

Different yellowing degrees and the industrial utilization of flue-cured tobacco leaves

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ABSTRACT: Yellowing is a key stage in the curing of flue-cured tobacco (*Nicotiana tabacum* L.) as much of the chemical transformation occurs during this period. This study examined the effect of different yellowing degrees on the value of flue-cured tobacco leaves at the farm level for both processing and manufacturing. The study was conducted in the counties of Chuxiong, Dali, and Yuxi in Yunnan, China over two years. Yellowing treatments have been designed to have either a mild or a regular yellowing degree. Yield, value, appearance, suction property, smoking characteristics, and physical resistance to further processing were investigated to evaluate the effect of degree of yellowing on the industrial utilization of flue-cured tobacco leaves. The regular yellowing degree enhanced yield, value, and appearance compared to the mild yellowing degree, regardless of cultivar or location; however, physical resistance to further processing and the suction property of the mild yellowing degree treatment were better than with the regular yellowing degree regardless of cultivar or location. Furthermore, although the regular yellowing degree recorded higher smoking characteristic scores than the mild yellowing degree immediately after flue-curing, the scores of mild yellowing degree leaves could be further augmented by increasing intensity in the re-drying stage. The smoking characteristic score in the regular yellowing degree can only be increased by low intensity re-drying, and significantly decreased by mild and high intensity re-drying. Therefore, in terms of industrial utilization, mild yellowing is the better choice for flue-curing tobacco. This study also suggested that the current regular yellowing stage in Yunnan should be shortened to meet the demands of the traditional tobacco industry.

Keywords: Hongda cultivar, K326 cultivar, curing barn, re-drying, leaf utility

Introduction

The flue-curing process is a way of curing flue-cured tobacco with artificial heat over a period of 6-7 days (Horne, 1980; Hawks and Collins, 1993; Peele, 2005); it entails a flue-curing stage and a re-drying stage (Figure 1). Multiple factors influence industrial utilization and the style of the tobacco leaf and include the ecological environment, cultivar, maturity, agronomic management, and curing technology (Reed et al., 2012). Among these factors, the yellowing stage in the flue-curing process is a key step during which complex physical, physiological, and biochemical reactions materialize in the tobacco leaves (Bacon et al., 1952; Weston, 1968; Koiwai and Kisaki, 1979; Alejar et al., 1988). Previous studies have focused on various aspects of the curing process for flue-cured tobacco leaves, including temperature, humidity, time, and draft fan control (Zhan et al.,

2011; Cui et al., 2013; Xie et al., 2013). These studies focused mainly on the commercial purchase of tobacco, which is set out as the First Sampling in Figure 1. However, few studies have concentrated on the extent of yellowing and its industrial usability in flue-cured tobacco leaves after threshing and re-drying as represented by the Second Sampling in Figure 1.

The current flue-curing mode for tobacco leaves in Yunnan is standardised to obtain dry, yellow, and fragrant leaves. However, the cigarette manufacturing industry gives poor evaluation scores to such tobacco leaves. A number of indices that are taken seriously in the industry are paid less heed during the flue-curing process. These indices include resistance to further processing, suction properties, shatter resistance, and the smoking characteristics of re-dried tobacco leaves (Walton et al., 1974; Wang et al., 1998). Resistance to further processing, and the suction properties, are closely re-

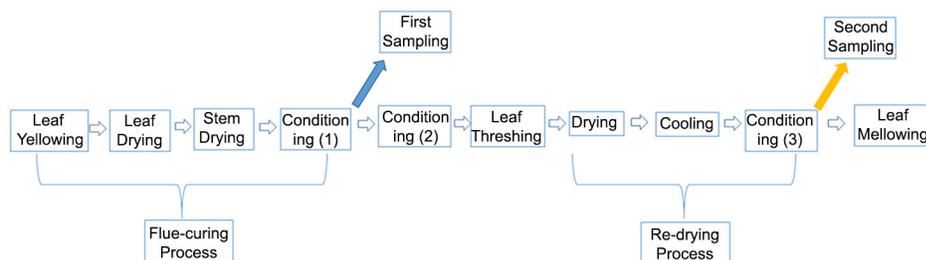


Figure 1 – The process stages for flue-cured tobacco.

lated to shatter resistance, which refers to the resistance of tobacco leaves to crushing under various mechanical forces. Moreover, shatter resistance has a close correlation with the machining properties of tobacco leaves and exhibits positive correlation with tobacco quality. The absorption equilibrium moisture content (AEMC) and desorption equilibrium moisture content (DEMC) of tobacco leaves exhibit significant correlation with important chemical contents, such as reducing sugar and potassium contents (Wang et al., 2011).

