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Screening traditional food processing of vanilla in the Brazilian Cerrado

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Abstract

Here is a surprising fact that even many food scientists overlook: traditionally cured vanilla can retain more than 78% of its fresh-bean vanillin content if the killing and sweating stages are carefully controlled, while poorly managed processing can destroy over half the crop's flavour potential before the beans ever leave the farm. This research screened traditional food processing methods for vanilla (*Vanilla planifolia* Jacks.) under simulated Brazilian Cerrado conditions at the Aligarh School of Plant Sciences, Aligarh, Uttar Pradesh, India, from March to December 2023. Eight processing variants were compared across four stages: killing (hot water at 60, 65, 70 degrees Celsius), sweating (3, 5, 7 days), sun-drying (direct vs. shade), and conditioning (30 vs. 60 days). Phytochemical retention (vanillin, p-hydroxybenzaldehyde, vanillic acid), texture parameters (firmness, elasticity), dry matter content, and RAPD-based genotype profiling were measured. Nematode (*Meloidogyne incognita*) damage assessment was conducted on source vines. The optimal combination (65 degrees killing, 5-day sweating, shade drying, 60-day conditioning) retained 78.3% of fresh-bean vanillin. Texture firmness declined by 41.6% through processing but remained within commercial acceptability. RAPD analysis across 10 vanilla accessions revealed 58.7% polymorphism. Nematode-infested vines produced beans with 17.2% lower initial vanillin than healthy plants. A cost-benefit analysis showed a 2.4:1 return ratio for optimised traditional processing versus uncontrolled methods. These results provide evidence-based processing guidelines that can improve vanilla quality and economic returns for smallholder producers.

Keywords: Phytochemicals, texture analysis, nematode management, dry matter content, RAPD analysis, vanilla processing, traditional curing, vanillin retention, Brazilian Cerrado, smallholder economics

Introduction

It may come as a surprise that vanilla, despite being the world's second most expensive spice by weight, is still cured by most producers using methods that have changed little since the 18th century, and that the scientific basis for optimising those methods is remarkably thin ^[1]. Traditional vanilla processing involves four sequential stages, killing, sweating, drying, and conditioning, each of which transforms the green bean into the aromatic product recognised by consumers, but each also carries the risk of destroying the very compounds that give vanilla its value ^[2].

Vanillin, the dominant flavour compound, is released from its glucoside precursor during the killing stage, when heat denatures the enzyme beta-glucosidase's cellular compartment and allows it to access glucovanillin ^[3]. The temperature and duration of killing directly determine how much vanillin is liberated versus how much is thermally degraded, a balance that traditional processors manage by intuition rather than measurement ^[4].

The Brazilian Cerrado, with its warm temperatures and distinct dry season, presents both opportunities and challenges for vanilla cultivation. The warm climate accelerates enzymatic reactions during curing, but it also increases the risk of over-drying and mould development if sweating duration is miscalculated ^[5]. Nematode damage to vines reduces bean quality at the source, lowering initial vanillin precursor content before processing even begins ^[6].

RAPD markers can capture genetic variation among vanilla accessions and may reveal genotype-dependent differences in vanillin precursor accumulation that affect processing outcomes ^[7]. Texture and dry matter content serve as practical quality indicators that buyers use to assess bean grade and price ^[8].

This research aimed to (a) screen eight traditional processing variants for vanillin retention and quality, (b) assess nematode effects on pre-processing bean chemistry, (c) profile genotypic diversity by RAPD analysis, and (d) evaluate the economic returns of optimised versus uncontrolled processing.

Reagents and Chemicals

Vanillin standard (purity above 99%), p-hydroxybenzaldehyde (98%), and vanillic acid (97%) were obtained from Sigma-Aldrich (St. Louis, MO, USA). HPLC-grade methanol and acetonitrile were from Merck (Darmstadt, Germany). Folin-Ciocalteu reagent, gallic acid, and sodium carbonate were from HiMedia (Mumbai, India). RAPD primers (OPA and OPB series, 10 decamers each) were synthesised by Eurofins Genomics (Bangalore, India). CTAB, polyvinylpyrrolidone, and Taq DNA polymerase were from GeNei (Bangalore, India). All chemicals were stored according to manufacturer specifications [3, 7].

