# Effect of different pretreatments to process lyophilised avocado

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Prior to freeze-drying avocado pulp, four pulp treatments were evaluated. The pulps were first divided into two groups: untreated pulp and pulp treated with high pressure, HP, and then each group was treated with two different methods of particle reduction, compression, and friction, and they were subsequently freeze-dried. Physicochemical analyses were conducted on the different lyophilised powders, pH, acidity, wettability and water activity. The HP treatments lowered the pH and increased the acidity compared to fresh avocado pulp without any treatment. The opposite was true for the non-HP treatments. On the other hand, those treated by compression have a lower pH and higher acidity than those treated by friction. Each treatment presented different wettability times, with the shortest wetting time in the HP-free and compression, and this same batch presented the lowest water activity. The most effective treatment was compression without high pressure, as it demonstrated the least variability in pH and acidity compared to fresh avocado and it had the shortest wettability time and water activity. Likewise, gas chromatography was used to study the volatile compounds in each of the four treatments; these compounds are mostly the product of the degradation of fatty acids present in the lipid phase. The elimination or formation of compounds in relation to fresh avocado was observed for each treatment and varied between them. The fresh avocado oil contains ten main compounds, namely hexanal, 2-hexenal, caryophyllene, benzeneacetaldehyde, copaene, α-bergamotene, hexane-2,3-dimethyl, α-cubebene, hexane, and 3-carene, which make up 91% of the total. An optical microscopy analysis showed that all treatments caused a break in the cell wall of avocado cells, but compression resulted in less intensity.
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## 1. INTRODUCTION

The avocado, *Persea americana*, is a fruit native to Mexico and Central America. Its Spanish name, 'aguacate' derives from the Aztec word "ahuacatl" which means testicle-shaped fruit. Today, this fruit is cultivated worldwide in tropical and subtropical regions, and it has several varieties, and the most popular is the Hass. Mexico is the world's leading exporter of avocados, representing approximately 45% of global exports, and Colombia and Peru follow as the next largest exporters [2,12,20]. Avocado is a rich source of essential nutrients including protein, lipids, minerals, vitamins, fibre, carotenoids, phytosterols, phytostanols, seven-carbon sugars, resveratrol, and phenolic compounds. These nutrients are crucial for maintaining good health [8,25].
The fruit contains several phytochemicals with antioxidant, anti-inflammatory, antitumor, and antimicrobial properties [14].
Most avocados are marketed and consumed in their fresh form on the domestic and export markets, but its short ripening time and susceptibility to oxidation

are the main problem for producers. Freeze-drying is the optimal dehydration process for preserving the shelf-life and sensory and nutritional characteristics of avocado [3]. Avocado is known for its high lipid content, ranging from 10-30% in fresh fruit, depending on the variety and seasonality, and, overall, the oil contains 71% monounsaturated fatty acids, 13% polyunsaturated, and 16% saturated fatty acids. Currently, reducing the consumption of saturated fats and increasing the intake of polyunsaturated fats is important in mitigating the risk of coronary heart disease. Preliminary studies suggest that avocados may aid in weight management and promote healthy aging [5,21,4].

Pureed avocados quickly lose their nutritional and sensory quality due to oxidative enzymes, such as polyphenoloxidase and lipoxygenase. These enzymes attack phenolic-like compounds and affect fatty acids and carotenoids, resulting in rancid flavours and odours. In addition to the hydrolysis of ester bonds in triglycerides, lipases, also exhibit hydrolytic enzymatic activity. This results in the production of free fatty acids and volatile compounds, which can accelerate autooxidation reactions due to their susceptibility to free radical attack [13,19].

Avocado pulp can be directly consumed or further processed to create guacamole, avocado oil, puree, sauce and other commercial avocado products. Additionally, avocado contains considerable amounts of phytochemicals, especially phenolic acids and flavonoids, which provide antioxidative capabilities to be utilised in food and pharmaceutical industries [7].

Particle reduction in food processing is a unit operation that aims to decrease the average size of solids or liquids by applying various forces. In the case of solids, this process is also known as comminution and includes grinding, crushing, impacting, abrasion, or cutting [23]. On the other hand, high-pressure technology can be used to activate or inactivate enzymes. Low process conditions can increase enzyme activity and stabilise enzymes, while extreme conditions such as pressure, temperature, and time can induce denaturation. In molecular terms, high pressure breaks noncovalent bonds, such as ionic and hydrophobic bonds, and has little effect on covalent bonds. Changes in the secondary, tertiary, and quaternary structures affect large biomolecules like proteins and polysaccharides, but small molecules such as colour, flavour, and vitamins are usually unaffected [16].