Thus, the aim of this study was to systematically investigate the effect of yellowing degree on the industrial utilization of tobacco leaves during the flue-curing process.

Materials and Methods

Study site description

The experiments were performed separately in Chuxiong, Dali, and Yuxi, (the three-major tobacco-growing regions), Yunnan Province, China, in 2015 and 2016. The curing barns were all bulk curing barns with a horizontal layout. The experiment arrangements are in Table 1. The three locations are all characterized by mild variation in mean monthly air temperatures, from 10 °C in Jan to 25 °C in June, but have a relatively uneven distribution in mean monthly precipitation, with an annual average rainfall of 850 mm and 80 % of the precipitation occurring from May to Oct in all three locations.

Experiment design

During the flue-curing process, two treatments were designed: regular yellowing (R) and mild yellowing (M). For regular yellowing, tobacco leaves were wilted at a relatively low temperature (kept in the yellowing stage before 42 °C) until they were 80-90 % yellowed. The entire yellowing process included vein yellowing and eventual color fixation after wilting and softening. Regular yellowing is currently the conventional flue-curing mode favored by most tobacco growers. For mild yellowing, tobacco leaves were wilted at a relatively low temperature (yellowing stage) until 60 to 70 % yellowed, and entered the subsequent, higher temperature color fixation/leaf drying stage with yellow lamina but stems still green. The Hongda and K326 cultivars are expressed as H and K, while Chuxiong, Dali, and Yuxi locations are represented by C, D, and Y, respectively (Table 2). Flue-curing technology is popular in Yunnan Province given the main change points of temperature and humidity (as measured by a hygrometer) namely, 35/33, 38/35, 42/36, 48/37, 54/38, 62/39, and 68/39 °C

(Figure 2), respectively. In the treatment process, the turning points were adjusted according to degree of yellowing and the flue-curing time of the tobacco leaves (Table 3). Each treatment had three replications or three curing barns at each location.

Table 3 indicates the time schedule difference between regular yellowing and mild yellowing for both K326 and Hongda cultivars. In the yellowing stage, it took 78 h for the K326 cultivar to undergo regular yellowing, which was 24 h longer than with mild yellowing. Similarly, regular yellowing took 23 h longer than mild yellowing for the Hongda cultivar. In the leaf drying stage, it took 63 h for the K326 cultivar to undergo mild yellowing, which was 9 h longer than regular yellowing. Similarly, mild yellowing took 10 more hours than regular yellowing for the Hongda cultivar. There was little difference in the stem drying stage for either treatment. In total, the cumulative curing time was 161 h regular yellowing in K326, which was 13 more hours than the mild yellowing treatment in K326. The cumulative curing time was 168 h in the Hongda regular yellowing treatment, which took 12 h longer than the mild yellowing treatment. Figure 3 presents a comparison of flue-cured K326 leaves (regular v. mild yellowing, Chuxiong County, 2016). The cured leaf chlorophyll data showed that leaf chlorophyll content (leaf chlorophyll a + b) was 8.5 µg g⁻¹ for mild yellowing, while regular yellowing resulted in a chlorophyll content of 7.2 µg g⁻¹.

In order to make a judgement about which flue-curing treatment (mild or regular) left more space or potential for improving the smoking characteristics in re-drying or further physical processing, the re-drying intensity levels, including low-, mild-, and high-intensity re-drying processes, were examined for the re-drying trial.

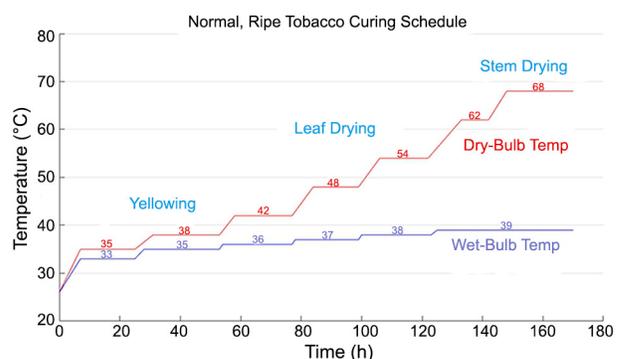


Figure 2 – The typical flue-curing scheme for Yunnan flue-cured tobacco.

Table 1 – Experiment arrangements.

Time	Site	Cultivar	Area	Leaf Position
2015	Miaojie village, Weishan county, Dali (24°19'1.39" N 102°38'17.28" E; Latitude 1720 m)	Hongda	8 ha	Middle
2015	Majiazhuang village, Jiangchuan county, Yuxi (25°26'56.04" N 101°33'7.26" E; Latitude 1940 m)	K326	8 ha	Middle
2016	Panmao village, Muding county, Chuxiong (25°18'26.56" N 100°16'78.53" E; Latitude 1762 m)	K326	13 ha	Middle

Table 2 – Experiment codes.

