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| RESEARCH ARTICLE

Effect of Pre-treatments on Shelf Life and Quality of Dried Pineapples (*Ananas comosus*)

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| ABSTRACT
This study aims to determine the effect of different pre-treatment and freezing on the quality of dehydrated pineapple using a food dehydrator with a convective drying method. The variations of pre-treatment conducted include control variation (K), immersion in sucrose solution (G), sucrose-citric acid mixture (GS), citric acid (S), thermal blanching (B), and *kapur sirih* or betel lime solution (KS), with and without freezing process before drying. The S variation resulted in the best shelf life of dried pineapple, lasting 106 days under room conditions using 0.75% citric acid solution. The shelf life of dried pineapple with pre-treatments K, G, GS, B, and K, respectively, were 61, 49, 33, 72, and 20 days. Drying and all types of pre-treatments resulted in a darker colour compared to fresh pineapple. Drying and all types of pre-treatments also yielded higher firmness values compared to fresh pineapple. Freezing prior to drying resulted in a darker colour for dried pineapple compared to unfrozen dried pineapple. Freezing prior to drying also yielded a softer texture compared to unfrozen dried pineapples. According to a group of 32 untrained panellists in the age group of 20-24 years old, the G variation was the most preferred variation of dried pineapple.

| KEYWORDS

Colour, drying, pineapple, shelf-life, texture

| ARTICLE INFORMATION

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1. Introduction

Indonesia is a tropical country with abundant food resources, such as fruits, which ranked as the seventh largest producer in the world in 2020 (FAO, 2020). However, the vast food resources in Indonesia would go to waste if not utilized properly. According to Bappenas, food loss and waste in Indonesia reaches 23-48 million tons per year, with the production process accounting for 7-12.3 million tons per year, post-harvest and storage resulting in 6.1-9.9 million tons per year, processing and packaging generating 1.1-1.8 million tons per year, distribution and markets contributing 3.2-7.6 million tons per year, and household waste amounting to 5-19 million tons per year with fruits account for 20% of the total food waste and loss in Indonesia. Generally, fresh fruits are challenging to sell and transport to distant locations. For example, bananas can only last for 6 days (Crismas et al., 2018), while freshly cut pineapples can only last for 3 days at room temperature (Antoniolli et al., 2007). The high water content in fruits, approximately 65-95% (Singh and Singh, 2011), leads to the short shelf life of fresh fruits (Zhao et al., 2020). In short, the short shelf life of fresh fruits hinders the distribution process in fresh conditions, necessitating solutions to address this issue, including preservation methods.

Fresh fruits can be preserved by drying them into dried fruit products to extend their shelf life (Sagar and Kumar, 2010). Several drying methods can be employed, such as freeze drying, vacuum drying, greenhouse drying, and hot air drying (Deng et al., 2019). Additionally, pre-treatment processes are commonly conducted before the drying process to accelerate the drying rate, maintain the colour and flavour of the fruits, and minimize energy consumption (Chavan and Amarowicz, 2012).

In order to extend the shelf life and utilize local fruits in Indonesia, an experiment was conducted to dry pineapples into dried pineapples with a maximum water content of 20% using a convective drying method, considering variations of pre-treatment and freezing process prior to drying.

2. Literature Review

2.1. Fruit Drying

One of the main objectives of fruit drying is to extend the shelf life of the fruit. Dried fruits have a lower water content compared to fresh fruits, which allows them to have a longer shelf life. Dried fruits also experience size shrinkage, resulting in smaller dimensions than fresh fruits. This can impact the texture of the fruit itself (Zotarelli et al., 2012). Additionally, the drying process itself alters the taste of the fresh fruit. The quality of dried products differs from that of fresh fruits, including in terms of texture, colour, volatile compounds, and aromatic components (Takougnadi et al., 2020).

In addition, ester and carboxylic acid compounds that produce aroma in fresh fruits can be degraded and damaged when exposed to inappropriate drying operation conditions. All types of drying lead to a decrease in the content of volatile compounds in the product compared to fresh fruit (Mui et al., 2002). Due to this phenomenon, operational conditions must be considered to minimize the percentage of damage or loss of volatile compounds in dried fruits.

One of the common food preservation methods employed in the industry is the hot air drying method, which utilizes hot air to dehydrate materials. This method is widely used in the food industry nowadays due to its simplicity and cost-effectiveness, but it comes with common issues such as non-enzymatic browning reactions, inadequate rehydration characteristics, loss of nutrients in the material, low thermal conductivity, and material hardening (Yao et al., 2020).

Hot air drying employs the principle of convective heat transfer. The heat from the surrounding air is transferred to the product through convection, causing the water within the fruit to evaporate into steam. The generated steam is then carried away into the external air through convection. In this drying process, the drying time needs to be carefully considered, as even drying at a temperature of 60°C can lead to degradation in the quality of the dried material (Antal, 2015). Apart from the quality degradation of the material, products subjected to prolonged high temperatures require higher energy consumption (Pu and Sun, 2017). Research on various types of dried fruits using hot air drying is provided in Table 1.

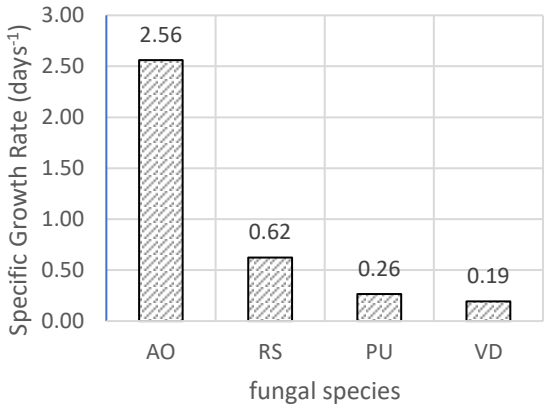
Table 1. Various Research Related to Fruit Drying