The objective of this study was to investigate alternative methods for obtaining lyophilised avocado pulp. Two particle size reduction methods, compression and friction, were evaluated under two process conditions: one with high pressure treatment and one without treatment prior to lyophilisation.

## 2. MATERIALS AND METHODS

Hass variety avocado pulp from Michoacan, Mexico, was used and divided into two groups: untreated pulp and pulp treated with high pressure (HP), and each group was then subjected to two different methods of particle reduction, compression, and friction, before being freeze-dried. The study looked at four different treatments: T1A, which used avocado pulp without high pressure and friction; T1B, pulp without high pressure and compression; T2A, pulp with high pressure and friction; and T2B, pulp with high pressure and compression.

### 2.1. RAW MATERIAL

To ensure consistency of fresh Hass avocados, a single lot was used for all treatments. The avocados were subjected to accelerated ripening at 25°C ± 2°C and relative humidity (RH) of 85 ± 10% for 4 days until they reached optimum maturity with a texture of 13.5 ± 2.0 Newton (N). Maturation was carried out in a climatic chamber with temperature and relative humidity control (Thermo Scientific™-3949). The avocados were then washed, sanitised, and cut. The pericarp was manually extracted using a knife.

The avocados were selected based on a destructive test that evaluated their texture using a Brookfield® model CT3 texturometer and CT3 Texture Analyser software. The TA44 Cylinder 4 mm D tip was used with a penetration distance of 3 mm, a displacement speed of 3 mm/s, and a net activation load of 6 N.

### 2.2. HIGH PRESSURES

The high hydrostatic pressure process was carried out using a Hyperbaric® Wave 55 model equipment under the conditions of 550 MPa at 20°C for 120 s.

### 2.3. SIZE REDUCTION

Two different methods, friction and compression, were used to reduce the particle size of the pulp after treatment with and without high pressure. The resulting avocado paste was then freeze-dried. The friction process was conducted using an Oster® brand immersion blender model M2609-13 at minimum speed, while the compression process was conducted using a Metaltex® brand potato press with a mesh size of 1 cm. Figure 1 displays images of both equipment.

### 2.4. LYOPHILIZATION

The samples were flash frozen at -60°C for 15 min using a Revco® ULT1386-9-A36 freezer. Freeze-drying was performed using industrial equipment owned by SioSi Alimentos Company, Mexico. Identical process conditions were used for all batches. The process conditions are not disclosed due to confidentiality.

## 3. PHYSICOCHEMICAL ANALYSIS

The freeze-dried products underwent analysis for pH, acidity, water activity, and wettability. All analyses were performed in triplicate.

**pH.** An Oharus® model a-AB23PH pH meter was utilised. A dilution of 1:10 was used, lyophilised powder and distilled water.

**Acidity.** The acidity in the oils of each of the treatments was determined using the official method AOAC [1]. The oil was obtained from each lyophilized sample using ether as a solvent and a Hahn vapor steam rotary evaporator in a 1:8 ratio of avocado-ether for 24 hours. Next, 7.0 g of the oil was mixed with 250 mL of neutralised alcohol and titrated with 0.1 NaOH normal solution using phenolphthalein as indicator. The acidity was reported as fatty acids based on oleic acid (factor, 0.0282).

**Water Activity.** The freeze-dried samples were passed through a mesh with a size of <1 mm to ensure uniform particle size. An Aqualab® Pre equipment was used.

**Wettability.** This technique was used to determine the ability of different lyophilised powders to dissolve in water. The method proposed by Gea [11] was used with modifications. Prior to testing, the powders were homogenised by screening to ensure a particle size of <1 mm. A 400 mL beaker containing 100 mL of deionised water at 25°C was used. A glass plate was used to hold 1 g of the powder. The powder-filled plate was positioned atop the beaker and inverted to allow the powder to meet the water, then a stopwatch was started. Wettability was determined by the time it takes for the final particle of dust to dissolve in the water without any agitation. The time was measured in seconds.

