Secondary Packaging Performance Assessment Based on Mechanical Damage Resistance Using Drop Testing and Forensic Packaging Methods at CV. Mubarokfood Cipta Delicia

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Abstract
Distribution is a process that could decrease the quality of food products biologically, chemically, and physically. Therefore, food packaging plays a crucial role in extending the shelf life and maintaining the quality and safety of food products. This research aims to gather evidence on packaging damage data that can be used to evaluate the effectiveness of product packaging, considering its durability and ability to protect products, and to understand the impact of packaging damage on product quality. Data collection was carried out by observing the packaging chosen as a research sample, specifically 9 Mubarok's Jenang secondary slop packaging. Each package contains 4 Jenang inside, so there were 36 Mubarok's Jenang in total. The author also conducted interviews to obtain relevant information about the topics in this section, including packaging, quality control, and the purchasing division. Drop testing and forensic packaging methods were performed manually by dropping the item from a fixed height onto a solid, hard, and flat surface, as specified in ISO 2248:1985. Based on the research result after testing from three variations of drop height (50 cm, 100 cm, 150 cm) with each height containing three sample packages, all of the packaging is in a "good" category, which is proven by the value of bruise susceptibility parameter is very low, packaging damage is in the light category, and the product's primary packaging is still tightly sealed so that it can maintain the quality and shelf life of Jenang during the retention period. Then, consecutively, the average values and their deviations for the bruise susceptibility of the packaging at heights of 50 cm, 100 cm, and 150 cm are 0.0549 cm³/Joule, 0.0735 ± 0.0164 cm³/Joule, and 0.0699 ± 0.0214 cm³/Joule.
Keywords: *bruise susceptibility, drop testing, flip carton, forensic packaging, Jenang*

1. INTRODUCTION

CV Mubarokfood Cipta Delicia is a company that produces *Jenang* Kudus, located at Glantengan Village, Kota District, Kudus Regency. *Jenang* is one of the traditional Indonesian dishes, especially in Javanese cuisine. Jenang Mubarok, produced by CV Mubarok Cipta Delicia, is a brown, chewy, and sweet treat made from brown sugar, coconut milk, and sticky rice flour. CV Mubarokfood Cipta Delicia company offers various types of packaging, categorized into several levels, including primary packaging, secondary packaging, tertiary packaging, and quaternary packaging. Primary packaging is a package that directly covers or wraps food ingredients. Secondary packaging is a package whose main function is to protect other packaging groups (containing several primary packaging groups). Furthermore, tertiary and quaternary packaging are additional types of packaging beyond primary and secondary packaging. This packaging is typically used during distribution to storage locations or final destinations, such as consumers (Aditri et al*.,* 2021).

Within this research, we will produce several outputs that are useful for the company. The first step is to establish a standard for the packaging material used by the company, which encompasses several attributes and parameters derived from testing results, particularly for the type of cardboard packaging that contains the *Jenang* product (ASTM D5639M-20, 2025). This output

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also correlates with the main objective of implementing this project. Secondly, the test result can be used to respond to negative feedback from consumers regarding Jenang Mubarok products in terms of durability and packaging (Emblem, A., & Emblem, H, 2012). The third output is to know and evaluate endurance and packaging ability to protect the product (Lengas et al., 2023). Lastly, we test the impact of mechanical damage on the *Jenang* product, specifically looking for any bruising that may cause a decrease in quality.

In the world of industry and forensics, research related to drop testing and the development of forensic packaging is vital. Based on Emblem, A., & Emblem, H. (2012), drop testing and forensic packaging can ensure product integrity during distribution and their benefits in reducing product damage. By understanding the importance of drop testing and forensic packaging techniques, it is hoped that this research will make a significant contribution to the development of manufacturing packaging durability test methods, as well as to reducing mechanical damage and improving packaging for a variety of contents, ranging from industry to the forensic world.

2. MATERIAL AND METHODS

This research method uses quantitative research methods. This research was conducted from January 2 to February 1, 2024. This research was also conducted at CV Mubarokfood Cipta Delicia located in Kudus, Central Java, Indonesia. The study is conducted in two company units: production units within the packaging division, collaborating with the research and development (R&D) division, as well as the quality control unit (QC). The objects observed in this research are secondary slop packaging of Jenang Mubarok products, specifically in the form of folding cartons, at CV. Mubarokfood Cipta Delicia. This secondary packaging features a structure made from duplex paper that exhibits a characteristic color difference between its layers. The inside layer is a darker color (grey) than the outside layer (white), which is usually used as a printing area in one sheet of duplex paper.

Based on observations, the authors collected information about each level of packaging, as shown in Table 1. Furthermore, additional information about materials, characteristics, suppliers, and other relevant details was obtained from interviews with the head of the purchasing department and the head of the packaging department.