References	Types of Fruits	Operation Conditions
(Yannick et al., 2019)	Mango (*Mangifera indica* L.)	Temperature: 40, 50, 60℃ Air flow: 0.6 m/s
(Kingsly et al., 2007)	Peach (*Prunus persica* L.)	Temperature: 55, 65℃ Types of pre-treatment: • Blanching, t = 2 minutes, T = 50℃, 1% Potassium metabisulfite • Blanching, t = 2 minutes,T = 50℃, 1% Ascorbic acid • Control (No pre-treatment)
(Krzykowski et al., 2020)	Strawberry (*Fragaria vesca* L.)	Temperature: 25, 40, 60℃ Air flow: 0.5 m/s
(Villa-Corrales et al., 2010)	Mango (*Mangifera indica* L.)	Temperature: 50, 55, 60, 65, 70℃ Sample thickness: 2, 3, 4, dan 5 mm *Relative Humidity:* 15±2.0% Air flow: 0.2 m/s
(Akoy et al., 2008)	Mango (*Mangifera indica* L.)	Temperature: 60, 70, 80℃ Sample thickness: 3 mm Air flow: 1.5 m/s
(Ramallo dan Mascheroni, 2012)	Pineapple (*Ananas comosus*)	Temperature: 45, 60, 75℃ Sample thickness: 6.0±0.5 mm Air flow: 1.5 m/s
(Macedo et al., 2020)	Banana (*Musa* spp.)	Temperature: 40, 60, 80℃ Sample thickness: 5 mm Air flow: 1.5 m/s

2.2. Shelf Life

Shelf life is an important factor in the drying process. Shelf life can be defined as the period during which a product remains safe to consume, retains the desired physical, sensory, and chemical properties, and still holds true to the label or claims stated on the packaging's nutritional information. Several factors affecting the shelf life of a product include raw material quality, product formulation, processing environment, processing and preservation techniques, packaging type, storage and distribution, and consumer handling. There are several methods to determine the shelf life of a product, including end point study, accelerated shelf-life testing (ASLT), kinetic models, and the Arrhenius model.

One of the methods that can be applied to dried fruits is the kinetic model. Microorganism growth, enzyme inactivation, and vitamin loss can be approximated with a first-order kinetic equation, while reactions causing browning and frozen food quality can be approached using a zero-order equation (Kilcast and Subramaniam, 2000). The parameter that can be used to determine shelf life is the specific growth rate (μ). The μ value represents the rate of microbial population increase per unit of time (Galvanauskas et al., 2019). The larger the μ value, the faster the fungal growth rate, leading to a shorter shelf life for dried fruits. Figure 1 indicates the specific growth rates (μ) for several fungal species (Sterne and McCarver, 1978; Bathe et al., 2013). Aspergillus oryzae shows the highest specific growth rates (μ) of 2.56 $days^{-1}$.



*AO: *Aspergillus oryzae*, RS: *Rhizoctonia solani*, PU: *Phytium ultimum*, VD: *Verticilium dahliae*

Figure 1. Specific Growth Rate for Several Fungal Species (Sterne and McCarver, 1978; Bathe et al., 2013)

2.3. Types of Pre-treatments

One way to enhance drying efficiency product quality and prevent browning reactions in dried fruits is by applying pre-treatments. Pre-treatments are methods conducted before the drying process takes place. According to Swanson (2009), there are six reasons for carrying out pre-treatments prior to initiating the fruit drying process. Pre-treatments can preserve colour and flavour, minimize nutrient loss, halt enzymatic decomposition, ensure lower moisture content in the dried fruit, extend shelf life, and reduce bacterial counts during drying. According to Deng et al. (2019), each pre-treatment method has its own advantages and disadvantages. The specific pre-treatment details applicable to fruit drying are outlined in Table 2.

Table 2. Effects of Pre-treatments on Dried Fruit Shelf-life from Previous Research

References	Types of Pre-treatments	Observable Effects
Chauhan et al., 2020	Immersion in potassium bisulfite solution (1%)	No microorganism detected for 45 days
Türkyılmaz et al., 2013	Immersion in sodium metabisulfite solution (200 ppm)	The dried fruit is still edible after storing for 2.6 months at 20°C.
Arendse dan Jideani, 2022	Immersion in citric acid solution (2%)	After storing for 120 days, the fungal count is still under 10 CFU/g.
Roy et al., 2021	Immersion in sucrose solution (10%)	Decreasing fungal count from 350,000 CFU/g to 9,000 CFU/g.
Roy et al., 2021	Immersion in NaCl solution (2%)	Decreasing fungal count from 350,000 CFU/g to 0 CFU/g

2.4. Texture

Texture is a complex parameter used to describe several physical attributes of a food (Kohyama, 2020). Due to its intricate nature, the texture parameter will be divided into several sub-parameters, and when all these sub-parameters are combined, they will collectively depict the overall texture parameter.

2.4.1 Hardness (N)

Hardness is defined as the maximum force a food product can withstand during the initial compression event or first bite in the mouth. Hardness can be understood simply as how tough a food product is when chewed. Excessively high hardness values can result in food being tough and difficult to chew and break down. The hardness parameter can be identified on a force-versus-time curve as the highest peak of the first compression cycle.

2.4.2 Cohesiveness

Cohesiveness is defined as the extent to which a food product can maintain its initial structure before eventually breaking apart and crumbling when chewed. Cohesiveness can be calculated by comparing the area under the second compression curve with the area under the first compression curve. Cohesiveness can be expressed using the formula:

$$\text{Cohesiveness} = A2/A1 \quad (1)$$

Where A2 is the area under the second compression curve, and A1 is the area under the first compression curve. A1 and A2 can be observed in Figure 2.

2.4.3 Springiness

Springiness can be defined as the height of a food product during the time between the first and second compression. Springiness can be expressed with the following formula:

$$\text{Springiness} = L2/L1 \quad (2)$$

Where L2 is the time taken by the sample to reach the highest F value in the second compression, and L1 is the time taken by the sample to reach the highest F value in the first compression. L2 and L1 can be seen in Figure 2.

2.4.4 Adhesiveness

Adhesiveness is the force required to pull a food sample that is adhered between the food surface and a specific table or platform surface. The adhesive area can be observed in Figure 2.

