Postprint of a Study on Changes in Nutrient Content During Avocado Fruit Development

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Date: 2022-07-05T00:00:00+00:00

Abstract

To determine the optimal harvest period for avocados, this study employed inductively coupled plasma optical emission spectrometry, combustion method, ninhydrin post-column derivatization ion-exchange chromatography, reflux extraction, and GC-MS combined techniques to investigate the content variations of crude fat, amino acids, mineral elements, and ash in the fruits of three avocado cultivars 'HASS', 'V3', and 'V4' during the period from June to December, aiming to elucidate the accumulation patterns of nutrients during avocado growth and development. The results showed: (1) The main component of oil in all three avocado cultivars was oleic acid, among which the crude fat content in 'HASS' and 'V4' fruits peaked in December, while that in 'V3' peaked as early as October and subsequently declined. (2) All three avocado cultivars contained 17 amino acids, including 7 essential amino acids for humans, 2 essential amino acids for children, and 8 non-essential amino acids for humans, among which the total content of 17 amino acids in 'HASS' and 'V3' fruits peaked in November, while that in 'V4' peaked in October. (3) All three avocado cultivars contained nine mineral elements including P, K, Ca, Mg, Zn, Fe, Mn, Cu, and Na, among which the contents of P, K, Zn, Fe, and Na accumulated to maximum levels during October-December, while the variation patterns of the remaining four mineral elements were not evident. (4) The variation pattern of ash content was similar to that of crude fat. The study demonstrated that the nutrient contents of all three avocado cultivars reached optimal values as early as October, and harvesting can be conducted according to specific requirements.

Full Text

Changes in Nutrient Content During Avocado Fruit Development

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Abstract

To determine the optimal harvest period for avocado, this study investigated the monthly changes in crude fat, amino acids, mineral elements, and ash content in three avocado cultivars ('HASS' , 'V3' , and 'V4') from June to December using inductively coupled plasma atomic emission spectrometry, combustion methods, post-column ninhydrin derivatization ion-exchange chromatography, reflux extraction, and GC-MS techniques, aiming to elucidate the accumulation patterns of nutrients during fruit development. The results showed: (1) Oleic acid was the predominant fatty acid in all three cultivars. The crude fat content in 'HASS' and 'V4' fruits peaked in December, while that in 'V3' peaked in October before declining. (2) All three cultivars contained 17 amino acids, including 7 essential amino acids for humans, 2 essential amino acids for children, and 8 non-essential amino acids. The total amino acid content in 'HASS' and 'V3' peaked in November, whereas 'V4' peaked in October. (3) All three cultivars contained nine mineral elements: P, K, Ca, Mg, Zn, Fe, Mn, Cu, and Na. The contents of P, K, Zn, Fe, and Na accumulated to maximum levels between October and December, while the remaining four elements showed less distinct patterns. (4) Ash content exhibited similar variation patterns to crude fat. These findings indicate that the nutrients in all three cultivars reached optimal values by October, suggesting that harvest can be scheduled according to demand from this time onward.

Keywords: avocado, harvest time, crude fat, amino acids, mineral elements, ash

Introduction

Avocado (*Persea americana*), known in English as avocado and also called alligator pear or butter pear, is an evergreen tree belonging to the family Lauraceae and genus *Persea*. Originating in South America, it is now cultivated globally in tropical and subtropical regions, with major production in Mexico, Chile, the Dominican Republic, southern United States, Colombia, Peru, Guatemala,

Cuba, and Indonesia (Bhuyan et al., 2019). Avocado fruit is rich in fats, primarily monounsaturated fatty acids such as linoleic and oleic acids, and also contains proteins, vitamins, and various minerals. The fruit exhibits multiple health benefits including digestive improvement, blood sugar and lipid reduction, blood pressure regulation, anticancer properties, and protection of cardiovascular and hepatic systems (Dreher et al., 2013). Introduced to China in the early 19th century, avocado is now cultivated in Guangdong, Guangxi, Fujian, Yunnan, Sichuan, and Hainan provinces (Qian et al., 2011).

Nutrient content in fruits typically serves as a criterion for physiological maturity. For instance, kiwifruit harvest maturity is determined when soluble solids reach 6.2% (Li et al., 1985), while soluble solids and fruit firmness are used as harvest indices for pears (Cui et al., 2019). Unlike most fruits such as kiwifruit and pears, avocado can remain on the tree for up to 12 months after reaching minimum harvest maturity, and freshly harvested fruit is not ready for consumption but requires a post-ripening period (Hurtado-Fernández et al., 2016; Cao et al., 2018).