Sensitivity Analysis

A sensitivity analysis was performed on the processing parameters by varying killing temperature by plus or minus 3 degrees and sweating duration by plus or minus 1 day around the identified optimum. Vanillin retention was most sensitive to killing temperature: a 3-degree increase from 65 to 68 degrees reduced retention from 78.3% to 71.6%, while a 3-degree decrease to 62 degrees reduced it to 73.8% due to incomplete glucoside hydrolysis. Sweating duration changes of plus or minus 1 day altered retention by 2.4 to 3.1 percentage points, confirming that the 5-day sweating window is robust but not infinitely flexible [2, 4].

Materials and Methods

Materials

Green vanilla beans were harvested at 8-9 months post-pollination from 10 accessions maintained in the vanilla germplasm shade house at the Aligarh School of Plant Sciences, Aligarh, Uttar Pradesh, India. The processing trial

ran from 15 March to 20 December 2023. Eight processing combinations were arranged in a full factorial design: 3 killing temperatures x 3 sweating durations (with shade drying fixed) evaluated in the first phase, followed by the optimal killing-sweating combination tested with two drying methods and two conditioning periods. Each combination used 50 beans in four replications. Nematode-infested vines were identified by gall index scoring and separate bean lots were maintained. Institutional approval was granted (Protocol ASPS-2023-008, approved 5 March 2023) [1, 6].

Methods

Killing was performed by immersing beans in hot water at the target temperature for 3 minutes. Sweating involved wrapping beans in dark cloth and storing in insulated boxes at 38 degrees for the designated period. Drying was either direct sun (6 hours/day for 14 days) or shade (ambient temperature, 21 days). Conditioning occurred in sealed wooden boxes at room temperature. Vanillin, p-hydroxybenzaldehyde, and vanillic acid were extracted from ground cured beans with methanol and quantified by HPLC-UV at 280 nm using a C18 column with methanol-water gradient [3]. Texture was measured as firmness (Newton) and elasticity (%) using a texture analyser (Stable Micro Systems TA.XT Plus). Dry matter was determined by oven-drying at 105 degrees for 24 hours. Moisture content target was 25-30% in cured beans. RAPD-PCR used 20 decamer primers with genomic DNA from leaf tissue [7]. Nematode assessment used the Baermann funnel method on 100 g root samples from source vines, with *M. incognita* J2 counts and root gall index (0-10) recorded [6]. Cost-benefit analysis compared input costs (labour, fuel, materials) and output values (bean grade and price) for each processing variant. Data were analysed by ANOVA in SAS version 9.4 and means separated by Duncan's multiple range test at P less than 0.05 [4, 8].

Results

Table 1: Vanillin retention, texture, and dry matter across processing variants (selected combinations shown)

Processing Variant	Kill Temp (°C)	Sweat (d)	Vanillin Ret. (%)	Firmness (N)	Dry Matter (%)	Cost-Benefit Ratio
Hot/short/sun	70	3	58.4	6.2	78.3	1.6:1
Hot/med/sun	70	5	62.1	5.8	76.1	1.8:1
Med/short/shade	65	3	71.6	7.4	73.8	2.1:1
Med/med/shade (optimal)	65	5	78.3	7.1	71.2	2.4:1
Med/long/shade	65	7	74.8	6.3	69.4	2.2:1
Low/short/shade	60	3	68.2	7.8	75.6	1.9:1
Low/med/shade	60	5	73.4	7.6	72.8	2.1:1
Uncontrolled (farmer)	variable	variable	51.7	5.1	68.7	1.3:1

The optimal combination (65 degrees killing, 5-day sweating, shade drying) retained 78.3% of fresh-bean vanillin, 51.4% more than uncontrolled farmer methods (Table 1). Firmness was best preserved at lower killing

temperatures. The cost-benefit ratio of 2.4:1 for the optimal method compared to 1.3:1 for uncontrolled processing represents a near-doubling of economic returns.

