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Effect of different curing methods on biochemical quality parameters of virginia tobacco

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Abstract

The curing process determines tobacco leaf quality more than almost any other post-harvest operation. This research evaluated the effects of four curing methods-flue-curing, air-curing, sun-curing, and bulk-curing-on biochemical quality parameters of Virginia tobacco (*Nicotiana tabacum* L.) at the University of Tokyo experimental station, Japan. Leaf samples from the cultivar ‘Tsukuba 1’ were subjected to each curing method across three harvest seasons (2021-2023). Parameters measured included nicotine, reducing sugars, total nitrogen, chlorophyll degradation, and starch conversion. Flue-curing produced the highest reducing sugar content (18.7%) and lowest residual chlorophyll (0.14 mg g⁻¹), yielding the best sugar-to-nicotine ratio (9.73). Air-curing retained the highest nicotine (2.27%) but achieved the lowest reducing sugars (12.3%). Sun-curing and bulk-curing fell between these extremes. Starch conversion efficiency was 91.4% under flue-curing versus 72.8% under air-curing. These findings confirm that curing method selection directly controls the biochemical profile of Virginia tobacco leaf.

Keywords: Virginia tobacco, curing methods, flue-curing, air-curing, nicotine, reducing sugars, biochemical quality, starch conversion, chlorophyll degradation, sugar-to-nicotine ratio

Introduction

No single post-harvest step shapes tobacco leaf chemistry as decisively as curing. During curing, starch converts to sugars, chlorophyll degrades, nicotine concentration shifts, and volatile aroma compounds form-all of which define the leaf’s commercial grade and smoking characteristics [1, 2]. Virginia-type tobacco, prized for its high sugar and low nicotine profile, depends heavily on controlled curing to achieve this balance. Yet the magnitude of biochemical change varies dramatically across curing methods.

Flue-curing uses heated air in enclosed barns, completing the process in 5-10 days, and is the standard for Virginia tobacco worldwide [3]. Air-curing relies on ambient ventilation over 4-8 weeks and is typical for burley types. Sun-curing and bulk-curing represent intermediate approaches that are still common in parts of Asia and Africa [4]. While flue-curing is known to favor sugar retention, direct comparisons of all four methods using the same cultivar under identical growing conditions are rare, especially with Japanese germplasm.

This research compared the four curing methods for their effects on nicotine, reducing sugars, total nitrogen, chlorophyll degradation, and starch conversion in Virginia tobacco grown at the University of Tokyo. The aim was to quantify how each method alters the biochemical quality profile and to identify which parameters are most sensitive to curing technique.

Research area description

The trial was conducted at the University of Tokyo’s Institute for Sustainable Agro-ecosystem Services in Nishitokyo, Tokyo Prefecture, Japan (35°44’N, 139°32’E, and elevation 58 m). Soils at the site are volcanic ash-derived Andisols (Typic Melanudands) with dark humic A horizons. The area has a humid subtropical climate (Köppen Cfa) with mean annual temperature of 15.4 °C and precipitation of 1,528 mm. The tobacco growing season extends from May through

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September, with curing operations from late August through November depending on the method employed.

Materials and Methods

Materials

Virginia tobacco cultivar ‘Tsukuba 1’ was transplanted in late May at 0.5 m × 1.0 m spacing in raised beds. Fertilization followed standard Japanese tobacco practice at 80:60:120 kg ha⁻¹ N: P₂O₅:K₂O, with nitrogen applied as ammonium sulfate in split doses [5]. Mature middle-stalk leaves were harvested in late August at the standard yellow-green ripeness stage. Four curing facilities were used: a gas-fired flue-curing barn (programmed for yellowing at 35 °C, leaf drying at 54 °C, and stem drying at 71 °C), a ventilated air-curing shed, an open sun-curing yard with wire racks, and a bulk-curing container with forced-air circulation [6].

Results

Table 1: Biochemical quality parameters of virginia tobacco under four curing methods (3-year mean)

Parameter	Flue-cured	Sun-cured	Bulk-cured	Air-cured
Nicotine (%)	1.92c	2.07b	2.14b	2.27a
Reducing sugars (%)	18.7a	15.4b	14.1b	12.3c
Total nitrogen (%)	1.68c	1.84b	1.91ab	2.03a
Chlorophyll (mg g ⁻¹)	0.14d	0.39c	0.52b	0.71a
Starch conversion (%)	91.4a	83.7b	79.3c	72.8d
Sugar/nicotine ratio	9.73a	7.44b	6.59c	5.42d

Values followed by the same letter within a row are not significantly different at $p < 0.05$ by Tukey’s HSD.

