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Review article

PREDICTIVE MODELLING AND COMPUTER VISION SYSTEMS (CVS) FOR MINIMIZING LOSSES ALONG AVOCADO (*PERSEA AMERICANA*) FRUIT DISTRIBUTION CHAIN

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Abstract

Avocado, a fruit from southcentral Mexico, is nowadays distributed worldwide due to its health-promoting properties. The long-distance transportation and storage conditions can significantly affect the fruit quality and shelf life. The mathematical modeling of avocado quality parameters at different storage temperatures can be a tool to manage the distribution chain and minimize quality losses.
In this study, "Hass" avocados were stored at three different temperatures of 5, 20, and 30ºC, and physical and physiological changes were evaluated over time. 30 avocados were used to follow mass loss, size, shape, color, and texture. Using computer vision system (CVS) analysis, co-occurrence matrices were generated, and standard features were calculated. Other 200 avocados were used to evaluate the firmness and chlorophyll degradation.
This work is a contribution to improving avocado fruits distribution under dynamic conditions by using a non-destructive computer vision system (CVS) method.

Keywords: “Hass” Avocado, Shelf life, Quality, Computer Vision System (CVS), Color, Mass loss, Firmness, Texture, Chlorophylls, Predictive mode

1. Introduction

Avocado is a tree derived from south-central Mexico. The avocado fruit (Persea americana) is part of the Lauraceae family (Figure 1). Avocados come in three varieties: Guatemalan, West Indian, and Mexican. The genetic discrepancy among the three ecological races corresponds to the defined horticultural races, and previously undetected genetic variation has two sub-populations from Central Mexico (Chen, Morrell, Ashworth, de la Cruz, & Clegg, 2009). “Hass” (a Mexican x Guatemalan hybrid) is recognized as the best overall quality avocado available and considered to be the most grown cultivar in the subtropics.
The fruit (berry)has a short neck and is pear-shaped, oval, or spherical. Fruit length can vary from 7.7cm to 33cm, and its width can be up to 15cm (Bill, Sivakumar, Thompson, &Korsten, 2014). It weighs between 140 to 400 g; it is a stone fruit with a creamy and smooth texture covered by dark green, purplish-black, and bumpy skin, that grows in tropical and Mediterranean climates. The flesh or pulp can be bright yellow, and the fruit flavor is described as a buttery or nut-like flavor. The avocado skin and seed consist of about 33% of the total weight (Dreher & Davenport, 2013).

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Figure 1. “Hass” Avocado fruit.

1.1. Avocado production: Avocados are commercially produced in Mexico, Chile, Israel, Spain, South Africa, Peru, Kenya, the USA, and the Dominican Republic (Bill, Sivakumar, Thompson, & Korsten, 2014). At present, the global avocado production registered in 2019 is estimated at a value of 7,179,689 million tons, from which 2,300,889 million tons were produced in the Aztec country, followed by the Dominican Republic and Peru (FAOSTAT, 2019). The Avocado production in Chile, South Africa, Israel, and Spain mainly focuses on exporting the fruit to two overseas markets, the European Union (EU), which imports 150,000 to 160,000 tons per year, and the United States 140,000 tons per year.
With the rapid growth of global demand for avocados due to the health benefits, avocado production has also increased (Avocado market growth, trend, COVID-19 impact, and forecasts 2021 – 2026), (2021). The global market is ruled by exporting fresh fruit, which poses a challenge in their supply chain concerning their quantitative and qualitative perishability. Long transit times and short shelf life represent a significant difficulty for avocado exporters, where the average avocado shipping transit periods are 33 to 44 days to reach European markets. (Estrada-Flores, 2003).

1.2. Avocado’s nutrition value: The nutrient composition of avocado fruit depends on the ecotype, cultivar, maturity stage, and growing conditions. Carotenoids (70% lutein) and chlorophylls are responsible for the greenish-yellow to the bright yellow color of the mesocarp. Carotenoids, present in the ripened mesocarp of “Hass” avocado include lutein (2.93μgg−1), zeaxanthin (0.11μgg−1), α- cryptoxanthin (0.25μg g−1), β-carotene (0.60μg g−1), and α-carotene (0.25μg g−1) (Bill, Sivakumar, Thompson, & Korsten, 2014).
Avocado consumers ingest significantly more critical nutrients in their diets, such as dietary fiber, vitamins K and E, potassium, and magnesium. Avocados have high levels of B5, and B6 vitamins, protein, unsaturated fatty acids, folate, niacin, pantothenic acid, choline, lutein/zeaxanthin, and fat-soluble vitamins lacking in other fruits (Dreher & Davenport, 2013). This fruit contains different oil levels in the pulp, which appear to improve nutrient and phytochemical bioavailability. In addition, it is known for its health benefits, mainly due to the compounds present in the lipid fraction, including phytosterols, tocopherols, and squalene (Dreher & Davenport, 2013).