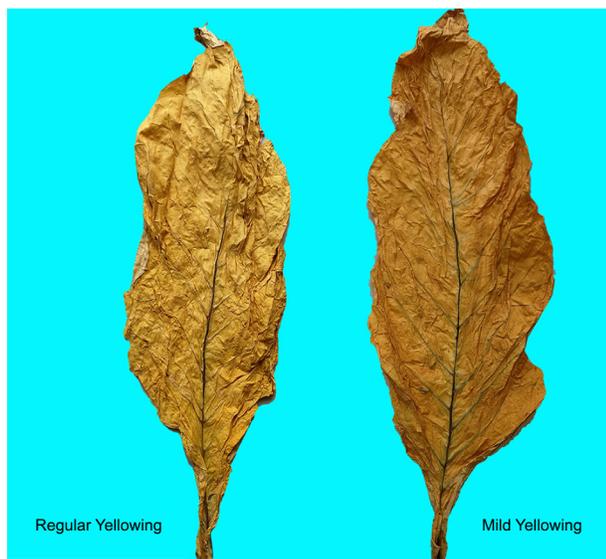
Treatment Code	Year	Site	Cultivar	Treatment
DHM	2015	Dali	Hongda	Mild
DHR	2015	Dali	Hongda	Regular
YKM	2015	Yuxi	K326	Mild
YKR	2015	Yuxi	K326	Regular
CKM	2016	Chuxiong	K326	Mild
CKR	2016	Chuxiong	K326	Regular

Note: For treatment code, Chuxiong, Dali, and Yuxi, locations are represented by C, D, and Y, respectively. The Hongda and K326 cultivars are expressed as H and K, respectively. M and R refer to mild or regular yellowing degree, respectively.

Table 3 – Flue-curing time required from regular yellowing to mild yellowing (unit: hours).

Treatment Code	Yellowing	Leaf drying	Stem drying	Total
KM	54	63	31	148
KR	78	54	29	161
HM	56	68	32	156
HR	79	58	31	168

Note: KM refers to K326 with mild yellowing treatment; KR refers to K326 with regular yellowing treatment; HM refers to Hongda with mild yellowing treatment; HR refers to Hongda with regular yellowing treatment.

**Figure 3** – Regular yellowing vs. mild yellowing treatments for flue-cured leaves (K326 cultivar).

Field agronomic management

The Hongda, and K326, cultivars were produced using high-quality and high-efficiency cultivation techniques with balanced nutrition, normal growth, and fresh leaves yellowed and matured on a layer-by-layer basis. In Aug, after cultivating for 90 to 95 days and topping for 35 to 40 days, the tobacco leaves turned pale yellow and 80 % of them were yellowed, with white and bright main veins, white branch veins, and down-rolled

leaf apices and leaf margins. When the leaves were wrinkled, the 12th to the 14th mature leaves were collected and flue-cured according to experiment requirements. Other agronomic practices were conducted according to local standards for cultivating high-quality tobacco.

Parameters

Yield and quality of tobacco leaves

All of the samples were preserved after flue-curing to describe their appearance. According to GB2635-92, which is the standard flue-cured tobacco grading system in China, the flue-cured tobacco leaves were graded, and the proportions of lower-, middle-, and higher-grade tobacco leaves, and those of orange and greenish tobacco leaves, were calculated along with their average prices.

Industrial appearance quality

C2F and C3F were the typical grades of flue-cured tobacco for conducting research and testing. After removing greenish tobacco from the flue-cured tobacco leaves, 10 kg of C2F and C3F samples were separately evaluated based on the Tobacco Industrial Classification Standard.

Physical resistance to further processing

C2F and C3F samples, each of 10 kg in mass, were also separately taken to conduct conventional chemical composition analysis after removing greenish tobacco from the flue-cured tobacco leaves. After equilibration for 72 h at constant temperature (22 °C) and humidity (60 %) levels, the samples were analysed according to the method for detecting the shatter resistance index of tobacco leaves provided by Chen et al. (2011).

Absorption and desorption properties

The absorption and desorption properties of the samples were assayed by the SPSx moisture-retention instrument for tobacco leaves. The detection conditions were as follows: the original environment temperature and relative humidity (RH) were 25 °C and 60 %, respectively. Next, they were adjusted to 25 °C and 75 %, respectively, after reaching equilibrium before studying the absorption and desorption properties of the samples. Subsequently, after reaching equilibrium, the ambient temperature and RH were adjusted to 25 °C and 60 % once again to observe the absorption and desorption that had taken place.

