942			
		Third priming, lots 21, 22 [2]		Fourth priming, lots 30, 31 [3]		Third priming, lots 21, 20 [4]		Fourth priming, lots 27, 29 [5]		Third priming, lots 12, 8 [6]		Third priming, lots 19, 17 [7]	
Days	Hours	Temperature	Humidity	Temperature	Humidity	Temperature	Humidity	Temperature	Humidity	Temperature	Humidity	Temperature	Humidity
		° F.	*Percent*	*° F.*	*Percent*	*° F.*	*Percent*	*° F.*	*Percent*	*° F.*	*Percent*	*° F.*	*Percent*
	0	84	92	85	96	81	96	80	96	90	96	94	92
	4	96	93	96	100	88	96	86	100	90	96	94	89
	8	100	93	97	96	90	96	86	100	90	92	94	89
	12	100	93	101	93	90	96	90	100	90	88	94	92
	16	101	93	101	93	90	92	90	96	91	88	94	92
	20	101	89	102	96	88	96	90	92	95	92	95	92
	24	101	89	99	96	88	96	90	96	95	96	97	93
1+	4	102	89	100	96	90	89	96	96	96	89	100	89
	8	102	86	101	96	97	92	96	96	96	85	100	89
	12	103	86	100	93	98	92	103	80	95	85	100	86
	16	103	86	100	93	100	89	107	80	95	82	100	86
	20	106	87	100	93	115	78	110	84	100	83	106	83
	24	113	68	108	90	115	84	110	78	108	71	111	83
2+	4	120	69	112	78	117	84	114	76	113	67	115	65
	8	133	64	116	74	122	76	125	72	114	62	117	52
	12	141	46	120	67	123	77	125	67	114	55	120	47
	16	148	36	129	61	130	70	126	61	114	53	120	47
	20	155	26	136	52	137	57	136	62	125	50	124	43
	24	177	23	148	46	139	49	138	54	127	45	127	38

3+	4	174	20	158	31	148	47	145	42	129	37	136	36
	8	174	18	165	25	151	36	146	39	137	37	137	36
	12	174	18	166	23	168	27	163	28	135	33	141	28
	16					169	20	168	23	135	30	142	24
	20					183	17	176	21	141	31	157	16
	24					181	20	180	18	143	27	180	12
4+	4					182	19	180	16	154	24	181	12
	8					182	18	180	15	154	18	181	10
	12									154	16	181	10
	16									158	13		
	20									176	11		
	24									176	11		

[1] After harvesting the tobacco for 1940 and the third priming of 1941, the lots remained in the closed compartments overnight before the heating, as shown above, was begun; for fourth priming of 1941 and for the 1942 tobacco, the heating was begun the same day the compartments were filled.

[2] Yellowed in 1 day 6 hours. Leaf tissue dry in about 2 days 22 hours. Curing completed in 3 days 9 hours.

[3] Yellowed in 1 day 6 hours. Leaf tissue dry in about 2 days 21 hours. Curing completed in 3 days 10 hours.

[4] Yellowed in 1 day 3 hours. Curing completed in 4 days 6 hours.

[5] Yellowed in 1 day 10 hours. Curing completed in 4 days 8 hours.

[6] Yellowed in 1 day 17 hours. Leaf tissue dry in 4 days. Curing completed in 4 days 23 hours.

[7] Yellowed in 1 day 19 hours. Leaf tissue dry in about 3 days 16 hours. Curing completed in 4 days 10 hours.

been carried out. Cooper, Delamar, and Smith (*5*) studied the curing of bright-leaf tobacco by means of conditioned air. Moss and Teter (*16*) reported on the curing of bright-leaf tobacco and charted the atmospheric condition that it is desirable to maintain in the barn during the curing. Also, the use of wood, oil, and coal as fuel was investigated, including their operating costs. Teter and Moss (*24*) made a special study of the installation and operation of coal stokers for tobacco curing.

The flue curing of tobacco as ordinarily carried out is an empirical process, the success of which depends to a considerable degree on the experience of the curer, and particularly his experience with the type and variety of leaf being processed. The tobacco of particular flue-cured types is not the same; soil and seasonal differences in tobacco-growing areas are large, and the degree of ripeness, the position of the leaf on the plant, the moisture condition of the leaf as harvested, and the cultural practices followed in growing it all have an effect on the tobacco produced. The various qualities in the tobacco will, to a considerable degree, determine the best plan to follow in curing it. The operator conducts the curing on the basis of his observation of the condition of the leaf, especially its color and degree of dryness, and on the temperature and humidity of the air within the barn and outside as well. While the ranges of temperature and humidity employed will not vary materially in a series of curings, the duration of the several conditions for each and the time of their application will be subject to change. The recent utilization of automatic heating equipment and controls in curing barns has greatly reduced the labor required in supervising the curing process.