Determining avocado harvest maturity based on appearance alone is challenging. Premature harvesting not only reduces yield and nutritional quality but also diminishes flavor and texture, potentially prolonging or preventing proper ripening and causing fruit rot. Conversely, delayed harvesting adversely affects storage and transport while increasing nutrient expenditure that compromises tree health (Chen, 2006; Yuan et al., 2020). Therefore, establishing scientifically sound indicators to guide avocado harvest is crucial.

The primary nutrient in avocado fruit is oil, with particularly high unsaturated fatty acid content (Donetti & Terry, 2014). Depending on cultivar and growing conditions, oil content ranges from 8% to 30% and remains relatively stable post-harvest (Lee et al., 1983; Quiñones-Islas et al., 2013). Avocado oil composition consists mainly of monounsaturated oleic acid (50–60%), saturated palmitic acid (15–20%), unsaturated palmitoleic acid (6–10%), polyunsaturated linoleic acid (11–15%), and linolenic acid ($±$1%) (Donetti & Terry, 2014). Oil content and composition serve as important maturity indicators, though minimum harvest standards vary by cultivar: Mexican avocados are harvested at 8% oil content, Guatemalan types at 7.5–18%, and West Indian types at 5–7% (Chen, 1985).

Beyond lipids, avocado is rich in various amino acids and mineral elements that significantly influence fruit aroma, taste, and texture quality (Pedreschi et al., 2019). Therefore, amino acids and mineral elements should be considered alongside fat content for comprehensive quality assessment. However, domestic research in this area remains limited.

Avocado fruit size, shape, weight, and composition are highly dependent on cultivar and climate (Rodríguez-López et al., 2017). Menglian County represents Yunnan' s primary avocado production region. This study examined three avocado cultivars from this region—the introduced 'HASS' and locally selected 'V3' and 'V4' —to compare changes in oil, amino acid, mineral, and ash content

during fruit development, thereby providing a scientific basis for determining optimal harvest timing.

Materials and Methods

1.1 Materials and Reagents **Materials:** Avocado fruits of cultivars 'HASS', 'V3', and 'V4' were collected from Haidongxin Village, Mangxin Town, Menglian County, Yunnan Province, at 800–1,300 m altitude. The trees were five-year-old, high-yielding plants grown in lateritic soil on karst terrain. 'HASS' is a Mexican introduced cultivar, while 'V3' and 'V4' were independently selected by Puer Lüyin Biological Co., Ltd. Ten trees per cultivar with similar growth vigor, trunk diameter, and fruit load were selected using five-point sampling method. Fruits were collected monthly from June to December 2020 (seven collections total), with 10 fruits sampled per cultivar each time.

Reagents: Nitric acid (GR), perchloric acid (GR), sodium citrate (GR), sodium hydroxide (GR), hydrochloric acid ($ 36 99.995 $99.995%) were purchased from Kunming Stone Man Gas Products Co., Ltd.

Instruments and Equipment: Amino acid analyzer (SYKAM S433D, Hitachi, Japan), inductively coupled plasma optical emission spectrometer (OPTIMA8000, D1-4-3, PerkinElmer, USA), and gas chromatography-mass spectrometer (HP6890GC/5973MS, Agilent Technologies, USA).

1.2.1 Crude Fat Content Determination **Sample Preparation:** For each cultivar, 10 individual fruits were chopped and mixed thoroughly. Five grams of pulp were accurately weighed, placed in a sealed glass container with appropriate sea sand, evaporated on a boiling water bath, filtered, dried, and subjected to Soxhlet extraction with ether. After extraction, the solvent was recovered, evaporated to dryness, and the residue was dried and weighed.

Analytical Method: Crude fat content was calculated according to GB/T 14772-2008 (National Food Safety Standard—Determination of Crude Fat in Foods) using the formula:

$$X = \frac{m_2 - m_1}{m} \times 100$$

where X represents fat content (%), m_2 is the mass of the flask plus crude fat (g), m_1 is the mass of the empty flask (g), and m is the mass of the sample (g).

1.2.2 Fatty Acid Content Determination **Sample Preparation:** Ten fruits per cultivar were chopped and mixed, and 5 g of pulp were accurately weighed. Fresh avocado flesh was extracted with methanol, then avocado oil was obtained via hexane extraction. The oil was saponified before GC-MS analysis.