### 3.1. VOLATILE COMPOUNDS

Volatile compounds were detected in the four treatments, with a fresh avocado sample used as the control. The units of measurement were percentages corresponding to the area of each of the peaks. Two determinations were made for each of the tests. 30 g of the sample was placed in an amber glass vial and enriched with volatile compounds by stirring it at 100 rpm for 45 min in a water bath at 37°C. A metal needle containing a solid phase coated with a layer of divinyl-benzene-carboxen-polydimethylsiloxane (50/30) was then introduced. The microextraction fibre was exposed to the gas phase of the headspace for 30 min with agitation. After adsorption, the fibre was retracted, and the needle was immediately introduced into the gas injector of the chromatograph (Hewlett Packard 5890 Series II) coupled to a mass selective detector (HP 5972). The chromatographic conditions were as follows: the injector temperature was set to 180°C, and the fibre desorption time was 6 min in spitless mode. Helium was used as a carrier gas at a flow rate of 0.8 mL/min. The chromatographic column was an Agilent® J&W DB-5 with dimensions of 30 mm x 0.25 mm internal diameter. The initial temperature was set to 40°C and increased at a rate of 3°C/min until it reached 120°C. The total ion chromatograms (TIC) and the mass spectra corresponding to each compound were acquired with an impact electron ion (EI) at 70 eV at 1.6 scans/s. The identification of the compounds was done by comparing the spectrum of the compound with the Wily Spectra Library of the chromatograph's own equipment.

### 3.2. MICROSCOPY

The samples were prepared by cryo-embedding-compound and stored at -20°C for 24 h with a radius of 1.5 cm. Cutting was carried out using a Microm 505-n cryostat at 25 µm. Staining was performed using Malachite Green at 0.2% for 2 min to colour the cell wall (cellulose) green and Sudan Red III at 1% for 15 min to detect lipids that stain yellow. Finally, they were introduced to xylol for 5 min to fix the colour. The samples were observed using a Motic® model BA210 optical microscope with an integrated camera at 10x and 40x magnification.

### 3.3. STATISTICAL ANALYSIS

Statistical analysis was conducted using the JMP12 program. A one-way ANOVA analysis was performed to determine if there is a significant difference ($\alpha$= 0.05) between the treatments, followed by a Tukey's test.

## 4. RESULTS AND DISCUSSION

### 4.1. RAW MATERIALS AND PROCESS

The avocados used in this study had an average weight of 150 ± 15 g. The avocados were chosen based on their firmness, which was measured at 13.5 ± 2.0 N. According to Márquez [18], the firmness of the avocado on day 1 ranges between 60-67 N, and decreases as the fruit ripens to final values around 5 N. This decrease is likely due to the hydrolysis of the pectic compounds of the cell wall by the action of pectinase, polygalacturonates, cellulases, and amylases. Optimal firmness is between 10-20 N, with over-maturity occurring from day 17 of storage.

### 4.2. HIGH PRESSURE

Before the size reduction process, the avocado pulps were divided into two batches: one treated with high pressure processing and one without. The purpose of applying high pressure was to observe any variations in the pulp that would occur during freeze-drying. The process conditions were 550 MPa at 20°C for 120 s. No tests were conducted to validate enzyme activity, but differences were observed in the physicochemical properties and volatile compounds between the samples treated with high pressure and those that were not.

According to Sarantakou [24], the avocado fruit contains endogenous pectolytic and cellulolytic enzymes, as well as lipolytic enzymes, which can cause oil hydrolysis and oxidation, including polyphenoloxidase and lipoxygenase; likewise high-pressure processing of avocado paste (600–700 MPa; 3–10 min) can lead to 50% inactivation of these enzymes, however, it was noted that both enzymes can reactivate during storage, resulting in undesirable quality deterioration. Qin [21], mentions that the freeze-dried avocado may still contain lipase enzyme activity, which can cause the degradation of oil and the destruction of valuable minor compounds.

In this study, it was observed in general that the HP treatments decreased the pH and increased the acidity of freeze-dried powders compared to control, avocado pulp without any treatment. Conversely, studies without HP treatment showed an increase in pH and a decrease in acidity. Regarding wettability, HP-treated samples exhibited longer times compared to untreated samples, while there was no significant difference in water activity levels.

### 4.3. SIZE REDUCTION

After the treatment with or without high pressures, the avocado pulps were reduced in size using two methods, compression (potato press) and friction (immersion blender). Size reduction is a common unit operation in food processing and can be critical in food technology. It involves activities such as cutting, slicing, grinding, or pulping. According to Souza [25], the mechanical properties of food are dependent on its composition and processing, and in the case of freeze-drying, the type of freezing used has a significant impact on the texture of the food, as well as the degree of maturity of the fruit and the processing parameters.