2.4.5 Gumminess

Gumminess can be defined as the energy required to chew semi-solid food into a ready-to-swallow state. The gumminess value can be determined using the formula:

$$\text{Gumminess} = \text{Hardness} \times \text{Cohesiveness} \quad (3)$$

2.4.6 Chewiness

Chewiness can be defined as the energy required to chew solid food into a ready-to-swallow state. The chewiness value can be determined using the formula:

Chewiness = Gumminess x Springiness (4)

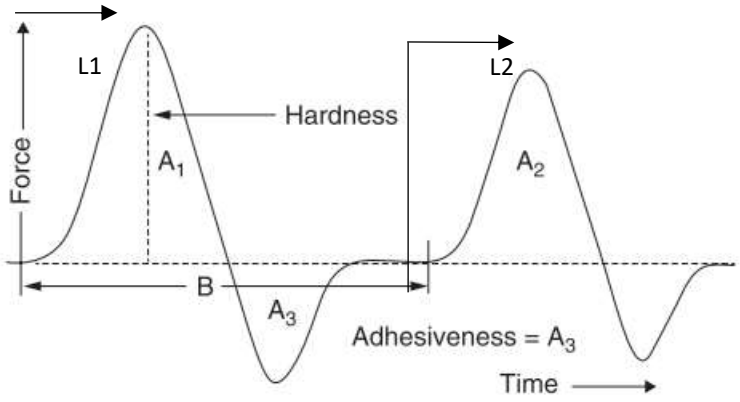


Figure 2. Texture Profile Analyzer Result Graph (Szczesniak, 2002)

2.5. Colour

Colour is a psychophysical quantity, acting as an impression during the stimulation of our visual system. The perception and comparison of colour itself are dependent on many external factors and individual human characteristics, thus making each person see colour differently. Due to the presence of three types of receptors in the human eye, the most common model is three-dimensional, and it creates a colour solid with independent parameters. The idea was to create a linear color space in which the distance between the points defining individual colors would be proportional to the perceptual difference between them (perceptual color spaces) and to present colors with the coordinates describing one of their key attributes, for example, lightness, chroma, and hue (Mokrzycki & Tatol, 2011).

2.5.1 Hue

Hue is the primary property of a parameter that we perceive as colour. Hue can also be understood as the visual stimulus received by the eyes in the form of colours like orange, red, blue, green, and so on. In Figure 3, a scheme divides hue into four dominant colours: red, green, yellow, and blue. A positive value of "a" indicates a purer red colour, a negative "a" value indicates a greener colour, a positive "b" value indicates a bluer colour and a negative "b" value indicates a more yellow colour. The hue value can be determined using the equation:

$$h* = tan^{-1}(\frac{b*}{a*}) \quad (5)$$

2.5.2 Saturation

Saturation can be defined as the hue mixed with white. The amount of white mixed with the hue is referred to as the variable "L." A higher value of "L" will result in a brighter colour, and conversely, a lower "L" value will lead to a darker colour approaching black. "L" can be observed on the vertical axis of Figure 3.

2.5.3 Chromaticity

Chromaticity can be understood as the purity of colour. The chromaticity value can be determined using the formula:

$$C* = \sqrt{a^{*2} + b^{*2}} \quad (6)$$

2.5.4 Total Colour Difference

The total colour difference can be expressed as ΔE*. ΔE* can be used to assess whether one colour can be distinguished from another to the eye. The ΔE* value can be determined using the formula:

$$\Delta E* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (7)$$

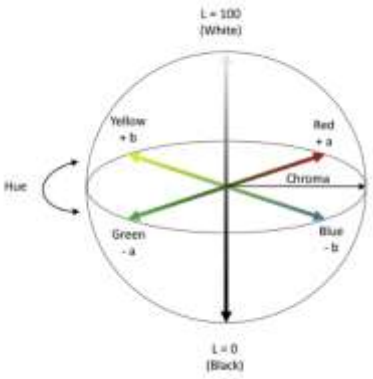


Figure 3. LAB CIE Colour Space Diagram (Ly et al., 2020)

3. Methodology

3.1. Sample Preparation

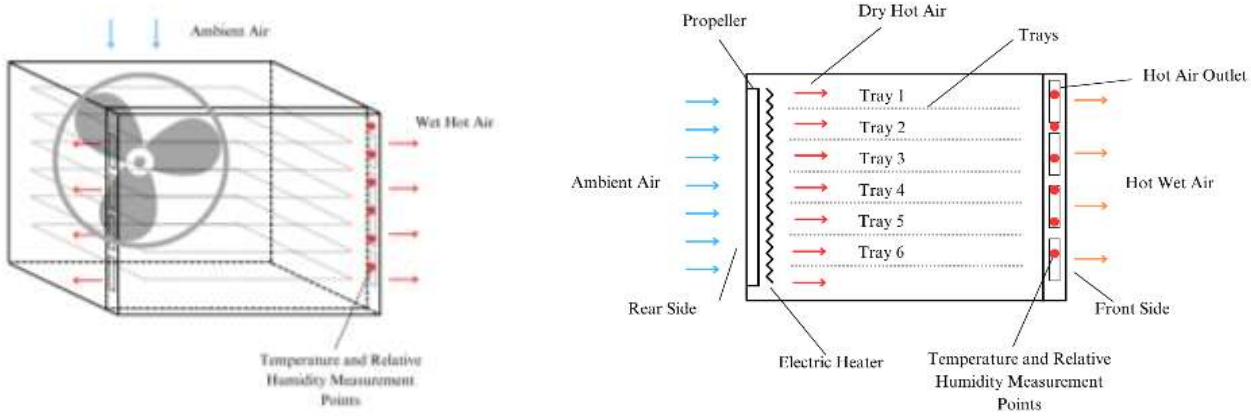
Ripe fresh "sunpride" pineapples were purchased at the supermarket. The pineapples were then washed and sliced with a knife into 5 mm thick slices. The purchase of fresh fruit was always done a day before starting the experiment to ensure uniform fruit ripeness.

3.2. Pre-Treatments

There are 6 types of pre-treatment variations performed, including the control variation, sucrose variation, sucrose-citric acid variation, citric acid variation, blanching variation, and calcium hydroxide variation. The control variation involves no pre-treatment (K), where the sliced pineapple is directly placed on the tray for drying. The sucrose variation involves soaking the pineapple in a 20% sucrose solution (G). The sucrose-citric acid variation involves soaking the pineapple in a solution of 20% sucrose and 0.75% citric acid (GS). The citric acid variation involves soaking the pineapple in a 0.75% citric acid solution (S). The blanching variation involves soaking the pineapple in water at 60°C for 2 minutes (B). The betel lime variation involves soaking the pineapple in a calcium hydroxide solution with a concentration of 1.5% (KS). Each pre-treatment sample is also frozen at -15 °C for 24 hours to observe the effect of freezing prior to drying on texture and colour.

