Vol. 14, No. 1, pp. 91-106, February 2026 DOI: https://doi.org/10.23960/jat.v14i1.10243

Jurnal Agrotek Tropika

P-ISSN: 2337-4993
E-ISSN: 2620-3138

Journal homepage: https://jurnal.fp.unila.ac.id/index.php/JA

STRATEGI PENINGKATAN KUALITAS TANAMAN PISANG *(Musa textilia)* BERDASARKAN FAKTOR LINGKUNGAN DAN JENIS IRIGASI

STRATEGY FOR IMPROVING THE QUALITY OF PLANTAIN (Musa textilia) BASED ON ENVIRONMENTAL FACTORS AND TYPES OF IRRIGATION

Rindra Yusianto[1]*, Rabei Raad Ali[2], and Pulung Nurtantio Andono[3]

[1]Department of Industrial Engineering, Faculty of Engineering, Universitas Dian Nuswantoro, Semarang, Indonesia
[2]Department of Computer Engineering Technology, Northern Technical University, Mosul, Iraq
[3]Department of Informatics Engineering, Faculty of Computer Science, Universitas Dian Nuswantoro, Semarang, Indonesia
* Corresponding Author. E-mail address: rindra@staff.dinus.ac.id

ARTICLE HISTORY:

Received: 16 January 2025
Peer Review: 04 February 2025
Accepted: 22 January 2026

KATA KUNCI:

Faktor lingkungan, iklim tropis, komoditas pertanian, pisang raja

ABSTRAK

Penelitian ini bertujuan untuk menentukan strategi yang paling efektif untuk meningkatkan kualitas budidaya pisang raja *(Musa textilia)* dengan mempertimbangkan faktor lingkungan dan metode irigasi. Penelitian ini melibatkan pengukuran komprehensif variabel ekologi—suhu, kelembaban, kadar air tanah—dan sifat fisik seperti kekerasan, kehilangan berat, dan perubahan warna. Dengan memanfaatkan teknologi IoT, sensor SHT_{11} dan pengukur hujan, data dikumpulkan dari 21 titik sampel di Karanganyar, Indonesia. Penelitian ini mengidentifikasi kondisi lingkungan yang optimal untuk budidaya pisang raja di iklim tropis. Tiga strategi irigasi—sederhana, semi-teknis, dan teknis—dievaluasi menggunakan metode kinetik. Temuan tersebut mengungkapkan korelasi yang signifikan (koefisien 0,76) antara variabel lingkungan dan faktor fisik, termasuk kekerasan, kehilangan berat, dan perubahan warna. Nilai kekerasan daging buah pisang terhadap penetrasi diukur menggunakan penetrometer rata-rata 0,4160 mm/5 detik untuk irigasi sederhana, 0,3093 mm/5 detik untuk irigasi semi-teknis, dan 0,3053 mm/5 detik untuk irigasi teknis. Penurunan berat tertinggi terjadi pada irigasi sederhana sebesar 7,32%, diikuti semi-teknis sebesar 1,21%, dan teknis sebesar 0,25%. Pada semua jenis irigasi, warna berubah dari kuning menjadi merah. Studi ini menyimpulkan bahwa irigasi teknis adalah metode yang paling efektif untuk membudidayakan pisang raja di iklim tropis, yang menawarkan wawasan berharga bagi petani dan pembuat kebijakan.

KEYWORDS:

Agricultural commodities, environmental factors, plantain, tropical climates

ABSTRACT

This research aims to determine the most effective strategy for improving the quality of plantain (Musa textilia) cultivation by considering environmental factors and irrigation methods. The study involved comprehensive measurements of ecological variables—temperature, humidity, soil water content—and physical properties such as hardness, weight loss, and color change. Utilizing IoT technology, specifically SHT_{11} *and rain-gauge sensors, data were collected from 21 sample points in Karanganyar, Indonesia. The study identified optimal environmental conditions for plantain cultivation in a tropical climate. Three irrigation strategies—simple, semi-technical, and technical—were evaluated using the kinetic method. The findings revealed a significant correlation (coefficient of 0.76) between environmental variables and physical factors, including hardness, weight loss, and color change. The firmness value of banana pulp against penetration, measured using a penetrometer, averaged 0.4160 mm/5 sec for simple irrigation, 0.3093 mm/5 sec for semi-technical irrigation, and 0.3053 mm/5 sec for technical irrigation. Weight loss was highest under simple irrigation at 7.32%, followed by semi-technical irrigation at 1.21%, and technical irrigation at 0.25%. Across all irrigation types, the color changed from yellow to red on average. The study concluded that technical irrigation is the most effective method for cultivating plantain in tropical climates, offering valuable insights for farmers and policymakers.*

