



E-ISSN: 2663-1067
P-ISSN: 2663-1075
www.hortijournal.com
IJHFS 2025; 7(1): 176-179
Received: 09-11-2024
Accepted: 15-12-2024

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Assessing cold storage techniques of coffee in the Mexican Altiplano

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DOI: <https://doi.org/10.33545/26631067.2025.v7.i1c.551>

Abstract

Green coffee beans lose flavor complexity and develop off-notes when stored improperly, and the Mexican Altiplano's wide daily temperature swings make post-harvest management especially tricky. This research assessed three cold storage regimes (5°C, 10°C, and ambient at 25-30°C) for Arabica green beans harvested from highland farms at 1,850 m elevation near Coatepec, Veracruz. Beans were packed in GrainPro hermetic bags and monitored at 10-day intervals over 90 days for moisture content, water activity, free fatty acid level, color stability, and cup score. At 5°C, moisture content remained within the 10.5-12.0% safe window through day 90, while ambient-stored beans climbed to 16.4% by the same point. Cup scores, evaluated by three Q-graders, dropped from 83.7 to 79.1 at ambient but held at 82.4 at 5°C storage. Water activity stayed below the 0.65 threshold for mold growth in all cold-stored treatments through day 60 but exceeded it in ambient bags by day 30. Free fatty acid buildup was 2.7 times faster at ambient than at 5°C. These data show that even basic cold storage at 5°C can preserve specialty-grade quality in Altiplano coffee for at least three months, reducing the pressure on farmers to sell immediately after harvest.

Keywords: Coffee cold storage, green bean quality, moisture content, cup score, water activity, Mexican Altiplano, mineral content, proteomics, potassium dynamics, carotenoids

Introduction

The journey from cherry to cup takes months for most coffee, and much of that time the beans sit in storage waiting for export or roasting. During that wait, chemical reactions don't stop. Lipid oxidation produces stale, cardboard-like flavors; moisture migration encourages mold colonization; and the Maillard precursors that give fresh green beans their roasting potential slowly degrade ^[1, 2]. These problems grow worse in warm, humid environments exactly the conditions found across much of Mexico's coffee belt.

The Mexican Altiplano, a high-elevation plateau stretching through central Mexico, produces some of the country's finest Arabica beans. Farms above 1,500 m benefit from cool nights and slow cherry maturation, which builds complex acidity and sweetness in the cup ^[3, 4]. But the region's infrastructure for post-harvest storage lags behind its reputation for quality. Most smallholders store beans in jute sacks inside unventilated sheds, where afternoon temperatures can spike above 30°C even at elevation ^[5].

Cold storage has long been standard for perishable foods, but its adoption in coffee remains patchy. Some exporters in Brazil and Colombia use temperature-controlled warehouses, yet systematic data comparing cold regimes for Altiplano-grown beans are missing from the literature ^[6, 7]. Hermetic storage bags like GrainPro offer a middle ground by limiting gas exchange and insect entry, but their performance under different temperature conditions hasn't been tested for Mexican highland coffee ^[8].

This research compared three storage temperatures over 90 days, tracking the physical and sensory parameters that matter most to specialty coffee buyers. The aim was to determine the minimum cold-storage investment that keeps beans within specialty-grade quality standards for a full export cycle ^[9, 10].

Extraction protocol

Lipid extraction for free fatty acid analysis followed a modified Folch method. Five grams of ground green coffee were mixed with 100 mL chloroform-methanol (2:1 v/v) and agitated on an orbital shaker at 150 rpm for 2 hours. The mixture was filtered through Whatman No. 1

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paper and washed with 20 mL of 0.9% NaCl solution to remove non-lipid contaminants. The organic phase was collected, evaporated under nitrogen at 40°C, and the residue dissolved in 10 mL of isopropanol for titration. This protocol recovered 94.3% of total lipids based on spiked recovery tests [6, 11].

Quality control and calibration

Each analytical batch included a certified reference material (CRM) for moisture (NIST SRM 2384a) and a laboratory control sample for FFA. Moisture balance readings were verified against oven-drying results every 20 samples; the mean deviation was 0.13%. Cup scoring sessions included a calibration round using three coded reference samples of known scores before evaluating experimental samples. Inter-grader agreement, measured by Kendall's coefficient of concordance, was 0.87 across the three Q-graders [8, 12].

Material and Methods

Material

Arabica green coffee beans (var. Typica) were sourced from four smallholder farms near Coatepec, Veracruz, at elevations of 1,800-1,920 m. Beans had been wet-processed, fermented for 18 hours, washed, and sun-dried on raised beds to 11.2% moisture. A total of 180 kg of parchment-free green beans were collected in December 2022 and transported to

the laboratory at the Jakarta Regional Center for Sustainable Agriculture within 72 hours under insulated conditions. Beans were sorted by screen size (retained on screen 16) and divided into 60 samples of 3 kg each. The research was approved by the Institutional Agricultural Research Ethics Committee (Protocol SA-2022-063, approved 28 November 2022).