3.3. Fruit Drying

Papalolo SS-06H Food dehydrator is used for the drying process of pineapples, with the schematic diagram as shown in Figure 4.



(A) (B

Figure 4. (A) 3D Isometric Diagram and (B) Side View of Food Dehydrator

The sliced fruit samples, which have undergone pre-treatment according to their respective variations, are placed on the food dehydrator tray for drying. The drying process is stopped when the samples reach a maximum moisture content of 20% or after a drying duration of approximately 23 hours, as recommended for dried fruits by FAO (2007). After the drying process is stopped, shelf life testing and characterization of the quality of the dried fruit can be conducted.

3.4. Moisture Content Determination

Using the SNI 01-2891-1992 method, dried fruit moisture content is determined by the Gravimetric Method.

3.5. Colour Characterization

The colour of dried fruit will be measured quantitatively using a CHNSpec CS-10 Colourimeter.

3.6. Texture Characterization

The firmness of dried fruit is measured using Stable Micro System Ta. XTplus Texture Profile Analyzer equipped with a guillotine blade set and heavy platform duty base.

3.7. Shelf-Life Testing

Dried pineapple is stored in polypropylene bags for 45 days in room condition after drying process. The number of molds on the surface of the pineapple is determined using the total plate count method. 0.5 grams of pineapple from every type of pre-treatment is taken and shaken with sterile distilled water to extract mold spores that adhere to the surface of the dried pineapple every 5 days. The extract solution is then diluted 100 times. The diluted solution is aliquoted to 0.5 mL and incubated on petri dishes containing potato dextrose agar (PDA) media for 5 days. On the 5th day after the incubation process, the number of molds on day 0 can be counted and recorded in colony-forming units per gram (CFU/g) using equation 8. The measurement of mold counts is repeatedly performed for 45 days. Assuming microbial growth follows first-order kinetic, the specific growth rate of molds (μ) can be determined by performing linear regression on the recorded mold count data over a period of 45 days. This value of μ can then be used in equation 9 to calculate the shelf life of dried pineapple, with Nt set at 10,000 CFU/g. Once the count exceeds 10,000 CFU/g, dried pineapple is considered unsafe for consumption.

$$Nt = Nc \cdot \frac{Vd}{Vi} \cdot \frac{Ve_1}{Ve_2} \cdot \frac{1}{m_s} \quad (8)$$

$$Ln(Nt) = Ln(N0) + \mu t \quad (9)$$

4. Results and Findings

4.1. Pineapple Drying Rate and Final Moisture Content Between Food Dehydrator Trays

Before conducting the drying process, the influence of tray position on the drying rate and final moisture content should be examined. Drying is performed at a temperature of 50 degrees Celsius for 23 hours, with all trays fully loaded with fresh and untreated pineapples. Two pineapple samples from each tray are weighed, and their masses are recorded to plot a graph of the mass ratio against drying time, as indicated in Figure 5.

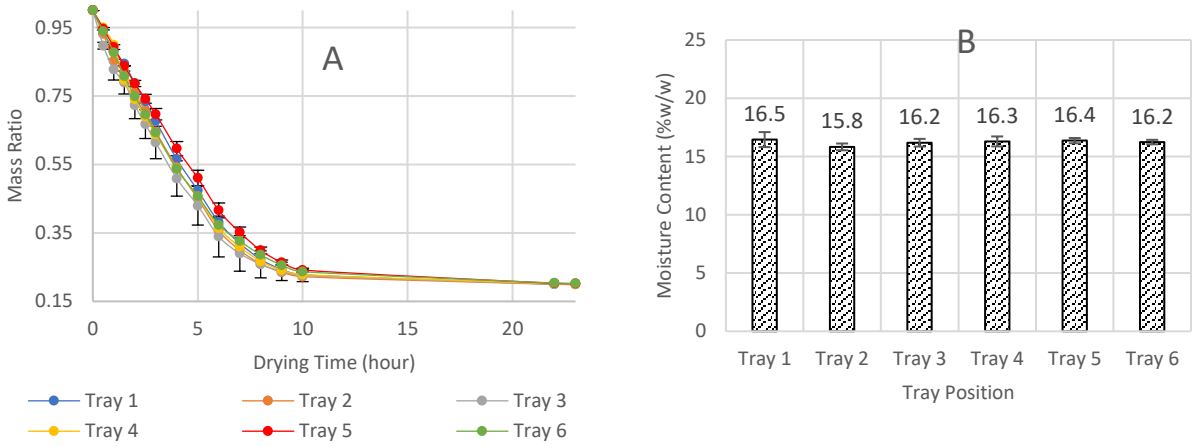


Figure 5. (A) Pineapple Drying Rate and (B) Untreated Dried Pineapple Moisture Content

According to Figure 5, it can be observed that Tray 3 has the fastest decrease in mass ratio value compared to the other trays. However, the tray position does not result in changes in the drying rate and final moisture content of the dried pineapple. From the first hour to the last hour of drying, there is no significant difference in the drying rate, indicated by the T-test yielding a p-value > 0.05 at each data point of the mass ratio. Therefore, the testing of shelf life, colour characteristics, texture, and organoleptic properties is only affected by the differences in pre-treatment and not affected by the tray position of the food dehydrator.

4.2. Identified Microorganisms on The Surface of Dried Pineapples

The species of mold growing on dried pineapples need to be identified. It is suspected that there are two types of mold and mold that grow on dried pineapples, namely *Aspergillus pseudoviridinutans* and *Cladosporium sphaerospermum*. According to Salvatore et al. (2021), *Cladosporium sphaerospermum* is the most commonly found fungal genus in indoor air, while *Aspergillus pseudoviridinutans* is a fungus commonly found everywhere, including in the air, water, and soil (Bilman and Yetik, 2017). According to Marigoudar and Kuppan (2022), exposure to *Cladosporium sphaerospermum* in humans can cause respiratory disorders such as coughing, sneezing, and asthma. In contrast to *Cladosporium sphaerospermum*, exposure to *Aspergillus pseudoviridinutans* in humans can cause liver damage and inflammation (Saeed et al., 2019). The comparison of fungal types obtained from the research and the literature is shown in Figure 6.