The exact conditions under which one lot of tobacco is properly cured will not necessarily be most desirable in another curing. This is especially true with respect to the conditions obtaining while the tobacco is in the yellowing stage. The destruction of the green color that should take place must be accomplished during that stage and before the curing process can be advanced safely to the next stage. Incomplete yellowing cannot be corrected later in the process, and its effect on the cured leaf will be self-evident and detrimental to the value of the tobacco produced. With the limited applicability of any particular set of curing conditions in mind, the record of a normal curing of a fourth priming of South Carolina tobacco has been charted in figure 1. The chart shows the usual time, temperature, and humidity relations, and also the changes in water content of the leaf as well as the fuel consumption. The curing was made in one of the electrically heated compartments of the specially constructed curing barn, which was equipped with return-air circulation.

The desired high humidity and low temperature during the yellowing stage are shown, as well as the very considerable loss of original green weight that took place at the same time. Losses in weight of around 30 percent were observed in a number of tests. These losses are desirable in order that too much moisture will not remain in the leaf when the temperature is increased and the remaining moisture will come off more rapidly. The thickness of the leaf determines to a considerable degree the temperature that can be safely used without causing the leaf tips to dry out when still containing some green color and also determines the length of time required to complete the

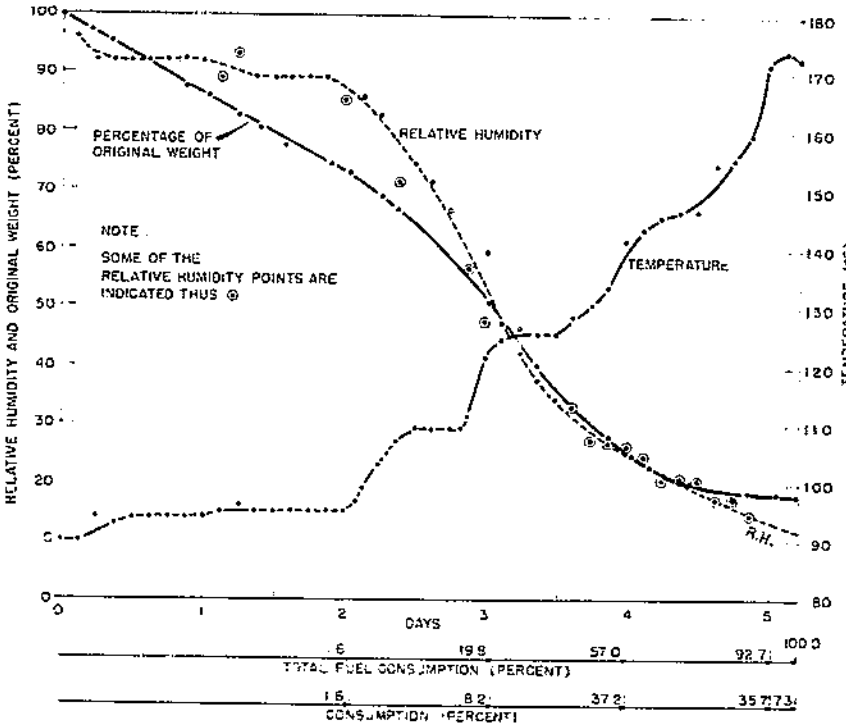

FIGURE 1.—The temperature and humidity conditions, percentage of original weight of tobacco, and fuel consumption during a curing by the flue-cured method.

yellowing of leaf web and leaf veins. Although 2 days may be required for yellowing, the fuel consumption during this period will be only a small percentage of the total.

The drying of the leaf continued rapidly as the temperature was raised. At a temperature of about 130° F. and a relative humidity of about 30 percent, after about 3¾ days there was an indicated loss of about 70 percent of the original green weight and a fuel consumption of about 50 percent of the total. The drying of the leaf tissue is frequently completed at this temperature, and the drying of the stem, which still contains a large amount of water, is carried out at a temperature of 175° F., or considerably higher. A final weight loss of 82 percent of the original green leaf was found, at which time the humidity was decreased to the very low figure of about 12 percent. The final leaf and stem drying can be accomplished without material change in the product at varying drying rates, depending to some extent on the capacity of the heating system.