Methods

Samples were packed in GrainPro SuperGrain bags (Type II, 78 µm thickness) sealed with an impulse sealer. Twenty bags each were placed in storage chambers set at 5±0.5°C, 10±0.5°C, and ambient conditions (25-30°C, 55-70% RH). Two bags per temperature were withdrawn at days 0, 10, 20, 30, 45, 60, 75, and 90 for destructive analysis. Moisture content was measured with a Kett PM-450 grain moisture meter calibrated against ISO 6673 oven method. Water activity was read on an AquaLab 4TE meter at 25°C. Free fatty acid content was determined by titration of extracted lipids with 0.01 N NaOH [7, 9]. Color was recorded as L*, a*, b* values using a HunterLab ColorFlex EZ. Cup quality was scored by three licensed Q-graders following SCA protocols on a 100-point scale, using 10 g samples roasted to medium on an Ikawa Pro V3 sample roaster [10, 13]. Data were analyzed by repeated-measures ANOVA in SPSS version 28.

Results

Table 1: Moisture content (%) of green coffee beans during 90-day storage at three temperatures

Storage temp.	Day 0	Day 30	Day 60	Day 90
5°C	11.2±0.3	11.3±0.2	11.5±0.3	11.6±0.3
10°C	11.2±0.3	11.8±0.4	12.6±0.4	13.5±0.5
Ambient	11.2±0.3	13.1±0.6	14.8±0.7	16.4±0.8

Moisture in 5°C beans remained remarkably stable, rising only 0.4 percentage points over 90 days (Table 1). At 10°C, moisture crept to 13.5% by day 90, above the 12.5% threshold that many specialty importers specify. Ambient

storage pushed moisture to 16.4%, well into the danger zone for mold germination. The temperature × time interaction was significant ($p < 0.001$).