1. INTRODUCTION

Agricultural commodities, including plantains *(Musa textilia)*, grow well in tropical and subtropical climates (Maseko *et al.*, 2024; Kumari *et al.*, 2023; Pareek, 2016). However, the cultivation of this commodity is different in the two climates. The tropical climate is around the equator at 23.5º N and 23.5º S. In this climate, the air humidity is more than 90%, the average rainfall is 1200 mm per year, the air pressure is low, the temperature is around 20 – 26^{0}C, and the area gets sunshine all year round (Douville *et al*., 2022). In contrast, the subtropical climate is usually north and south of the equator. Namely, 23.5^0 to 66.5^0 N and 23.5^0 to 66.6^0 S. Air humidity in subtropical climates is lower than in tropical climates. The lower humidity is due to the subtropical region having four seasons (Kim *et al*., 2023). Rainfall is evenly distributed between 750 mm to 1000 mm per year. In the summer, it experiences an arid drought; the average temperature is over 30 ^{0}C; in winter, it reaches -3^{0}C – 18^{0}C, and the natural conditions become humid and wet (Yin *et al*., 2024). The ten largest countries producing plantains are in Asia, Africa, North America, and South America, with tropical and sub-tropical climates (Table 1).

Environmental conditions in tropical climates greatly determine the quality of agricultural commodities such as oxygen, temperature, humidity, and soil water content (Yusianto *et al.*, 2023; Xu *et al.,* 2021). High temperatures can cause the respiration of commodities to run fast, so these commodities experience high weight loss and a decrease in freshness (Parthasarathi *et al*., 2022). Factors that cause a reduction in the quality and weight loss of agricultural commodities are reduced moisture content, mechanical damage, evaporation, and microbial growth (Stathers *et al*., 2020). Furthermore, high humidity and soil water content will trigger the development of spoilage microorganisms and product destroyers. In postharvest, exposure to sunlight will cause chemical and enzymatic damage, such as loss of vitamin C, discoloration, increased acidity, and other damage (Lee & Kader, 2000; Etefa *et al.*, 2022).

In plantain cultivation, environmental factors can be controlled based on the type of irrigation. Irrigation affects changes in environmental temperature, humidity, and soil water content (Gabr *et al*., 2024). According to Perez-Blanco *et al.,* (2020) irrigation consists of simple, semi-technical, and technical irrigation. *Simple irrigation* is an irrigation network without measuring structures or irrigation gates (Hidayat and Ferdina, 2020). When irrigation gates are installed, they are usually temporary. Simple irrigation management is a farmer or a group of farmers, so their equipment and ability to measure and regulate are limited. The available water is generally abundant and has a moderate to steep slope, making it easier to distribute. Irrigation networks are easy to set up because they involve farmers with the same social background. However, this type of irrigation has the disadvantage of wasting water due to a large amount of wastewater, where wasted water only sometimes reaches the more fertile soil below. Semi-technical irrigation has a basin structure and permanent buildings (Arbat and Masseroni, 2024). However, the system has been unable to regulate and measure water distribution, so this type of irrigation has more complex problems than other systems. The water distribution system is similar to a simple network. The water in this network can be regulated but cannot be measured. At the same time, technical irrigation is an irrigation system equipped with an irrigation gate to regulate the entry and exit of water and measuring devices (Arbat and Masseroni, 2024). This type of irrigation has a fixed exploitation structure. An irrigation gate building structure and a separation between the drain and feeder channels exist. Alignment and measurements were carried out from the infiltration building to the tertiary site. Level 3 plots have a central role in this irrigation. A map organization has been formed to expedite the irrigation service system, including primary, secondary, and tertiary plots as small units (Tirtalistyani *et al*., 2022).