The large difference in rate of loss of water from the leaf web and leaf stem greatly extends the time required for curing. Using tobacco grown at Oxford, N. C., the moisture content of the two parts of the leaf was determined at several stages of the curing in two tests and the results averaged. The following average percentages of moisture content were obtained: Original uncured leaf—whole leaf, 84.2, blade, 81.4, stem, 90.7; yellowed leaf—whole leaf, 76.7, blade, 70.9, stem, 86.5; leaf-dry stage—whole leaf, 40.0, blade, 16.1, stem, 78.3; cured leaf—whole leaf, 5.8, blade, 5.4, stem 6.9.

EFFECTS OF CHANGING THE CURING CONDITIONS ON THE COMPOSITION OF THE TOBACCO

Several tests were made on the effects of departures from the normal curing conditions on the composition of the tobacco produced. The compartment curing units were used, and in each test in which the Gold Dollar variety was employed a comparison was made with similar tobacco cured in the normal manner. As the changes made in the curing conditions were not great enough to destroy the value of the tobacco, the differences found in composition were in the degree of change only rather than in qualitative differences. The values given in the tables are the composition values of the material itself at the completion of the treatments. The value figures are not corrected to an original dry-weight basis, as comparisons based on the final composition of the material itself seemed of most interest.

Effects of Different Yellowing Temperatures

A series of three curings was made of second primings of tobacco in which a temperature difference of about 10° F. was used during the yellowing of the leaf. A lower temperature range of about 85° to 95°, a normal temperature range of about 90° to 100°, and a higher temperature range of about 95° to 105° were used. The yellowing periods used for the lower, normal, and higher treatments were 49, 46, and 46 hours, respectively. The yellowing of the leaves at the lower temperature treatment was not so complete as at the normal and higher temperatures. The curings were completed at the same relative rates, with a final temperature of about 170°, and good colored tobacco was obtained in all the tests. Curing time was 5 days 5 hours for the lower, 4 days 23 hours for the normal, and 4 days 18 hours for the higher yellowing temperature treatment. Grading of the cured tobacco at the station put 3.7 percent of the leaf from the lower temperature treatment, 0.8 from the normal, and 6.1 from the higher temperature into a "Green" grade. Results of chemical composition determinations recorded are given in table 8.

At the yellowed stage of the curings the content of reducing sugars in the tobacco from the three yellowing treatments differed by only 1.28 percent, and at the cured stage by 3.79 percent. The sucrose values were all about the same at the yellowed stage, regardless of the treatment used, but at the cured stage the sucrose value from the lower temperature treatment was slightly less than when the normal or the high temperature treatments were used. The total sugars in the tobacco at the yellowed stage of the tests were practically the same from the three different temperature treatments, and at the cured stage there was a range of only slightly more than 3 percent in the total sugar values. Apparently the different yellowing temperature treatments had little or no effect on the sugar content of the tobacco. Regardless of the yellowing treatment used, the starch values were about the same for all comparisons, and no material differences were found in total nitrogen content of the tobacco obtained from any of

TABLE 8.—*Composition of second priming of tobacco yellowed at three different temperatures*

[Moisture- and sand-free basis]

Condition of leaf and yellowing temperature	Free reducing sugars	Sucrose	Total sugars	Starch	Nicotine	Total nitrogen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Original green	3.58	1.70	5.28	27.99	1.97	1.42
Yellowed, at temperatures of—						
85° to 95° F	13.88	5.27	19.15	11.73	2.01	1.58
90° to 100° F	15.12	5.07	20.19	10.97	1.96	1.48
95° to 105° F	13.84	5.77	19.61	10.31	1.98	1.50
Cured, with yellowing temperatures of—						
85° to 95° F	14.21	8.89	23.10	2.71	2.06	1.64
90° to 100° F	13.22	11.47	24.69	2.20	2.10	1.59
95° to 105° F	10.42	11.16	21.58	1.75	2.31	1.65

the yellowing treatments. The indicated increase of 0.25 percent in the nicotine content of the cured tobacco from the higher yellowing temperature treatment over the lower temperature treatment was not considered significant.

EFFECTS OF USING HIGHER TEMPERATURE DURING THE SECOND HALF OF THE YELLOWING PERIOD

As is well known, attempts to increase the temperature very much above 95° F. at the beginning of the yellowing usually results in fixing the green color in the tips of some of the thinner leaves. The possibility of increasing the temperature during the second part of the yellowing was tested. The curing of three lots of leaves of a third priming (table 9) was begun at a temperature of about 88°, and the yellowing continued without material change for about 17 hours, after which different yellowing temperatures were employed. Temperature differences of about 10° and 20° above the normal were used, and when the leaves were yellowed the normal temperature was 95°, the intermediate 105°, and the upper 115°. The curings were completed at the same relative rates, and final temperatures of 175° were used.