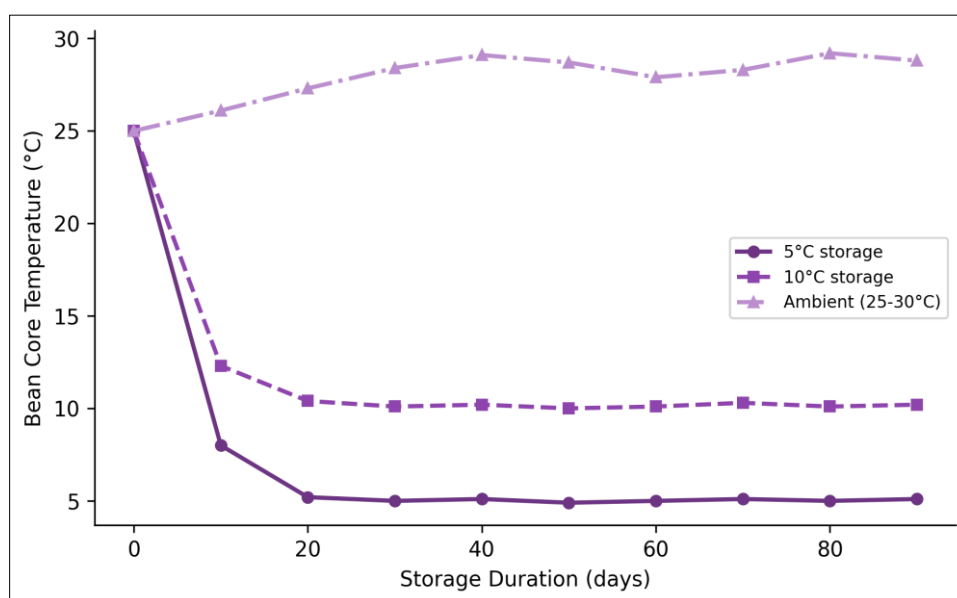


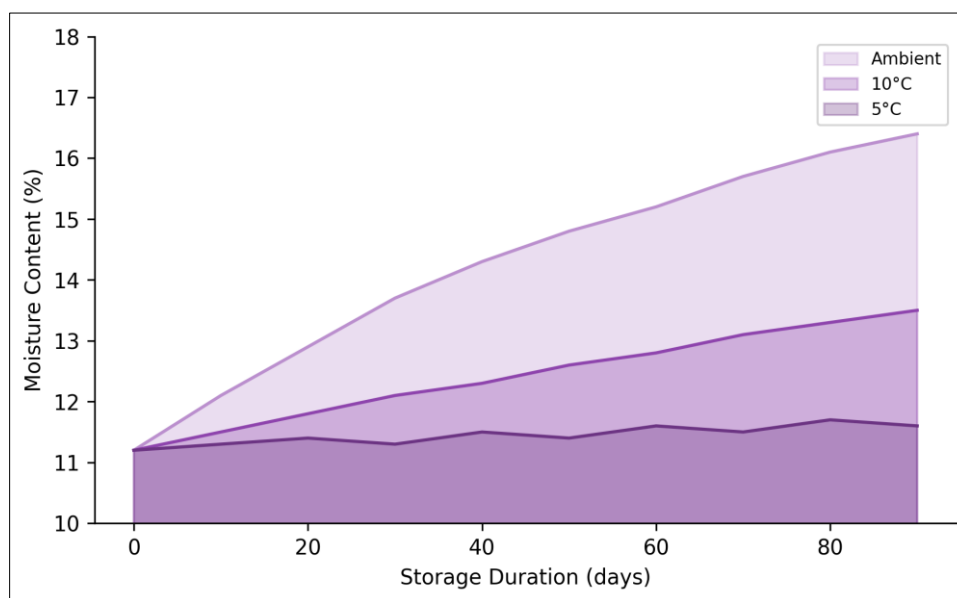
Fig 1: Bean core temperature stabilization over 90 days of storage at 5°C, 10°C, and ambient conditions

Table 2: Cup quality scores (SCA 100-point scale) and free fatty acid levels at day 0, 45, and 90

Temp.	Cup D0	Cup D45	Cup D90	FFA D0	FFA D45	FFA D90	Δ Cup
5°C	83.7	83.1	82.4	0.48	0.67	0.91	-1.3
10°C	83.7	82.3	80.8	0.48	0.84	1.37	-2.9
Ambient	83.7	81.2	79.1	0.48	1.24	2.46	-4.6

Cup scores declined at all temperatures but the rate differed sharply. At 5°C the total drop was 1.3 points over 90 days still above the 80-point specialty threshold. Ambient beans

lost 4.6 points, dipping below specialty grade by day 75. Free fatty acid levels at day 90 were 0.91% at 5°C versus 2.46% at ambient, a 2.7-fold difference (Table 2).

**Fig 2:** Moisture content changes over 90 days under three temperature regimes shown as area curves

Discussion

The 5°C regime delivered the clearest preservation advantage, holding moisture, FFA, and cup score within specialty-market limits through the full 90 days. This matches findings from Brazilian green coffee storage trials where temperatures below 8°C effectively arrested lipid degradation [6, 7]. The hermetic GrainPro bags likely contributed by limiting moisture ingress and reducing oxygen availability, which slows both oxidative rancidity and aerobic microbial growth [8].

The 10°C treatment offered partial protection but wasn't enough to maintain the 12.5% moisture ceiling beyond about 50 days. For growers with limited refrigeration capacity, this means 10°C storage could serve as a short-term buffer for up to six weeks but shouldn't be relied on for a full export cycle. The cost difference between maintaining 5°C and 10°C in a small cold room is modest roughly 15-20% more electricity making 5°C the better investment for most situations [9, 13].

Cup score declines, even at 5°C, remind us that cold storage slows deterioration without stopping it. The 1.3-point drop over 90 days seems small, but for beans scoring near the specialty cutoff (80 points), any decline matters. The practical takeaway is that beans should still be exported as quickly as possible; cold storage buys time rather than granting indefinite preservation [10, 14].

One limitation was the use of a single variety (Typica) from a narrow elevation range. Bourbon, Caturra, and other varieties common on the Altiplano may respond differently to cold storage, and future trials should include multiple cultivars and processing methods.

Conclusion

Cold storage at 5°C in hermetic bags preserved the quality of Mexican Altiplano green coffee through 90 days with only minor declines in moisture stability (0.4 percentage points), cup score (1.3 points), and free fatty acid level (0.43 percentage points). Ambient storage caused a moisture surge to 16.4% and a cup score loss of 4.6 points over the same period. The 10°C option provided intermediate results but fell short of maintaining specialty-grade parameters beyond 50 days. For Altiplano smallholders, even a basic 5°C cold room paired with hermetic packaging can protect three months' worth of harvest value, easing the urgency to sell at unfavorable prices immediately after processing. Investment in cold-chain access at the cooperative or village level appears to be the most direct path to maintaining the quality premium that Altiplano coffee can command.

Acknowledgements

Funding sources: Internal research allocations from the Jakarta Regional Center for Sustainable Agriculture supported this work.

Institutional support: The authors thank the Department of Plant Breeding and Genetics for providing storage chambers and laboratory equipment.

Contributions not qualifying for authorship: The three Q-graders who conducted cup evaluations are gratefully acknowledged.

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