GC-MS Conditions: Initial column temperature was 50 °C, increased at 5 °C · min^{-1} to 150 °C (held 3 min), then increased at 10 °C · min^{-1} to 300 °C (held 3 min). Injection volume was 1 L, injector temperature 280 °C, carrier gas high-purity helium at 1.0 mL · min^{-1}. Relative content was calculated based on peak area integration.

1.2.3 Amino Acid Content Analysis Sample Preparation: Ten fruits per cultivar were chopped and mixed, and 3 g of pulp were accurately weighed. Samples were hydrolyzed with 10 mL of 6 mol · L^{-1} HCl and 3-4 drops of phenol under vacuum in sealed tubes at (110 ± 1) °C for 22 h. After cooling, the hydrolysate was filtered into a 25 mL volumetric flask, diluted to volume, and mixed. One mL of hydrolysate was dried under reduced pressure at (45 ± 5) °C, and the residue was dissolved in 2 mL water, vortexed, filtered through a 0.22 m membrane, and transferred to an autosampler vial.

Analytical Method: Analysis followed GB 2009.124-2016 (National Food Safety Standard—Determination of Amino Acids in Foods) using a sodium ion-type standard analytical column (4.6 × 150 m), reaction column temperature 57.0 °C, reactor temperature 130 °C, and injection volume 20 L. Amino acid content was calculated as:

$$X = \frac{C \times F \times V \times M}{m \times 1000}$$

where X represents amino acid content (g · kg^{-1}), C is the milligrams of amino acid in the sample solution divided by the corresponding amino acid molar mass, F is the dilution factor, V is the final volume (mL), M is the molecular weight of each amino acid, and m is the sample mass (mg).

1.2.4 Mineral Element Content Determination Sample Preparation: Ten fruits per cultivar were chopped and mixed, and 2.0 g of the homogeneous sample was accurately weighed into a polytetrafluoroethylene digestion vessel. Ten mL of nitric acid-perchloric acid mixture (10:1) was added, and the sample was digested on an electric hot plate until white fumes appeared and the digest became colorless or slightly yellow. After cooling, the solution was diluted with water to 25 mL, mixed, and stored; a blank test was performed simultaneously.

Detection Method: Analysis followed GB 5009.268-2016 (National Food Safety Standard—Determination of Multiple Elements in Foods) using inductively coupled plasma atomic emission spectrometry with plasma gas flow 15 L · min^{-1}, auxiliary gas flow 0.5 L · min^{-1}, nebulizer gas flow 0.65 L · min^{-1}, and analysis pump speed 50 r · min^{-1}.

Mineral element content was calculated as:

$$X = \frac{(\rho - \rho_0) \times V \times f}{m}$$

where X represents the element content in the sample ($mg \cdot kg^{-1}$), ρ is the mass concentration of the element in the sample solution ($mg \cdot L^{-1}$), ρ_0 is the mass concentration in the blank solution ($mg \cdot L^{-1}$), V is the final volume of the digested sample (mL), f is the dilution factor, and m is the sample mass (g).

1.2.5 Ash Content Determination **Sample Preparation:** Ten fruits per cultivar were chopped and mixed, and 3 g of pulp were accurately weighed, evaporated to dryness on a boiling water bath, carbonized on an electric hot plate until smoke-free, then ashed in a muffle furnace at approximately 550 °C for 4 h. After cooling to about 200 °C, the crucible was transferred to a desiccator, cooled for 30 min, and weighed.

Analytical Method: Ash content was calculated according to GB 5009.4-2016 (National Food Safety Standard—Determination of Ash in Foods) using the formula:

$$X = \frac{m_1 - m_2}{m_3 - m_2} \times \frac{100}{\omega}$$

where X represents ash content (%), m_1 is the mass of crucible plus ash (g), m_2 is the mass of the empty crucible (g), m_3 is the mass of crucible plus sample (g), and ω is the dry matter content of the sample (mass fraction, %).

Results and Analysis

Monthly analyses were conducted on crude fat, amino acids, mineral elements, and ash content in three avocado cultivars ('HASS' , 'V3' , and 'V4') from Menglian County, Yunnan, between June and December.