The cured leaf yellowed at the highest temperature contained some green color but had a better yellow color than that yellowed at the normal temperature. The intermediate-temperature leaf had perhaps the best color, as it was lighter than the normal and had less green than the higher temperature leaf. The normal-temperature leaf contained more orange color than the others. The farm grades of the tobacco cured in the same barns at the highest temperature contained about 14.2 percent green leaf, at the intermediate temperature about 3.2, and at the normal 1.4. The average price of the leaf from the two higher yellowing temperature treatments was about the same; and because of the large amount of the less desirable orange color in it, the price of the tobacco from the normal-temperature treatment was about $7.50 per hundred pounds less.

TABLE 9. *Curing conditions used in tests on effects of using higher temperatures during the second half of the yellowing period*

Test, curing stage, and condition	Normal	10° F. increase	20° F. increase
Test with third primings:			
First part of yellowing time	17 hours	17 hours	17 hours.
Temperature	88° F	88° F	88° F.
Second part of yellowing time	29 hours	25 hours	24 hours.
Temperature	88° to 95° F	88° to 105° F	88° to 115° F.
Curing time	4 days 23 hours	4 days 16 hours	4 days 5 hours.
Final temperature	175° F	175° F	175° F.
Test with fourth primings:			
First part of yellowing time	16 hours	16 hours	16 hours.
Temperature	88° F	88° F	88° F.
Second part of yellowing time	29 hours	27 hours	24 hours.
Temperature	88° to 98° F	88° to 106° F	88° to 116° F.
Curing time	4 days 16 hours	4 days 7 hours	3 days 20 hours.
Final temperature	170° F	175° F	175° F.

The content of reducing sugars in the leaf (table 10) at the yellowed and the cured stages of the treatments was in agreement within 2 percent, and the corresponding values for sucrose within 3 percent. The values for the total sugars differed by about 4 percent at the yellowed stage, but when cured all values were within 1.5 percent. The differences found in total nitrogen and nicotine contents in both the yellowed and the cured stage were so small that they were not significant. The differences in composition did not appear to have been caused by the different temperatures during the second half of the yellowing, although a less desirable orange color was present in one of the tests.

TABLE 10.—*Composition of third primings of tobacco from tests using higher temperatures during the second half of the yellowing period* [1]

[Moisture- and sand-free basis]

Condition of leaf and temperature increase	Free reducing sugars	Sucrose	Total sugars	Nicotine	Total nitrogen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Original green	1.78	1.29	6.07	1.31	1.38
Yellowed, with temperature increase in second half of					
Normal	15.41	6.42	21.83	1.54	1.53
10° F. increase	15.19	7.70	22.89	1.50	1.56
20° F. increase	16.34	9.37	25.71	1.51	1.50
Cured, with temperature increase in second half of yellowing period of					
Normal	16.79	9.20	25.99	1.47	1.60
10° F. increase	15.46	10.27	25.73	1.46	1.63
20° F. increase	14.86	12.32	27.18	1.62	1.59

[1] See table 9 for other data of test.

The test of the effects of increasing the temperature during the second half of the yellowing was essentially duplicated with a fourth priming of tobacco. The yellowing was begun at about 88° F. (table 9) and continued for 16 hours. The temperatures were then increased and when the leaves were considered yellowed, the normal temperature was about 102°, although it had been at about 98° for nearly all the period, the medium-increased temperature was about 106°, and the high temperature about 116°. The normal sample was well yellowed, that from the medium temperature had considerable green color, and that from the high-temperature treatment had the most green and the leaf tips were drying out. The cures were finished in the same relative manner and the final temperature was about 170° for the normal- and about 175° for the medium- and high-temperature treatments.

The cured sample of the normal treatment was of a very good yellow color, while the other two samples contained some green, the amount being greatest in the high-temperature material. The color of the tobacco in the barns was similar to that of the samples. Two of the farm grades containing green color made up more than 50 percent of the high-temperature tobacco. The normal-temperature lot contained 21 percent and the medium-temperature lot 25 percent of the same farm grade carrying green color. The price per 100 pounds varied inversely with the amount of the green color present, namely, $40.60, $46.59, and $48.23.

The sugar, total nitrogen, and nicotine compositions of the tobacco (table 11) did not show any material differences as a result of the different treatments and were similar to those of the first tests. The presence of green color resulting from the high temperature used in yellowing decreased the market value.