1.3. Respiration rate and ethylene production: Avocado growth and development are intense, differing from other fruit species. Avocado classifies as a climacteric fruit, and it is highly unusual since the fruit does not ripen while on the tree. Figure 2 presents four main physiological stages of fruit’s development: growth, maturation, ripening, and senescence (Blakey, 2011). Avocado fruit produces higher concentrations of ethylene (80-100μl) in comparison to other climacteric fruits such as mangoes (3μl/ *l*) and bananas (40μl/l). Mature

fruit displays a characteristic respiratory pattern that coincides with an increase in ethylene production.
This increase in respiration rate and ethylene biosynthesis goes along with a complex of biochemical changes, including an increased cellulose activity, resulting in fruit softening, flesh color changes, and synthesis of flavor and aroma chemicals (Pesis, Fuchs, & Zauberman, 1978). The increase in the CO2 and ethylene (C2H4) production rate coincides with ripening (Bill, Korsten, Sivakumar Thompson, & Korsten, 2014). During the ripening phase, temperature control is essential. Favorable temperatures for avocado cultivars vary between 20°C and 25°C.

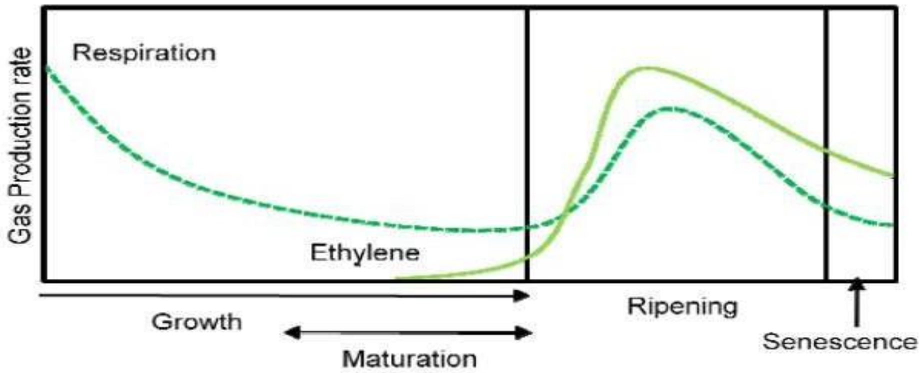

Figure 2. Physiological developmental stages of avocados fruits (Blakey, 2011).

1.4. Avocado maturity: The maturity index for harvesting avocados is essential to prevent the harvesting of immature or over mature fruit and to reduce post-harvest losses (Blakey, Bower, & Bertling, 2010). Generally, the oil content present in the mesocarp is used as an indicator to harvest avocados (Landahl, Meyer, &Terry, 2009). Harvesting immature fruit can result in unripe fruit, resulting in inferior quality. Blakey et al. (2010) commented that "avocado fruits are highly variable, and even those graded for similar size and appearance do not behave in the same manner after harvest. Hence, it is particularly problematic for those involved in sales to the ‘ready-ripe’ market".
With increased maturity, avocado oil content will improve and allow the fruit to accumulate more oil while the water content decreases (Fonseca, Chaves, Borges, & Mendonça, 2016). The avocado industry generally adopts two quantitative indices to harvest their fruit for export or domestic markets; the oil and moisture content indices (Landahl, Meyer, &Terry, 2009).
During maturation, a loss of firmness (texture) occurs due to rapid changes in the ultrastructure of the cell wall and its components. These cell wall changes are due to the degradation activity of cellulase enzymes in the cell wall and polygalacturonate, resulting in decreased tissue cohesiveness due to pectin and cell disarrangement (Bill, Sivakumar, Thompson, & Korsten, 2014).