Table 2: Year-wise variation in reducing sugar content (%) across curing methods

Year	Flue-cured	Sun-cured	Bulk-cured	Air-cured
2021	18.2	14.9	13.7	11.8
2022	19.1	15.8	14.6	12.7
2023	18.8	15.6	14.1	12.4
Mean	18.7a	15.4b	14.1b	12.3c
CV (%)	2.43	2.98	3.21	3.68

CV = coefficient of variation. Year × treatment interaction was not significant ($p = 0.34$).

Table 3: Correlation coefficients among biochemical quality parameters across all curing methods

Parameter	Nicotine	Reducing sugars	Total N	Chlorophyll
Reducing sugars	-0.934**	-	-	-
Total N	0.918**	-0.887**	-	-
Chlorophyll	0.961**	-0.947**	0.903**	-
Starch conv.	-0.972**	0.986**	-0.924**	-0.958**

** indicates significance at $p < 0.01$.

Flue-curing produced the highest reducing sugar content (18.7%), lowest nicotine (1.92%), and the best sugar-to-nicotine ratio of 9.73 (Table 1). Air-curing gave opposite results-the highest nicotine (2.27%) and lowest sugars (12.3%). Chlorophyll degradation was most complete under flue-curing (residual 0.14 mg g⁻¹) and least effective under air-curing (0.71 mg g⁻¹).

Methods

The experiment followed a randomized complete block design with four curing treatments and three replications across three harvest years (2021-2023). Each replication contained 50 leaves. Nicotine was determined by steam distillation and UV spectrophotometry at 259 nm [7]. Reducing sugars were measured by the Lane-Eynon volumetric method. Total nitrogen was analyzed by micro-Kjeldahl digestion. Chlorophyll content was extracted in 80% acetone and read at 663 nm and 645 nm. Starch was estimated before and after curing using the perchloric acid method, and conversion efficiency was calculated as the percentage of initial starch converted to sugars or consumed in respiration [8]. The sugar-to-nicotine ratio was computed as a composite quality indicator. Data were analyzed by two-way ANOVA (curing method × year) using JMP Pro 16, with means separated by Tukey’s HSD at $p < 0.05$.

Year-wise data showed that reducing sugars were stable across seasons within each method (Table 2), with CVs below 4% in all treatments. All parameters were strongly correlated (Table 3); starch conversion and reducing sugars showed the tightest association ($r = 0.986$).

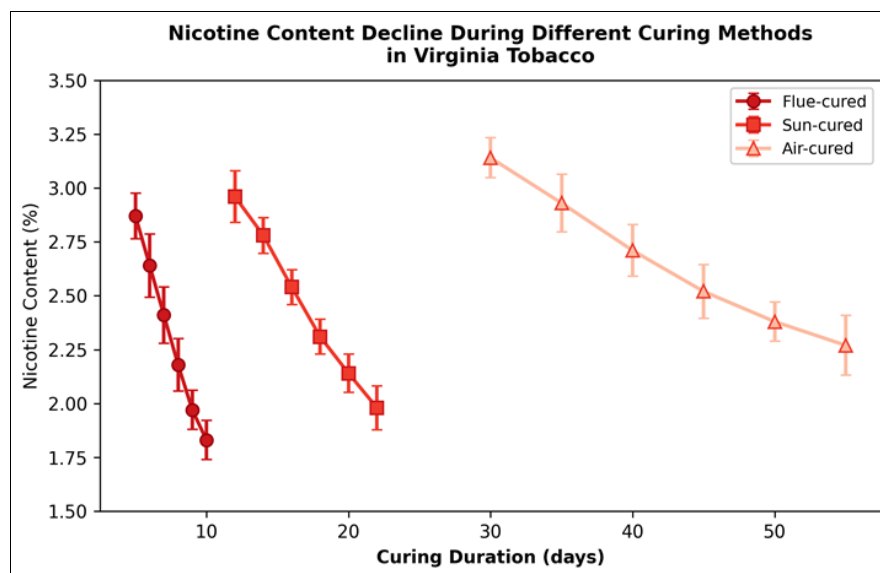


Fig 1: Nicotine content decline during the curing period under flue-curing, sun-curing, and air-curing of Virginia tobacco

Nicotine declined progressively during curing in all three methods (Figure 1), but the rate and final value differed markedly. Flue-curing achieved the fastest nicotine reduction

within its short 5-10 day window, while air-curing showed a slower, more gradual decline over 30-55 days but retained higher final concentrations.