TABLE 11.—*Composition of fourth primings of tobacco from tests using higher temperatures during the second half of the yellowing period* [1]

[Moisture- and sand-free basis]

Condition of leaf and temperature increase	Free reducing sugars	Sucrose	Total sugars	Nicotine	Total nitrogen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Original green	3.32	1.24	4.56	1.54	1.57
Yellowed, with temperature increase in second half of—					
Normal	15.53	5.52	21.05	1.72	1.76
10° F. increase	14.31	8.99	23.30	1.74	1.62
20° F. increase	13.52	9.43	22.95	1.66	1.76
Cured, with temperature increase in second half of yellowing period of—					
Normal	13.66	8.74	22.40	1.69	1.81
10° F. increase	12.31	10.65	22.96	1.67	1.75
20° F. increase	11.69	10.48	22.17	1.66	1.77

[1] See table 9 for other data of test.

EFFECTS OF YELLOWING FOR DIFFERENT PERIODS OF TIME

Tests were made on the effects of reducing and extending the length of the yellowing time on the composition of the tobacco. The effect of a reduced time of yellowing—about 30 hours, a normal time—about 44 hours, and an extended period—about 64 hours, was tested in the yellowing of a third and of a fourth priming (tables 12, 13, 14). A yellowing temperature of about 94° F. was used and the final curing temperature was about 172°. The completion of the curing of the tobacco subsequent to the yellowing treatments was made in the same relative manner. Approximate time for the completion of the curings was 4 days 17 hours for the reduced-time yellowing tests, 5 days 1 hour for the normal-time tests, and 5 days 17 hours for the extended-time yellowing tests.

TABLE 12.—*Curing conditions used in the length-of-yellowing-period tests*

Test, curing stage, and condition	Underyellowed	Normal-yellowed	Overyellowed
Test with third primings:			
Yellowing time	1 day 6 hours	1 day 19 hours	2 days 17 hours.
Yellowing temperature	92° to 96° F	92° to 96° F	92° to 96° F.
Curing time	4 days 16 hours	5 days 2 hours	5 days 17 hours.
Final temperature	170° F	172° F	172° F.
Loss of original weight at end of yellowing	16.4 percent	22.1 percent	29.9 percent.
Test with fourth primings:			
Yellowing time	1 day 5 hours	1 day 21 hours	2 days 16 hours.
Yellowing temperature	95° to 95° F	94° to 95° F	94° to 95° F.
Curing time	4 days 17 hours	5 days 1 hour	5 days 16 hours.
Final temperature	170° F	172° F	170° F.
Loss of original weight at end of yellowing	16.7 percent	23.2 percent	30.7 percent.

TABLE 13.—*Composition of third primings of tobacco produced by yellowing for different periods of time* [1]

[Moisture- and sand-free basis]

Condition of leaf and yellowing time	Free reducing sugars	Sucrose	Total sugars	Starch	Nicotine	Total nitrogen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Original green	3.97	1.31	5.28	13.29	1.77	1.16
Yellowed—						
Under normal time	14.29	4.83	19.12	11.09	1.85	1.21
Normal time	18.60	5.82	24.42	8.44	1.92	1.28
Over normal time	20.81	5.98	26.79	6.30	1.89	1.24
Cured, when yellowing period was—						
Under normal	14.09	12.89	26.98	4.51	1.75	1.24
Normal	16.68	11.57	28.25	1.82	1.79	1.27
Over normal	17.87	8.97	26.84	3.38	1.74	1.37

[1] See table 12 for other data of test.

TABLE 14.—*Composition of fourth primings of tobacco produced by yellowing for different periods of time* [1]

[Moisture- and sand-free basis]

Condition of leaf and yellowing time	Free reducing sugars	Sucrose	Total sugars	Starch	Nicotin	Total nitrogen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Original green	3.66	1.15	4.81	11.23	1.68	1.24
Yellowed—						
Under normal time	13.34	4.45	17.79	5.88	1.68	1.35
Normal time	16.75	6.07	22.82	5.45	1.73	1.39
Over normal time	19.95	7.47	27.42	4.01	1.81	1.44
Cured, when yellowing period was—						
Under normal	16.03	11.96	27.99	3.40	1.69	1.40
Normal	18.29	9.92	28.21	2.98	1.75	1.48
Over normal	18.90	8.59	27.49	2.56	1.76	1.55

[1] See table 12 for other data of test.

The leaves of the tobacco receiving the underyellowed treatment contained green color at the end of this treatment and also contained green color at the end of the curing, although the leaf color on the whole was clear and bright. The leaves given the normal-time treatment were well yellowed, although there was some green remaining in the fourth priming test. The leaves of the extended-time tests were of a definite orange color and were dull. A green farm grade was separated from the leaves of the underyellowed treatment lot in the first test that represented about 3 percent of the total; and from the normal- and extended-yellowing-time treatment lots that represented about 1 percent of the total. In the case of the fourth priming test more green, 18 percent, was found in the normal-time lot than in the underyellowed lot, in which 11 percent was found. Even the extended-yellowing-test material contained 6 percent of the green grade. The market value per 100 pounds of the tobacco from all the treatments varied only $0.60.

