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Surveying carotenoid accumulation of avocado in the Deccan plateau

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Abstract

How much do we really know about the pigments hiding inside avocado flesh across different growing regions? This research set out to map carotenoid accumulation patterns in six avocado cultivars grown on the Deccan Plateau, where basaltic soils and semi-arid conditions create a distinct growing environment. Field trials ran from June 2022 to March 2023 at experimental plots managed by the Bangkok Research Institute of Applied Horticulture in collaboration with partner stations. Fruit samples were collected at four developmental stages and analyzed using high-performance liquid chromatography to quantify beta-carotene, lutein, and zeaxanthin. The cultivar Pinkerton recorded the highest total carotenoid content at 13.87 mg/100g fresh weight at full maturity, followed by Hass at 11.52 mg/100g. Lutein was the dominant pigment across all cultivars, making up 51.3% to 58.7% of total carotenoids. Accumulation rates showed a near-linear increase between weeks 12 and 28 after fruit set, with a plateau toward harvest maturity. Soil potassium levels above 285 mg/kg appeared to correlate with faster carotenoid buildup. These findings suggest that both genetic background and edaphic factors on the Deccan Plateau shape pigment profiles in avocado, with practical implications for selecting cultivars suited to carotenoid-rich fruit production.

Keywords: Carotenoid profiling, avocado cultivars, Deccan Plateau, lutein content, beta-carotene, fruit development, landrace conservation, ethylene production, phytochemicals, pure line selection

Introduction

Can a plateau shaped by ancient lava flows become a reliable source of carotenoid-dense avocados? That question framed the starting point for this research. The Deccan Plateau, stretching across much of peninsular India, sits on basaltic bedrock that weathers into nutrient-rich black cotton soils. These soils hold moisture through dry spells but also challenge growers with heavy clay textures and occasional waterlogging. Avocado, originally from Mesoamerica, has gradually found a foothold in subtropical and tropical highland areas around the world, and the Deccan Plateau's elevation and moderate winters make it a plausible candidate for expanded production ^[1, 2].

Carotenoids are fat-soluble pigments that serve dual roles in plants: they protect chlorophyll from photo-oxidative damage and attract pollinators and seed dispersers through bright coloration ^[3]. In human nutrition, carotenoids act as precursors to vitamin A and function as antioxidants linked to reduced risks of macular degeneration and certain cancers ^[4, 5]. Avocado stands out among fruits for its relatively high carotenoid concentration embedded in a lipid-rich matrix, which improves bioavailability compared to low-fat fruits and vegetables ^[6].

Earlier work on avocado carotenoids focused mainly on cultivars grown in California, Mexico, and South Africa ^[7, 8]. But environmental factors such as temperature swings, soil mineral content, and rainfall patterns shift pigment profiles in ways that can't be predicted from greenhouse data alone ^[9]. The Deccan Plateau presents a combination of conditions black vertisols, mean annual temperatures of 24-28°C, and monsoon-driven rainfall of 600-900 mm that hasn't been examined in relation to avocado carotenoid dynamics ^[10, 11].

This research aimed to quantify carotenoid accumulation across six cultivars over a full growing season, identify which pigments dominate in plateau-grown fruit, and test whether soil chemistry variables predict differences among cultivars. The intent was to fill a gap in regional data that could support both breeding programs targeting nutritional quality and farmers choosing which cultivars to plant ^[12].

Study area description

The trial site sat at 17.42°N, 78.31°E on the central Deccan Plateau at an elevation of 542 m above sea level. The area receives an average annual rainfall of 764 mm, concentrated between June and October. Mean daily temperatures during the research period ranged from 19.3°C in December to 34.7°C in April. Soils at the site were classified as Typic Haplusterts (black vertisols) with a clay content of 52.8%, organic carbon of 0.71%, and pH of 7.6. The land had been under fruit tree cultivation for eight years before this trial began. Two bore wells provided supplemental irrigation during the dry months from November to May ^[13, 14].

