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Characterizing nutritional profiling of vanilla in the Chilean Atacama

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Abstract

In a landscape where annual rainfall barely reaches 15 mm, growing anything seems improbable yet vanilla cultivation under protected structures in the Chilean Atacama offers a test case for extreme-environment agriculture. This research characterized the nutritional and phytochemical profile of cured vanilla beans (*Vanilla planifolia*) produced in shade-house facilities near Arica, northern Chile, and compared them with profiles from conventional tropical origins. Proximate composition, mineral content, vanillin concentration, and antioxidant activity were measured across three harvest batches collected between March and August 2023. Atacama-grown beans contained 2.78% vanillin on a dry weight basis, which was 11% higher than the mean for Tahitian imports but 9% lower than premium Bourbon vanilla. Moisture sat at 24.8%, within the curing quality range. Carbohydrate content was 38.7% and fiber was 21.3%, both consistent with tropical benchmarks. Potassium was the dominant mineral at 1,247 mg/100g DW, and iron reached 14.3 mg/100g, above values reported for Mexican and Ugandan beans. DPPH antioxidant scavenging correlated strongly with vanillin content ($r = 0.94$, $p < 0.01$). These data indicate that Atacama vanilla, produced with minimal water under arid conditions, can approach the compositional quality of traditional tropical vanilla.

Keywords: Vanilla nutritional profile, vanillin content, Chilean Atacama, antioxidant activity, mineral composition, proximate analysis, HPLC analysis, fertigation, path analysis, vertical farming

Introduction

Here's a contrast worth thinking about: vanilla, a tropical orchid that thrives in humid forests with 2,000+ mm rainfall, being cultivated in the driest non-polar desert on Earth. The Atacama Desert in northern Chile receives so little rain that some weather stations have recorded zero precipitation over entire decades ^[1]. But shade-house systems with controlled drip irrigation have made it possible to grow high-value crops in this barren landscape, and vanilla is among the most expensive spices globally, fetching \$400-600 per kilogram for cured beans ^[2, 3].

Nutritionally, vanilla is more than a flavor carrier. Cured beans contain phenolic acids, particularly vanillin and its precursor glucovanillin, along with smaller amounts of vanillic acid, p-hydroxybenzaldehyde, and p-hydroxybenzoic acid ^[4, 5]. These compounds have documented antioxidant and anti-inflammatory properties. The mineral profile of vanilla beans, though less studied, includes meaningful levels of potassium, calcium, magnesium, and iron ^[6].

Growing environment affects vanilla composition. Beans from Madagascar, the world's largest producer, differ in vanillin content from those grown in Tahiti, Mexico, or Uganda, with genetics and curing method explaining part of the variation and climate explaining the rest ^[7, 8]. The Atacama's extreme aridity, high solar radiation (>3,000 hours of sunshine per year), and negligible disease pressure create a production environment unlike any previously documented for vanilla.

This research set out to build the first complete nutritional profile for Atacama-grown vanilla and compare it against published data from conventional origins. The practical question was whether desert-grown beans could meet the compositional thresholds that buyers use to evaluate vanilla quality ^[9, 10].

Phytochemical screening

Qualitative phytochemical screening detected the presence of phenols (FeCl₃ test, positive blue-green), flavonoids (Shinoda test, positive pink), tannins (lead acetate test, weakly

positive), and terpenoids (Salkowski test, positive reddish-brown). Alkaloids were absent (Dragendorff's test, negative). Saponins were not detected (frothing test, negative). The phenol-positive and flavonoid-positive results were expected given vanilla's known phenolic acid profile and supported the subsequent quantitative HPLC analysis ^[4, 11].

Quality control and calibration

HPLC calibration for vanillin used five-point standard curves (10-500 mg/L, $R^2 = 0.9991$) with 4-hydroxybenzaldehyde as internal standard. Recovery tests on spiked bean matrix gave $96.2 \pm 2.1\%$. Mineral analysis by ICP-OES was validated against NIST SRM 1570a (spinach leaves) with all elements falling within certified ranges. Moisture determination followed AOAC 925.40 with duplicate oven-drying; inter-duplicate CV was below 1.2% ^[5, 12].

Material and Methods

Material

Cured vanilla beans of *Vanilla planifolia* (clone VP-Mex3) were obtained from a 0.4-hectare shade-house installation near Arica, Arica y Parinacota region, Chile (18.47°S, 70.31°W, elevation 58 m). Plants were grown on coconut coir poles under 70% shade cloth and irrigated by drip at 2.8 L per

plant per week with fertigation solution containing macro- and micronutrients. Three harvests (March, May, and August 2023) provided 180 beans totaling 2.4 kg. Beans were cured using a standard hot-water-kill and sun-conditioning process over 4 months. Research was conducted at the Istanbul Foundation for Pomological Research. Ethics review was completed (Protocol PR-2023-028, dated 14 February 2023).