In both tests the free reducing sugars in the leaves at the yellowed stage were considerably less in the underyellowed (4.3 and 3.4 percent) than in the normal, and about 6.5 percent less than in the overyellowed material. There was also less sucrose in the underyellowed leaves than in the tobacco from the other two treatments at the same stage. When the leaf had been cured, the underyellowed tobacco still contained from 2.3 to 3.8 percent less free reducing sugars than the tobacco from the other two treatments. The sucrose at the cured stage in the underyellowed tobacco averaged 1.7 percent more than the normal and 3.6 percent more than the overyellowed leaf. Apparently the free reducing sugars were increased when the yellowing was extended, but extended yellowing reduced the sucrose content of the cured materials. The total sugar content of the underyellowed at the yellowed stage averaged 5.2 percent less than that of the normal and 8.6 percent less than the overyellowed material. When cured, however, the greatest difference found between any of the treatments was only 1.4 percent. The starch content at the yellowed stage was approximately 1.9 to 4.8 percent greater in the underyellowed than in the material from the other treatments. When cured, however, the underyellowed in one comparison was about 0.3 percent less than the normal and 1.1 percent more than the overyellowed; but in the other comparison the values were from 0.4 to 0.8 percent larger than the normal or overyellowed tobacco. No change considered large enough to be significant was indicated in either the nicotine or total-nitrogen values in any of the treatments.

Effects of Drying the Leaf at Different Temperatures

The curing of three lots of tobacco was carried out under the same conditions up to the time the leaf drying was begun (table 15). A lower temperature of about 5° F. below the normal and a higher temperature of about 10° above the normal was used. The completion of the curings was made in the same relative manner and at the same final temperatures. All the samples at the yellowed stage and also at the end of the curings were uniform in appearance and of a similar light-yellow color.

Analyses were made of the tobacco when the leaf tissue was dry, as well as at the other curing stages. The differences in the free reducing sugars (table 16) from the three different treatments—normal temperature, lower temperature, and higher temperature—at the three stages ranged from 0.88 to 1.61 percent. The sucrose-content variations for the several comparisons were also within practically the same range difference, between 0.70 and 1.82 percent. The range difference in the total sugar content was also practically the same. The small differences between the nicotine values found were without significance. The total nitrogen content of the tobacco dried at the higher temperature was lower at all stages than that dried at the

TABLE 15.—*Curing conditions used in tests at different leaf-drying temperatures*

Curing stage and condition	5° F., lower temperature	Normal temperature	10° F., higher temperature
Yellowing time	1 day 23 hours	1 day 22 hours	1 day 23 hours.
Yellowing temperature	88° to 100° F	88° to 100° F	88° to 100° F.
Time to end of leaf drying	3 days 19 hours	3 days 18 hours	3 days 17 hours.
Leaf-drying temperature	100° to approximately 130°	100° to approximately 135° F	100° to approximately 145° F.
Curing time	4 days 20 hours	4 days 19 hours	4 days 17 hours.
Final temperature	175° F	175° F	175° F.
Loss of original weight when leaf tissue dry.	Approximately 68.1 percent	Approximately 72.5 percent	Approximately 77.1 percent.

normal or reduced temperatures. These differences ranged from 0.14 to 0.30 percent and may indicate a response to leaf drying at a higher temperature.

TABLE 16.—*Composition of second primings of tobacco produced by drying the leaf at three different temperatures* [1]

[Moisture- and sand-free basis]

Condition of leaf and leaf-drying temperature	Free reducing sugars	Sucrose	Total sugars	Nicotine	Total nitrogen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Original green	4. 87	2. 26	7. 13	1. 19	1. 53
Yellowed, for leaf-drying tests with temperature of—					
5° F. below normal	15. 29	5. 73	21. 02	1. 20	1. 61
Normal	14. 41	5. 10	19. 51	1. 25	1. 64
10° F. above normal	15. 22	6. 16	21. 38	1. 35	1. 47
Leaf tissue dry, leaf-drying temperature of—					
5° F. below normal	13. 33	10. 56	23. 89	1. 42	1. 79
Normal	13. 65	9. 91	23. 56	1. 33	1. 63
10° F. above normal	14. 94	8. 74	23. 68	1. 28	1. 49
Cured, with leaf-drying temperature of—					
5° F. below normal	12. 20	9. 04	21. 24	1. 30	1. 74
Normal	12. 18	9. 47	21. 65	1. 30	1. 78
10° F. above normal	13. 18	8. 77	21. 95	1. 17	1. 53

[1] See table 15 for other data of test.