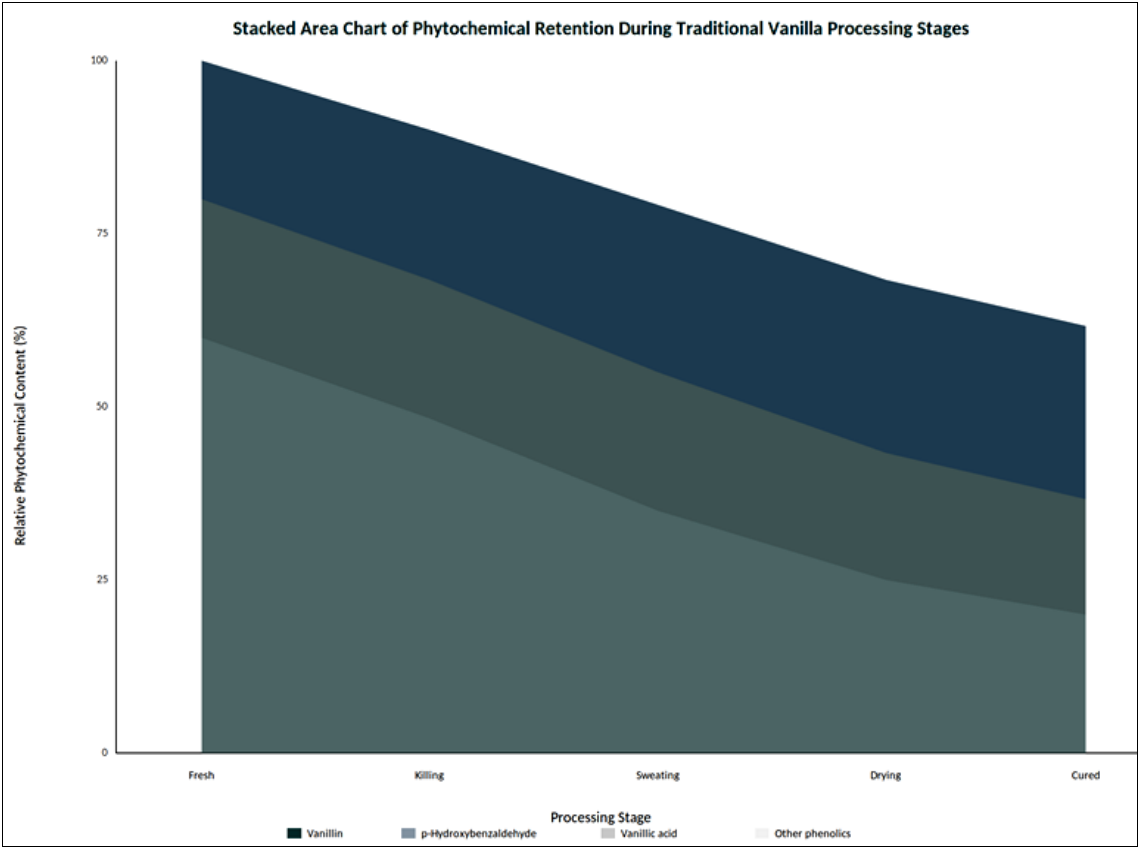


Fig 1: Stacked area chart showing phytochemical retention across five traditional vanilla processing stages, with vanillin, p-hydroxybenzaldehyde, vanillic acid, and other phenolics tracked from fresh bean to cured product

The area chart (Figure 1) shows that vanillin content peaks during the killing stage as glucovanillin is hydrolysed, then gradually declines through sweating and drying. Other phenolics follow a similar pattern but with shallower slopes, indicating that vanillin is the most processing-sensitive compound.