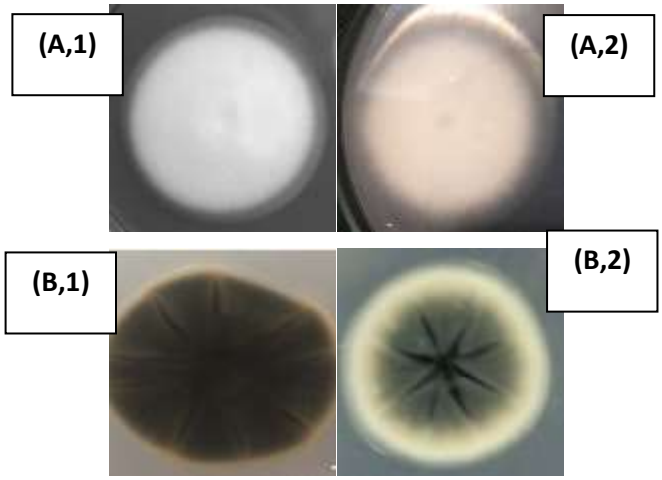


Figure 6. (A,1) *Aspergillus pseudoviridinutans* from Sugui et al., (2014), (B,1) *Cladosporium sphaerospermum* from Yew et al., (2016), (A,2) and (B,2) Research Documentation

4.3. Effects of Different Pre-treatment on Dried Pineapples Shelf Life

Six variations of pre-treatment conducted at room temperature (27.3°C) result in different shelf life, as shown in Figure 7. Variations G and GS have shorter shelf life compared to the control variation due to higher sugar content than other variations. In fact, high sugar content can help preserve fruit products (Niranjan et al., 2018). Sugar can absorb water contained in microorganisms through the cell membrane into the environment through osmosis. This water loss phenomenon experienced by microorganisms can inhibit and even kill microorganisms growing on the surface of dried pineapples (Cichowska et al., 2020). However, when testing the amount of mold on dried pineapples, there is a stage of extracting fungal spores using aqua dm to be subsequently dropped into

a petri dish. The extraction process dissolves most spores and dilutes the sugar attached to the dried pineapple. Therefore, when the spore extract solution is dropped onto a petri dish for incubation, the extracted molds have more nutrients to grow compared to other variations (Mäkelä et al., 2018).

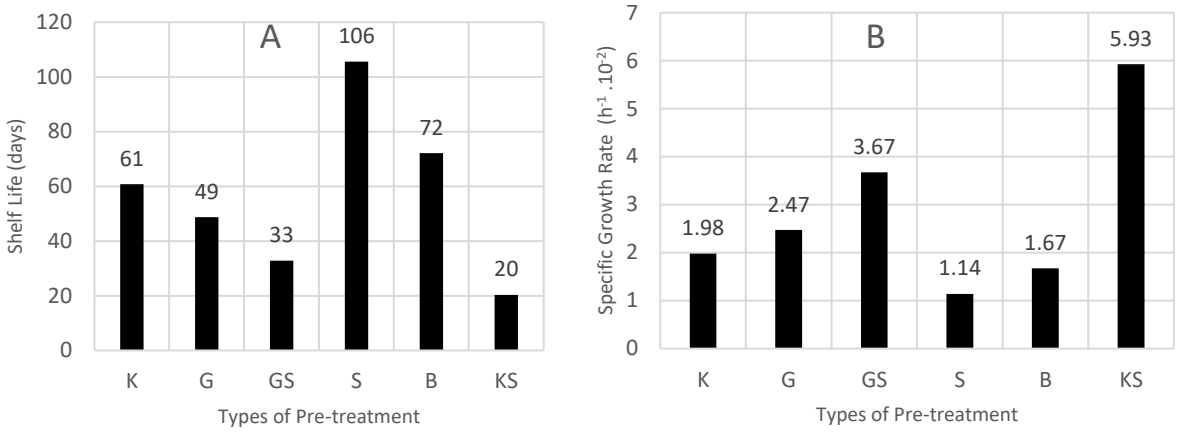


Figure 7. (A) Shelf Life of Dried Fruit and (B) Mold Specific Growth Rate at Room Temperature

Variation KS also has a shorter shelf life than variation K. According to Kim and Kim (2014), betel lime or calcium hydroxide has antimicrobial properties. Calcium hydroxide can kill microorganisms by releasing hydroxyl ions when mixed with water. Hydroxyl ions affect the cytoplasmic membrane, proteins, and DNA of microorganisms by altering enzyme activity on the cell membrane, thereby inactivating the microorganisms (Estrela and Holland, 2003). Calcium hydroxide can also kill various types of microorganisms, ranging from endodontic pathogens to molds. It has been proven that calcium hydroxide is less effective in eradicating *Enterococcus faecalis* and *Candida albicans*, which fall into the category of fungal microorganisms (Kim and Kim, 2014). In addition, this phenomenon is suspected to be caused by the use of less hygienic betel lime sources. Several prevention measures have been taken, such as separating impurity particles found in betel lime, using nitrile gloves during experiments, and boiling then cooling the water used as a diluent for betel lime dilution and rinsing water. Nevertheless, considering the purity of the *betel lime* used is unknown, and the KS variation requires additional treatment to rinse off the remaining betel lime powder residue, sample handling becomes longer and the potential for contamination increases.

Variation S have a longer shelf life compared to the control variation. Variation S can suppress the μ value because the added citric acid has antimicrobial properties (Burel et al., 2021). Citric acid can damage the cell membrane and reduce the viability of microorganisms by interacting with metal compounds such as zinc and potassium that help stabilize the cell membrane. In addition, the measured pH of the citric acid solution used for pre-treatment is 2.44. According to Chengdong, W. (2013) and Zhan, X. (2009), *Cladosporium* and *Aspergillus pseudoviridinutans* have an optimal conditions for growth at pH 5 to 6.

Variation B yields a longer shelf life than the control variation. According to Bishop et al. (2016), water temperature starting from 41.5°C can kill microorganisms depending on the contact time used. Temperature is one of the inhibitory factors for microbial growth because, at a certain temperature, the proteins present in microorganisms can denature and cause damage to the cell membrane (Samtani et al., 2022). From the experimental results, it is evident that a duration of 2 minutes is sufficient to kill some microorganisms, resulting in a longer shelf life compared to variation K.