Table 1. Plantain-Producing Countries in the World.

Country	Continent	Climate	Production (tons/year)
India	Asia	Tropical	20,460,000
China	Asia	Tropical, Sub Tropical	11,998,329
Indonesia	Asia	Tropical	7,280,659
Brazil	South America	Tropical, Sub Tropical	6,812,708
Ecuador	South America	Tropical	6,583,477
Philippines	Asia	Tropical	6,048,601
Guatemala	North America	Tropical	4,341,564
Angola	Africa	Tropical	4,046,959
Tanzania	Africa	Tropical	3,406,936
Columbia	South America	Tropical	2,914,419

Table 2. Plantain Fruit Taste and Texture.

Variety	Shape of fruit	Size	Taste/Texture
French	Long	Medium	Gently Sweet
French Horn	Long	Big	Slightly Sweet
False Horn	Short and Curved	Big	Mildly Sweet, Starchy
Horn	Very Long	Very Big	Less Sweet, Starchy

Plantains fruits have different physical properties, such as size, texture, and color. Plantains harvested at the right level of maturity will experience a perfect ripening process after being harvested (Bhuiyan *et al*., 2020). The cooking process is marked by a change in texture from hard to soft and a shift in color from green to yellow (Singh and Ramaswamy, 2023). The texture of the plantain fruit depends on several factors, including cultivation techniques and ripening procedures (Adi *et al*., 2019). Plantain tastes include gently sweet, slightly sweet, mildly sweet, and less sweet with a starchy texture (Table 2). Plantain, a crop that requires irrigation in terms of quantity and frequency, is greatly influenced by the infiltration rate, physical condition of the soil, soil capacity, water, and evapotranspiration. Understanding the physical condition of the soil is crucial in determining the right irrigation strategy (Nikolaou *et al*., 2020). The application of irrigation has been shown to increase bunch weight, fruit weight diameter, and fruit length (Ghazzawy *et al*., 2023). However, limited water availability often hinders timely nutrient delivery to banana plants. Many previous studies have shown that irrigation type, soil temperature, soil moisture content, rainfall, and humidity affect the postharvest quality of agricultural commodities. Different environmental factors interact with each other, further complicating the impact of environmental factors on the quality of agricultural commodities, such as hardness, weight loss, and discoloration (Liang *et al.,* 2024). Temperature, humidity, and soil water content affect the quality of the harvest of banana agricultural commodities, including the cultivation of plantain *(Musa textilia)*.

In this research, we studied the influence of environmental factors on agricultural commodities in banana cultivation. This research aims to determine the most effective strategy for improving the quality of plantain *(Musa textilia)* cultivation by considering environmental factors and irrigation methods. We measured environmental variables, namely temperature, humidity, and soil water content based on the type of irrigation, and physical variables, namely hardness, weight loss, and discoloration in plantain commodities in Karanganyar, Indonesia.

2. MATERIAL AND METHOD

2.1 Research Area

The research area, Karanganyar Regency, with an area of 77,378.64 ha, is located at coordinates 7° 36' 0" S, 110° 56' 0" E with the lowlands of the Bengawan Solo valley in the west and the Lawu mountains in the east (Figure 1). Karanganyar is one of the potential plantain-producing areas in Indonesia.

2.2 Materials

The research was conducted at the Laboratory of Applied Science, Packaging, Quality Control, Department of Agricultural Industrial Technology, Faculty of Agricultural Technology - IPB University, and in the Laboratory of Production Systems, Faculty of Engineering, Dian Nuswantoro University, Indonesia. We use penetrometers, thermometers, chromameters, RH meters, analytical balances, fruit scales, and other supporting equipment such as performance plastic, scissors, knives, cutters, markers, label paper, and clear tape. We used plantain samples from 21 points in the study area with simple, semi-technical and technical irrigation types. Our sample is coded with S_1 to S_{21}.