1.5. Effect of harvest factors on the quality of avocado: There are several pre-harvest and harvest factors that, if not well managed, can severely affect the quality of the fruit. Understanding these factors and how to handle it can help to minimize postharvest losses of avocado fruit (Bill, Sivakumar, Thompson, & Korsten, 2014).
Harvesting has a vital role in the fruit's quality characteristics. Fruit must be harvested without mechanical damage, which could affect the fruit's appearance and act as an opening wedge for postharvest pathogens that cause decay during storage and transportation. Harvesting methods affect the postharvest fruit quality of the 'Fuerte' variety for which pedicels must be manually clipped (Köhne & Kremer-Köhne, 1995). On the other hand, 'Hass' can be snap-picked without causing an undesirable effect on their fruit quality (Köhne & Kremer-Köhne, 1995). However, it is well known that during wet weather conditions, the fruit cannot be harvested because water

on the fruit's surface can cause postharvest diseases during distribution and storage (Bill, Sivakumar, Thompson, & Korsten, 2014).

1.6. Storage temperature and controlled atmosphere: Due to the fruit's perishability, it is essential to focus on fruit storage conditions as an expensive and food product requirement. Fruit export must be graded according to the Perishable Products Export Control Board (PPECB, 2019). During the supply chain, the postharvest life of avocados is extended in cold storage, prolonging the overall quality properties such as nutritional composition, texture, and taste.

Controlled atmosphere storage is mainly used for the long-term storage of fruits such as apples, but it is also increasingly used to transport fruit by sea. Generally, CO2 delays many responses of fruit to ethylene. The higher CO2 and lower O2 in controlled atmosphere storage were reported to reduce respiration and ethylene production rates. Due to this phenomenon, a controlled atmosphere can affect the postharvest physiology of the fresh avocado fruit produce depending on the O2/CO2 balance (Bill, Sivakumar, Thompson, & Korsten, 2014).

Respiration rate is directly affected by low temperature, which is an indication of perishability. The climacteric rise in CO2 and C2H4 that occurs with ripening is slowed by low-temperature storage (Kassim & Workneh, 2020). At lower temperatures, many enzymes involved in C2H4 formation, carbohydrates, organic acids, and volatile substances are suppressed, delaying ripening-related changes in color, taste, texture, and scent. Avocado's shelf-life extension is possible by retarding the metabolism through reduced respiration rates and ethylene evolution (Kassim & Workneh, 2020). Nevertheless, current studies show that avocado's effect of different storage temperatures can lead to some physiological changes and losses.

The fruit's quality decreases after storage for 3-4 weeks at low temperatures (Estrada-Flores, 2003). Cold storage temperature recommendations vary with race, harvest season, cultivar, maturity, or ripeness (Thompson, 2010). Valle-Guadarrama et.al. (2004) reported that storage at 5 °C for 6 weeks resulted in excessive softening, browning, and storage rots, while four days at 20 °C resulted in fruit of better quality (Bill, Sivakumar, Thompson & Korsten, 2014).

When kept below 13 °C, several avocado cultivars have been observed to be sensitive to chilling injury. Fruit stored below 8°C can suffer from chilling injury, while 'Hass' held at 5°C for 4 weeks showed irregular ripening, altered respiratory patterns, and lower ethylene peaks when ripened at 20 °C (Bill, Sivakumar, Thompson, & Korsten, 2014).

Therefore, it is crucial to maintain optimum temperatures, humidity, and a controlled atmosphere for the efficient marketing of avocados to retain the overall fruit quality.

1.7. Mass loss: Several quality issues need to be considered when the fruit is kept for long after harvest (Bower, 2005).

Avocado is a highly perishable commodity and yet valued for export. Avocado fruit has been considered to have a high postharvest mass loss. Postharvest loss can be defined as the degradation of food production's quantity and quality from harvest to consumption. Quantity losses refer to those that result in the loss of the amount of a product. These losses are primarily due to moisture loss throughout (Kiaya, 2014).

Many food products are not reaching consumers, mainly due to postharvest losses during harvesting, handling, transporting, storage, processing, packaging, and distribution. Minimizing losses is of high importance, and several studies regarding the effect of postharvest storage conditions have been developed. Mass loss is evaluated with a digital balance. The fruit weight is followed along the process. Each value at the end is divided by the corresponding initial weight of the fruit; this is also known as normalization (Arzate- Vázquez et al., 2011).

The literature presents several research studies on “Hass” avocado mass loss along storage time (Table 1). For example, Perez, Mercado & Soto-Valdez (2004) reported a 3% mass loss at 10°C for 22 days and 3% at 20°C after 5 days. In another study by Bower, Dennison & Fowler (2003), a mass loss of 16.4% at 8°C for 20 days was observed. It would be interesting to have a predictive tool that could estimate avocado fruit mass losses under isothermal and non-isothermal conditions.

