UNIVERSITI PUTRA MALAYSIA

DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF GREEN NIPAH BANANA (Musa acuminata x balbisiana Colla ABB GROUP) PEELING TOOL FOR SMALL SCALE INDUSTRY

FARAHANA NABILAH BT ZAINAL A'BIDIN

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FARAHANA NABILAH BT ZAINAL A'BIDIN

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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FARAHANA NABILAH BINTI ZAINAL A'BIDIN

August 2021

Chair : Prof. Rosnah Shamsudin, PhD
Faculty : Engineering

Peeling is one of the processes in the making of banana chips. In the current Malaysian industry, the peeling process is still done using the manual method, which uses hand and kitchen knife. The weakness of using manual peeling is that it requires knife-handling skills to prevent pulp from being damaged, time-consuming, and unsafe. Therefore, the study aims to develop a banana peeling tool that successfully removes the skin of green Nipah banana in a shorter time and with minimal pulp loss. In banana chips processing, bananas under certain conditions are essential as they will affect the texture for drying and frying. The fruit needs to be stiff and starchy; thus, certain properties during its ripening period need to be evaluated to examine the suitable ripening days to process the bananas. The study involves several properties evaluated, such as the physicochemical and mechanical, throughout its ripening days. Based on the result, the green Nipah banana's colour and mechanical properties were correlated with ripening days. The colour of the peel also gradually changes from dark green to lighter green and yellow tint. As for proximate analysis, only crude fibre and crude protein correlate with ripening days. Crude fibre increases by 52.69 % on the upper bunch and 52.12 % for the lower bunch from day 1 to day 5, while crude protein decreases by 61.11 % for the upper bunch and 93.55 % for the lower bunch from day 1 to 5. Total soluble solids (TSS) and fructose also correlate with ripening days. TSS increases throughout its ripening days when the fructose decreases. TSS on the upper bunch increases by 36.73 % on the upper bunch, while the lower bunch decreases to 41.67% on day 3 and increases back by 38.23 % to day 5. Firmness, adhesiveness, and penetration force decrease while compression force increases throughout its ripening days.

Firmness decreases by 12.04 %, 21.25 %, and 9.18 % for top, middle and bottom finger positions respectively for upper bunch position. As for the lower bunch, firmness decreases by 11.15 %, 9.09 % and 20.60% for top, middle and bottom,

respectively. Adhesiveness decreases by 26.72 %, 37.85 % and 36.26 % for top, middle and bottom finger positions respectively for upper bunch position. As for the lower bunch, adhesiveness decreases by 57.50 %, 64.68 % and 63.94 % for top, middle and bottom, respectively. Penetration force decreases by 13.15 %, 12.14 % and 27.92 % for top, middle and bottom finger positions respectively for upper bunch position. As for the lower bunch, penetration force decreases by 15.65 %, 14.61 % and 13.15 % for top, middle and bottom, respectively. Compression force increases by 64.06 %, 44.43 % and 60.75 % for top, middle and bottom finger positions respectively for upper bunch position. For the lower bunch, compression increases by 129.62 % and 46.22 % for top and middle finger position respectively while the bottom remains constant

The development of the peeling tool started with design considerations from a morphology chart, and then several conceptual designs were generated. After that, a matrix decision was made to evaluate the best design and assembly parts for fabrication was discussed in this study. A peeling tool was designed and developed as an alternative to the current manual method. The final design was developed by improving the first design. The weakness of the first design is that the force needed for the peeling process is high and takes longer peeling time as the user needs to use one hand to hold the banana while the other hand to push between the skin and pulp of the banana for banana skin removal. Performance of the peeling tool was obtained from its peeling time, pulp loss, force and deformation analysis. The peeling tool is tested to increase the peeling rate by 60% with less than 1.9% peel loss. Minimal deformation was obtained from the Finite Element Method (FEM) analysis. Besides, the maximum force on the tool was smaller than the yield force of the material; thus, the material is suitable for the application of fruit peeling.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKA BENTUK, PEMBANGUNAN DAN PERNILAIAN PRESTASI PENGUPAS PISANG *NIPAH* HIJAU (*Musa acuminata x balbisiana* Colla GRUP ABB) UNTUK INDUSTRI BERSKALA KECIL