Table 1. Specification About Mubarok's Jenang Product & Packaging of Each Level

Product & Packaging		Specification		Characteristic
Jenang Product		Sample Variance	Smooth mocha flavored	1. Smooth, Chewy, and Elastic Texture. *Jenang* has a soft texture, is not too sticky, and is chewy when eaten. 2. Long Shelf Life. *Jenang* has a longer shelf life due to a well-controlled and long cooking process. 3. Tempting Brown Color. A blend of coffee and chocolate flavors gives *Jenang* its distinctive brown color and enticing aroma. 4. Traditionally Packaged. Packaged by BOPP plastic film and wrapped in the signature of Kudus *Jenang* packaging.
		Production Date	08-01-2024	
		Mass	20 gram	
		Size	5.5 x 2 x 2 cm	
		Materials	Glutinous rice flour, coconut milk, and sugar	

Product & Packaging		Specification		Characteristic
Primary Package (BOPP Film)		Mass	0.1 gram	1. Transparent & Glossy. It has a clear and shiny appearance, giving it a premium look. 2. Strong & Tear-Resistant. Highly durable against tearing and pressure 3. Water & Oil Resistant. Does not get easily damaged by moisture or liquids 4. Easy to Print On. Suitable for high-quality printing with sharp and long-lasting colors 5. Lightweight & Flexible. Easily shaped to fit various packaging needs 6. Eco-friendly. It can be recycled, although it requires a typical process 7. Widely Used. It is commonly used for food packaging, beverages, pharmaceutical products, and labeling on bottles.
		Size	8 x 8 cm	
		Capacity	1 film for each *Jenang*	
		Final Process	Wrapping	
		Material	biaxially oriented polypropylene (BOPP)	
Secondary Package Specification		Mass	7.192-7.49 gram	1. It consists of two different layers. One white (smoother) for high-quality printing, and the other grey (rougher) 2. Medium strength. Stronger than HVS paper but not as sturdy as cardboard or corrugated board 3. Eco-Friendly. Often made from recycled materials, making it more environmentally friendly. 4. Affordable. Cheaper than other packaging materials like plastic or cardboard
		Size	11.3 x 5.4 x 2.1 cm	
		Capacity	4 *Jenang* pieces	
		Product Placement	2x2 (Horizontal)	
		Product Proportion	91.291-91.8501%	
		Final Process	Folding	
		Material	Duplex Paper	
		Outside Layer Color	White (for printing layer)	
		Inside Layer Color	Grey	
Tertiary Package (Duplex Paper)		Size	27.5 x 11.6 x 4.5 cm	Similar to secondary packages
		Capacity	10 pieces of secondary	
		Packaging	40 pcs *Jenang*	
		Amount	5x5 (Vertical)	
		Product Placement	Folding	
		Final Process	Duplex Paper	
		Material	White (for printing layer)	
		Outside layer color	Grey	

Data collection was conducted using both primary and secondary data. This research some primary data is needed for this research, such as drop testing and forensic packaging experiment results on packaging and data on packaging damage after it occurs impact, packaging material characteristics (mechanical properties and material resistance packaging against pressure, friction, and impact strength), simulation conditions (parameters such as drop height and environmental conditions during the drop test and time retention), and forensic data (information resulting from forensic analysis of damaged packaging including traces and signs of damage). Furthermore, for secondary data, several data needed for this research, such as scientific journal that discusses characteristics of packaging and its impact on the product, packaging specifications (information from the manufacturer packaging regarding materials, design, and technical limitations), industry statistics (history shipping or distribution accident statistics that can provide insight about packaging vulnerabilities), and packaging guidelines (guidelines or standards industry related to testing and packaging safety criteria).

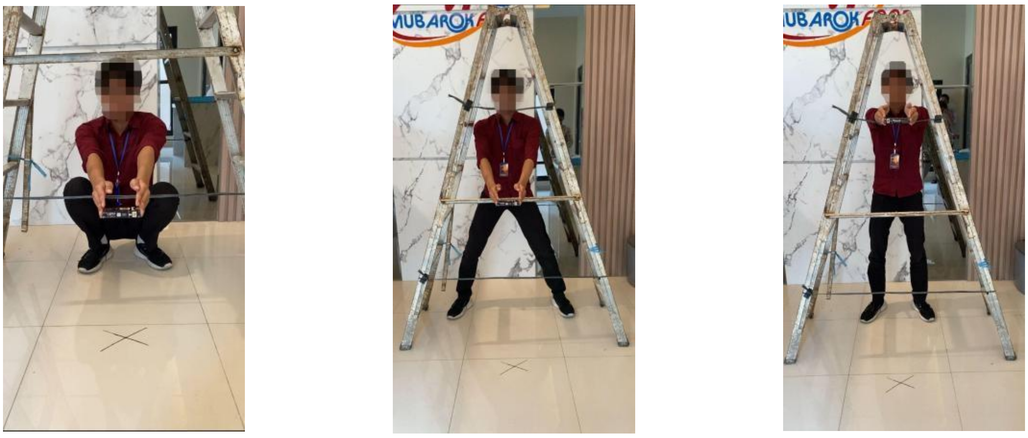
As mentioned earlier, the authors selected several respondents, including the head of QC & R&D, the head of purchasing, and the head of the packaging division, to gather information about product and packaging specifications. Based on information obtained from the head of QC & R&D, it can be concluded that several factors affecting defects in *Jenang* products are the activity of water and airflow. *Jenang* products contain an enzyme called lipoxygenase, which is typically found in products made from coconut milk. Water activity can explain why the lipoxygenase enzyme is active when in contact with water, allowing for the formation of brown color in semi-moist food (intermediate moisture food), such as *dodol* (Kusnandar, 2019). Airflow that contains oxygen (O_2) also activates enzymes during the production, storage, or handling process. These two factors can directly affect the product if the product's primary packaging (BOPP) isn't sealed correctly, resulting in gaps in the packaging that expose the product directly.