2.1 Changes in Crude Fat Content and Composition During Fruit Development Crude fat content is a critical indicator for evaluating avocado quality and determining harvest time. From June to December, crude fat content in 'HASS' , 'V3' , and 'V4' fruits ranged from 1.63–21.72%, 1.99–20.60%, and 2.31–21.82% (fresh weight), respectively, showing significant variation [Figure 1: see original paper]. Although the maximum crude fat accumulation was similar across cultivars (approximately 21%), the timing differed: 'V3' reached maximum fat content in October, two months earlier than 'HASS' and 'V4' .

Specifically, 'HASS' crude fat content increased significantly each month, with the fastest growth occurring from June to November, reaching a maximum of 21.72% in December with a slight final increase. 'V3' showed slow accumulation from June to September, rapid increase from September to October to a maximum of 20.60%, followed by a decline. 'V4' exhibited a consistent monthly increase, reaching its maximum of 21.8% in December.

Fatty acids in the three cultivars were categorized as: (1) saturated fatty acids, primarily stearic acid and tetradecanoic acid; (2) monounsaturated fatty acids,

mainly oleic acid and palmitic monoenoic acid; and (3) polyunsaturated fatty acids, primarily linoleic acid. The major fatty acid contents showed an initial increase, slight decrease, then secondary increase. Oleic acid, the most abundant fatty acid, peaked in July for 'HASS' and 'V4' and in September for 'V3' , then gradually decreased before reaching a second peak in December. Similar patterns were observed for tetradecanoic acid, stearic acid, palmitic acid, palmitic monoenoic acid, linoleic acid, and total saturated, monounsaturated, and polyunsaturated fatty acids .

2.2 Changes in Amino Acid Content During Fruit Development Seventeen amino acids were detected across the three cultivars, including 7 essential amino acids (EAA: THR, MET, VAL, LEU, ILE, PHE, LYS), 2 children essential amino acids (CEAA: ARG, HIS), and 8 non-essential amino acids (NEAA: PRO, TYR, CYS, ALA, GLY, GLU, SER, ASP). All cultivars contained the same amino acid types but in different quantities.

In 'HASS' fruits, EAA, CEAA, and NEAA contents increased continuously from June to November, peaking in November before declining. Among the 7 EAAs, LYS was most abundant, followed by LEU, with MET being the lowest. Except for MET, ARG, CYS, ALA, and GLU, the other 12 amino acids reached maximum content by late November .

In 'V3' fruits, the three amino acid categories also accumulated to maximum levels in November. Among EAAs, LYS was highest, LEU second, and MET lowest. Except for ASP, SER, PRO, MET, and ILE, the remaining 12 amino acids peaked in November .

In 'V4' fruits, maximum EAA, CEAA, and NEAA contents occurred in October. Among EAAs, LEU was most abundant, followed by LYS, with MET lowest. Except for PRO, ASP, and CYS, the other 14 amino acids reached highest levels in October .

When amino acid accumulation peaked, 'HASS' fruits contained significantly higher EAA, CEAA, NEAA, and total amino acid (TAA) contents than 'V3' and 'V4' , which showed similar amino acid levels.

2.3.1 Macronutrient Content Changes From June to December, accumulation of macronutrients phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) varied considerably among cultivars and developmental stages [Figure 2: see original paper].

P content in 'HASS' fruits increased from 179 to 518 $mg \cdot kg^{-1}$ (fresh weight), with two rapid accumulation phases: slow growth from June to July, first rapid increase from July to August, second rapid increase from September to November, peaking in late November before stabilizing. 'V3' and 'V4' fruits showed similar P content ranges (196–488 and 181–499 $mg \cdot kg^{-1}$, respectively), with slow growth from June to August, rapid increase from September to October, and maximum values in late October—one month earlier than 'HASS' . At peak

accumulation, 'HASS' P content was higher than 'V3' and 'V4' , which did not differ significantly.

K content ranges were 1,113–4,604 $mg \cdot kg^{-1}$ in 'HASS' , 1,448–5,737 $mg \cdot kg^{-1}$ in 'V3' , and 1,752–5,496 $mg \cdot kg^{-1}$ in 'V4' . All cultivars showed two distinct rapid accumulation periods: the first from July to August. The second rapid accumulation period and peak timing varied: 'HASS' and 'V4' peaked in late October, while 'V3' showed a prolonged second rapid phase from September through late November. At maximum accumulation, 'V3' had the highest K content, followed by 'V4' , with 'HASS' lowest.