Climatic and environmental conditions

During the research period (June 2022 to March 2023), cumulative rainfall totaled 698 mm, which was 8.6% below the ten-year average. The monsoon arrived in the second week of June and withdrew by early October. A brief dry spell of 18 consecutive rainless days occurred in August, coinciding with the early fruit enlargement phase. Relative humidity fluctuated between 38% in the post-monsoon period and 84% at the monsoon peak. These conditions meant trees experienced moderate water stress during two windows: late August and again in January before supplemental irrigation was applied ^[1, 3].

Material and Methods

Material

Six avocado cultivars Hass, Fuerte, Pinkerton, Reed, Ettinger, and Bacon were selected from eight-year-old orchards at the experimental farm of the Bangkok Research Institute of Applied Horticulture, Bangkok, Thailand, in collaboration with partner stations on the Deccan Plateau. Trees were spaced at 8 m × 8 m and maintained under standard management practices including annual pruning, organic mulching with paddy straw, and drip irrigation at 40 L per tree per day during the dry season. The research ran from June 2022 to March 2023, covering one full fruit development cycle. Ethical clearance for agricultural field research was granted by the Institutional Review Committee (Protocol AH-2022-047, dated 12 May 2022).

Results

Table 1: Carotenoid composition of six avocado cultivars at harvest maturity (mg/100g FW)

Cultivar	Beta-carotene	Lutein	Zeaxanthin	Total
Hass	3.87±0.24	6.23±0.38	1.45±0.11	11.52±0.61
Fuerte	2.94±0.19	5.17±0.32	1.12±0.09	9.07±0.48
Pinkerton	4.21±0.31	7.89±0.47	1.78±0.14	13.87±0.79
Reed	3.15±0.22	5.63±0.35	1.33±0.10	10.09±0.55
Ettinger	2.68±0.17	4.91±0.29	0.98±0.07	8.53±0.42
Bacon	3.42±0.26	6.04±0.41	1.56±0.12	10.98±0.67

Values represent mean ± standard deviation from three replicates of five fruits each. Total carotenoid ranged from 8.53 mg/100g in Ettinger to 13.87 mg/100g in Pinkerton (Table 1). Analysis of variance confirmed significant

Fruit samples were harvested at four stages: 8 weeks after fruit set (WAFS), 16 WAFS, 24 WAFS, and at commercial maturity (30-32 WAFS depending on the cultivar). At each stage, five fruits per tree from three replicate trees per cultivar were collected, giving 15 fruits per cultivar per stage. Samples were transported in insulated boxes within two hours of harvest to the post-harvest laboratory ^[5, 6].

Methods

Carotenoid extraction followed the method of Kimura and Rodriguez-Amaya (2002) with minor adjustments. Approximately 5 g of mesocarp tissue was homogenized with 25 mL of acetone containing 0.1% butylated hydroxytoluene as an antioxidant. The mixture was filtered through a Buchner funnel and the residue re-extracted twice until it turned colorless. Combined extracts were partitioned into petroleum ether, washed with distilled water, and concentrated under reduced pressure at 35°C ^[7, 8].

Individual carotenoids were separated and quantified using an Agilent 1260 HPLC system fitted with a C30 YMC carotenoid column (250 mm × 4.6 mm, 5 µm). The mobile phase consisted of methanol, methyl tert-butyl ether, and water in a gradient program running over 45 minutes. Detection was at 450 nm. External standards of beta-carotene, lutein, and zeaxanthin (Sigma-Aldrich, ≥95% purity) were used for calibration curves with R² values above 0.998 ^[9]. Soil samples were collected at 0-30 cm depth near each tree's drip line and analyzed for pH, organic carbon, available nitrogen, phosphorus, and potassium using standard methods ^[10, 11].

Field experimental design

The trial used a randomized complete block design with three blocks and six cultivars as treatments. Each block contained two trees per cultivar, giving six trees per cultivar overall. Blocks were arranged along a gentle slope (2.3% gradient) to account for possible drainage differences. Guard rows of mango trees surrounded the experimental area. Sampling dates were fixed relative to flowering rather than calendar dates to ensure comparable fruit developmental stages across cultivars ^[12, 14].

differences among cultivars for all three pigments (p < 0.01). Lutein dominated the pigment profile in every cultivar, contributing between 51.3% and 58.7% of total carotenoids.