Smoking characteristics

C2F and C3F samples, each of 5 kg mass, were separately taken to evaluate the smoking characteristics and quality after removing greenish tobacco from the flue-cured tobacco leaves. After re-drying, the scored smoking characteristics were provided by testers employed by the re-drying enterprise. Each sample was evaluated by seven certified experts and the results were the mean of seven reports.

Statistical analyses

Data were analysed by the General Linear Model (GLM) Procedure in SAS (Statistical Analysis System, version 9.3). Replicate measurements on composite leaf samples were averaged for statistical analysis of the treatment effects. Treatment effects were declared significant when the probability (p) of a greater F statistic was ≤ 0.05 . Mean separation was undertaken by Tukey's honest significant difference (HSD) test at the 95 % level of confidence. For smoking characteristics, the data shown in this study was the average of seven reports.

Results

Effect on yield and quality of tobacco leaves

During the production of tobacco leaves, yield and quality are mainly influenced by factors such as climate, soil, cultivation, harvest maturity, and degree of yellowing in the flue-curing process. The position, shape, physical feeling and color are the four key components of leaves which determine tobacco value in China. In this study, tobacco leaves with the same position and shape were cured and evaluated to identify the degree of yellowing that would exert a significant influence on the final yield and quality. The highest quality tobacco leaves were obtained after regular yellowing in the flue-curing process, which is conducive to increasing the flue-curing quality. High-class tobacco leaves, thus processed, exhibited maximum proportions of 78-84 % after different degrees of yellowing, respectively (Table 4). Moreover, mid- to high-class tobacco leaves, processed using regular yellowing, exhibited maximum proportions of 96-98 %, respectively, while fetching average prices of 30.50 to 34.77 yuan.

Effect on appearances of tobacco leaves

The appearance of the submitted samples was assessed against the Tobacco Industrial Classification Standard and the classifications of different samples are summarised in Table 5. CO₂ indicates the highest-class level of tobacco leaves in the middle stalk position, while minor components indicate the acceptable level of tobacco leaves. The samples in the three experi-

ment sites subjected to regular yellowing exhibited the best appearance with the highest proportion of CO₂ and lowest proportion of minor components. This was most significantly reflected in tobacco leaves from Chuxiong where there was a difference in proportion (24 %) of CO₂ in tobacco leaves in the two treatments.

Effect on physical resistance to further processing

The samples were analysed after pre-treatment according to the method for detecting the shatter resistance index provided by Chen et al. (2011). The proportions of tobacco leaves < 1 mm and ≥ 4 mm from the samples in the three experiment sites subjected to mild yellowing exhibited the best shatter resistance (Table 6). Of the three experiment sites the tobacco leaves in Chuxiong showed the best physical resistance to further processing. The shatter resistance of flue-cured tobacco leaves decreased as the degree of yellowing increased.

Effect on the absorption and desorption properties

During processing, tobacco leaves with a large moisture absorption rate readily absorb moisture during storage and transportation, thus increasing the shatter resistance and decreasing the losses due to shattering. In contrast, tobacco leaves with a large moisture desorption rate readily lose moisture in the re-drying process to achieve ideal moisture conditions. Thus, the shatter resistance decreases while the losses due to shattering increase. For moisture absorption and desorption characteristics, fewer hours indicate a higher absorption rate. The moisture absorption and desorption rates of flue-cured tobacco leaves both decreased with increased degree of yellowing in the flue-curing process.

The samples of the three experiment sites subjected to mild yellowing exhibited the largest moisture absorption and desorption rates (Table 7). Moreover, the moisture absorption and desorption rates of the Hongda cultivar were both less than those of the K326 cultivar at each location. In terms of sites, the moisture absorption rate of the tobacco leaves in Chuxiong was greater than those in Dali and Yuxi, while the moisture desorption rate of the first was lower than those of the last.

Table 4 – Effect of yellowing degree on tobacco leaf yield.

Treatment	High-class leaves	High-mid class leaves	Average price yuan kg ⁻¹
	%		
DHM	53 b	95 a	25.34 b
DHR	79 a	96 a	31.28 a
YKM	58 b	97 a	24.90 b
YKR	84 a	98 a	30.50 a
CKM	65 b	95 a	32.75 b
CKR	78 a	97 a	34.77 a

Note: Standardised by selling price of tobacco leaves in that year; different letters indicate a statistically significant difference at $p \leq 0.05$. For treatment, Chuxiong, Dali, and Yuxi, locations are represented by C, D, and Y, respectively. The Hongda and K326 cultivars are expressed as H and K, respectively. M and R refer to mild or regular yellowing degree, respectively.