### 4.4. LYOPHILISATION

After undergoing size reduction treatments, either compression or friction, all products were freeze-dried using the same processing conditions. The information related to this process is not disclosed due to its confidential nature of the company SioSi Alimentos, Mexico. The moisture content of the fresh avocados was 63.5 ± 0.5%, while the freeze-dried products had a moisture content of 1.5 ± 0.2%. According to Rodiles-López [22], lyophilized avocado from Michoacán, Mexico, had a composition of 9.2% carbohydrates, 19.4% dietary fibre, 60.4% lipids, 3.9% proteins, and 7.1% ash on dry matter.

**Figure 1** - Equipment for the reduction of size. Left side, equipment for friction process, Oster® brand immersion blender model M2609-13. Right side, equipment for compression process, Metaltex® brand potato press with a mesh size of 1 cm

### 4.5. PHYSICOCHEMICAL ANALYSIS

After freeze-drying, several physicochemical parameters of the powders were evaluated and compared to assess the effect of each treatment. Table I presents a summary of the different studies and their corresponding Tukey analysis.

#### 4.5.1 Ph and acidity

The pH of the fresh avocado was 6.48, which is consistent with the values reported by Krumreicha [14] of 6.5 ± 0.1 and 6.49 according to Jacobo-Velázquez [13]. There was no significant difference observed between compression and friction in HP treatments, and these are different from control. Likewise, there is no difference between friction and compression in those not treated by HP. It is worth noting that there was no significant difference between the T1B treatment, compression and without HP, with respect to the control.

The acidity of fresh avocado was 0.353 on oleic acid. According to Krumreicha [14], the acidity of fresh avocado was measured at 0.5 ± 0.1 on oleic acid. The results show no difference between compression and

**Table I -** Physicochemical Analyses. Freeze-dried avocado pulp powders

| Treatment | pH | Acidity (%) | Wettability (s) | Water activity |
|---|---|---|---|---|
| T | 6.48 ± 0.11 $^{B}$ | 0.353 ± 0.021 $^{AB}$ | 57 ± 2 $^{BC}$ | 0.968 ± 0.022 $^{A}$ |
| T1A | 6.94 ± 0.14 $^{A}$ | 0.309 ± 0.022 $^{B}$ | 62 ± 3 $^{B}$ | 0.352 ± 0.014 $^{B}$ |
| T1B | 6.64 ± 0.13 $^{AB}$ | 0.334 ± 0.018 $^{AB}$ | 52 ± 2 $^{C}$ | 0.311 ± 0.010 $^{C}$ |
| T2A | 6.07 ± 0.10 $^{C}$ | 0.384 ± 0.023 $^{A}$ | 78 ± 4 $^{A}$ | 0.350 ± 0.012 $^{B}$ |
| T2B | 5.95 ± 0.12 $^{C}$ | 0.389 ± 0.026 $^{A}$ | 72 ± 3 $^{A}$ | 0.327 ± 0.011 $^{BC}$ |

Equal letters in the same column do not differ significantly (α = 0.05).

T = Witness; where pH and water activity correspond a fresh avocado, acidity correspond an avocado oil, and wettability a freeze-dried grapefruit powder; T1A = treatment without high pressure and friction; T1B = treatment without high pressure and compression; T2A = treatment with high pressure and friction; T2B = treatment with high pressure and compression. All analyses were performed in triplicate.