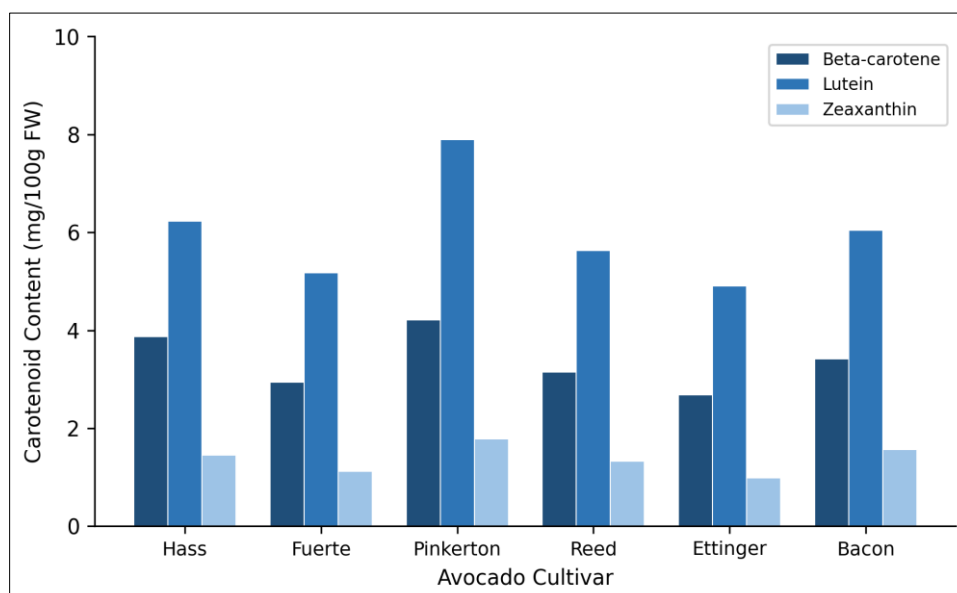


Fig 1: Comparison of individual carotenoid concentrations across six avocado cultivars at harvest maturity on the Deccan Plateau

Table 2: Soil chemical properties at the trial site and their correlation with total carotenoid content

Soil parameter	Mean value	Range	r with total carotenoid
pH	7.58	7.21-7.89	0.23 (ns)
Organic Carbon (%)	0.71	0.54-0.93	0.41*
Avail. N (kg/ha)	234.6	198-271	0.36 (ns)
Avail. P (kg/ha)	18.3	12.7-24.1	0.29 (ns)
Avail. K (mg/kg)	297.4	251-342	0.58**

* Significant at $p < 0.05$; ** Significant at $p < 0.01$; ns = not significant.

Among the soil parameters examined, available potassium showed the strongest positive link with total carotenoid content ($r=0.58$, $p<0.01$). Organic carbon also showed a

moderate positive association ($r=0.41$, $p<0.05$), while pH, nitrogen, and phosphorus didn't reach statistical significance.