EFFECTS OF DRYING THE STEM AT DIFFERENT TEMPERATURES

A test was made of the effects on the composition of tobacco of varying the temperature in the stem-drying, or final, stage of the curing. Stem-drying temperatures of 140°, 170° (normal), and 190° F. were employed with similar lots of tobacco that had been cured in the earlier stages under essentially the same conditions (table 17). Good curing was obtained in all the tests, but the leaf from the high-temperature treatment was of a darker yellow or orange color and carried the odor of strongly heated tobacco. The lightest colored leaf was from the lowest temperature treatment, and the color of the normal was intermediate. The market price of all the leaf was the same, and the distribution between the grades was quite uniform.

At the end of the yellowing the reducing sugar values were within 1.2 percent of each other under all the temperature treatments, and at the cured stage the largest difference was 2.6 percent, which was found between the lowest and highest temperature-treatment samples (table 18). The differences in sucrose values were all within 1.0 percent at the yellowed stage, and in the cured stage the greatest difference of 2.6 occurred between the low-temperature and normal-temperature treatments. The variations in total-sugar values were within 2.1 percent of each other at the yellowed stage, but when cured the low-temperature-treatment figure was 4.0 percent more than that

TABLE 17.—*Curing conditions of different stem-drying temperatures used in tests*

Curing stage and condition preceding stem drying	140° F.	170° F.	190° F.
Yellowing temperature	90° to 103° F	90° to 103° F	90° to 102° F.
Yellowing time	1 day 22 hours	1 day 21 hours	1 day 20 hours.
Leaf-drying temperature	103° to 140° F	103° to 144° F	102° to 142° F.
Leaf-drying time	3 days 17 hours	3 days 17 hours	3 days 17 hours.
Curing time	5 days 14 hours	4 days 17 hours	4 days 15 hours.
Final temperature	140° F	170° F	190° F.

of the high-temperature dried leaf. The starch values were unusually uniform in all cases; the greatest difference was only about 0.4 percent. A material change is not considered to have occurred in the nicotine or total-nitrogen values, as the largest differences found, in the yellow or cured stages, were 0.10 percent in the nicotine value and 0.15 percent in the total-nitrogen value.

TABLE 18.—*Composition of second primings of tobacco produced by use of three different stem-drying temperatures* [1]

[Moisture- and sand-free basis]

Condition of leaf and stem-drying temperature	Free reducing sugars	Sucrose	Total sugars	Starch	Nicotine	Total nitrogen
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Original green	0.35	2.45	2.80	21.24	2.02	1.76
Yellowed, for stem-drying tests with temperature of—						
140° F	13.02	5.08	18.10	3.24	2.25	1.83
170° F	13.50	5.27	18.77	3.59	2.28	1.91
190° F	14.21	6.01	20.22	3.26	2.22	1.86
Cured, with stem-drying temperature of—						
140° F	11.48	8.66	20.14	1.22	2.20	1.80
170° F	10.49	6.01	16.50	.97	2.15	1.95
190° F	8.86	7.28	16.14	.88	2.11	1.88

[1] See table 17 for other data of test.

SUMMARY

The biochemical changes in the carbohydrates of flue-cured tobacco from North Carolina, South Carolina, and Georgia during the usual storage of the leaf in a pack house prior to marketing were investigated. At the end of the barn curing the tobaccos contained a considerable quantity of sucrose, but following completion of the bulking process the quantity had been greatly reduced and there was a corresponding increase in free reducing sugars. Published analyses of tobacco ordinarily show only a small quantity of sucrose; this is because the leaf has previously been bulked and the inversion of sucrose has already occurred. The hydrolysis of sucrose readily took place when powdered tobacco was exposed in a desiccator to a moist atmosphere. The increase in reducing sugars on acid hydrolysis is usually assumed to be due to sucrose. Special methods of anlaysis for sucrose itself as well as the finding of about equal parts of dextrose and levulose, appear to confirm the presence of this sugar in considerable quantity in flue-cured tobacco.

The biochemical changes that occurred in 16 constituents of flue-cured tobacco during the curing process were determined. Analysis of the tobacco was made when harvested, when yellowed, and at the end of the curing process. From the study of two curings for each of 3 years it was found that the outstanding changes in composition were in the carbohydrate group. An average original value of about 29 percent of starch was reduced to about 12 percent when the leaf was yellowed and to about 5 percent when cured. There was an increase of about 10 percent in the free reducing sugars and about 4 percent of levulose, practically all of which took place during the yellowing stage. Sucrose had increased by about 3.5 percent when the leaf was yellowed and by about 5.5 percent when cured. The very stable component cellulose, as represented by the crude fiber value, remained practically constant.