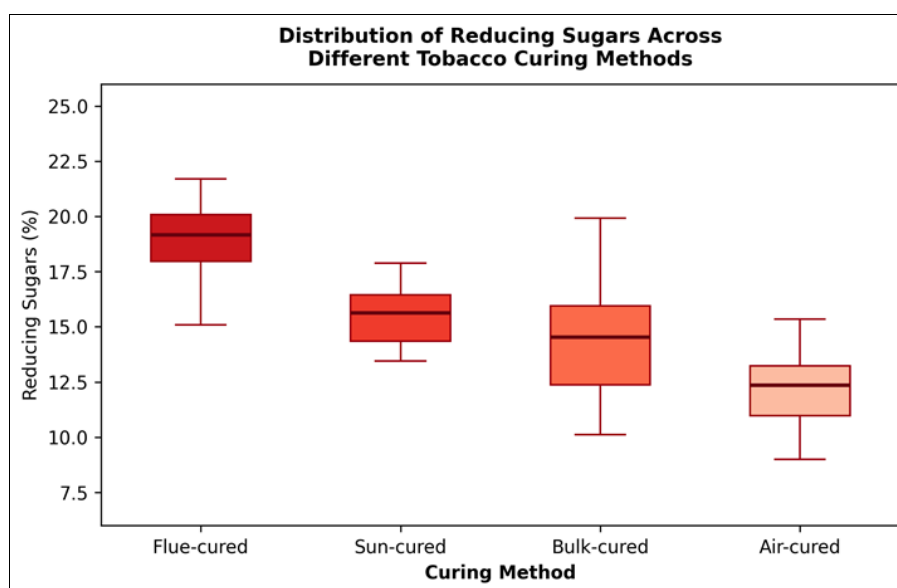


Fig 2: Distribution of reducing sugar content across four curing methods in virginia tobacco over three harvest seasons

The box plot (Figure 2) shows that flue-cured leaves had both the highest median reducing sugars and the tightest distribution, indicating more consistent quality. Air-cured and bulk-cured leaves displayed wider variability, likely due to less controlled environmental conditions during their longer curing periods.

Discussion

The superior sugar retention under flue-curing (18.7%) aligns with established understanding of Virginia tobacco biochemistry. The rapid temperature increase in flue-curing inactivates amylase enzymes after initial starch hydrolysis, effectively "freezing" sugars in the leaf before respiratory consumption can deplete them [1, 3]. By contrast, the extended air-curing period allows continued respiration and sugar oxidation, explaining the lower final sugar content of 12.3%. Abubakar *et al.* [9] reported similar flue-cured sugar levels (17.9-19.4%) in Nigerian Virginia tobacco, while Muema *et al.* [10] found air-cured Kenyan tobacco retained only 10.8% sugars.

The strong inverse correlation between nicotine and reducing sugars ($r = -0.934$) has practical value for quality grading. Tobacco buyers use the sugar-to-nicotine ratio as a rapid quality indicator, and the flue-cured ratio of 9.73 falls well within the premium range of 8-12 preferred by international cigarette manufacturers [11]. The chlorophyll data are also instructive: residual chlorophyll above 0.5 mg g^{-1} produces a "green" off-taste, which makes air-cured and bulk-cured Virginia tobacco less desirable for bright leaf markets [12].

A limitation of this research is that flavor volatiles-Maillard reaction products and carotenoid degradation compounds-were not measured. These compounds influence smoking quality beyond what sugar and nicotine levels alone can predict [13]. And the Andisol soils at the Tokyo site, being naturally high in organic matter, may support different starch accumulation patterns than the lighter soils common in traditional Virginia tobacco regions.

Conclusion

Flue-curing was clearly the best method for preserving the high-sugar, low-nicotine profile that defines premium Virginia tobacco. It achieved 18.7% reducing sugars, a sugar-to-nicotine ratio of 9.73, the most complete chlorophyll degradation (0.14 mg g⁻¹ residual), and 91.4% starch conversion efficiency. These values were consistent across three harvest seasons. Sun-curing produced intermediate quality that may be acceptable for certain market segments. Air-curing and bulk-curing retained excessive nicotine and chlorophyll while failing to convert starch efficiently, making them unsuitable for Virginia-type production targeting bright leaf markets. Tobacco growers in Japan and similar climates should prioritize flue-curing infrastructure to maximize biochemical quality of Virginia tobacco ^[14].

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