The authors also gathered information from the head department of purchasing and packaging about the specification of the packaging materials, characteristics, third-party suppliers, packaging resistance due to mechanical damage, existing standard parameters of packaging (if any), and the main point of how often buyers or consumers give feedback or complain about packaging resistance. Furthermore, the authors have arranged Table 1 to display the specifications of the product and packaging. Based on the ISTA 1A procedure, cartons and products weighing less than 10 kg are dropped from a minimum height of 76 cm (30 inches). The authors created three height variations within a 76 cm range to ensure the result was significant and multifunctional, representing the real condition. There was no certainty whether the conditions, product, and sample were dropped from a height of 76 cm. The first height fall of 50 cm represents material handling conditions when laborers are packaging products using a table, and 50 cm reflects the distance between the table surface and the floor. A second height fall of 100 cm represents material handling conditions when load-in and load-out processes are carried out on distribution vehicles, where many workers are found to be carrying out inappropriate material handling actions (dropping & throwing). A height of 150 cm represents whether a product displayed at a shopping outlet can withstand being dropped to test the durability of the packaging. Data processing in this research is carried out using drop testing and forensic packaging methods analysis from 3 different heights within three samples of each drop fall:

2.1 Drop Testing

Drop testing, also known as packaging drop test, is a test process used to measure the extent to which a package, product, or object can withstand damage when falling from a specified height. Drop testing is a type of testing designed to assess a package's ability to resist damage (Lengas et al., 2023). Thus, drop testing is an important tool in packaging development and testing to ensure product safety, quality, and durability.

The working principle of packaging drop testing, which is carried out manually without the use of a tool, involves testing the dropping of goods at a fixed point and specific angles and heights in accordance with existing regulations (Pratama et al., 2018). In this experiment, the packaging will be dropped in a horizontal position (0 ° angle), referring to its arrangement in the tertiary packaging, to observe how the drop position of the packaging changes. Figures 1a-c show that the packaging will be dropped at each height.



(a) (b) (c)

Figure 1. Packaging Drop Testing Illustration in Each Height Fall (a) 50 cm (b) 100 cm (c) 150 cm

Several regulations serve as references, including ASTM D5276-98, which outlines packaging testing standards that incorporate drop tests and forensic packaging methods. Based on ASTM D5276-98, each product container that is under 50 kg must comply with ISO 2206:1987 for the segmented areas on packaging samples, ISO 2248:1985, and ISTA 1A for the procedure of the testing, and ISO 2233:1996 for the retention control time, as the bruise may affect the quality degradation of the product. When carrying out drop testing, the packaging box is more likely to land on the rib or packaging point when dropped with the eccentricity of the center of gravity (Nica et al., 2023). The packaging box will absorb the force and only transfer it to a limited extent to these products. When the packaging has fallen to the ground, it will have obtained maximum kinetic energy after experiencing maximum potential energy at a certain height before being dropped. Such a condition is what is known as the law of conservation of energy in mechanics. The maximum kinetic energy will be absorbed by the material, causing the packaging to deform or break. The amount of energy that the material can absorb before experiencing deformation is a measure of the material's resistance. Material is considered tough if it can absorb large shock loads without easily experiencing deformation. This test is based on the potential energy absorption of the load dropped vertically to a certain height until the specimen experiences deformation. The amount of energy absorbed by the specimen until it fractures is a measure of the material's impact resistance (Rifqoh, 2016). The mechanical energy (impact energy) that hits each package is calculated. The impact energy that is absorbed by the packaging samples after experiencing a collision is calculated using the equations (1) and (2).

$$\text{Impact Energy (J)} = \text{Potential Energy} = m.g.h \quad (1)$$

or

$$\text{Impact Energy (J)} = \text{Kinetical Energy} = \tfrac{1}{2}.m.v^2 \quad (2)$$

By using three samples of secondary packaging to drop at each height, the standard deviation of impact energy absorbed at each height must be determined to allow us to know the error value of the measurements using the formula (3).

$$\text{Impact Energy Absorbed Standard Deviation (50 cm; 100 cm; 150 cm)} = \frac{\sqrt{\sum(xi-x)^2}}{n-2} \quad (3)$$