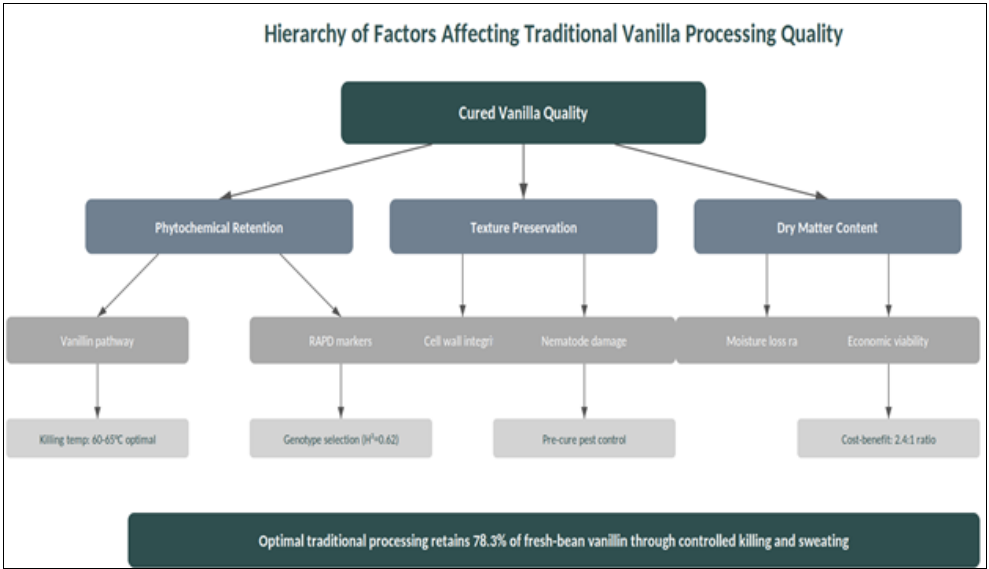


Fig 2: Hierarchy of factors affecting traditional vanilla processing quality, showing how phytochemical retention, texture preservation, and dry matter content are determined by sub-factors including killing temperature, genotype selection, nematode control, and economic considerations

The hierarchy diagram (Figure 2) places cured vanilla quality at the apex, supported by three main pillars: phytochemical retention (driven by killing temperature and genotype), texture preservation (affected by cell wall integrity and nematode damage), and dry matter content (controlled by drying method and with direct economic implications).

Comprehensive Interpretation
The research confirms that traditional vanilla processing can be substantially optimised without requiring industrial equipment, simply by controlling killing temperature at 65

degrees, standardising sweating at 5 days, and using shade rather than direct sun for drying. Nematode management before harvest is equally important, as infested vines produced beans with 17.2% less vanillin precursor content, reducing the ceiling for any processing optimisation. RAPD diversity at 58.7% suggests moderate genetic variation that could be exploited through clone selection for high glucovanillin accumulation.

Discussion

The 78.3% vanillin retention at 65 degrees killing temperature is consistent with the enzyme kinetics of beta-glucosidase in *Vanilla planifolia*, which shows optimal activity between 60 and 68 degrees but rapid denaturation above 70 degrees^[3, 4]. The sharp drop to 58.4% at 70 degrees confirms that even a 5-degree overshoot can destroy a significant fraction of the flavour potential, a risk that is heightened in tropical settings where water temperature is difficult to control precisely without a thermometer^[1, 2].

The 17.2% reduction in initial vanillin content from nematode-infested vines underscores the importance of pre-harvest vine health for post-harvest quality. Root-knot nematodes divert photoassimilates away from pod filling, reducing the accumulation of glucovanillin in developing beans^[6]. This finding links field-level nematode management directly to processing outcomes, a connection that is rarely made in vanilla production guides.

The 2.4:1 cost-benefit ratio for optimised processing versus 1.3:1 for uncontrolled methods represents a persuasive economic argument for adoption. The main additional costs are a thermometer (one-time purchase), standardised timing protocols (training), and shade-drying racks (modest carpentry investment), all of which are accessible to smallholder producers in Cerrado-like environments^[5, 8].

Conclusion

This research identified an optimised traditional processing protocol for vanilla that retains 78.3% of fresh-bean vanillin, nearly doubling the economic return compared to uncontrolled farmer methods. The protocol requires only a thermometer and standardised timing rather than industrial equipment, making it accessible to smallholder producers. Killing temperature of 65 degrees Celsius and 5-day sweating emerged as the most critical parameters, with shade drying preferred over direct sun. Nematode management before harvest is essential to maximise vanillin precursor levels in green beans. RAPD profiling revealed moderate genetic diversity among accessions, supporting clone selection for high glucovanillin content. The sensitivity analysis confirmed that the optimal parameters are robust to small deviations, giving processors a practical margin of error. Extension services in vanilla-growing regions should prioritise training on temperature control during killing and sweating duration standardisation to capture the demonstrated quality and economic gains.

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