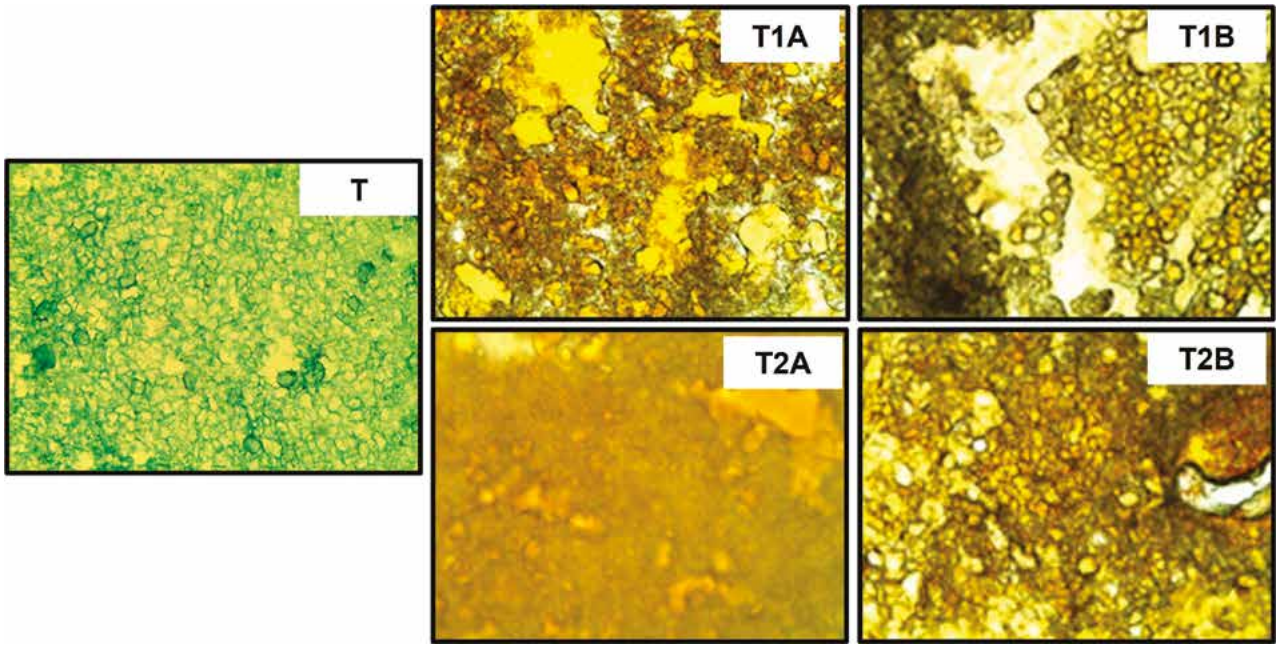


**Figure 2 -** Micrographs. 10x. T = Witness, fresh avocado; T1A = treatment without high pressure and friction; T1B = treatment without high pressure and compression; T2A = treatment with high pressure and friction; T2B = treatment with high pressure and compression

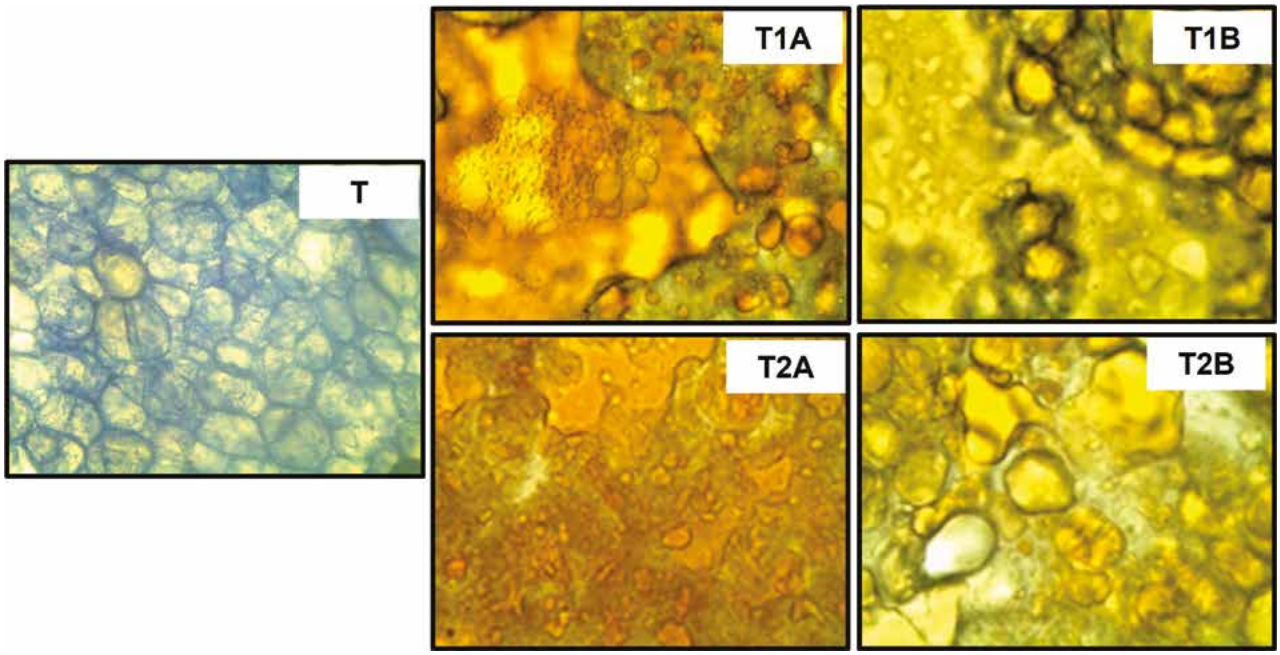


**Figure 3 -** Micrographs. 40x. T = Witness, fresh avocado; T1A = treatment without high pressure and friction; T1B = treatment without high pressure and compression; T2A = treatment with high pressure and friction; T2B = treatment with high pressure and compression

friction in HP treatments, and they are not different from the control. In non-HP, there is also no difference between friction and compression, and they are no different from control.
It can be concluded that the treatment which generated the least changes in comparison to the control was the sample without HP and compression, T1B. In this case, the pH changed by only 2.5% and the acidity by 5.5% in comparison to the witness, avocado fresh.