Oleh

FARAHANA NABILAH BINTI ZAINAL A'BIDIN

Ogos 2021

Pengerusi : Prof. Rosnah Shamsudin, PhD
Fakulti : Kejuruteraan

Mengupas adalah salah satu proses dalam pembuatan kerepek pisang. Proses pengupasan di dalam industri Malaysia masih menggunakan kaedah manual iaitu dengan menggunakan pisau dapur dan tangan. Kelemahan cara ini adalah ia memerlukan kemahiran dalam pengendalian pisau bagi mengelakkan kerosakkan isi pisang disamping memakan masa serta kurang selamat. Projek ini dijalankan bagi mencipta alat pengupasan yang dapat menanggalkan kulit pisang Nipah hijau dalam masa yang singkat dengan kerosakan isi yang minimum. Dalam pemprosesan kerepek pisang, tahap kematangan pisang sangat penting kerana ia akan mempengaruhi tekstur bagi tujuan pengeringan dan menggoreng. Isi pisang perlu keras dan berkanji. Jadi ciri-ciri tertentu dalam tempoh pematangan pisang perlu dikenalpasti bagi mengetahui tahap kematangan yang sesuai dalam memproses pisang. Beberapa ciri-ciri pisang dinilai dalam kajian ini seperti fiziko-kimia dan mekanikal. Berdasarkan data yang diperolehi, warna dan sifat mekanikal pisang berkorelasi dengan hari matang. Warna kulit juga berubah secara beransur-ansur dari hijau gelap menjadi warna hijau muda dan kekuningan. Bagi analisis proksimat, hanya serat kasar dan protein kasar yang mempunyai kaitan dengan hari matang. Serat kasar meningkat sebanyak 52.69 % di tandan bahagian atas dan 52,12 % di tandan bahagian bawah sepanjang pematangan sementara protein kasar menurun sebanyak 61.11 % pada tandan bahagian atas dan 93.55 % pada tandan bahagian bawah. Jumlah pepejal larut (TSS) dan fruktosa juga didapati mempunyai kaitan dengan hari matang. TSS meningkat sepanjang hari pematangannya manakala fruktosa menurun. TSS pada tandan bahagian atas meningkat sebanyak 36.73 % pada tandan bahagian atas, manakala bahagian bawah menurun sebanyak 41.67 % pada hari ketiga dan meningkat kembali sebanyak 38.23 % pada hari kelima. Daya tusukan, kadar lekatan dan penembusan menurun sementara daya mampatan meningkat sepanjang lima hari kematangannya.

Daya kepejalan pada kedudukan jari atas, tengah dan bawah masing-masing berkurangan sebanyak 12.04 %, 21.25 % dan 9.18 % bagi kedudukan tandan atas. Bagi kedudukan tandan bawah pula, daya kepejalan pada kedudukan jari atas, tengah dan bawah masing-masing berkurangan sebanyak 11.15%, 9.09% dan 20.60%. Kadar lekatan pada kedudukan jari atas, tengah dan bawah masing-masing berkurangan sebanyak 26.72 %, 37.85 % dan 36.26 % bagi kedudukan tandan atas. Bagi kedudukan tandan bawah pula, kadar lekatan pada kedudukan jari atas, tengah dan bawah masing-masing berkurangan sebanyak 57.50 %, 64.68 % dan 63.94 %. Daya penembusan pada kedudukan jari atas, tengah dan bawah masing-masing berkurangan sebanyak 13.15 %, 12.14 % dan 27.92 % bagi kedudukan tandan atas. Bagi tandan bawah pula, daya penembusan pada kedudukan jari atas, tengah dan bawah masing-masing berkurangan sebanyak 15.65 % 14.61 % dan 13.15 %. Daya mampatan pada kedudukan jari atas, tengah dan bawah masing-masing meningkat sebanyak 64.06 %, 44.43 % dan 60.75 % bagi kedudukan tandan atas. Bagi tandan bawah pula, daya mampatan pada kedudukan jari atas dan tengah masing-masing meningkat sebanyak 129.62 %, 46.22 % manakala daya mampatan jari bawah tidak berubah.

Pembangunan pengupas kulit pisang bermula dengan gabungan idea dari carta morfologi yang kemudiannya menghasilkan beberapa konsep reka bentuk pengupas. Setelah itu, keputusan matriks dibuat bagi menilai bahagian reka bentuk dan pemasangan terbaik untuk fabrikasi. Pengupas pisang dicipta dan dihasilkan sebagai alternatif dari kaedah manual pada ketika ini. Reka bentuk akhir dihasilkan dengan memperbaiki reka bentuk pertama. Kelemahan reka bentuk pertama dipercayai perlu menggunakan daya yang tinggi bagi proses pengelupasan dan memerlukan waktu pengelupasan yang lebih lama. Ini adalah kerana, pengguna perlu menggunakan satu tangan untuk memegang pisang sementara tangan kedua digunakan untuk memegang alat pengupas bagi mengupas kulit pisang tersebut. Prestasi pengupasan diperoleh dari masa pengupasannya, kerosakan isi dan analisis kekuatan alat serta perubahan bentuk alat. Alat pengupas ini telah diuji dapat meningkatkan kadar pengupasan kulit pisang sebanyak 60% dan mempunyai kadar kehilangan isi pisang pada 1.9% sahaja. Keputusan yang diperoleh daripada analisis Kaedah Unsur Terhingga (FEM) menunjukkan perubahan bentuk yang minimum. Di samping itu, daya maksimum pada alat didapati lebih rendah daripada daya hasil bahan menjadikan bahan ini sesuai untuk digunakan dalam penghasilan alat pengupas tersebut.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Rosnah binti Shamsudin, PhD
Professor, Ts
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Salahuddin bin Mohd Basri, PhD
Senior Lecturer, Ts
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Zanariah Mohd Dom
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

_____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:20 January 2022

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research and the writing of this thesis were done under our supervision;
- supervisory responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2015-2016) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: _____