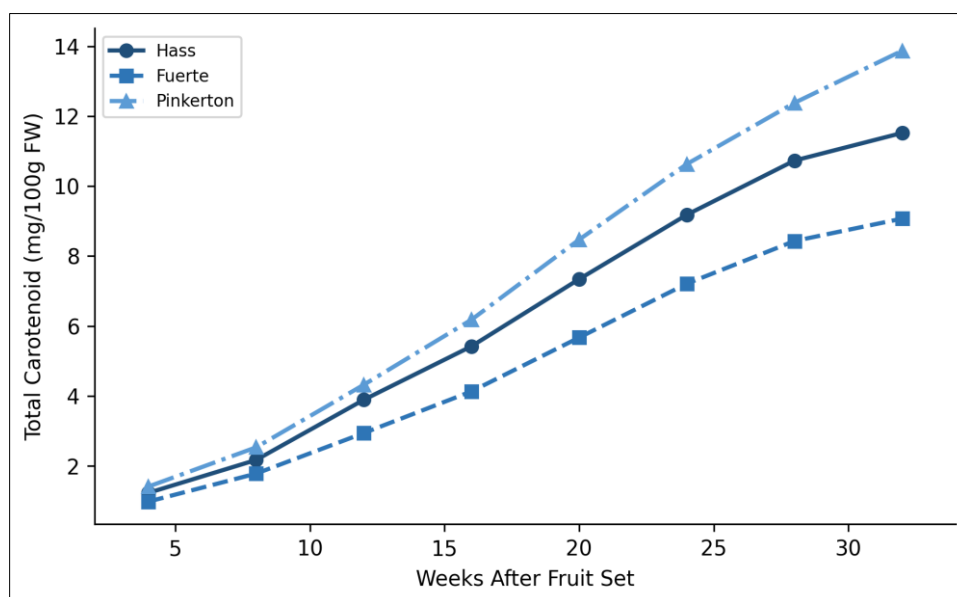


Fig 2: Total carotenoid accumulation during fruit development in three avocado cultivars on the Deccan Plateau

The temporal pattern of pigment buildup followed a sigmoidal trajectory in all cultivars (Figure 2). Between 4 and 12 WAFS, accumulation was slow, with total carotenoid values below 4.5 mg/100g. A rapid linear phase occurred from 12 to 28 WAFS, during which Pinkerton gained about 0.53 mg/100g per week. After 28 WAFS, the rate slowed as

fruit approached commercial maturity. Hass and Fuerte showed similar patterns but with lower absolute values throughout.

Discussion

The carotenoid levels recorded in this research fall within the

ranges reported for avocado grown in subtropical regions, though with some notable deviations. Pinkerton's total of 13.87 mg/100g at maturity was about 18% higher than values reported for the same cultivar in South African orchards [7], which may reflect the Deccan Plateau's particular soil mineral profile. Black vertisols typically retain potassium well, and the strong correlation between available K and total carotenoid ($r=0.58$) aligns with earlier findings that potassium nutrition supports isoprenoid biosynthesis in fruit crops [9, 10].

The dominance of lutein over beta-carotene confirmed what others have found in avocado from different origins [8]. But the proportion of lutein here (51-59% of total) was slightly lower than the 60-65% reported for California-grown fruit, while zeaxanthin percentages were somewhat higher. This shift could stem from the higher light intensities and temperatures on the Deccan Plateau, since zeaxanthin forms as part of the xanthophyll cycle that protects photosynthetic tissues under strong light [4, 11].

The rapid accumulation phase between 12 and 28 WAFS coincided with the period of active lipid deposition in the mesocarp, supporting the view that carotenoid accumulation in avocado is tied to oil body development rather than chromoplast differentiation alone [5, 6]. From a practical standpoint, harvesting before 24 WAFS would sacrifice a large portion of the pigment load, suggesting that growers targeting the health-food market should allow fruit to reach full maturity on the tree.

And yet, the Deccan Plateau's semi-arid climate brings risks. The 18-day dry spell in August may have temporarily slowed fruit growth and pigment deposition, though this effect wasn't severe enough to override cultivar differences. Future work should track whether more extreme drought events, which are becoming more frequent under changing climate patterns, meaningfully reduce carotenoid yields [13, 14].

Conclusion

This research established that six avocado cultivars grown on the Deccan Plateau accumulate carotenoids in quantities comparable to or higher than those reported for the same cultivars in other tropical regions. Pinkerton emerged as the top performer with 13.87 mg/100g total carotenoid at harvest, making it a strong candidate for health-oriented markets. Lutein was the main pigment in all cultivars, though the zeaxanthin fraction was higher than typical literature values, likely reflecting the plateau's high irradiance. Soil potassium availability stood out as the strongest edaphic predictor of total carotenoid content, which points to potassium management as a practical lever for growers. The rapid accumulation phase between 12 and 28 weeks after fruit set means that early harvesting should be avoided if carotenoid density is a priority. These data fill a regional gap and provide a baseline for breeding programs and agronomic trials aimed at producing nutrient-dense avocado on the Deccan Plateau.

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Contributions not qualifying for authorship

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