Table 1. Research results on avocado mass loss along storage time and temperature.

Sample	Storage Time (Days)	Storage Temperature (°C)	Relative Humidity (%)	Mass Loss (%)	Reference
'Hass' Avocado	3 Days	20	65	2.5	Dixon, Elmlsy, Smith, & Pak, 2004
'Hass' Avocado	3 Days	20	65	1.3	Dixon, Elmlsy, Smith, & Pak, 2004
'Hass' Avocado	3weeks	4	90-95	5.02	Mahendran & Prasannath, 2008
'Hass' Avocado	4weeks	7	90-95	5.32	Mahendran & Prasannath, 2008
'Pinkerton' Avocado	20 Days	8		16.4	Bower, Dennison & Fowler, 2003
'Hass' Avocado	12 Days	20	75	11.17	Arzate-Vázquez, 2011
'Hass' Avocado	23 Days	10	88–92	3.0	Perez, Mercado, & Soto-Valdez, 2004
'Hass' Avocado	5 Days	20	88–92	3.0	Perez, Mercado, & Soto-Valdez, 2004

1.8. Texture: A very determining factor in avocados' quality and stability during storage is texture. Firmness is a well-known quality indicator of fruits that has been widely used as a suitable criterion for consumers. Firmness is used mainly to indicate the handling characteristics of many fruits (Vasighi-Shojae et al., 2018).

The impact of storage conditions on the product's firmness over time is substantial (Estrada-Flores, 2003). Firmness is performed and measured by the Texture Profile Analysis (TPA) analysis. TPA is a double compression test for determining the textural properties of foods. During a TPA test, samples are compressed twice using a texture analyzer to interpret how samples behave when chewed. Because the texture analyzer simulates the mouth's biting motion, the TPA test is also known as the "two-bite test."

Understanding a single quality like hardness or cohesiveness is rarely enough to determine a food's textural identity. TPA's analytical strength is that it can measure several textural characteristics in a single experiment, as shown in Table 2. ("Texture Profile Analysis," 2020).

Arzate-Vázquez et al., (2011) carried out a storage study on "Hass" avocado fruit, under darkness conditions, at 20 °C and 75% of relative humidity.

Table 2. TPA attributes definitions ("Texture Profile Analysis", 2020)

Parameter	Definition
Firmness	The maximum force of the first compression.
Fracturability	The force at the first peak.
Cohesiveness	The area of work during the second compression divided by the area of work during the firstcompression.
Springiness	Springiness is now expressed as a ratio or percentage of a product's original height.
Chewiness	Chewiness applies only to solid products.

1.9. Computer Vision System (CVS): The food industry has begun to devote considerably more significant attention to developing rapid and reliable food-evaluation systems as customer concerns about food quality and safety have grown. (Ma et al., 2016). A very determining factor in evaluating changes in physical features of fresh avocado storage is visual appearance. Implementing computer vision systems in the food industry is a feasible choice for classifying food products into specific grades, detecting defects, and estimating properties (Ma et al., 2016). Computer Vision System (CVS) is one of the fastest-growing and most researched disciplines nowadays. CVS is the hardware and software involved in capturing and analyzing an image with a computer. It can estimate the shape, size, color, and position of food consistently and rapidly. It is part of the fruit quality grading category. This grading is a binary process that is performed by computers. (Thor, 2017).

2. Objectives

The objectives of this research are:

1. Evaluate Hass avocado quality along with storage as a function of temperature.
2. Incorporate of kinetic modelling on avocado quality properties changes along the distribution chain.
3. Study the impact of temperature on avocado’s color, texture, size and shape along time by implementing Computer Vision System (CVS).
4. Study avocado’s physiological changes along the distribution chain.
5. Correlate CVS parameters with other physical properties.

3. Materials and Methods

3.1. Sampling: Raw and fresh “Hass” avocado fruits were acquired at the central market of Porto (Portugal). Samples were immediately transported to the laboratory of the CBQF research centre. A batch of 230 avocados of the same size, shape, weight (206 – 294g) and color was stored in darkness conditions, at 5˚C, 20˚C and 30˚C, and at 50 % relative humidity.
The avocado fruits were washed under cold fresh water and dried before the experiments were performed to minimize the chance of any contamination that can affect the study's final results. The avocado fruits were divided into three groups and then transferred to the three different plant growth chambers (FITOCLIMA S 600).