Signature: _____
Name of Member of Supervisory Committee: _____

Signature: _____
Name of Member of Supervisory Committee: _____

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
B	Bunch position
D	Width
d	Height
D	Ripening days
D_g	Geometric mean diameter
D_i	Width for diameter
D_o	Height for diameter
FAMA	Federal Agricultural Marketing Authority
FEM	Finite Element Method
HPLC	High-Performance Liquid Chromatography
L	Length
LB	Lower bunch
N	Newton
P	Finger Position
P_{ell}	Projected area
S_{ell}	Surface area
SS	Stainless steel
SPSS	Statistical Package for the Social Sciences
T_E	Edge thickness
T_s	Side thickness
TSS	Total soluble solids
UB	Upper bunch
UPM	University of Putra Malaysia
V_{ell}	Ellipse volume

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is well-known for its tropical weather, which results in a lot of agricultural activities. It contributed 7.1 per cent (RM101.5 billion) to Gross Domestic Product in 2019 (Department of Statistics Malaysia Official Portal). Various types of fruits are available in the country, e.g., watermelon, pineapple, orange, banana, and more. For example, bananas can be found anywhere and easily planted.

Bananas are found in many places across the wet tropics and subtropics, such as America, Africa, South Asia Island, Southeast Asia, Malaysia and the Pacific. The commercial banana belongs to the family Musaceae genus Musa. It is called “pisang” in Malaysia. When mature, the genomic grouping AAA exhibits pulp that tastes sweet and edible, although it is uncooked, thus is eaten raw as table fruit. It also tastes better when cooked, whether as a fried banana, banana cue, or maruya. Meanwhile, genomic groupings AAB and ABB need to be cooked.

The banana plantation is the 2nd largest production area & 5th in export revenue within Malaysia and locally consumed with per capita of 9.4 kg in 2019 (Department of Statistics, 2019). Despite its tremendous benefits, the shelf life of fresh banana fruit is only a week when stored in a normal condition, which will become shorter if the fruit was cut, torn, or damage occurred during the pre- or post-harvesting process. Planted crops are harvested within 12-15 months after planting (Natural Horticulture Board of India). It is harvested when the second hand from the top is ¾ rounded. ¾ rounded means that all the banana is towards the upward direction. One tree may contain 100-400 fruits. The fruits grow in a hanging cluster with twenty fruits to a tier and 3-20 tiers to a bunch. It is usually harvested in the unripe (green) stage. Normally, bananas are manually harvested by human labour when they reach a maturity stage and are ready to enter the market.

About 90% of the banana produced is consumed domestically as fresh fruit, while 2.5% is consumed as banana by-products and the rest as an ingredient in the food product. One of the popular by-products of bananas is banana chips. Deep-fried banana chips are a very popular snack food in many countries. As the growth of the snack food industry has been increasing, there is a certainty that the banana chips market is on its uprising.

There are two common types of banana used for banana chips in Malaysia, i.e., Tanduk (Musa paradisiaca) and Nipah (Musa acuminate balbisiana), as seen in

Figures 1.1 and 1.2. Both bananas are physically different. Tanduk is long and more curvature in shape and has a circular cross-sectional shape. The skin is also thin and easy to peel. Meanwhile, Nipah is short and straight. It has a polygon cross-sectional shape. The skin is thick and is stickier to peel.

Banana chips are prepared by frying the green banana. There are four major operations involved, i.e., peeling, cutting, frying, and packaging. Figure 1.3 shows the process of making banana chips from a banana chips factory.

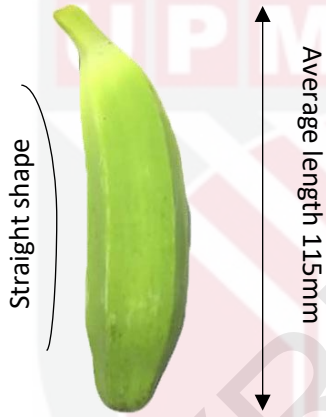

Figure 1.1*:* Nipah banana

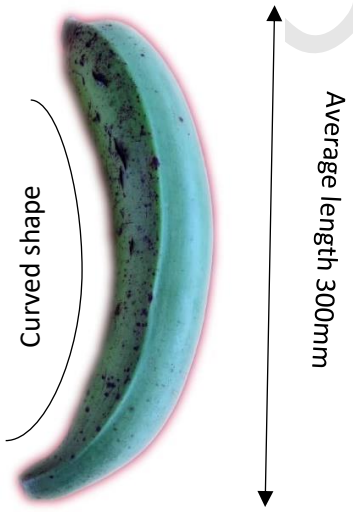

Figure 1.2*:* Tanduk banana
(Source : Shopbah, 2021)

Whereby, currently, peeling is still done manually, as seen in Figure 1.3a. As bananas have uneven and irregular shapes and are sticky due to their mucilaginous nature, they are critical to peel. Thus, manual peeling by hand is slow and involves substantial labour when many bananas are needed to peel. Manual peeling is not only dreary, but also challenging to manage and maintain hygiene. Many banana chip companies complain about the difficulty of peeling off the banana manually, as workers tend to take a lot of time during the peeling process. To solve this problem, a tool to peel the *Nipah* banana skin should be invented.