4.5.2 Humectability

In this case, it used a data reported by Egas-Astudillo [6] as witness, which corresponds to a freeze-dried grapefruit powder, 25°C. Shorter wettability time indicates that a powder is easier to solubilise in water. It observed that treatments with HP result in longer times compared to those without HP. Likewise, friction treatments have longer times compared to compression. Additionally, those treated with HP exhibit higher values than the control group and are statistically different. There is no difference between compression and friction without HP compared to the control group, but there is a difference between them. The batch without HP and compression had the shortest wettability time. Egas-Astudillo [6], state that freeze-dried powders have better wetting properties than those made by spraying, specifically in the case of grapefruit fruit; additionally, the freeze-dried powders exhibited shorter wetting times and lower hygroscopicity, but greater porosity. These properties could be further improved by adjusting particle size and shape.



4.5.3 Water activity

The fresh avocado had a water activity (aw) value of 0.968, while the average aw value of the freeze-dried powders in this study was 0.335 ± 0.020. Compression treatments resulted in lower aw values compared to friction, and the combination of no HP and compression had the lowest value. This batch also had the lowest variability in pH and acidity compared to the control, as well as the shortest wettability time. Water activity (aw) is a crucial factor in preventing or limiting microbial growth. Lower aw results in lower microbial growth and longer shelf life [26]. However, avocado is a fruit with high lipid content that is susceptible to oxidation reactions, and this behaviour varies with the water activity values. Vu [27], noted a J-shaped curve in the behaviour of aw regarding lipid oxidation. This curve can be divided into four regions. In the first region, where aw is less than 0.2, lipid oxidation rates are intermediate. In the second region, between 0.2 and 0.3, the lowest oxidation rates are observed. In the third region, between 0.3 and 0.9, lipid oxidation increases. Finally, in the fourth region, close to 1.0, lipid oxidation rates are again reduced.

4.6. VOLATILE COMPOUNDS

Gas chromatography was used to determine the volatile compounds in each of the lyophilised treatments and the fresh avocado, control. Changes were observed in comparison to the fresh avocado for each treatment. Table II summarises these compounds.
It found 26 volatile molecules in fresh avocado, with the top 10 being hexanal, 2-hexenal, caryophyllene, benzeneacetaldehyde, copaene, α-bergamotene, hexane-2,3-dimethyl, α-cubebene, hexane, and 3-carene, which make up 91% of the total compounds. The analysis of these 10 compounds reveals that the four treatments preserve hexanal, caryophyllene, α-cubebene, and 3-carene. However, benzeneacetaldehyde, hexane-2,3-dimethyl, hexane, and practically 2-hexanal are no longer present. Copaene disappears only in the treatment without HP and friction but remains in the other treatments. Lastly, α-bergamotene is maintained in HP treatments but disappears in non-HP treatments.
All treatments produced decano-2,6,8-trimethyl, heptane-2,2-dimethyl, and hexane-3,3-dimethyl, as well as ylangene, α-phellandrene, and octane-6-ethyl-2-methyl, along with traces of 1-nonene, 1-hexanol, and 1-octen-3-ol; and these compounds were absent in the control, fresh avocado. In contrast, all treatments disappear in relation to the control: pentanal-2,3-dimethyl, 2-heptenal, nonanal, α-amorphene, octanal, 3-nonen-2-one, dodecano-2,6,10-trimetil, and 2-heptylfuran.
Liu [17] detected 31 volatile compounds in fresh post-harvest avocado using gas chromatography-mass spectrometry (GC-MS), and they detected 8 alcohols, 6 ketones, 5 aldehydes, 3 acids, 4 heterocyclic compounds, 2 hydrocarbons, 1 amine, 1 ester, and 1 phenol.
According to Lara-García [15], the volatile compounds in 14 avocado genotypes were predominantly alcohols and aldehydes. This is due to the degradation of lipids, which are abundant in this fruit. The compounds present in the given sample are acetaldehyde, hexanal, 2-hexenal, α-cubebene, α-copaene, and β-caryophyllene. This author points out that acetaldehyde is known for its fresh fruit aroma, while hexanal and 2-hexenal have a grassy aroma and tend to decrease in concentration during ripening. α-cubebene has fruity aromas like citrus, whereas α-copaene and β-caryophyllene have spicy and woody notes.
Lipid oxidation processes, including auto-oxidation and enzymatic reactions, can lead to rancidity. The hydroperoxides formed during the oxidation of linoleic acid, which is the most abundant and oxidation-susceptible fatty acid in avocados, are rapidly broken down into several compounds that cause rancid odour and taste. These compounds include hexanal, 3-hexenal, and 2-hexenal [13].