Ca content ranges were 88–166 $mg \cdot kg^{-1}$ in 'HASS' , 39.7–116 $mg \cdot kg^{-1}$ in 'V3' , and 28.90–128 $mg \cdot kg^{-1}$ in 'V4' . All cultivars showed rapid Ca increase from June to July, peaking in late July when 'HASS' Ca content was substantially higher than 'V3' and 'V4' (which were similar). Ca content then declined and stabilized from September to December.

Mg content showed similar trends across cultivars: rapid accumulation from June to July, slight decline from July to September, and slow increase from September to November. Both 'V3' and 'V4' reached maximum Mg content in July (276 and 227 $mg \cdot kg^{-1}$, respectively), approximately 2.7- and 2.0-fold higher than June values, followed by decline from October to December. 'HASS' Mg content was also high in July (2.5-fold higher than June), then increased slowly to reach maximum (256 $mg \cdot kg^{-1}$) in December when 'V3' and 'V4' contents were decreasing.

2.3.2 Micronutrient Content Changes Micronutrients zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and sodium (Na) also showed cultivar- and developmental stage-dependent accumulation patterns [Figure 3: see original paper].

Zn content increased overall from June to December. 'HASS' Zn content peaked in late November (5.85 $mg \cdot kg^{-1}$) with minimal subsequent change. 'V3' Zn content increased continuously through December, reaching maximum (5.53 $mg \cdot kg^{-1}$) at month-end. 'V4' Zn peaked in late October (4.05 $mg \cdot kg^{-1}$), then declined in November and December. At maximum accumulation, 'HASS' and 'V3' Zn contents were significantly higher than 'V4' , with 'HASS' showing the highest level.

Fe content in all three cultivars increased overall during the June–December growth period. 'V4' Fe content was elevated during October–November, with maximum value (7.30 $mg \cdot kg^{-1}$ fresh weight) in November, declining significantly to 4.85 $mg \cdot kg^{-1}$ in December. 'HASS' and 'V3' Fe contents increased continuously through October before stabilizing. At peak, 'V4' Fe content was significantly higher than 'HASS' and 'V3' , which did not differ substantially.

Mn content increased initially, then decreased, followed by slow increase to a stable level. 'HASS' Mn content remained higher than other cultivars throughout June–December, with two prominent peaks in late August (11.70 $mg \cdot kg^{-1}$)

and late October (10.70 $mg \cdot kg^{-1}$), then declined to a stable range of 6.63–6.87 $mg \cdot kg^{-1}$ during November–December. 'V3' and 'V4' Mn contents remained relatively stable throughout the growth period, with slow increase during November–December and 'V3' content higher than 'V4' .

Cu content in 'V3' and 'V4' was highest in June, then generally decreased to minimum by late October, with slight increase during November–December. 'HASS' Cu content decreased slowly from June to July, increased continuously from July to November, peaked in late November, then decreased in December. During September–December, 'HASS' Cu content was significantly higher than 'V3' and 'V4' , with 'V4' showing the lowest content.

Na content increased overall from June to December [Figure 3E: see original paper]. 'HASS' and 'V3' Na contents increased rapidly from June to December-end, reaching maxima of 5.21 and 5.05 $mg \cdot kg^{-1}$, respectively, with minimal difference. 'V4' rapid Na accumulation occurred one month earlier, peaking at 4.94 $mg \cdot kg^{-1}$ in November, slightly lower than 'HASS' and 'V3' maxima.

2.3.3 Ash Content Changes Ash, representing total inorganic matter in fruit, is an important quality indicator. Ash content increased overall during fruit development (June–December), with ranges of 0.49–1.27% ('HASS'), 0.53–1.20% ('V3'), and 0.53–1.18% ('V4'), showing substantial increase particularly during September–December [Figure 3F: see original paper].

Discussion

3.1 Relationship Between Oil Content and Fruit Maturity Unlike most fruits, avocado accumulates substantial fat rather than sugar during development (Ozdemir & Topuz, 2004). Consequently, crude fat content is a key determinant of avocado quality. Literature reports indicate that late-harvested avocado fruits contain higher oil content than early-harvested ones (Villa-Rodríguez et al., 2011). For example, 'HASS' oil content increased from 14.36% to 17.77% between November and January, while 'Fuerte' increased from 11.02% to 19.57% (Ozdemir & Topuz, 2004). Climate and growing location also affect oil content, which varies among cultivars (Rodriguez et al., 2018). In this study, crude fat content in 'HASS', 'V3', and 'V4'showed significant changes from June to December, increasing with later harvest dates, consistent with literature reports. The predominant fatty acids were oleic acid (highest content), linoleic acid, palmitic acid, and palmitoleic acid, with unsaturated fatty acids far exceeding saturated fatty acids, aligning with findings by Wang et al. (2018).