Where:

xi : value of impact energy absorbed at a certain height in the i-repetition

x : average value impact energy absorbed at a certain height

n : number or value of repetition

In addition, the damage level to the packaging parts on the sides, corners, and ribs is calculated to obtain the percentage of damage to the parts and determine critical points of the packaging with the equation (4), (5), and (6).

$$\text{Percentage of damage to the sides} = \frac{\text{Number of Damaged Sides}}{\text{Number of Packaging Sides}} \times 100\% \quad (4)$$

$$\text{Percentage of damage to the ribs} = \frac{\text{Number of Damaged Ribs}}{\text{Number of Packaging Ribs}} \times 100\% \quad (5)$$

$$\text{Percentage of damage to corners} = \frac{\text{Number of Corners Sides}}{\text{Number of Corners Sides}} \times 100\% \quad (6)$$

2.2 Retention Control Time

The ISO 2233:1996 standard regulates control behavior during packaging and product retention time. Factors include air humidity. At room temperature (27 °C or 300 K), the Rh value is maintained at 65%. Retention time, also known as residence time, aims to determine the impact of mechanical testing on the quality characteristics of *Jenang* products due to the bruising they cause. Additionally, check for any extensive bruising on the product and packaging. Retention time during drop testing also aims to ensure that the product or material being tested can survive under specific conditions for a specified period. It is essential to understand how well products and materials can withstand the impact of falls over time, ensuring their safety in everyday use.

2.3 Forensic Packaging

Forensic packaging is a method used to determine the cause of failure or damage to the packaging that causes the product to fail, resulting in packaged products suffering losses (such as decreased quality and physical defects) (Waszkiewicz, 1991). Forensic packaging methods can be a useful tool for determining the success or failure of certain packaging features. Forensic packaging can also be useful as a development tool in determining the potential success and failure of tamper-proof packaging features.

The working principle of forensic packaging is to determine bruises, which is defined as a ratio of bruise volume to internal energy or energy absorbed by the product. This value is expressed in the amount of damage per unit of energy, internal or absorbed energy, that is commonly used to measure potential damage. Observations are conducted through manual inspection, machine vision assistance, and microscopic imaging. With this approach, the bruise volume estimation model is based on the width and depth of the bruise. Then, an incision is made on the surface of the bruised product to form an ellipse to the depth of the bruise. Sample slicing was performed after the sample was left in the laboratory at 25 °C for 24 hours, following the drop test, to allow the product bruising to spread (Du et al., 2019)

Forensic packaging analysis started after products and packaging samples had passed the retention control period. Each package and product will be identified if any bruising appears after drop testing. On the packaging, the sliced part was chosen based on the area with the highest percentage of bruising that occurs after drop testing and the retention time control period. Then, the dimensions of the bruise that has been sliced are identified, starting from the length of the bruise (w1), the width of the bruise (w2), and the depth of the bruise (db). This variable is used to determine the bruise area and bruise volume of the packaging, and the packaging bruise susceptibility (BS) value is determined by calculating the ratio between the impact energy of the packaging and its bruise volume. According to Du et al. (2019), forensic packaging involves several equations used to derive results from the analysis, as shown (7), (8), and (9).

$$\text{Bruise Area (cm}^2\text{)} = \frac{\pi . w1 . w2}{4} \quad (7)$$

$$\text{Bruise Volume} = \frac{\pi . db}{4} \times (3. w1. w2 + 4. db^2 \quad (8)$$

$$\text{Bruise Susceptibility (cm}^3\text{/Joule)} = \frac{Bruise\ Volume}{Impact\ Energy} \quad (9)$$

However, because the samples used at each height are of three types, the bruise susceptibility value for each height fall must be determined using the standard deviation formula (10).

$$\text{Bruise Susceptibility Standard Deviation (50 cm; 100 cm; 150 cm)} = \frac{\sqrt{\sum (xi - x)^2}}{n-2} \quad (10)$$

Where:

xi : value of bruise susceptibility at a certain height in the i-repetition

x : average value of bruise susceptibility at a certain height

n : number or value of repetition

3. RESULTS AND DISCUSSION

The samples used in this research were packaging samples of foldable cardboard-based secondary or more with a flip carton. The secondary slop packaging used is made of duplex paper, which can be identified due to differences in color on the packaging layer. On layers, the inside has a gray or darker color and a rough surface. Then, the outer layer is a white layer, which can be used for image printing because it has a smooth surface and is slippery. In packaging printing, duplex paper is a type of high-quality packaging cardboard because it can produce text, and the printed image will be sharper, especially when equipped with a high-tech printing machine. Furthermore, the duplex paper raw material has a layer side. The back is thick enough to make this paper last longer and better under certain conditions. In terms of strength, duplex paper exhibits characteristics such as resistance to tearing, impact resistance, heat resistance, and resistance to sunlight (Paramita, 2015).