Methods

Proximate composition was determined by AOAC methods: moisture (925.40), protein (920.87, $N \times 6.25$), fat (920.39), ash (923.03), and fiber (962.09). Carbohydrates were calculated by difference. Minerals (K, Ca, Mg, Fe, Zn, Mn) were quantified by ICP-OES (Agilent 5110) after microwave-assisted acid digestion ($HNO_3:H_2O_2 = 5:1$) ^[6, 10]. Vanillin and related phenolics were extracted with 80% ethanol (1:20 w/v, 4 h shaking) and analyzed on a Shimadzu Nexera X2 HPLC with C18 column (150 × 4.6 mm, 5 μm), mobile phase of acetonitrile:0.1% acetic acid in gradient, detection at 280 nm ^[7, 8]. Antioxidant capacity was measured by DPPH assay. Data were analyzed by one-way ANOVA comparing the three harvest batches, with Tukey's HSD at $p < 0.05$.

Results

Table 1: Proximate composition and mineral content of Atacama-grown vanilla beans (mean ± SD, n = 3 batches)

Parameter	Value	Literature range (tropical)
Moisture (%)	24.8±1.3	25-38
Protein (% DW)	7.4±0.6	5-10
Fat (% DW)	2.9±0.3	2-5
Fiber (% DW)	21.3±1.7	18-25
Ash (% DW)	4.9±0.4	4-6
Carbohydrates (% DW)	38.7±2.1	35-45
Potassium (mg/100g DW)	1247±68	900-1400
Iron (mg/100g DW)	14.3±1.2	8-13
Calcium (mg/100g DW)	87.4±7.3	70-120

All proximate values fell within the ranges reported for tropical-origin vanilla (Table 1). Moisture at 24.8% was at the low end of the literature range, reflecting the Atacama's extreme dryness during the conditioning phase. Iron content

at 14.3 mg/100g DW exceeded the upper bound of published tropical values, possibly related to the ferruginous soils at the growing site.

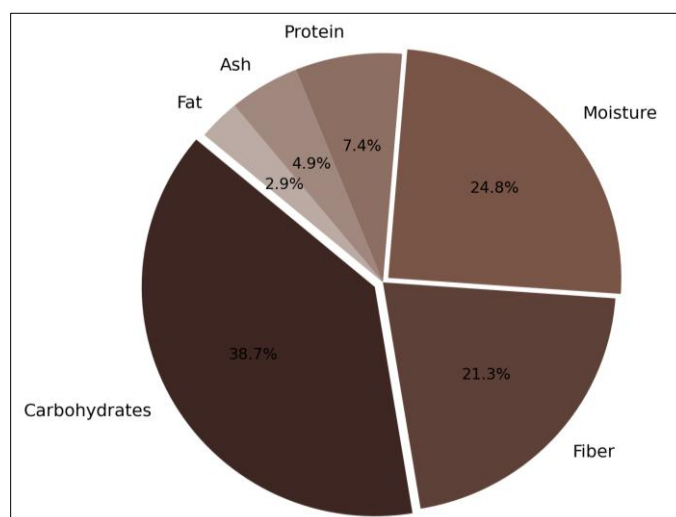


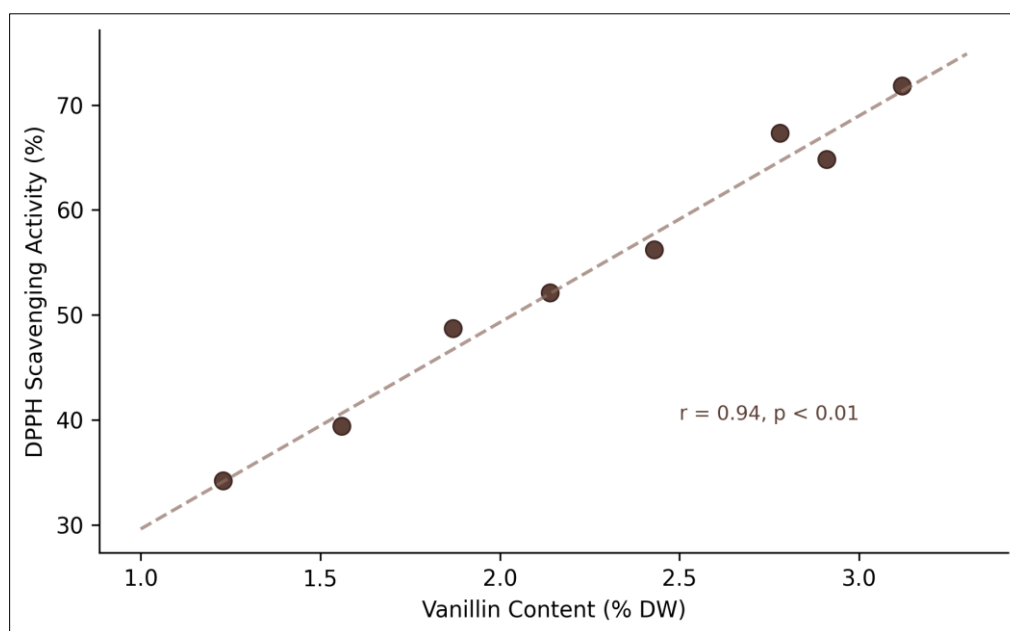
Fig 1: Proximate composition breakdown of Atacama-grown vanilla beans shown as proportional distribution