2.3 Research Framework

Measurements of air temperature, air humidity and soil moisture content were carried out based on the type of irrigation, namely simple irrigation, semi-technical irrigation and technical irrigation in banana cultivation in the study area (Figure 2). We measure it using IoT with the SHT_{11} and rain gauge sensors. We installed them at 21 sample points in the study area using random grid sampling. This research was conducted over a period of 10 months from planting to harvesting. Physically, the ripeness level of plantain can be recognised through the typical characteristics of a ripe fruit. Physically, plantain ripeness can be observed from changes in skin colour, texture, aroma, and fruit shape that indicate that the plantain has reached the ripe phase. The characteristics of a fully ripe plantain are as follows: 1) the plantains appear dense; 2) the flesh is no longer angular; 3) yellowish green color; for plantain fruit with full ripeness, then in the bunch, there is already ripe fruit (2-3 pieces); 4) stalks picked have fallen. We obtained data on temperature, humidity, and soil water content for each type of irrigation. Then, we measured three physical variables of plantain fruits, namely hardness *(Hd)*, weight loss *(WL)*, and discoloration *(Dc)*, for each plantain produced from three different types of irrigation treatment: simple, semi-technical, and technical irrigation.

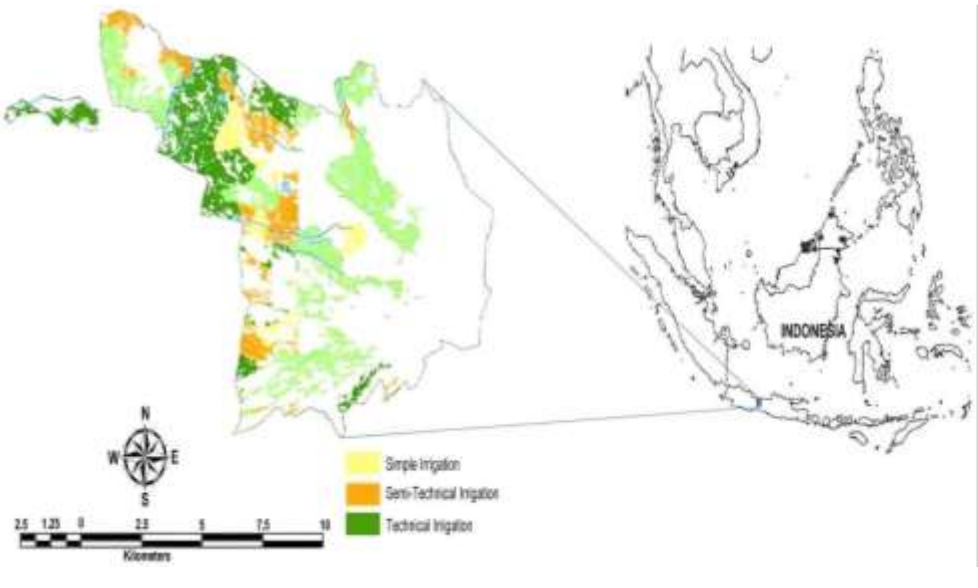


Figure 1. Research area location.

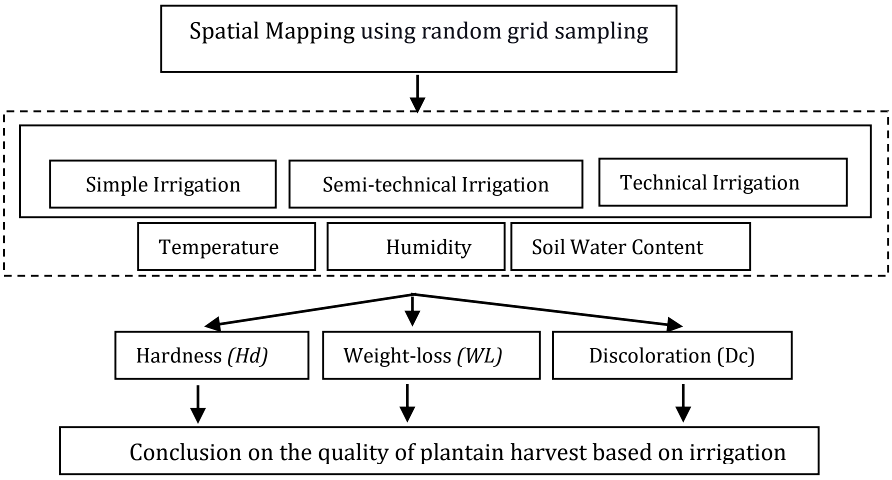


Figure 2. Research Framework.