Table 5 – Effect of yellowing degree on tobacco leaf appearance.

Treatment	Gross mass	CO ₂ mass	CO ₂ content	Mass of minor components	Proportion of minor components
	kg	kg	%	kg	%
DHM	28.40 a	20.10 b	71 b	8.20 a	29 a
DHR	31.20 a	25.40 a	81 a	5.60 b	18 b
YKM	31.65 a	23.40 b	74 b	8.10 a	26 a
YKR	29.75 a	25.10 a	84 a	4.45 b	15 b
CKM	30.40 a	18.70 b	62 b	11.55 a	38 a
CKR	29.15 a	25.15 a	86 a	2.95 b	10 b

Note: the higher CO₂ proportion indicates a higher-grade classification; different letters indicate a statistically significant difference at $p \leq 0.05$. For treatment, Chuxiong, Dali, and Yuxi, locations are represented by C, D, and Y, respectively. The Hongda and K326 cultivars are expressed as H and K, respectively. M and R refer to mild or regular yellowing degree, respectively.

Effect on smoking characteristics

The smoking characteristics of the tobacco leaves subjected to regular yellowing obtained at the three experiment sites (Figure 1, First Sampling) were superior to those using mild yellowing (Table 8), and were reflected, in the main, by indices including aroma, aroma quantity, aroma quality, and purity. In terms of test sites, the smoking characteristics of tobacco leaves from Dali and Yuxi were superior to those from Chuxiong, which was primarily reflected in three indices including irritability, offensive odor, and purity; however, the after-taste of tobacco leaves from Chuxiong was better than those from the other two experiment sites. Various technologies such as re-drying are required in industrial processes based on industrial demands. However, according to feed-back related to industrial products, although tobacco leaves subjected to regular yellowing had a high

score, they offered a thin smoke, light offensive odors, and a poor after-taste. Thus, the tobacco quality, close to that subjected to a re-drying process, cannot be as readily adjusted on the scale of industrial production. In contrast, tobacco leaves subjected to mild yellowing offered thick smoke and an intense impact, but were irritating; thus, their quality can be improved further according to industrial needs after the re-drying process.

Effect on smoking characteristics of re-dried tobacco leaves

The score representing the smoking characteristics of tobacco leaves subjected to mild yellowing increased (*i.e.*, improved) with increasing intensity in the re-drying stage (Table 9). However, the score when using regular yellowing can rise when subjected to mild re-drying while the total smoking characteristic score

Table 6 – Effect of yellowing degree on physical resistance to further processing.

Treatment	Proportion ≥ 4 mm	Proportion ≥ 2 mm	%	
			Proportion ≥ 1 mm	Proportion < 1 mm
DHM	94.0 a	1.5 b	0.9 a	3.0 b
DHR	93.5 b	1.8 a	0.8 a	3.6 a
YKM	94.1 a	1.6 b	1.0a	2.8 a
YKR	93.7 b	1.7 a	1.0 a	2.9 a
CKM	96.2 a	1.3 b	0.9 a	0.4 b
CKR	95.9 b	2.7 a	1.4 a	0.8 a

Evaluation standard: the larger the proportion < 1 mm, the worse the shatter resistance of the samples, while the larger the proportion ≥ 4 mm, the better the shatter resistance thereof; different letters indicate a statistically significant difference at $p \leq 0.05$. For treatment, Chuxiong, Dali, and Yuxi, locations are represented by C, D, and Y, respectively. The Hongda and K326 cultivars are expressed as H and K, respectively; M and R refer to mild or regular yellowing degrees, respectively.

Table 7 – Effect of yellowing degree on moisture absorption and desorption properties.

Treatment	Equilibration time at 60 %-75 % RH	Equilibrium mass changes at 60 -75 % RH	Equilibration time at 75 %-60 % RH	Equilibrium mass changes at 75 %-60 % RH
	h	%	h	%
DHM	10.8 b	17.3 a	16.5 b	15.3 a
DHR	15.5 a	15.4 a	29.3 a	11.9 b
YKM	8.0 b	16.9 a	20.6 b	13.4 a
YKR	10.5 a	20.2 a	25.4 a	12.0 b
CKM	6.8 b	20.2 a	16.4 b	8.2 a
CKR	8.8 a	22.9 a	18.6 a	4.6 b

Note: equilibration time at 60 %-75 % RH indicates absorption, and that at 75 %-60 % RH indicates desorption; a lower number of hours indicates a higher absorption or desorption rate; different letters indicate a statistically significant difference at $p \leq 0.05$. For treatment, Chuxiong, Dali, and Yuxi, locations are represented by C, D, and Y, respectively. The Hongda and K326 cultivars are expressed as H and K, respectively. M and R refer to mild or regular yellowing degree, respectively.