4.4. Effects of Different Pre-treatment on Dried Pineapples Colour

Using ANOVA with Tukey post hoc test in the Minitab application, the L parameter of fresh pineapples and all variations did not show significant differences, as shown in Table 3. However, there were significant changes in the values of a* and b* for some variations compared to fresh pineapples. Looking at the a* value, variation K showed a significant difference in colour in the red-green range. Dried pineapples in variation K had a redder colour compared to fresh pineapples and other variations. This phenomenon is indicated by the highest value of a* belonging to variation K. Considering the b* value, several variations, such as K, G, and GS, showed a more yellowish colour compared to other variations. This phenomenon is indicated by higher b* values compared to other variations.

Table 3. Lightness, a*, b*, and ΔE values of pretreated dried pineapples

Types of Pre-treatment	L	a*	b*	ΔE
R	66.3±2.72	-3.69±0.67	31.7±2,86	0.0
K	65.5±3.82	-1.53±1.39	45.5±5,14	14.4
G	63.5±4.27	-3.13±0.92	45.2±3,53	14.6
GS	67.3±5.92	-3.23±1.25	42.2±4,43	11.9
S	61.3±7.76	-4.14±1.02	34.0±7,68	12.1
B	62.9±8.25	-4.10±1.85	36,5±8,64	12.4
KS	65.2±9.19	-3.43±1.30	34.0±7,60	10.5

Using the total colour difference (ΔE), the higher the ΔE value, the more noticeable the total colour difference between fresh and dried pineapples becomes. All pre-treatments and drying processes result in dried pineapple with a slightly different colour. Variations K and G have the highest ΔE values. This phenomenon is believed to be caused by the Maillard reaction that occurs on the surface of pineapples during the drying process, involving amino acids and reducing sugars present in the fruit (Tamanna and Mahmood, 2015). In fresh pineapples, reducing sugars have a concentration of about 30-40% (Manasa et al., 2022), while amino acids such as aspartic acid, glutamic acid, and lysine have concentrations of approximately 570, 450, and 250 ppm, respectively (Kermasha et al., 1987). Additionally, temperature and time are factors that contribute to the occurrence of the Maillard reaction during heating or drying processes (Al-Baarri et al., 2018). Variation G is also believed to undergo the Maillard reaction. The difference is that dried pineapples in variation G have a higher sucrose content than variation K due to the pre-treatment performed before drying. However, the slightly higher sucrose content in variation G only slightly increases the ΔE value. This phenomenon is likely because household sugar or sucrose added during the pre-treatment process does not fall under the category of reducing sugars (Benedict, 1907). Although sucrose can be hydrolyzed into glucose and fructose, which act as reducing sugars, the hydrolysis process requires an acidic environment to occur (Okumura et al., 2011). Pineapples do contain citric acid to create an acidic environment (Lu et al., 2014), but further investigation is needed regarding the role of citric acid in pineapple fruit in sucrose hydrolysis.

Variations GS, S, and B have lower ΔE values compared to variations K and G. The phenomenon of colour change in relation to fresh pineapples is believed to be due to the addition of citric acid in variations GS and S. According to Jiang et al. (1999) and Kumara et al. (2021), citric acid can interact with copper ions, which are crucial for the enzymatic activity of polyphenol oxidase (PPO), thus inhibiting enzymatic discolouration reactions. Variation B can inhibit enzymatic discolouration due to the blanching pre-treatment. According to Liu et al. (2010), PPO enzymes can be inactivated at temperatures starting from 55°C. High temperatures can alter the enzyme structure, as enzymes are proteins, and their activity heavily depends on the three-dimensional protein structure. High temperatures can disrupt and denature this structure, leading to changes in the active site of the enzyme, preventing it from binding to substrates and diminishing its ability to react (Struvay and Feller, 2012; Kavanau, 1950).

Variation KS has the lowest ΔE value, indicating that it has a colour most similar to fresh pineapples. So far, no research has proven that betel lime or $Ca(OH)_2$ can prevent the Maillard reaction, enzymatic discolouration, or lighten the colour of dried fruit products. However, this phenomenon is believed to occur not because discolouration does not happen but because there is still white calcium hydroxide residue on fresh pineapples, making the colour of variation K dried pineapples paler and resembling fresh pineapples.

4.5. Effects of Different Pre-treatment on Dried Pineapples Texture

Using ANOVA with Tukey Post Hoc Test, all variations showed a significant increase in the F value compared to fresh pineapples, as shown in Figure 8. All dried pineapple variations had a tougher texture that was harder to cut or bite into due to the evaporation of water from the fruit matrix. The fruit matrix, when undergoing water evaporation, shrinks and becomes denser than before (Norinbaev et al., 2021). Variations G and GS, which have higher sucrose content than other variations, exhibit a harder texture, presumably due to the rubbery phase provided by sucrose (Kawai, 2018). To achieve the rubbery phase, sucrose must reach its glass transition temperature, which results in a sticky and difficult-to-cut texture when cooled. According to Roos & Karel (1991), pure sucrose has a glass transition temperature of around 57°C, and the presence of water is expected to lower this temperature (Shalaev and Steponkus, 2001). This theory is also supported by Drake et al. (2018), who found that the glass transition temperature of trehalose sugar decreases when mixed with water. During the pre-treatment process, sucrose used in variations G and GS needs to be dissolved by heating the aqua dm until it dissolves. This dissolution process and drying at 50°C are believed to reach the glass transition temperature of the diluted sucrose, resulting in a harder texture of dried pineapple.

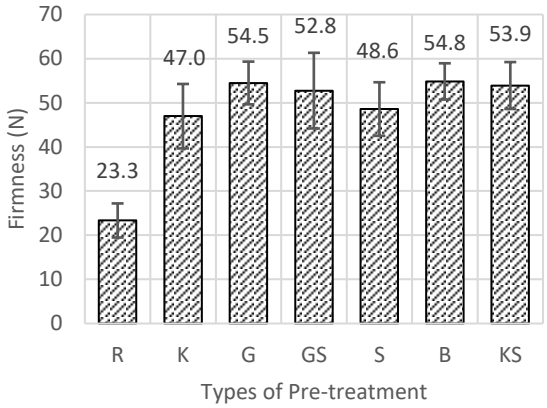


Figure 8. Firmness of Pre-treated Dried Pineapples

Variation GS and S can produce a harder texture, presumably due to the addition of citric acid during the pre-treatment process. According to Yang et al. (2019), citric acid can help maintain the firmness of fruit texture. However, the exact mechanism of how citric acid maintains firmness is not well understood. The strongest assumption, according to Yang et al. (2019), is that citric acid can inhibit the degradation of organic acids contained in the fruit because, according to Ercan, N. (2002), degraded organic acids can cause cell wall and membrane damage. Additionally, leaching organic acids can lead to pectin breakdown, resulting in a softer fruit texture (Sweetman et al., 2014).