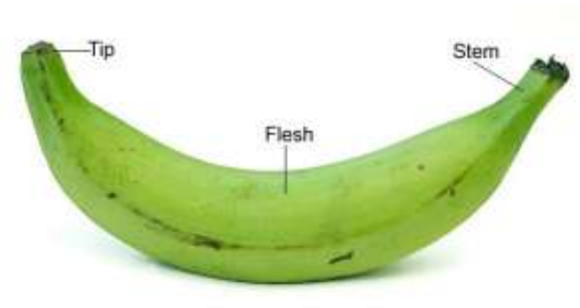


Figure 3. The part of plantain.

2.1.1 Hardness (Hd)

Hd is an objective quality parameter to see the quality of agricultural commodities such as plantains. The rate of change in fruit firmness is influenced by moisture content, fat content, fruit carbohydrates such as cellulose and pectin, and protein during the fruit ripening process. Some of these ingredients cause a change in texture from hard to softer texture (Liu *et al*., 2024). Naturally, the fruit at the base ripens earlier than the fruit underneath in plantains. Ripening of plantain fruit starts from the tip of the fruit. During the ripening process of plantains, there is an increase in water content; when the fruit is ripe, it reaches 77.19%, and when it is very ripe, it reaches 79.01%. The increase in water content during in the fruit ripening process greatly affects the hardness of plantains fruits, where the fruits plantains will become softer with increasing water content (Ayeh *et al*., 2023).

We measured the *Hd* at three different points: the stem, the flesh, and the tip of the plantain fruits every day for five days (Figure 3). Plantain hardness was measured quantitatively using a penetrometer. We set the tool at a load of 10 g with a distance of 0.05 cm to 0.3 cm needle prick into the fruit flesh for 5 seconds. The deeper the needle is inserted into the fruit flesh, the softer the plantain. Measurements were made thrice at different locations; the hardness value was then averaged. The hardness value is displayed on the screen in mm/5 seconds, representing the depth of probe penetration into the fruit pulp during a 5-second measurement period, where higher values indicate softer fruit and lower values indicate firmer texture. Plantains have a maturity level of 4-8 days better than other banana commodities.

2.1.2 Weight-Loss (WL)

After harvest, the plantains experience a decrease in weight due to water loss. The drying rate negatively correlates with fruit ripening time; the higher the *WL* rate, the shorter the fruit ripening time. Postharvest water loss significantly impacts fruit and vegetable quality and is a significant cause of spoilage. The economic impact of considerable water losses, resulted from substantial fresh *WL*, underscores the urgency of addressing this issue, especially when commodities are sold by weight. *WL* occurred during storage for the evaluated fruit or vegetable type. However, the rate of water loss depends on the type of crop being assessed and is strongly related to the physiological and morphological characteristics of each fruit or vegetable and the expected shelf-life under the environmental conditions used (Gidado *et al*., 2024).

The precision and reliability of our research is demonstrated by the use of an analytical balance in measuring fruit weight loss. This measurement was carried out by comparing the weight of the plantain fruit before storage and at the end when the fruit reached the color scale index 6. The formula used is (Equation (1)) (Kader *et al*., 2002):

$$\%WL = \frac{A-B}{A} \times 100\% \qquad (1)$$

Note: A= Storage initial sample weight (g), B= Sample weight at the time of collection after storage time (g).

2.1.3 Discolorations (Dc)

The color measurement uses international color measurement standards obtained from Commission Internationale d'Eclairage (CIE), which produce values L, *a, *b. The Lightness (L) value is between 0 and 100, where 0 is dark or black, and 100 is bright or white. Meanwhile, a* value is between -120 and 120, where a negative value indicates green and a positive value indicates red. The b* value is between -120 to 120, where a negative value indicates a blue color and a positive value indicates a yellow color change. *Chroma* is a term that describes the brightness or discoloration of a food ingredient. The higher the chroma value, the higher the brightness for that color; conversely, the lower the chroma value, the lower the brightness of the material in question. During the fruit ripening process, chlorophyll degradation occurs, followed by the formation of new pigments. Furthermore, the magnesium (Mg) content resulted in a decrease in ripe and very ripe fruit. This decrease is related to the degradation of chlorophyll and the formation of carotenoid pigments, which will produce the characteristic color of plantains, namely yellow when ripe (Ohno, 2000).