Table 8 – Effect of different yellowing degree on smoking characteristics.

Treatment	Aroma (10)	Aroma quantity (15)	Aroma quality (15)	Concentration (10)	Irritability (15)	Impact (5)	Offensive odors (10)	Purity (10)	Wetness (5)	After-taste (5)	Sum
DHM	7.5	12.5	12.5	7.5	13.0	5.0	7.5	7.5	4.0	3.5	80.5
DHR	8.5	13.0	13.0	8.5	13.0	5.0	8.5	8.5	4.0	3.5	85.5
YKM	7.5	12.5	12.5	7.5	13.0	5.0	7.5	7.5	4.0	3.5	80.5
YKR	8.0	13.0	13.0	8.0	13.0	5.0	8.0	8.0	4.0	3.5	83.5
CKM	7.5	12.5	12.4	7.3	7.5	4.9	7.1	7.3	4.0	3.9	74.4
CKR	8.0	13.0	13.5	7.5	7.5	5.0	7.5	7.5	4.0	4.0	77.5

Note: each leaf sample was evaluated by seven certified experts and the data in this table are the mean of seven reports. For treatment, Chuxiong, Dali, and Yuxi, locations are represented by C, D, and Y, respectively. The Hongda and K326 cultivars are expressed as H and K, respectively. M and R refer to mild or regular yellowing degree, respectively.

Table 9 – Effect of different yellowing degree on smoking characteristics following re-drying.

Treatment	Sample	Enjoyment (10)	Fineness (5)	Smoothness (5)	Duration (5)	Aroma quantity (10)	Sweetness (10)	Concentration (10)	Irritability (10)	Impact (5)	Offensive odors (10)	Purity (10)	Wetness (5)	After-tastes (5)	Sum
YKM	Before re-drying	7.5	3.9	3.4	3.6	7.1	7.0	7.3	7.5	5.0	7.1	7.3	4.0	3.9	74.6
YKM	Re-drying Trt. 1	7.6	3.9	3.5	3.8	7.2	7.0	7.5	7.3	5.0	7.0	7.2	3.8	3.9	74.7
YKM	Re-drying Trt. 2	7.8	3.9	3.5	4.0	7.5	7.2	7.6	7.5	5.0	7.3	7.3	4.0	4.0	76.6
YKM	Re-drying Trt. 3	8.1	4.0	3.5	4.1	7.7	7.5	7.8	7.6	5.0	7.5	7.5	4.0	4.2	78.5
YKR	Before re-drying	8.0	4.0	3.5	4.0	7.5	7.5	7.5	7.5	5.0	7.5	7.5	4.0	4.0	77.5
YKR	Re-drying Trt. 1	8.0	4.0	3.5	4.2	7.7	7.6	7.5	7.5	5.0	7.5	7.6	4.0	4.0	78.1
YKR	Re-drying Trt. 2	7.9	4.0	3.5	4.0	7.5	7.5	7.5	7.5	5.0	7.3	7.5	4.0	4.0	77.2
YKR	Re-drying Trt. 3	7.6	4.0	3.3	3.9	7.3	7.3	7.3	7.4	5.0	7.3	7.5	3.8	4.0	75.7
DHM	Before re-drying	7.6	3.9	3.4	3.6	7.0	7.0	7.3	7.3	5.0	7.1	7.3	4.0	3.9	74.4
DHM	Re-drying Trt. 1	7.6	3.9	3.5	3.8	7.2	7.2	7.5	7.3	5.0	7.0	7.2	3.8	3.9	74.9
DHM	Re-drying Trt. 2	7.8	3.9	3.5	4.0	7.5	7.4	7.6	7.5	5.0	7.3	7.3	4.0	4.0	76.8
DHM	Re-drying Trt. 3	8.1	4.0	3.5	4.1	7.5	7.7	7.7	7.5	5.0	7.5	7.5	4.0	4.2	78.3
DHR	Before re-drying	8.0	4.0	3.5	4.0	7.5	7.7	7.5	7.5	5.0	7.5	7.5	4.0	4.0	77.7
DHR	Re-drying Trt. 1	8.0	4.0	3.5	4.2	7.6	7.8	7.6	7.5	5.0	7.5	7.5	4.0	4.0	78.2
DHR	Re-drying Trt. 2	7.9	4.0	3.5	4.0	7.5	7.7	7.5	7.5	5.0	7.3	7.5	4.0	4.0	77.4
DHR	Re-drying Trt. 3	7.6	4.0	3.3	3.9	7.3	7.5	7.3	7.4	5.0	7.3	7.5	3.8	4.0	75.9
CKM	Before re-drying	7.6	4.0	3.4	3.4	6.9	7.1	7.2	7.5	5.0	7.1	7.5	3.9	3.7	74.3
CKM	Re-drying Trt. 1	7.6	4.0	3.5	3.5	7.2	7.2	7.3	7.5	5.0	7.2	7.5	4.0	3.8	75.3
CKM	Re-drying Trt. 2	7.9	4.0	3.7	4.0	7.5	7.3	7.5	7.5	5.0	7.5	7.5	3.6	3.5	76.5
CKM	Re-drying Trt. 3	8.2	4.0	4.0	4.0	8.0	7.7	7.9	7.5	5.0	7.5	7.5	4.0	4.0	79.3
CKR	Before re-drying	8.0	4.0	3.9	3.9	7.9	7.5	7.5	7.6	5.0	7.5	7.5	4.0	4.0	78.3
CKR	Re-drying Trt. 1	8.0	4.0	4.0	4.0	8.0	7.5	7.8	7.5	5.0	7.5	7.5	4.0	4.0	78.8
CKR	Re-drying Trt. 2	7.8	4.0	3.5	3.8	7.5	7.2	7.5	7.6	5.0	7.5	7.5	4.0	3.7	76.6
CKR	Re-drying Trt. 3	7.3	4.0	3.5	3.5	7.2	7.0	7.0	7.2	5.0	7.2	7.5	3.5	3.0	72.9