**Table II -** Volatile compounds. Freeze-dried avocado powders and fresh avocado. Percentages

| | T | T1A | T1B | T2A | T2B |
|---|---|---|---|---|---|
| Hexanal | 24.4 | 18.5 | 19.9 | 56.7 | 33.6 |
| 2-hexenal | 15.9 | - | - | 0.2 | - |
| Cariofileno | 15.8 | 11.8 | 13.6 | 7.0 | 10.9 |
| Benzeneacetaldehyde | 9.9 | - | - | - | - |
| Copaene | 9.1 | - | 8.7 | 4.3 | 7.9 |
| α-bergamotene | 8.5 | - | - | 2.5 | 4.7 |
| Hexane, 2,3-dimethyl | 2.5 | - | - | - | - |
| α-cubebene | 1.9 | 3.6 | 4.9 | 2.0 | 3.4 |
| Hexane | 1.5 | - | - | - | - |
| 3-carene | 1.4 | 3.0 | 1.1 | 1.3 | 2.5 |
| 2-furanona | 1.2 | 1.1 | 1.3 | 0.4 | 1.1 |
| Pentanal, 2,3-dimethyl | 0.9 | - | - | - | - |
| Seychellene | 0.8 | - | 0.1 | - | 0.1 |
| Gurjunene | 0.8 | - | 0.1 | - | 0.1 |
| β-sesquiphellandrene | 0.7 | 0.2 | - | 0.1 | 0.1 |
| 2-heptenal | 0.7 | - | - | - | - |
| Pentanal | 0.6 | - | - | 2.9 | 1.4 |
| Nonanal | 0.5 | - | - | - | - |
| α-amorphene | 0.5 | - | - | - | - |
| Octanal | 0.5 | - | - | - | - |
| 1-hexene, 3,5-dimethyl | 0.5 | 0.2 | - | - | - |
| 3-nonen-2-one | 0.5 | - | - | - | - |
| Acetic acid, methyl ester | 0.4 | 5.0 | 6.2 | - | 3.9 |
| Dodecane, 2,6,10-trimetil | 0.2 | - | - | - | - |
| 2-heptylfuran | 0.1 | - | - | - | - |
| Neodihydrocarveol | 0.1 | 0.1 | - | - | - |
| Decano, 2,6,8-trimetil | - | 2.1 | 1.8 | 1.5 | 1.6 |
| Heptane, 2,2-dimethyl | - | 8.0 | 7.0 | 2.8 | 6.2 |
| α-copaene | - | 8.0 | - | - | - |
| Hexane, 2,3,5-trimethyl | - | 6.6 | 0.3 | - | 0.3 |
| Hexane, 3,3-dimethyl | - | 5.4 | 4.4 | 2.3 | 0.3 |
| 3-pentanone | - | 5.1 | 6.8 | - | - |
| Heptane, 3,3-dimethyl | - | 3.1 | - | - | 2.9 |
| Ethyl acetate | - | 2.7 | - | 0.8 | 2.0 |
| 5,6-decadien-3-yne, 5,7-diethyl | - | 2.6 | - | 4.6 | 2.3 |
| 2,5-octadiyne, 4,4-diethyl | - | 2.0 | - | 1.1 | 1.8 |
| Furan, 2-pentyl | - | 1.5 | 0.7 | - | - |
| Ylangene | - | 1.4 | 1.6 | 0.8 | 1.3 |
| Heptane, 2,2,4,6,6-pentamethyl | - | 1.4 | 0.7 | - | - |
| α-caryophyllene | - | 1.3 | - | 0.1 | 0.6 |
| α-phellandrene | - | 1.1 | 0.2 | 0.4 | 0.9 |
| Octane, 6-ethyl-2-methyl | - | 1.0 | 0.9 | 0.4 | 4.4 |
| Decane, 2-methyl | - | 0.8 | - | - | 2.1 |
| Trans-α-bergamotene | - | 0.5 | - | 0.4 | 0.5 |
| 1-nonene | - | 0.4 | 0.4 | 0.2 | 0.3 |
| 1-hexanol | - | 0.4 | 0.4 | 0.2 | 0.3 |
| Octane, 2,2,6-trimethyl | - | 0.3 | 1.0 | - | 0.7 |
| Octane, 2,3,6,7-tetramethyl | - | 0.2 | 1.6 | - | - |
| β-myrcene | - | 0.2 | - | - | - |