In addition, we measured the percentage reduction in the weight of plantain fruits by weighing plantains on day 0 after harvest and re-weighing on each day of observation using an analytical balance. Then, we measure the color change. The response of label color changes to volatile acids was measured using a colorimeter. The measurement table will obtain L, a, and b values. On discoloration, we calculate the Croma value using Equation (2) (Markovic *et al*., 2013).

$$C = \sqrt{a^2 + b^2} \qquad (2)$$

Note: C= the Croma value, a= is the red/green coordinate, and b= is the yellow/blue coordinate.

The value of ^{0} hues using Equation (3) (CIELAB 2013).

$$^0\text{hue} = \tan^{-1}\left(\frac{b}{a}\right) \qquad (3)$$

In 1931, the Vienna-based international standards body, the International Commission on Illumination, devised a mathematical model to describe all colors visible to the human eye numerically—the CIE XYZ Color Space. CIE XYZ became the basis of several successive, more refined colorimetric systems for measuring and specifying color. In addition to CIE XYZ, systems include CIE

LUV (L, *u, *v), CIELAB (L, *a, *b), and CIE LCH (L, *C, *h). Unlike RGB and CMYK color models, color definitions characterized by CIE systems are unambiguous, absolute, and device-independent—i.e., not tied to, influenced by, or dependent on the characteristics or capabilities of any color capturing or rendering device. The attribute system in CIELAB can be seen in the Figure 4.

CIELAB, the reference color model used by the paper-making and graphic arts industries, is not just a tool. It's the very foundation of your work in color management. It's the ICC profile connection space used for gamut mapping, guiding you in achieving accurate and consistent colour reproduction. The basic architecture and operating premise of CIELAB are based on scientific theory demonstrating that the brain translates retinal color stimuli into distinctions between light and dark (lightness) and between mutually exclusive zones of opposing colors: red/green and blue/yellow. The CIELAB color model (Equation (4)): L* = Lightness; the lightness or darkness of a color; a* = red to green (+a = redder, -a = greener); b* = yellow to blue (+b = yellower, -b = bluer); Where the two “color” axes intersect = neutral gray.

$$\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)} \tag{4}$$

Note: $\Delta L = L_{sample} - L_{standard}$, $\Delta a = a_{sample} - a_{standard}$, $\Delta b = b_{sample} - b_{standard}$

Determination of the visual chromatic color range area is carried out using the hue values listed in Table 3. Several numeric-based models or systems exist for measuring, specifying, and categorizing colors by assigning reference points that define hue, saturation, and lightness. Three-dimensional color specification systems must include methods to individually assign data points to the three components of color about independent axes, emphasizing the complexity and depth of color science. One axis will characterize lightness/brightness separately, while two axes form a chromatic plane where numeric coordinates define the color. Equation 5 shows the basic equation of zero-order reaction kinetics (Vallance, 2024).

$$Q_t = Q_0 - kt \tag{5}$$

Note: Qt = color change at time t = t; Q0 = color change at time t = 0; k = reaction rate constant; t = time (days).

A reaction is said to have first order if the reaction rate is directly proportional to the concentration of the reactant. If the reactant concentration is increased twice, the reaction rate will also increase by 2 times. Equation 6 shows the basic equation of first-order reaction kinetics (Equation (6)) (Vallance, 2024).

$$Qt = Q0\ e^{-kt} \tag{6}$$

Note: Qt = color change at time t = t; Q_0 = color change at time t = 0; k = reaction rate constant; t = time (days).

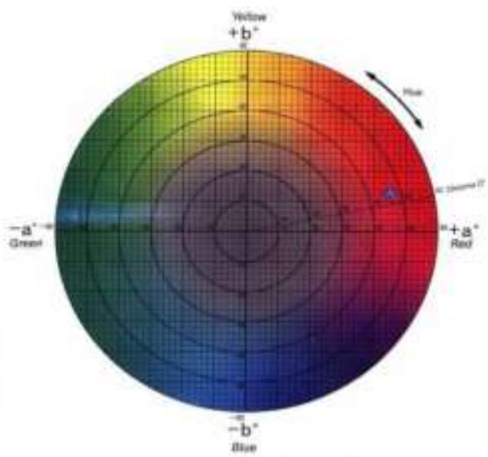


Figure 4. The attribute system in CIELAB. Source : CIELAB (2013).