Note: Treatment (Trt) 1, 2, and 3 represent low-, mid-, and high-intensity re-drying processes, respectively. Each leaf sample was evaluated by seven certified experts and the data in this table are the mean of seven reports. The maximum possible score is indicated in parentheses. For treatment, Chuxiong, Dali, and Yuxi, locations are represented by C, D, and Y, respectively. The Hongda and K326 cultivars are expressed as H and K, respectively. M and R refer to mild or regular yellowing degree, respectively.

decreased with a mid-and/or high-intensity re-drying process. Moreover, tobacco leaves subjected to mild yellowing with three re-drying stages, and those using regular yellowing with one re-drying stage, exhibited the best smoking characteristics. The trend was similar in each location regardless of cultivar. Thus, mild yellowing can most favorably meet the demands of industry according to the requirements of the industrial re-drying processes used.

Discussion

Effect on yield and value of tobacco leaves

In flue-cured tobacco production, the flue-curing process exerts an important influence on the yield and value of tobacco leaves and directly influences the appearance of flue-cured tobacco leaves and conversion of internal chemical constituents, such as polyphenols (Roberts, 1941; Gong et al., 2009). Specifically, the degree of yellowing plays an important role in the whole curing process because the peak period of the conversion of primary chemical components in fresh tobacco leaves occurs upon yellowing, which is extremely important when forming tobacco quality (Gong et al., 1996). Different degrees of yellowing can directly influence the appearance of flue-cured tobacco leaves, their chemical composition, the coordination and contents of neutral aroma components, and production value (Qian et al., 2012; Liu et al., 2015). The appearance of the Hongda cultivar improved with increased yellowing, while in terms of chemical composition, the total nitrogen content gradually decreased, the reducing sugar content increased, and there was no significant influence on other indices (Wang et al., 2007; He et al., 2014). These results are similar to those obtained by Qian et al. (2012).

The authors of much other research believe flue-cured tobacco leaves have the greatest yield with a regular degree of yellowing while Qian et al. (2012) suggest that different degrees of yellowing can influence the yield and value of flue-cured tobacco. Most previous research is based on the processes used in tobacco leaf production and has concentrated on yellowing standards in different ecological environments, for other cultivars, locations, and curing barns. Similarly, it is generally believed that 80 to 90 % is considered as optimal yellowing for middle tobacco leaves (Song et al., 2010); however, the re-drying process was given greater attention in the Song et al. (2010) study. The purpose of re-drying tobacco leaves is to achieve and control a uniform moisture content within a certain range so that physico-chemical properties of tobacco leaves change favorably and consistently. This can improve the quality of tobacco leaves and makes their storage easier, thus benefiting industrial production. Compared with flue-curing, re-drying provides better control and has a greater effect on various aspects of tobacco leaves including physical, physiological, biochemical, quality, safety, individuation, and specialization. In our study, regular yellowing treatment (R)

resulted in a higher proportion of high quality leaves as determined by the current market grading system, and higher average prices, compared to mild yellowing treatment (M). Therefore, from the grower's perspective, regular yellowing is the proper choice. This will be true until prices of grades are adjusted to reflect the greater value of tobacco from mild yellowing at the manufacturing stage.