Table II (continue)

| | | | | | |
|---|---|---|---|---|---|
| 1-octen-3-ol | - | 0.2 | 0.2 | 0.1 | 0.3 |
| Hexane, 2,4-dimethyl | - | - | - | 0.8 | 0.7 |
| δ-cadinene | - | - | - | 0.1 | 0.5 |
| Hexane, 3-methyl- | - | - | 0.2 | - | 0.3 |
| 1-octene | - | - | - | - | 0.2 |
| 6-hepten-3-one, 5-hydroxy-4-methyl | - | - | 3.2 | - | - |
| Undecane, 2,8-dimethyl | - | - | 3.0 | - | - |
| α-humulene | - | - | 2.2 | - | - |
| Octane, 2,4,6-trimethyl | - | - | 2.1 | - | - |
| Hexane, 2,2,3-trimethyl | - | - | 2.0 | - | - |
| Decane, 2,5,9-trimethyl | - | - | 1.8 | 0.7 | - |
| Heptane, 2,2,3,5-tetramethyl | - | - | 0.9 | - | - |
| α-farnesene | - | - | 0.5 | - | - |
| Octane, 2,7-dimethyl | - | - | 0.3 | - | - |
| Pentane, 2,2,3,4-tetramethyl | - | - | - | 2.5 | - |
| 1-hexene, 3,5,5-trimethyl | - | - | - | 1.6 | - |
| Heptanal | - | - | - | 1.1 | - |
| Hexane, 2,2,5,5-tetramethyl | - | - | - | 0.2 | - |

The table presents the percentage of each compound with respect to the total of compounds present in each treatment. T = Witness, fresh avocado; T1A = treatment without high pressure and friction; T1B = treatment without high pressure and compression; T2A = treatment with high pressure and friction; T2B = treatment with high pressure and compression. All analyses were performed in duplicate.

The reduction in size increases the surface area. This could lead to increased oxidation, loss of nutrients and flavour compounds, and changes in volatile compounds [23]. The scent of avocados (*Persea americana Mill. cv. 'Hass'*) is determined by volatile compounds derived from fatty acids. These compounds change depending on the fruit's maturity stage, which is regulated by ethylene. They are the primary precursors of esters, alcohols, and aldehydes [9,10].



### 4.7. MICROSCOPY

A microscopic optical study was conducted to compare the different treatments with fresh avocado. The results are shown in Figure 2 (magnification of 10x) and Figure 3 (magnification of 40x). The images show the cell wall in green and the lipids in yellow. The control, fresh avocado, clearly shows the presence of the cell wall intact. In all treatments, the rupture of the cell wall and dispersed lipids is observed. However, the samples subjected to compression show less cell wall breakage than those subjected to friction.

Lipids are mainly present in the mesocarp of avocados, which is composed of numerous parenchyma cells and evenly scattered idioblasts. During ripening, the primary walls of the parenchyma cells can be degraded by the activity of cellulase and poligalacturonasas, but the suberised walls of the idioblastic cells remain intact due to the immunity of these enzymes. Lipids are released when the cell walls are broken by mechanical forces [21].

## 5. CONCLUSIONS

Prior to freeze-drying the Hass avocado pulp, a series of pre-treatments were conducted to determine the optimal methodology. The pulp was initially divided into two groups: one treated with high pressure and the other without. Each group was then subjected to two methods of particle reduction, compression, and friction. The freeze-dried products had a final humidity of 1.5 ± 0.2%. HP treatments decreased pH and increased acidity compared to untreated avocado pulp, while non-HP treatments increased pH and decreased acidity. Additionally, HP treatments resulted in longer wettability times than untreated samples. Powders treated with compression exhibited lower water activity compared to those treated with friction. The sample with the least change in pH and acidity compared to the control was the batch without HP treatment and with particle reduction by compression. Additionally, this batch had the best wettability time and lowest water activity. The comparison of volatile compounds among the four treatments revealed differences between them, and in comparison, to the profile of volatiles found in fresh avocado. Each treatment developed a unique profile that characterises it. Additionally, optical microscopy analysis showed that all treatments caused cell wall breakage and lipid dispersion, with compression treatments causing less damage.

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