Figure 1.3: Banana chips processing (a) Peeling; (b) Frying; (c) Packaging; (d) Storage

1.2 Problem statement

Most banana chips factories in Malaysia are still using the traditional method of using a kitchen knife to cut and peel the banana skin. Banana production in Malaysia is mostly found in Johor, Pahang, and Sabah (Tumin & Ahmad Shaharudin, 2019). Most of the factories in Malaysia process 100 kg to 200 kg of bananas per day to make banana chips. Production of banana chips on average for a factory was 54 kg per day. Based on an interview made with various companies in Banting, Selangor, they pay up to three workers to peel the banana skin with a wage of RM3/hour for up to 200 kg of bananas. The time consumes to peel the banana is around six hours. The conventional method poses a danger to the worker's finger by inflicting injury if not done properly, as the banana's skin is uneven, has an irregular shape and is sticky due to its mucilaginous nature. Trained workers are needed for the banana to peel effectively. Thus, to avoid the laborious process involved in manual peeling,

evading injury to the workers, and increasing efficiency and high-quality standards and hygiene, a Nipah banana peeling tool needs to be created.

1.3 Objectives

This project aims to design and develop a banana semi-auto green *Nipah* banana peeling tool that can be used in small and medium industries. The objectives of this project are :

1. To determine the effect of physicochemical (mass, pulp to peel ratio, peel thickness, length, diameter, mass modelling, colour, proximate analysis, sugar content) and mechanical properties (firmness, adhesiveness, penetration, compression) of green banana variety Nipah throughout ripening days
2. To design and develop a banana peeling tool that can peel the skin of green Nipah banana and fruits to reduce damages on the pulp by using SolidWork software
3. To evaluate the performance of a green Nipah banana peeling tool, including the peeling time and peel loss at different blade thickness

1.4 Significance of study

The findings of this study will benefit the banana chips industry, considering the banana peeling process plays an essential role in its production. The greater demand for banana chips product export justifies the need for a more practical approach. Thus, the peeling tool created can be introduced to the Malaysian market for better production, increasing its productivity and process time. It will create an opportunity for Malaysia to increase product exports of banana chips since the production rate increased as global volume sales grew at 3.6%, from 1,825,000 tonnes in 2000 to 18,90,600 tonnes in 2001.

1.5 Research scope

The work scope focused on the determination of green Nipah banana variety fruit properties and its relation during ripening, where physicochemical and mechanical properties of whole banana fruit and pulp were determined. Physical properties of whole green Nipah banana fruit were determined in terms of weight, volume, and dimensions. Chemical properties of green Nipah banana fruit pulp were studied. Meanwhile, the mechanical properties (puncture and compression tests) of the whole banana fruit were determined with different probe types and positions. The property could be used as a preliminary study to design and develop the Nipah banana peeling tool.

The work was focused on developing a green Nipah banana peeling tool to effectively remove the skin of the banana with less time taken for peeling and able to obtain minimal pulp loss with less physical damage. The peeling tool needs to be portable, hygienic, easy to use, safe and ergonomic. The performance of the peeling tool was evaluated in terms of peeling time and peel loss at different blade thicknesses. The performance was then compared with the conventional peeling method, which is by using manual hand labour
.

However, the banana peeling tool was designed mainly for peeling Nipah banana, so it might not be suitable for other plantains. A peeling tool was constructed to cut the edge plane of the fruit and remove the skin from the pulp. The project proposes to be used in the banana chips industry to increase their productivity in their peeling process. Since banana chips processing needs a hard texture and certain maturity of banana, which becomes a significant impact on the end product, thus, the properties of the banana must be considered well.

1.6 Thesis outline

In the thesis, the work conducted was mainly on the studies of properties of green Nipah banana peel and pulp and the development of banana peeling tool. Chapter 2 introduces the green Nipah banana fruit, its benefits, physicochemical, and mechanical properties of varieties of banana fruits. The prior art and past studies of fruit peeling tools were also reviewed to get a general idea of the new concept of banana fruit peeling tool.

Chapter 3 describes the materials, methods, procedures, equipment, design approach, and statistical analysis used for the entire research. The research work was performed in three parts. In the first part, a brief introduction was explained in this chapter with the procedure for evaluating the physicochemical and mechanical properties of the banana. Physical properties determined were mean length (mm), diameter (mm), peel thickness (mm), mass (g) and colour. Chemical properties determined were proximate analysis (moisture content, crude protein, crude fat, ash, crude fibre) and sugar content (sucrose, fructose, glucose, TSS). While the mechanical properties determined were firmness (N), adhesive (N), penetration (N), and compression (N). Then, using the properties, a banana peeling tool was designed and developed. A few concepts in the banana peeling tool were generated, and the best concept was chosen based on selected requirements. Lastly, the design is then fabricated, tested, and modified. Methods for determining the efficiency of the tool are obtained.

Chapter 4 mentioned the results of the analysis and discussion of the experimental work. The physicochemical and mechanical properties of Nipah banana fruit at different bunch positions and finger positions were evaluated as the preliminary study. The final design which are separator and slitter was analysed using the Finite Element Method (FEM) tool (Solidwork). Manual calculations were done for separator on its material suitability and critical parts.

The peeling time of the fabricated peeling tool was evaluated and compared with the conventional method. The performance of the developed peeling tool was tested based on the peeling time (s) and pulp loss percentage.