Variation B results in a harder texture of dried pineapple compared to fresh pineapple and control pineapple. No research has yet proven that blanching pre-treatment can significantly affect the texture of dried pineapple. According to Shamsudin et al. (2021), blanching fresh fruit at temperatures of 60-100°C does not cause significant texture changes; however, according to Eboibi et al. (2018), who studied cucumbers, lower water content results in a harder texture.

Considering the final water content of dried pineapple, variation B has the lowest water content (11.2% wb) compared to other variations, As shown in Figure 9. Variation KS can produce the highest F value for texture because betel lime or $Ca(OH)_2$ can react with pectin present in the pineapple fruit. Low methoxyl pectin can react with calcium ions to form a strong gel structure, thereby strengthening the pineapple fruit matrix tissue (Trisnawati et al., 2019).

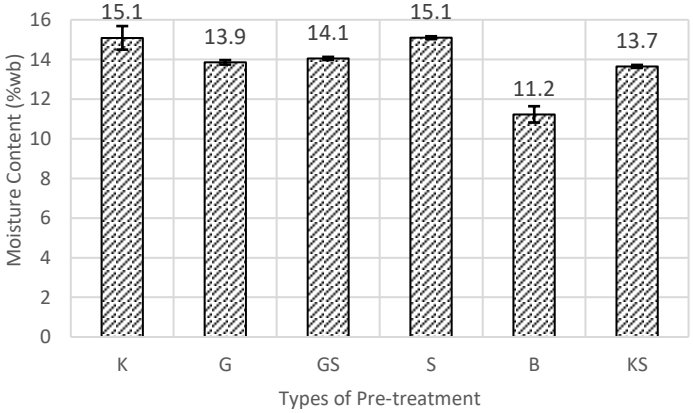


Figure 9. Moisture Content of Pre-treated Dried Pineapples Used for Texture Measurement

4.6. Effects of Freezing Process on Dried Pineapples Moisture Content

Figure 10 shows that freezing before drying tends to result in a lower water content of pineapple compared to without freezing. This is supported by studies conducted by Ando et al. (2019) on the drying process of apples, Junqueria et al. (2017) on the drying of cape gooseberries, and Zhang et al. (2022) on the drying of lotus roots using freezing before drying. All three studies found that the drying rate was faster when freezing pre-treatment was applied. This is because the ice crystals formed during the freezing process disrupt cell integrity and create microchannels or micro-sized holes that enhance water mass transfer and improve drying efficiency (Zhang et al., 2022). The cell size changes can reach 60-200% of their original size. Additionally, freezing can cause damage to cell integrity, resulting in a decrease in immobile water content and an increase in free water content (Zhang et al., 2022).

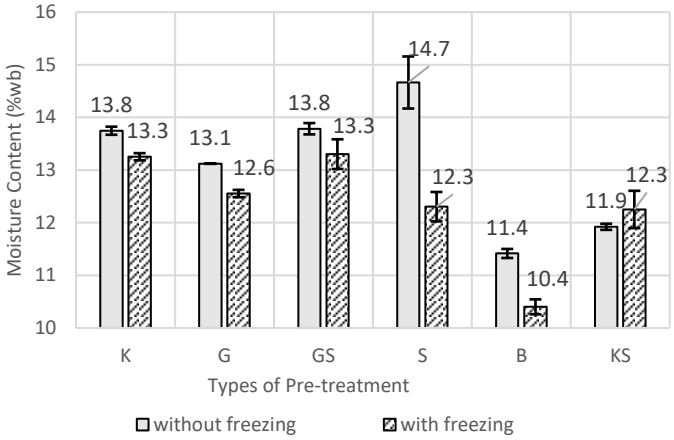


Figure 10. Moisture Content of Pre-treated Dried Pineapples with Freezing Variations

4.7. Effects of Freezing Process on Dried Pineapples Colour

The influence on colour can be determined using the total colour difference (ΔE), and a graph depicting the total difference in colour between fresh and dried pineapples can be generated, as shown in Figure 11. Frozen pineapples have a larger ΔE value compared to unfrozen pineapples. This may be due to the formation of ice crystals speculated to increase the rate of enzymatic browning reactions on enzymes and polyphenols (Zhang et al., 2022), resulting in more significant colour changes compared to pineapples dried without freezing. The absence of chemical and physical treatments in dried fruits may preserve the pigments in the fruit, and non-enzymatic browning reactions may become more apparent after cell damage occurs (Junqueira et al., 2017).

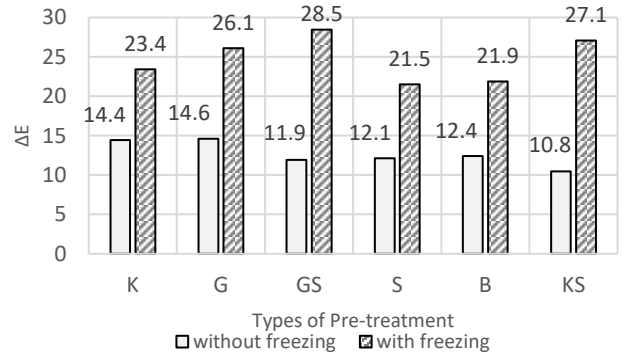


Figure 11. Total Colour Difference of Pre-treated Dried Pineapples with Freezing Variation

4.8. Effects of Freezing Process on Dried Pineapples Texture

The effect of freezing on the texture of raw pineapples was examined and compared to raw pineapples without freezing, followed by a T-test analysis. The results showed no significant difference ($P>0.05$) between the two raw pineapples, indicating that the firmness of pineapples for each pre-treatment can be seen in Figure 12. The firmness of dried, frozen pineapples is lower compared to dried, unfrozen pineapples. When a product is cooled for an extended period or at low temperatures, the formation of ice crystals can create air pockets and disrupt the texture of the frozen product. As a result, when the product is thawed, it becomes soft and loses its initial hardness (Vu et al., 2023). The formation of ice crystals also damages the cellular structure and tissue in the fruit after drying, leading to lower firmness values (Junqueira et al., 2017). However, pineapples treated with KS does not show a drastic decrease in firmness. This is because betel lime or calcium hydroxide can react with pectin to form a strong gel structure, thereby enhancing the integrity of the pineapple fruit matrix (Trisnawati et al., 2019).