A set of 30 avocados (ten per temperature) were selected for image processing analysis, mass loss, and colorimeter skin color measurement (at two different sides). The other 200 avocados (five samples each day) were used to evaluate the avocado firmness and chlorophylls content.

4. Conclusion

The quality evaluation of avocado fruit, using a non-destructive CVS method, as a function of storage time and temperature will contribute to better managing avocado fruit's distribution under dynamic conditions.
First-order kinetic (Eq. 1) and lag type (Eq. 3) models were used to describe the quality parameters changes of "Hass" avocados fruit as a function of storage time and temperature conditions. These models fitted well the experimental data with high values for the coefficient of determination $R2$ and low root means square error (RMSE). The temperature effect on the rate of change was well described by the Arrhenius model, and a linear behavior was adequate for the temperature effect on the lag time.
The avocados' shelf life was 22, 20, and 10 days, at 5˚C, 20˚C, and 30˚C, respectively. The image features obtained by using the computer vision system provided a good description of the "Hass" avocado ripening process along with storage. Mass and firmness show a tremendous visual difference along with temperature storage conditions.

5. Suggestions for Future Work

The following suggestions for further research and analysis were identified:

- Validate developed models´ predictions under real dynamic storage and distribution conditions.
- Texture analyzes of the avocado pulp along storage time and temperature conditions, using non-destructive CVS methods.

References

[1] Arabshahi A. & Lund, D.B. (1985). Consideration in calculating kinetic parameters from experimental data. Journal of Food Processing Engineering, 239-251.

[2] Arzate-Vázquez, I., Chanona-Pérez, J. J., de Jesús Perea-Flores, M., Calderón- Domínguez, G., Moreno-Armendáriz, M. A., Calvo, H., ... & Gutiérrez-López, G. (2011). Image processing applied to classification of avocado variety Hass (Persea americana Mill.) during the ripening process. Food and Bioprocess Technology, 4(7), 1307-1313.

[3] Avocado market growth, trend, COVID-19 impact, and forecasts (2021 - 2026). (2021) https://www.mordorintelligence.com/industry-reports/avocado-market

[4] Beaudry, R., Luckanatinvong, V., & Solomos, T. (2006, August). Maintaining quality with CA and MAP. In IV International Conference on Managing Quality in Chains- The Integrated View on Fruits and Vegetables Quality 712 (pp. 245-252).

[5] Bill, M., Sivakumar, D., Thompson, A. K., & Korsten, L. (2014). Avocado fruit quality management during the postharvest supply chain. Food Reviews International, 30(3), 169-202.

[6] Blakey, J.P. (2011). Management of avocado postharvest physiology. PhD thesis - School of Agricultural Sciences and Agribusiness Faculty of Science and Agriculture University of KwaZulu-Natal Pietermaritzburg South Africa.

[7] Blakey, R., Bower, J., & Bertling, I. (2010). Post-harvest avocado physiology. South African growers association yearbook, 33, 56-60.

[8] Boekel, M. A. J. S. V. (2008). Kinetic Modeling of Food Quality. Models for Safety, Quality, and Competitiveness of the Food Processing Sector. Vol 7: 145-150.

[9] Bower, J. P. (2005). Resolving long distance dhipping disorders in "Hass" Avocados

[10] . In New Zealand and Australia Avocado Growers' Conference, Session (Vol. 6).

[11] Bower, J. P., Dennison, M. T., & Fowler, K. (2003). Avocado and mango cold storage damage as related to water loss control. Acta Hortic. 628, 401-406

[12] Chen, H., Morrell, P. L., Ashworth, V. E., De La Cruz, M., & Clegg, M. T. (2009). Tracing the geographic origins of major avocado cultivars. Journal of Heredity, 100(1), 56-65.
[13] Cox, K. A., McGhie, T. K., White, A., & Woolf, A. B. (2004). Skin colour and pigment changes during ripening of 'Hass' avocado fruit. Postharvest Biology and Technology, 31(3), 287-294.
[14] Dixon, J., Elmlsy, T. A., Smith, D. B., & Pak, H. A. (2005).Increasing pick to paxk times increases ripe rots in "Hass" avocadoNew Zealand Avocado Growers' Association Annual Research Report, 5, 43-50.