3.2 Relationship Between Amino Acid Content and Fruit Maturity Avocado contains the highest protein content among fruits (Landahl et al., 2009), and protein quality is determined by amino acid composition and content (Ma et al., 2021). Amino acid profiles significantly influence avocado quality and flavor. This study found that 'HASS', 'V3', and 'V4' fruits contained 7 essential human amino acids, 2 essential child amino acids, and 8 non-essential amino acids,

demonstrating rich amino acid diversity. Aspartic acid (ASP) and glutamic acid (GLU), closely associated with umami taste, were substantially more abundant than other amino acids. Total amino acid content in 'HASS' was significantly higher than in 'V3' and 'V4' , indicating significant cultivar differences. Total amino acid content in all three cultivars showed S-shaped curves over the harvest period, similar to changes observed in hawthorn fruits at different maturity stages (Pu et al., 2020). Amino acid metabolism provides precursors for protein synthesis, respiration, and various specialized metabolites (Zhang et al., 2015), indicating continuous amino acid synthesis and consumption during avocado development.

3.3 Mineral Element Accumulation and Fruit Maturity Mineral elements directly affect fruit maturation and provide guidance for harvest timing. The three studied cultivars contained nine mineral elements, with K being most abundant, followed by P, Ca, and Mg as macronutrients, and Zn, Fe, Na, Mn, and Cu as micronutrients. All elements showed similar trends of initial increase, subsequent decrease, and final stabilization, though peak timing varied. This pattern resembles mineral changes during persimmon development (Clark et al., 1990) and relates to plant mineral absorption, transport, and nutrient requirements at different growth stages (Gao et al., 2005).

K, P, and Fe regulate soluble solids and secondary metabolite production, affecting fruit yield and quality. P accumulation effectively promotes fruit weight gain. As avocado growth slows in later stages, P content stabilizes (Cao et al., 2015). Ca plays crucial roles in fruit quality development and postharvest maintenance. Avocado Ca content initially increased then decreased during development, closely related to Ca^{2+} absorption, transport, and storage. Ca^{2+} uptake is rapid during young fruit stages, with over 90% of total Ca absorbed during fruit expansion (Tagliavini et al., 2000). However, accumulating calcium oxalate crystals during fruit growth obstruct vascular tissues, hindering later Ca^{2+} absorption and causing content decline (Tuason & Arocena, 2009). Fruit Ca content also correlates with hormone levels: indoleacetic acid (IAA), which promotes Ca^{2+} absorption, decreases during development, while abscisic acid (ABA), which inhibits Ca^{2+} absorption, increases, leading to progressive Ca decline (Tonetto de Freitas et al., 2014). High Ca content maintains kiwifruit firmness (Xu et al., 2020) and influences ripening by regulating soluble sugars, organic acids, and other primary metabolites (Jia et al., 2021).

Conclusion

This study of nutrient content changes during development of three avocado cultivars ('HASS' , 'V3' , and 'V4') revealed: (1) Oleic acid was the predominant oil component in all cultivars. Crude fat content increased continuously from June to December, peaking in December for 'HASS' and 'V4' but in October for 'V3' before declining. (2) All three cultivars contained 17 amino acids (7 essential for humans, 2 essential for children, and 8 non-essential), with 'HASS' and 'V3'

peaking in November and 'V4' in October. (3) All cultivars contained nine mineral elements (P, K, Ca, Mg, Zn, Fe, Mn, Cu, Na), with P, K, Zn, Fe, and Na accumulating to maximum levels during October–December. (4) Ash content showed similar variation patterns to crude fat. Overall, nutrients in all three cultivars reached optimal values by October. Given avocado' s characteristic of remaining on the tree without ripening or dropping, and based on accumulation patterns and maximization of crude fat, amino acids, and mineral elements, fruits of 'HASS' , 'V3' , and 'V4' can be harvested according to demand beginning in October. Further research is needed on nutrient changes during avocado ripening.

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Note: Figure translations are in progress. See original paper for figures.