The use of slop secondary packaging as a test sample in this study was due to research limitations. In this research, the testing method was carried out manually without the use of tools, namely by dropping goods at various points, angles, and heights in accordance with existing rules. This limitation means that researchers cannot calculate the value of energy absorbed from the packaging to the product because the more layers there are and the higher the level of packaging that protects the product, the impact energy when it falls will be absorbed into the packaging material in each layer, and it is possible that it will not hit the product and prevent the packaging is deformed. Additionally, the use of secondary packaging for testing samples will facilitate the collection and processing of data. Manual testing methods are unable to calculate the energy absorbed in each package that is packaged for higher packaging levels, resulting in uncertainty about whether the energy that hits the package will be distributed evenly across all packages or concentrated in certain ones. Therefore, in this study, secondary slop packaging was chosen, each packaging containing 4 *Jenang* products, which had been packaged in primary packaging made from BOPP (biaxially oriented polypropylene) plastic. By testing this slop secondary packaging, the mechanical energy that hits the packaging will have a damaging effect on both the packaging in terms of durability and the product in terms of quality, as the sample directly packages the product.

The implementation of this test is based on packaging testing standards, including drop tests and forensic packaging methods, as outlined in ASTM D5276-98. The drop test applies to product containers weighing less than 50 kg, so they must comply with ISO 2206:1987, which specifies the division of packaging areas into quadrants based on their shape. For packages or packaging in the form of packaging. Parallelogram beams or parallelepiped packages, such as packaging forms. In this experiment, the packaging area was divided based on the numbering of each side of the packaging. Figures 2a-d illustrate the classification of packaging areas and their implementation.

(a) (b) (c) (d)

Figure 2. Illustration and Implementation View of Packaging Areas Classification Based on ISO 2206:1987 (a) Illustration of Packaging (b) Top View (c) Right Side View (d) Front View

Sample packaging is divided into 3 parts that identify the sides, edges, and angles of the packaging. On the sides, there are symbols in the form of capital letters from "A" to "F", based on the number of sides of the packaging, there are 6 pieces. On the ribs, symbols are indicated in the form of numbers 1 to 12, corresponding to the number of ribs in the package, totaling 12. Then, the corners are assigned the letters A to H according to the number of corners on the package, totaling 8. Packaging is also assigned a sample code to facilitate more straightforward naming. Table 2 shows that the packaging sample code is used based on the repetition and height of the test.

Table 2. Information on the Drop Height Test and Sampling Code

No	Test Height (cm)	Sample Code (Repetition Height)
1	50	1.1
		2.1
		3.1
2	100	1.2
		2.2
		3.2
3	150	1.3
		2.3
		3.3

Based on the ISTA 1A procedure, cartons and products weighing less than 10 kg are dropped from a minimum height of 76 cm (30 inches). The weight of the secondary packaging itself ranges from 7 to 7.5 grams per package. However, in this test, three height variations were used: 50 cm, 100 cm, and 150 cm. Three height variations were used to ensure that the data and results of this research were more multifaceted, as there was uncertainty about whether consumers, employees, or even third-party companies would drop the packaging at a height of 76 cm. Therefore, by testing packaging at various heights, the research results can be more comprehensive, and the quality of the packaging in terms of resistance to mechanical damage at specific heights can be determined.

The number of packages tested at each height is 3 samples, allowing for statistical analysis.

This research focuses on the ability of packaging to protect products from mechanical damage during testing. *Jenang* products are packaged in primary packaging, namely BOPP (biaxially oriented polypropylene) plastic. BOPP (or OPP) plastic is a plastic film that is widely used for plastic packaging purposes in the food and beverage industry, cigarettes, pharmaceuticals, detergents, shampoo, garments, cosmetics, and so on. BOPP film is made from polypropylene resin and other synthetic chemicals, making BOPP plastic a material that is difficult to decompose naturally (Santoso and Widyamurti, 2019). Furthermore, the author presents an indicator for assessing packaging resistance to mechanical damage based on several parameters in Table 3.

Table 3. Assessing Indicators for Packaging Resistance to Mechanical Damage

No	Primary Packaging Conditions (BOPP)	Secondary Packaging Conditions (Flip Carton)	Packaging Assessment Indicators
1	Not Damaged	Not Damaged	Very Good
2	Not Damaged	Damaged	Good
3	Damaged	Not Damaged	Poor
4	Damaged	Damaged	Very Poor

Park et al (2013) outlined that packaging damage can be assessed at the packaging seal. For example, a package that isn’t tightly sealed or opened has a significant impact on food safety. This condition allows the entry of air, microorganisms, and other contaminants that can facilitate pathogen growth and degradation of product quality (Park et al., 2013). Defects in *Jenang* products are organoleptically noticeable due to the BOPP plastic being open, allowing more air and water to enter. Excess air and water can affect food stability and durability, as well as chemical reaction rates, enzyme activity, and microbial growth, which are typically influenced by water activity (Aw). Water activity can explain why the lipoxygenase enzyme is active when in contact with water, allowing for the formation of brown color in semi-moist food (intermediate moisture food), such as *dodol* (Kusnandar, 2019). Organoleptic defects commonly found in *Jenang* products include a hardened texture due to shelf-life aging, the appearance of mold due to excessive water activity, and contamination from air, which can occur if the primary packaging is opened. Therefore, this research focuses on the packaging's ability to protect the product's primary packaging from being opened, thereby minimizing the amount of water and air entering the product.