Effect on industrial appearance, resistance to further processing, and absorption and desorption properties

The industrial appearance of flue-cured tobacco leaves was consistent with grade quality evaluation of appearance in commercial systems, and that obtained using regular yellowing was slightly higher than that resulting from mild yellowing. However, in view of the industrial processes used in flue-cured tobacco, mild yellowing was superior to regular yellowing. The moisture absorption characteristics and resistance to further processing of flue-cured tobacco leaves directly influenced the crumbliness of the leaves during processing. Generally speaking, more than 5 % of tobacco material is lost from tobacco leaves with poor resistance to further processing during subsequent defoliation and cigarette manufacture: this causes losses and increases the cost of tobacco and directly influences the economic value of tobacco leaves (Mutasa et al., 1990). Thus, the physical resistance to further processing of tobacco leaves is the focus of enterprises involved in re-drying tobacco and the greater the physical resistance to further processing, the less the loss of tobacco during defoliation. The data show that physical resistance to further processing represented by shatter resistance decreases as yellowing increases. Therefore, tobacco leaves with mild yellowing are easily processed during defoliation. With a rapid moisture absorption rate, tobacco leaves can quickly absorb moisture to enable defoliation in the re-drying process. Similarly, with a rapid moisture desorption rate, moisture in tobacco leaves can be quickly lost in the attempt to reach the required dry state. The data show that the moisture absorption and desorption rates of tobacco leaves with mild yellowing are greater than those of tobacco leaves with regular yellowing. Therefore, tobacco leaves with mild yellowing are more easily processed (*i.e.*, defoliated and re-dried). From the perspective of appearance, it is appropriate to choose a slightly higher degree of yellowing, while mild yellowing is more conducive to physical resistance to further processing and improved suction properties.

Effect on smoking characteristics of flue-cured, and re-dried tobacco leaves

Smoking characteristic scores are a core index used to evaluate the quality of tobacco leaves and the primary method of assessing the internal quality of tobacco leaves (Stedman, 1968; White et al., 1979; Weybrew et al., 1983; Tso, 1990); however, evaluating the

influence of the flue-curing process on tobacco qualities generally focuses on the smoking characteristics of tobacco leaves after flue-curing (Dai et al., 2008). The curing processes include flue-curing and re-drying; thus, the quality of tobacco leaves evaluated on the basis of the smoking characteristics of re-dried tobacco leaves is closer to that of 'as-produced' cigarettes and exhibits broader significance. This research studied the influence of different degrees of yellowing in flue-curing process on the smoking characteristics of re-dried tobacco to further optimize flue-curing processes. After being treated with different intensities in the re-drying stages, tobacco leaves with different degrees of yellowing had dissimilar smoking characteristics. In view of the processing effect, tobacco leaves with mild yellowing were more conducive to subsequent re-drying efficacy compared with the current degree of yellowing seen in flue-curing processes.

Conclusions

The following conclusions are drawn from the experiments undertaken at three sites over a two-year period: first, in view of grower income, the appearance, proportion of upper-class tobacco leaves, and proportions and average prices of middle- and upper-class tobacco leaves subjected to regular yellowing are superior to those subjected to mild yellowing, regardless of cultivar. Second, from the perspective of industrial flue-cured tobaccos, samples with mild yellowing exhibit the greatest shatter resistance among the tobacco leaves tested and there is no significant difference between cultivars. Moreover, among the samples collected from the three sites, the samples with mild yellowing show quicker moisture absorption and desorption rates than those subjected to regular yellowing. Third, the scored smoking characteristics of tobaccos subjected to the flue-curing process with a regular degree of yellowing at the three test sites were all higher than those with mild yellowing. Despite this, the quality of flue-cured tobaccos with regular yellowing could be adjusted slightly from an industrial point of view and smoking scores decreased as intensity during the re-drying stage increased. In comparison, the quality of tobacco leaves with mild yellowing could be improved through subsequent re-drying to meet industrial demand. Therefore, the results suggest that the conventional degree of yellowing in the flue-curing process needs to be reduced according to the settings of the flue-curing process from the re-drying perspective in the tobacco industry.

From the perspective of re-drying and cigarette processing, the authors propose an appropriate degree of yellowing for flue-curing as driven by the reform requirement from the supply side to improve the effectiveness of re-drying and tobacco processing. The conclusion is that it is necessary to treat both Hongda and K326 cultivars in tobacco-growing areas of Yunnan Province with 60 to 70 % yellowing before 42 °C with a flue-curing

process. This change would be most effectively brought about if the price structure was adjusted to render the tobacco obtained from mild yellowing more valuable to the farmer than that from regular yellowing in China.

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Authors' Contributions

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