Lastly, chapter 5 concludes the main findings obtained in this research. The recommendation works were also suggested for future research.There should be at least two tertiary headings to justify having tertiary headings.

REFERENCES

Adeyemi, O.S., & Oladiji, A. (2009). Compositional changes in banana (Musa ssp.) fruits during ripening. African Journal of Biotechnology, 8, 858-859.

Adi, D. D., Oduro, I. N., & Tortoe, C. (2019a). Physicochemical changes in plantain during normal storage ripening. Scientific African, 6, e00164.

Ahmed, J., & Rahman, M. S. (2012). Handbook of Food Process Design, 2 Volume Set (Vol. 2) [E-book]. Wiley.

Ammawath, W., Man, Y.B., Yusof, S., & Rahman, R.B. (2001). Effects of variety and stage of fruit ripeness on the physicochemical and sensory characteristics of deep-fat-fried banana chips. Journal of the Science of Food and Agriculture, 81, 1166-1171.

Anonymous. Banana. (n.d.). National Horticulture Board. Retrieved February 27, 2019, from http://nhb.gov.in/report_files/banana/BANANA.htm

Anonymous. Tanaman Pisang 9 : Pisang Nipah. (2019, July 19). Warisan Petani. Retrieve June 11, 2020, from http://warisanpetani. blogspot.com/2016/07/tanaman-pisang-9-pisang-nipah.html

Aquino, C. F., Salomão, L. C. C., Cecon, P. R., Siqueira2, D. L. D., & Ribeiro, S. M. R. (2017). Physical, Chemical and Morphological Characteristics of Banana Cultivars Depending on Maturation Stages. Revista Caatinga, 30(1), 87–96.

Aurand, L. W., Woods, A. E., & Wells, M. R. (1987). Sampling and Proximate Analysis. Food Composition and Analysis, 19–34.

Ayo-Omogie, H. N., Adeyemi, I. A., & Otunola, E. T. (2010). Effect of ripening on some physicochemical properties of cooking banana (Musa ABB Cardaba) pulp and flour. International Journal of Food Science & Technology, 45(12), 2605–2611.

Azam Ali, S. (2008, March). Banana Chips. Practical Action. Retrieved February 4, 2019, from https://www.ctc-n.org/sites/www.ctc-n.org /files/resources/ kno-100181_banana_chips.pdf

Azoulay Shemer, T., Harpaz-Saad, S., Belausov, E., Lovat, N., Krokhin, O., Spicer, V., Standing, K. G., Goldschmidt, E. E., & Eyal, Y. (2008). Citrus Chlorophyllase Dynamics at Ethylene-Induced Fruit Color-Break: A Study of Chlorophyllase Expression, Posttranslational Processing Kinetics, and in Situ Intracellular Localization. Plant Physiology, 148(1), 108–118.

Bartley, G. E., & Scolnik, P. A. (1995). Plant Carotenoids: Pigments for Photoprotection, Visual Attraction, and Human Health. The Plant Cell, 7(7), 1027.

Bembenek, M. (2020). Exploring Efficiencies: Examining the Possibility of Decreasing the Size of the Briquettes Used as the Batch in the Electric Arc Furnace Dust Processing Line. Sustainability, 12(16), 6393.

Campuzano, A., Rosell, C. M., & Cornejo, F. (2018). Physicochemical and nutritional characteristics of banana flour during ripening. Food Chemistry, 256, 11–17.

Cen, H., Lu, R., Mendoza, F., & Beaudry, R. M. (2013). Relationship of the optical absorption and scattering properties with mechanical and structural properties of apple tissue. Postharvest Biology and Technology, 85, 30–38.

Chauhan, O., Raju, P., Dasgupta, D., & Bawa, A. (2006). Instrumental Textural Changes in Banana (Var. Pachbale) During Ripening Under Active and Passive Modified Atmosphere. International Journal of Food Properties, 9(2), 237–253.

Cordenunsi, B. R., & Lajolo, F. M. (1995). Starch Breakdown during Banana Ripening: Sucrose Synthase and Sucrose Phosphate Synthase. Journal of Agricultural and Food Chemistry, 43(2), 347–351.

Cox, K. A., McGhie, T. K., White, A., & Woolf, A. B. (2004). Skin colour and pigment changes during ripening of 'Hass' avocado fruit. Postharvest Biology and Technology, 31(3), 287–294.

Dadzie, B. K., & Orchard, J. E. (1997). Routine Post-harvest Screening of Banana/plantain Hybrids: Criteria and Methods. IPGRI.

Cruz, F. S. D. (2008). Farmers' Handbook on Introduced and Local Banana Cultivars in the Philippines. Biodiversity International.

Department of Statistics Malaysia Official Portal. Supply and Utilization Accounts Selected Agricultural Commodities, Malaysia 2016–2020. (2021, August 26). Retrieved September 7, 2021, from https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat

Durán-Soria, S., Pott, D. M., Osorio, S., & Vallarino, J. G. (2020). Sugar Signaling During Fruit Ripening. Frontiers in Plant Science, 11.