The implementation of drop testing is regulated in ISO 2248:1985, which regulates the technical Implementation of drop tests (surface selection, procedures, working principles, and test reporting). According to ISO 2248:1985, the working principle of the drop testing method is to lift the test sample above a rigid plane surface and release it to impact a specific packaging surface (impact surface) after undergoing a free-fall motion. Atmospheric conditions, fall height, and control treatments were carried out at the start of the test. Griffin et al. (1985) stated that in drop testing, the packaging must be dropped on a flat and sturdy surface.

3.1 Drop Testing

Drop testing was conducted using a total of 9 packaging samples, with 3 samples at each height drop of 50 cm, 100 cm, and 150 cm. Each package can pack up to 4 pieces of *Jenang,* so the required number of Jenang samples is 36, which have been assigned a number. During testing, the room temperature was maintained at 27 °C to ensure optimal conditions. The packaging that is dropped first is the 50 cm packaging in sequence, which is 1.1, 2.1, to 3.1, followed by heights of 100 cm and 150 cm. Next, the packaging is inspected on each side, rib, and corner, and any new bruises are noted after drop testing. Results from drop testing are summarized in Table 4, which provides information obtained after the drop testing.

Table 4. Sample Packaging Drop Testing Result

Height (cm)	Sample Code	Product + Packaging Mass (g)	Impact Energy Absorbed (J)	Std. Deviation of Impact Energy (J)	Number of Bruises After Testing (Packaging)	Percentage Increase in Packed Bruise
50	1.1	86.333	0.420	0.004	1 (Corner H)	12.5% (Corner)
	2.1	87.316	0.428		1 (Rib 5)	8.333% (Rib)
	3.1	85.685	0.420		4 (Rib 3, 5, 9, 10) 3 (Corner A, C, E)	33.333% (Rib) 37.5% (Corner)
100	1.2	86.737	0.850	0.022	1 (Corner G)	12.5% (Corner)
	2.2	85.388	0.836		1 (Corner A) 3 (Rib 3, 5, 11)	12.5% (Corner) 25% (Rib)
	3.2	89.745	0.880		3 (Corner A, B, C)	37.5% (Corner)
150	1.3	87.866	1.292	0.039	1 (Rib 5) 2 (Corner A, E)	8.333% (Rib) 25% (Corner)
	2.3	83.558	1.230		1 (Rib 3) 2 (Corner A, E)	8.333% (Rib) 25% (Corner)
	3.3	88.590	1.302		1 (Rib 3) 3 (Corner A, D, H)	8.333% (Rib) 37.5 (Corner)

Based on the results obtained from drop testing, it can be concluded that the critical point for packaging on the ribs is rib 5, and on the corners, it is corner A. This is because this section experiences the most damage in each sample test. However, after passing an inspection on the *Jenang* product, each product packaged in the sample was found to be free from mechanical damage. The next step is to carry out retention controls on product samples and packaging.

3.2 Retention Control Time

According to Du et al. (2019), using kiwi fruit test samples as drop testing samples in their research, the samples were left in the laboratory at 25 °C for 24 hours after drop testing and then sliced. Kiwi fruit itself has a shelf life of 7 days if left open without using certain handling materials. Furthermore, on other fruit samples, apples have a relatively short shelf life, especially at room temperature, because apples, after being picked, undergo changes in composition, and damage occurs due to continued physiological activities (Isyuniarto and Purwadi, 2007). Since there is no previous literature regarding the retention time of *Jenang* samples, the researchers established a direct comparison relationship to determine the retention time of *Jenang* products. Based on the two studies above, the relationship between drop testing sample retention time and product shelf life is approximately 1:7. The *Jenang* product itself has a shelf life of roughly 75 days or around 2.5 months. Therefore, it can be determined that the retention time for *Jenang* products is 10 to 11 days, including drop testing and forensic packaging testing days.

3.3 Forensic Packaging Analysis

After a retention time of 10 to 11 days, the packaging samples and *Jenang* products are continued to the next stage, namely forensic packaging. On the last day of observation, it was found that the relative air humidity value increased from 64% to 77%. The data is presented in graphical form, as shown in Figure 3.