The nitrogen and nicotine contents of the flue-cured type used were very low, and the changes that took place during the curing were small. Losses of a few hundredths percent of nitrogen were found; there was a loss of about 0.1 percent of protein nitrogen when the leaf was yellowed and about 0.15 percent when cured. The very low nicotine value of about 1.1 percent was reduced by about 0.1 percent when the curing was complete.

The ash content of the leaves, of course, was not changed and remained at about 9.25 percent at all stages of the curing. The calcium content of the harvested leaf was about 1.4 percent, and the content of this element was used as a basis for calculating the loss of weight during the curing process.

The organic acids, oxalic, citric, and malic, made up about 10 percent of the original leaf. There was an indicated loss of about 0.05 percent of oxalic acid when the leaf was yellowed and about 0.10 percent when it was cured. Less than 0.5 percent of citric acid was found, and the indicated changes in quantity were so small as to be considered negligible. A malic acid content of about 9 percent was present in the original leaf, and changes of about 1 percent were found; but, owing to the nature of the method of analysis employed, the differences found were not considered as necessarily significant.

The content of resins, which include various compounds of the nature of resins, gums, and waxes, was about 7 percent. Although there was a loss of about 0.5 percent in resins at the yellowed and cured stages, this loss was not considered material, because of the nature of the compounds being determined.

The original leaf contained about 11 percent of materials determined as pectinic acid. Considerable variation in changes was observed but no significance was attached to them. The acidity of flue-cured tobacco is higher than that of other tobacco types. The pH values were around 5.5, and, as the greatest differences found were about 0.20 pH, no real change was considered as having taken place.

Continuous records of the temperature and humidity in the curing barns during the curing of the special samples analyzed were obtained. The temperature tolerance of the tobacco leaf enzymes, which bring about the changes in the leaf during the yellowing stage, varies with the different lots of tobacco being cured. The leaf itself is a good index of the progress of its curing. In most curings a certain amount of undesirable green color is left in some of the leaves for the reason that limiting conditions are reached for at least those leaves.

The record of an entire curing is given in which the temperature, humidity, percentage of original weight, and fuel consumption are shown as curves. Losses of original weight of about 30 percent at the end of the yellowing stage were found from a number of tests and were considered desirable. The leaf lamina was dried at around 130° F., with a relative humidity of about 30 percent. A final drying temperature of 175° was used, at which time the humidity had been reduced to about 12 percent and there had been an indicated loss of original weight of about 82 percent. The large difference in rate of moisture loss between the leaf web and stem extends the curing time and requires the use of elevated temperatures. When the leaf tissue was practically dry and contained only about 16 percent of water, the stem was found to still contain about 78 percent moisture, which can readily be removed only by increasing the temperature.

To determine the effects of varied curing conditions on leaf composition, departures from the normal curing practice were intentionally made and samples of the tobacco produced were analyzed. An increase of about 10° F. in the yellowing temperature did not result in an important change in the analytical results of the tobacco produced. Some green color, however, remained in the cured leaf that was yellowed at the highest temperature. An increase in temperature of about 20° during the second half of the yellowing period resulted in the retention of considerable green color in the tobacco, and the leaf from the lower temperature treatment was of an undesirable orange color. Material differences in composition were not found on analysis of the cured tobacco obtained. Tobacco was yellowed for periods of 30, 44, and 64 hours. Green color remained in the tobacco yellowed under the shorter period, but the yellow color was bright, while the cured leaf from the longest yellowing period was of a dull-orange color. The smallest amount of sugars was found in leaf yellowed for the shortest period at the completion of the yellowing stage, but there was no real difference in the quantity of sugar found in the final cured leaves.

Differences in temperature of 15° F., maintained during the leaf-drying period, resulted in the production of tobacco of about the same desirable yellow color. The carbohydrate and nicotine contents of the leaf from the different treatments were nearly the same, although some nitrogen was lost at the higher temperature treatment. Stem-drying temperatures of 140°, 170°, and 190° all produced good tobacco, although the leaf subjected to the highest temperature was of an orange color and carried the odor of strongly heated tobacco. The only material difference in composition of tobacco used in these tests was a small loss of sugars in the product dried at the highest temperature.

On the whole the departures from the normal curing practice, which reflected moderate rather than radical changes, resulted for the most part in only small quantitative differences in the constituents for which analyses were made.

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