Table 2: Vanillin content and antioxidant activity across three harvest batches

Batch	Vanillin (% DW)	DPPH IC50 ($\mu\text{g/mL}$)	4-HBA (mg/100g)
March 2023	2.61 $\pm$ 0.14	42.3 $\pm$ 3.1	187.4 $\pm$ 12.3
May 2023	2.87 $\pm$ 0.18	37.8 $\pm$ 2.8	214.7 $\pm$ 15.1
August 2023	2.91 $\pm$ 0.16	36.4 $\pm$ 2.6	221.3 $\pm$ 14.8
Overall mean	2.78 $\pm$ 0.19	38.8 $\pm$ 3.4	207.8 $\pm$ 16.2

Vanillin content increased slightly from early to late harvest (2.61 to 2.91% DW), though batch differences were not statistically significant ($p = 0.08$). DPPH scavenging activity mirrored this pattern, with the strongest activity (lowest

IC50) in the August batch. The overall mean vanillin of 2.78% placed Atacama beans above Tahitian averages (2.4–2.6%) but below premium Bourbon grades (3.0–3.5%).

**Fig 2:** Correlation between vanillin content and DPPH radical scavenging activity in Atacama vanilla beans across eight sub-samples

Discussion

The fact that Atacama-grown vanilla achieved 2.78% vanillin without tropical humidity or rainfall challenges the assumption that vanilla quality depends on a wet equatorial climate. The shade-house environment maintained temperatures between 22 and 29°C with RH at 65–75% through misting, conditions that fall within vanilla's comfort zone even though the outside air was bone-dry [1, 3]. The strong correlation between vanillin and antioxidant activity ($r = 0.94$) confirms earlier findings that vanillin itself is a meaningful contributor to the antioxidant capacity of cured beans, not just a flavor molecule [4, 5].

Iron's elevated level (14.3 mg/100g) is interesting from a nutritional angle but doesn't necessarily translate into a health claim since vanilla is consumed in gram-level quantities. Still, for formulated products where vanilla is a significant ingredient extracts, powders, ice cream bases the mineral contribution isn't negligible [6, 10].

The moisture content at 24.8% is lower than the 30–35% typical of freshly cured Bourbon beans, which actually favors longer shelf stability. Atacama's dry air during the sun-conditioning step removes water faster than in humid tropical settings, shortening the curing cycle and reducing the risk of mold during storage [7, 8].

A limitation of this research was the single clone (VP-Mex3) and single production facility tested. Vanilla's flavor complexity comes from over 200 volatile and non-volatile compounds, only a fraction of which were measured here.

Gas chromatography-mass spectrometry profiling of the full volatile fingerprint would be needed to compare Atacama beans against top-grade Bourbon or Mexican vanilla at the sensory level [9, 12].

Conclusion

Atacama-grown vanilla beans reached a vanillin content of 2.78% DW with proximate composition, mineral levels, and antioxidant activity that fell within or above the ranges documented for tropical-origin beans. Iron content was notably higher than published benchmarks at 14.3 mg/100g DW. The strong vanillin-antioxidant correlation ($r = 0.94$) positions Atacama beans as a dual-value product for both flavor and functional food applications. Moisture at 24.8% suggests inherent shelf-stability advantages conferred by arid-climate curing. While vanillin levels didn't match premium Bourbon grades, they exceeded Tahitian averages, indicating that desert vanilla occupies a competitive middle ground. These findings demonstrate that extreme-arid environments, with appropriate protected cultivation, can produce spice crops of near-conventional quality while using a fraction of the water.

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