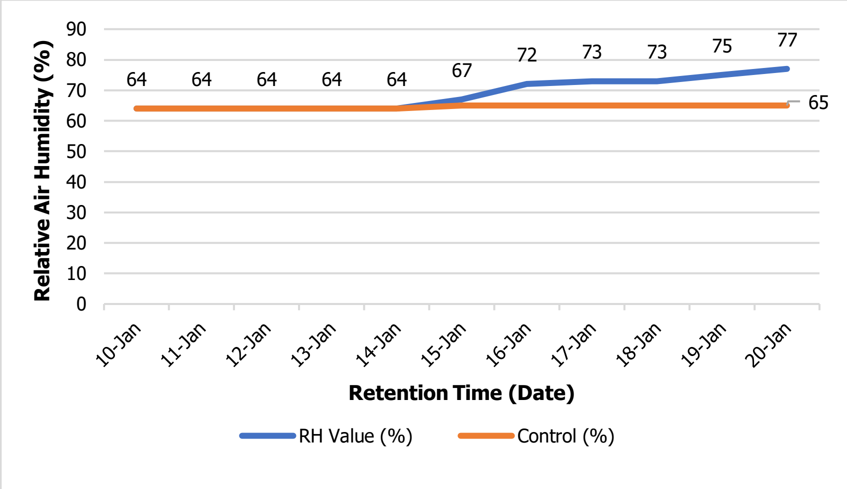


Figure 3. Chart of Samples Humidity Value During Retention Time

This increase in relative air humidity indicates a decrease in temperature in the sample compared to the beginning of the retention time. According to Edar and Wahyuni (2021), temperature affects the humidity value; if the room temperature falls, the relative humidity will rise, while if the temperature increases, the relative humidity will fall. During the retention time, the sample temperature is maintained at a range of 30 °C to 35 °C. This temperature range is the optimal temperature for activating lipoxygenase enzyme activity, which generally has an optimal temperature range of activation between 20°C and 40 °C. Activation of the lipoxygenase enzyme can also be triggered by mechanical damage to food products, exposing the enzyme to its substrate and thereby activating it. Then, exposure to oxygen can activate enzymes through the air, either during the production, storage, or handling processes. Furthermore, microbial contamination in food products can also affect the lipoxygenase enzyme, leading to the growth of fungi, mold, and algae in these products.

Based on observations, the *Jenang* did not appear bruised after undergoing the drop testing and retention time testing stages, and the product remained in intact condition. The condition is due to the characteristics of *Jenang* products, which have a chewy and elastic texture, making it difficult to identify bruises on the product and to slice it cleanly. Furthermore, the BOPP plastic packaging that packages *Jenang* products as a whole is still tightly packed, and some are slightly open. Therefore, the forensic packaging stage is carried out on packaging samples that have been identified as having bruises during drop testing. Based on the assessment indicators applied by the researchers, of the 9 packaging samples, there were 8 packaging samples in the "good" category and 1 packaging sample in the "very good" category, namely packaging 2.1, so in this sample, no part of the packaging was sliced because the damage to this sample was only small tear, not bruise. The determination of the cutting section is based on the part of the packaging with the highest percentage of damage and the deepest dents. Each package is sliced at the corners because it has the smallest number of parts (6 pieces) and the smallest contact surface area so the impact of the energy hitting the package will be greater due to the pressure being concentrated at one point. Based on Equations (7), (8), and (9), the summarized results of forensic packaging analysis are obtained, which are outlined in Table 5.

Table 5. Summarized Result of Forensic Packaging Analysis from Sample

Samples Code	Sliced Part from the Packaging	w1 (cm)	w1 (cm)	db (cm)	Bruise Area (cm^2)	Bruise Volume (cm^3)	Bruise Susceptibility (cm^3/Joule)
1.1	H Corner	0.600	0.400	0.040	0.189	0.023	0.054
2.1	Unsliced	Unsliced	Unsliced	Unsliced	Unsliced	Unsliced	Unsliced
3.1	E Corner	0.840	0.615	0.038	0.405	0.046	0.111
1.2	G Corner	0.800	0.600	0.043	0.368	0.049	0.057
2.2	A Corner	1.000	0.800	0.040	0.628	0.076	0.090
3.2	C Corner	0.780	0.720	0.048	0.441	0.064	0.073
1.3	E Corner	1.020	0.600	0.048	0.565	0.070	0.054
2.3	H Corner	1.050	0.710	0.043	0.585	0.076	0.062
3.3	E Corner	1.070	1.010	0.048	0.848	0.123	0.094

Therefore, the final results of the bruise susceptibility values and the inaccuracies in their calculation can be seen in the final results in Table 6.

Table 6. Final Result of Bruise Susceptibility Value and Its Standard Deviation

Height (cm)	Samples Code	Bruise Susceptibility (cm^3/Joule)	Average Bruise Susceptibility (cm^3/Joule)	Standard Deviation Value (cm^3/Joule)	Bruise Susceptibility ± Standard Deviation Value
50	1.1 2.1 3.1	0.054 - 0.111	0.055	(**n.a**)	**0.0549 cm^3/J**
100	1.2 2.2 3.2	0.057 0.090 0.073	0.073	0.016	**0.0735 ± 0.0164 cm^3/J**
150	1.3 2.3 3.3	0.054 0.062 0.094	0.070	0.021	**0.0699 ± 0.0214 cm^3/J**

Furthermore, the data on bruise susceptibility value is presented in a scatter plot chart type to analyze the trend due to the increase in drop fall height and the value of bruise susceptibility for sample packaging. Based on the graphic shown Figure 4, there is a positive trend between height fall and bruise susceptibility, with a coefficient of 0.0004. Therefore, a change in height of 1 unit cm can affect the bruise susceptibility value by 0.0004 cm^3/J. Additionally, the R-squared value is 99.9%, indicating that the fall height accounts for 99.9% of the variation in bruise susceptibility values. The square root value of R-squared is also referred to as the correlation coefficient (r), so the value of the r coefficient is 0.999. The value indicates a very strong positive correlation. The graph is shown in Figure 4.