Federal Agricultural Marketing Authority. Siri Panduan Kualiti Pisang. Retrieved November 3, 2020, from https://www.fama.gov.my/documents/20143/0/Pisang.pdf/171a4bfc-aba1-a1c9-eadb-0f84e692db0d

Frenkel, C., & Hartman, T. G. (2012). Decrease in Fruit Moisture Content Heralds and Might Launch the Onset of Ripening Processes. Journal of Food Science, 77(10), S365–S376.

Gomes, J. F. S., Vieira, R. R., & Leta, F. R. (2013). Colorimetric indicator for classification of bananas during ripening. Scientia Horticulturae, 150, 201–205.

Gross, K. C., & Wallner, S. J. (1979). Degradation of Cell Wall Polysaccharides during Tomato Fruit Ripening. Plant Physiology, 63(1), 117–120.

Hamir, N. A., & Mohd Ariff, M. K. (2006). Market potential of banana chips industry in Malaysia. Economic and Technology Management Review, 1(1), 83–90.

Harborne, J. (1971). The biochemistry of fruits and their products. Vol. I. Phytochemistry, 10(11), 2857.

Harker, F. R., Redgwell, R. J., Hallett, I. C., Murray, S. H., & Carter, G. (2010). Texture of Fresh Fruit. Horticultural Reviews, 121–224.

Hasanah, R., Daningsih, E., & Titin, T. (2017). The analysis of nutrient and fiber content of banana (Musa paradisiaca) sold in Pontianak, Indonesia. Biofarmasi Journal of Natural Product Biochemistry, 15(1), 21–25.

Hibbeler, R. (2016). Statics and Mechanics of Materials (5th ed.). Pearson.

Hou, J. C., Hu, Y. H., Hou, L. X., Guo, K. Q., & Satake, T. (2015). Classification of ripening stages of bananas based on support vector machine. International Journal of Agricultural and Biological Engineering, 8(6), 99–103.

Hunt, D. C., Jackson, P. A., Mortlock, R. E., & Kirk, R. S. (1977). Quantitative determination of sugars in foodstuffs by high-performance liquid chromatography. The Analyst, 102(1221), 917.

Jaiswal, P., Jha, S. N., Kaur, P. P., Bhardwaj, R., Singh, A. K., & Wadhawan, V. (2012). Prediction of textural attributes using color values of banana (Musa sapientum) during ripening. Journal of Food Science and Technology, 51(6), 1179–1184.

Jullien, A. (2001). Within-bunch Variability in Banana Fruit Weight: Importance of Developmental Lag Between Fruits. Annals of Botany, 87(1), 101–108.

Kachru, R., Kotwaliwale, N., & Balasubramanian, D. (1995). Physical and mechanical properties of green banana (Musa paradisiaca) fruit. Journal of Food Engineering, 26(3), 369–378.

Kajuna, S. T. A. R., Bilanski, W. K., & Mittal, G. S. (1997). Textural changes of banana and plantain pulp during ripening. Journal of the Science of Food and Agriculture, 75(2), 244–250.

Karim, R., Rahmatullah, N.M., Nordin, M.F., & Rajin, S.M. (2018). Effect of stage of maturity and frying time on the quality of Banana springs, 1097-1110.

Karthiayani, A., Varadharaju, N., & Siddharth, M. (2013). Textural Properties Of Banana (Musa Acuminata) Stored Under Modified Atmosphere Conditions Using Diffusion Channel. Journal of Agricultural Engineering and Biotechnology, 17–22.

Khawas, P., & Deka, S. C. (2016). Comparative Nutritional, Functional, Morphological, and Diffractogram Study on Culinary Banana (MusaABB) Peel at Various Stages of Development. International Journal of Food Properties, 19(12), 2832–2853.

Kheng, T. Y., Ding, P., & Abdul Rahman, N. A. (2011). Determination of optimum harvest maturity and physico-chemical quality of Rastali banana (Musa AAB Rastali) during fruit ripening. Journal of the Science of Food and Agriculture, 92(1), 171–176.

Khurmi, R.S. and Gupta, J.K. (2005) A Textbook of Machine Design. 14th Edition, Eurasia Publishing House (PVT.) Ltd.

Li, Z., Miao, F., & Andrews, J. (2017). Mechanical Models of Compression and Impact on Fresh Fruits. Comprehensive Reviews in Food Science and Food Safety, 16(6), 1296–1312.

Lim, T. K. (2011). Musa acuminata × balbisiana (ABB Group) 'Bluggoe.' Edible Medicinal and Non Medicinal Plants, 557–559.

Lustre, A., Soriano, M., Morga, N., Balagot, A., & Tunac, M. (1976). Physico-chemical changes in 'Saba' bananas during normal and acetylene-induced ripening. Food Chemistry, 1(2), 125–137.

Maduwanthi, S. D. T., & Marapana, R. A. U. J. (2019). Induced Ripening Agents and Their Effect on Fruit Quality of Banana. International Journal of Food Science, 2019, 1–8.

Magwaza, L. S., & Opara, U. L. (2015). Analytical methods for determination of sugars and sweetness of horticultural products—A review. Scientia Horticulturae, 184, 179–192.