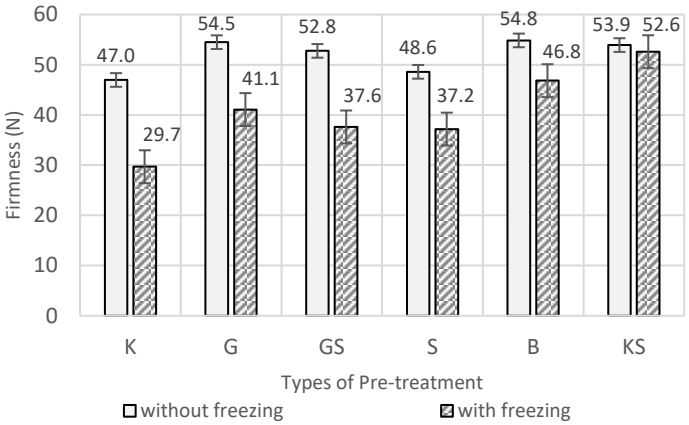


Figure 12. Firmness of Pre-treated Dried Pineapples with Freezing Variation

4.9. Effects of Pre-treatment on Dried Pineapple Acceptance

Organoleptic testing indicates that the product preferred by the public is pineapple soaked in sucrose, followed by the control pineapple, sucrose-citric acid mixture, blanching, citric acid, and betel lime, as shown in Figure 13. This indicates that the panelists in certain age groups prefer pineapple with a high level of sweetness. Further organoleptic testing is needed to assess the acceptance of this dried pineapple product, as the panelists belonged to only one age group out of 18 age groups, specifically the 20-24 age group (WHO, 2001). Some comments that can be noted from the panelists are that pineapple with the G variation only shows an increasing level in sweetness. The GS variation provides a taste like control variation, but the sweetness and acidity increase, making it more intense. The S variation gives a dry and overly acidic taste, but some panelists like it. The B variation provides a bland taste, not too acidic and not too sweet. The KS variation is the least liked variation. This phenomenon is caused by its hard texture and bitter taste due to the presence of betel lime.

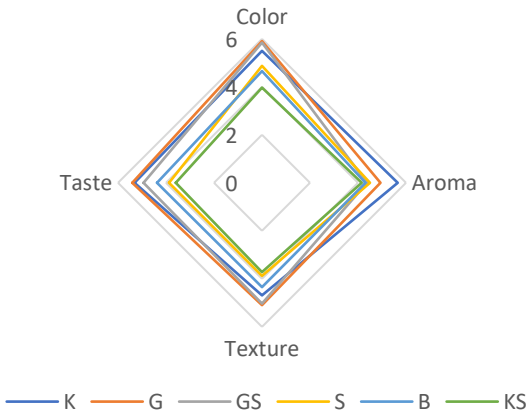


Figure 13. Hedonic Test on 32 Untrained Panelists

5. Conclusion

This research concludes that the best shelf life of dried pineapples was achieved for 106 days under room conditions with a pre-treatment of 0.75% citric acid solution. The shelf life of dried pineapples with pre-treatment variations K, G, GS, B, and K, respectively, were 61, 49, 33, 72, and 20 days. Drying and all types of pre-treatments resulted in a darker colour of dried pineapples compared to fresh pineapples. The delta E values of dried pineapples with pre-treatment variation K, G, GS, S, B, and K, compared to fresh pineapples, were 14.4, 14.6, 11.9, 12.1, 12.4, and 10.4, respectively. Drying and all types of pre-treatments also resulted in a higher firmness value of dried pineapples compared to fresh pineapples. Fresh pineapples had a firmness value of 23.3, while dried pineapples with pre-treatment variation K, G, GS, S, B, and K had firmness values of 47.0, 54.5, 52.8, 48.6, 54.8, and 53.9 N, respectively.

Freezing before drying resulted in a darker colour of dried pineapples compared to dried pineapples without freezing. The increase in delta E value for dried pineapples with pre-treatment variation K, G, GS, S, B, and KS was 62, 79, 139, 77, 76, and 159%, respectively. Freezing before drying also resulted in a softer texture of dried pineapples. The freezing process yielded a softer texture of dried pineapples. The decrease in firmness value for dried pineapples with pre-treatment variation K, G, GS, S, B, and KS, respectively, was 37, 25, 29, 23, 15, and 2%. According to a group of 32 untrained panelists in the age group of 20-24 years old, the G variation was the most preferred variation of dried pineapple. Since shelf life testing takes a lot of time, yet this research needs to be done within a limited time, it is recommended to use another shelf life testing method or polish existing methods to get more accurate data with a shorter duration. Replicating shelf-life testing research more frequently is also recommended.

Declaration of Competing Interest: The authors of this paper state that they have no financial interests or personal relationships that could influence the findings or conclusions reported in this paper.

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List of Symbols

R: Fresh pineapples used for drying without using freezing treatment

K: Control variation

G: Sucrose 20% variation

GS: Sucrose 20% - citric acid 0.75% variation

S: Citric acid 0.75% variation

B: Blanching variation

KS: Betel lime or calcium hydroxide variation

F: Firmness of Fruit (N)

Nt: Number of fungal colonies per gram of dried pineapple (CFU/g)

Nc: Number of fungal colonies on the petri dish (CFU)

Vd: Total volume of dilution solution (mL)

Ve1: Total volume of extract solution (mL)

Ve2: Volume of extract solution used in dilution (mL)

Vi: Volume of dilution solution used in the incubation process (mL)

Ms: Mass of dried pineapple sample (g)

μ: Specific Growth Rate ($days^{-1}$)

t: Time (days)

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