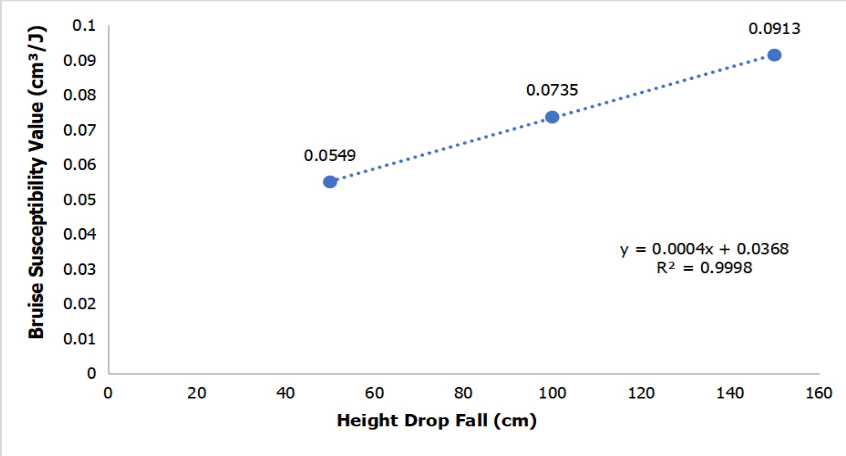


Figure 4. Scatter Plot Diagram: Height Drop Fall and Bruise Susceptibility Value

Figure 4 shows an upward trend in data, resulting from the average bruise susceptibility and its standard deviation from 3 repetitions at drop heights of 50 cm, 100 cm, and 150 cm. At the first height fall (50 cm), the value of bruise susceptibility was approximately 0.0549 cm^3/J. Then, on the second height fall (100 cm), the value of bruise susceptibility obtained was approximately 0.0735 cm^3/J. For the third height fall (150 cm), the value of bruise susceptibility obtained was approximately 0.0913 cm^3/J. The third height fall sample has the highest value of bruise susceptibility among the others due to its bruise size being affected by more damage (length, width, and depth) than the first and second height fall samples.

Based on the graph shown Figure 4, the relationship between increasing the falling height used and the level of damage experienced by the packaging is directly proportional. The relationship means that the higher the fall, the more severe the damage to the packaging, which in turn will affect the product.

4. CONCLUSIONS

Based on the research conducted by the researcher, it can be concluded to some extent that there is an indirect influence of mechanical defects on *Jenang's* quality degradation. Changes in *Jenang's* characteristics are caused by the activity of the lipoxygenase enzyme in the product due to various substrates, including a decrease in temperature, an increase in relative humidity (RH), excessive water activity, air (O_2 gas content), and microbial contamination. Then, the packaging used by the company is supplied by PT. Bima Perkasa Semarang is already in the "good" category. Proven by three times repetitions of testing at each of three heights (50 cm, 100cm, 150cm), the bruise susceptibility value is very low, packaging damage is in the light category, and the product's primary packaging is still tightly sealed, so that it can maintain the quality and shelf life of *Jenang* during the retention period. Furthermore, the average values and their deviations for bruise susceptibility of the packaging at heights of 50 cm, 100 cm, and 150 cm, respectively, were 0.0549 cm^3/Joule, 0.0735 ± 0.0164 cm^3/Joule, and 0.0699 ± 0.0214 cm^3/Joule.

The packaging standard itself is made from the result of this test specification because the secondary flip carton packaging from a third-party company, which was tested in this study, has been categorized as "good to very good" indicators based on the test method carried out so that it can be used as a standard and reference for the carton packaging used. The creation of its standard can be used as historical company data because no standards have been applied regarding secondary packaging parameters. If there are any new alternative packaging options from other suppliers, the testing selection methods must be carried out using the same test method. Also, the quality of the new packaging to avoid deformation (resistance) should be better than the previous packaging vulnerability value applied to the standard. Therefore, it is hoped that this research will help companies adapt and evaluate better material handling practices, determine standard packaging attributes and parameters based on test results data, and provide information on the packaging's ability to protect *Jenang* products, along with damage simulations and forensic evidence.

Based on the research, the researcher can provide suggestions to ensure the research is utilized effectively. The first factor for selecting new packaging alternatives from other suppliers is not limited to mechanical durability alone but also considers price, design, and other factors. Furthermore, there are various techniques for decision-making analysis, such as the analytical hierarchy process (AHP), analytical network process (ANP), and the TOPSIS method, among others, to determine priority factors from attributes.

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