Miraei Ashtiani, S. H., Golzarian, M. R., Baradaran Motie, J., Emadi, B., Nikoo Jamal, N., & Mohammadinezhad, H. (2015). Effect of Loading Position and Storage Duration on the Textural Properties of Eggplant. International Journal of Food Properties, 19(4), 814–825.

Mustaffa, R., Osman, A., Yusof, S., & Mohamed, S. (1998). Physico-chemical changes in Cavendish banana (Musa cavendishiiL var Montel) at different positions within a bunch during development and maturation. Journal of the Science of Food and Agriculture, 78(2), 201–207.

Nath, K., Ku, S., Mahatma, M.K., Madhubala, & Swami, R.M. (2015). Role of Total Soluble Sugar, Phenols and Defense Related Enzymes in Relation to Banana Fruit Rot by Lasiodiplodia theobromae [(Path.) Griff.and

Maubl.] During Ripening. Journal of Plant Pathology & Microbiology, 6(8), 1-6.

Natural Horticulture Board of India. BANANA. Retrieved November 13, 2019, from http://nhb.gov.in/report_files/banana/BANANA.htm#:~:targetText= The planted crop gets ready,soil%2C weather condition and elevation.

Newilah, G. N., Tomekpe, B. K., Fokou, B. E., & Etoa, B. F.-X. (2009). Physicochemical Changes during Ripening of Bananas Grown in Cameroon. Fresh Produce 3.1, 3(1), 64–70.

Nielsen, S. S. (2017). Food Analysis Laboratory Manual (3rd ed.) [E-book]. Springer Publishing.

Norton, I., Fryer, P., & Moore, S. (2006). Product/process integration in food manufacture: Engineering sustained health. AIChE Journal, 52(5), 1632–1640.

Obiageli, O., Pauline, I.A., & Ukamaka, O.G. (2016). Proximate Compositions of fruits of Three Musa Species at Three Stages of Development, 15(6), 107-117.

Padam, B. S., Tin, H. S., Chye, F. Y., & Abdullah, M. I. (2014). Banana by-products: an under-utilized renewable food biomass with great potential. Journal of food science and technology, 51(12), 3527–3545.

Palapol, Y., Ketsa, S., Stevenson, D., Cooney, J., Allan, A., & Ferguson, I. (2009). Colour development and quality of mangosteen (Garcinia mangostana L.) fruit during ripening and after harvest. Postharvest Biology and Technology, 51(3), 349–353.

Paniagua, C., Posé, S., Morris, V. J., Kirby, A. R., Quesada, M. A., & Mercado, J. A. (2014). Fruit softening and pectin disassembly: An overview of nanostructural pectin modifications assessed by atomic force microscopy. Annals of Botany, 114(6), 1375–1383.

Pathak, S. S., Pradhan, R. C., & Mishra, S. (2019). Physical characterization and mass modeling of driedTerminalia chebulafruit. Journal of Food Process Engineering, 42(3), e12992.

Patil, S. K., & Shanmugasundaram, S. (2015). Physicochemical Changes During Ripening Of Monthan Banana. International Journal of Technology Enhancements and Emerging Engineering Research, 3(02), 18–21.

Pérez-López, A., Chávez-Franco, S., Villaseñor-Perea, C., Espinosa-Solares, T., Hernández-Gómez, L., & Lobato-Calleros, C. (2014). Respiration rate and mechanical properties of peach fruit during storage at three maturity stages. Journal of Food Engineering, 142, 111–117.

Persson, S. (1987). Mechanics of Cutting Plant Material (Asae Monograph No 7) (7th ed.). American Society of Agricultural Engineers.

Photo Story : Industi Rumahan Keripik Pisang “Bu gun.”. Retrieved October 25, 2019, from https://wowipan.blogspot.com/2016/03/photo-story-industri-rumahan- keripik.html?showComment=1571978691486#c5 7375970620875350 48

Pickover, C. A. (2010). The Math Book: From Pythagoras to the 57th Dimension. Choice Reviews Online.

Pisang Tanduk Banana Paradisia 牛角香蕉. (n.d.). Shopbah Grocer On The Wheel. Retrieved October 14, 2021, from https://www.shopbah.com/ pisang-tanduk-banana-paradisia

Ploetz, R.C., A.K. Kepler, J. Daniells, and S.C. Nelson. 2007. Banana and plantain—an overview with emphasis on Pacific island cultivars, ver. 1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR).

Pugh S. (1981), “Concept Selection: A Method that Works,” Proceedings of International Conference on Engineering Design, Heurista, Zürich, 497-506.

Reginio, F. C., Ketnawa, S., & Ogawa, Y. (2020). In vitro examination of starch digestibility of Saba banana [Musa ‘saba’(Musa acuminata × Musa balbisiana)]: impact of maturity and physical properties of digesta. Scientific Reports, 10, 1811.

Rodriguez-Amaya, D., & Kimura, M. (2004). HarvestPlus Handbook for Carotenoid Analysis. HarvestPlus Technical Monographs.

Salvador, A., Sanz, T., & Fiszman, S. (2007). Changes in colour and texture and their relationship with eating quality during storage of two different dessert bananas. Postharvest Biology and Technology, 43(3), 319–325.

Sahin, S., & Sumnu, S. G. (2006). Size, Shape, Volume, and Related Physical Attributes. Food Science Text Series, 1–37.

Shahir, Sultan, & Visvanathan, R. (2014). Changes in Colour Value of Banana var. Grand Naine during Ripening. Bioscience Trends, 7(9), 726–728.

Shahir, Sulthan, Rangaraju, V., Eyarkai, N. V., & Veerapandian, C. (2015). Modeling the mass of banana fruit by geometrical attributes. Scientific Journal of Agriculture Engineering, 91–99.

Sharma, V., Basu, S., Lal, S. K., Anand, A., Hossain, F., & Munshi, A. D. (2017). Chemical Science Review and Letters Comparison of Physical and Physiological Properties of Specialty Maize Inbred Lines. Chem Sci Rev Lett, 6(23), 1758-1763.

Soltani, M., Alimardani, R., & Omid, M. (2010). Prediction of Banana Quality during Ripening Stage Using Capacitance Sensing System. Australian Journal of Crop Science, 4(6), 443-447.

Soltani, M., Alimardani, R., & Omid, M. (2010). A New Mathematical Modeling of Banana Fruit and Comparison with Actual Values of Dimensional Properties. Modern Applied Science. 4(8):104-113

Soltani, M., Alimardani, R., & Omid, M (2010). Comparison of Some Chromatic, Mechanical and Chemical Properties of Banana Fruit at Different Stages of Ripeness. Modern Applied Science. 4(7), 34-41.

Soltani, M., Alimardani, R., & Omid, M (2010). Changes in physico-mechanical properties of banana fruit during ripening treatment. Journal of American Science, 7(5), 5–10.

Soltani, M., Alimardani, R., & Omid, M (2011). Modeling the Main Physical Properties of Banana Fruit Based on Geometrical Attributes. International Journal of Multidisciplinary Sciences and Engineering, 2(2), 1-6.

Soltani, M., Alimardani, R., & Omid, M (2011). Some physical properties of full-ripe banana fruit (Cavendish variety). International Journal of Agricultural Science, Research and Technology, 1(1), 1-5.

Soorianathasundaram, K., Narayana, C. K., & Paliyath, G. (2015). Bananas and Plantains. In Encyclopedia of Food and Health (1st ed.). Academic Press. 320-327

Staughton, J. (2021, June 25). 5 Proven Benefits of Saba Banana. Organic Facts. Retrieved July 1, 2021, from https://www.organicfacts. net/saba-banana.html.

Thompson, A. K., Supapvanich, S., & Sirison, J. (2019). Banana Ripening (1st ed.). Springer Publishing.

Tumin, S. A., & Shaharudin, A. A. (2019, February). Banana: The World's Most Popular Fruit. Khazanah Research Institute. http://www.krinstitute.org/ Views-@-Banana-;_The_Worlds_Most_ Popular_Fruit.aspx

Udroiu, R., & Bere, P. (2018). Product Lifecycle Management: Terminology and Applications [E-book]. Intechopen.

Ueda, M., Sasaki, K., Utsunomiya, N., & Shimabayashi, Y. (2001). Changes in Properties during Maturation and Ripening of "Chiin Hwang No.1" Mango Fruit Cultivated in a Plastic Greenhouse. Food Science and Technology Research, 7(3), 207–213.

Ulrich, K. T., & Eppinger, S. D. (2011). Product Design and Development, 5th Edition (5th ed.). McGraw-Hill Education.

Usenik, V., Kastelec, D., Veberič, R., & Štampar, F. (2008). Quality changes during ripening of plums (Prunus domestica L.). Food Chemistry, 111(4), 830–836.

Wakabayashi, K. (2000). Changes in Cell Wall Polysaccharides During Fruit Ripening. Journal of Plant Research, 113(3), 231–237.

Ware, M. R. (2020, January 13). Benefits and health risks of bananas. Medical News Today. Retrieved March 12, 2020, from https://www.medical newstoday.com/articles/271157

Warechowska, M. (2014). Some Physical Properties of Cereal Grain and Energy Consumption of Grinding. Agricultural Engineering, 149(1), 239-249.

Wasala, W. M. C. B., Dharmasena, D. A. N., Dissanayake, T. M. R., & Thilakarathne, B. M. K. S. (2015). Physical and Mechanical Properties of Three Commercially Grown Banana (Musa acuminata Colla) Cultivars in Sri Lanka. Tropical Agricultural Research, 24(1), 42-53.

Yahia, E. M., & Carrillo-Lopez, A. (2018). Postharvest physiology and biochemistry of fruits and vegetables. Elsevier B.V.

Yap, M., Fernando, W. M., Brennan, C. S., Jayasena, V., & Coorey, R. (2017). The effects of banana ripeness on quality indices for puree production. LWT, 80, 10–18.

Yemiş, O., Bakkalbaşı, E., & Artık, N. (2012). Changes in pigment profile and surface colour of fig (Ficus carica L.) during drying. International Journal of Food Science & Technology, 47(8), 1710–1719.

Zulkifli, N., Hashim, N., Abdan, K., & Hanafi, M. (2016). Evaluation of physicochemical properties of Musa acuminate cv. Berangan at different ripening stages. International Food Research Journal, 23, 97-100.