Table 3. Determination of The Visual Chromatic Color Range Area.

No	^{0}hue value	Color range area
1	342° - 18°	purple - red
2	18° - 54°	red
3	54° - 90°	red - yellow
4	90° - 126°	yellow
5	126° - 162°	yellow - green
6	162° - 198°	green
7	198° - 234°	blue – green
8	234° - 270°	blue
9	270° - 306°	blue - purple
10	306° - 342°	purple

Source : CIELAB (2013).

Table 4. Irrigation Streams' Temperature.

Sample	Temperature			TDS (mg/L)	DHL (ds/m)	Suitability
	Water (^{0}C)	Air (^{0}C)	Deviation (^{0}C)			
1	33	31	2.0	1,323.0	1.67	Suitable
2	30	31	1.0	1,150.0	1.68	Suitable
3	32.5	29.5	3.0	1,560.0	2.19	Suitable
4	32.5	29.5	3.0	1,475.0	1.60	Suitable
5	28.5	32	3.5	390.5	0.59	Suitable
6	27.5	32	4.5	412.5	0.57	Suitable
7	29	34.5	5.5	867.5	1.18	Suitable
8	28.5	31	2.5	740.5	1.09	Suitable
9	29.5	31	1.5	199.0	0.30	Suitable
10	30	33	3.0	379.5	0.49	Suitable
11	31.5	33	1.5	312.0	0.57	Suitable
12	29	34.5	5.5	867.5	1.18	Suitable
13	29	34.5	5.5	505.0	0.79	Suitable
14	31.5	31	0.5	1,295.0	0.67	Suitable
15	28.5	31	2.5	740.5	1.09	Suitable
16	31	30.5	0.5	1,410.0	0.66	Suitable
17	30	30.5	0.5	807.5	0.80	Suitable
18	30	31	1.0	914.5	1.01	Suitable
19	30.5	31	0.5	624.0	1.14	Suitable
20	29.5	31	1.5	199.0	0.30	Suitable
21	29	31	2.0	187.00	0.29	Suitable

Note: TDS = Total dissolved solids.

3. RESULT AND DISCUSSION

We studied the influence of environmental factors on the fruit physical properties in plantain cultivation in tropical climates by measuring environmental variables, namely temperature, humidity, and soil water content based on irrigation type, and physical variables of the fruits, namely hardness, weight loss, and color changes in Karanganyar, Indonesia. Figure 5 shows that for most areas in Karanganyar, Indonesia, the irrigation system is directly proportional to the level of plantain production.

3.1 Environmental Variables

The environmental variables show the irrigation streams' temperature deviation, humidity, and soil water content. Temperature deviation is the difference between water temperature and air temperature (Table 4). The temperature deviation is greatest at samples number 12 and 13, which is 5.5 ^{0}C, which means it is not by the quality standard because it is above the water quality standard, 5.0 ^{0}C, while at other points, it is at 0.5 – 3.5 ^{0}C (Sremac *et al.*, 2021). In the observation of water temperature, the lowest water temperature occurred at point 3, 27.5 ^{0}C and the highest temperature at point 1, 33 ^{0}C.

Based on Table 4, The lowest temperature for growing plantain fruit is 27.5 ^{0}C, and the highest temperature is 33 ^{0}C. Based on experiments, the average relative humidity (RH) for simple irrigation was 69.7%, semi-technical 74.5%, and technical 77.6%. Based on research by Andreux (1996), plantains grow well in soil with a high humus content, a clay content below 40% with neutral to slightly acidic pH (pH 5.5-7.0). Plantains grow well in soil with sufficient water content with the ideal groundwater depth usually between 50-150 cm below the soil surface, good drainage, and consistent soil moisture stability, namely, constantly moist but not wet soil.

3.2 Average Hardness *(Hd)*

The results of piercing with a penetrometer on plantain using simple, semi-technical, and technical irrigation treatment on each part showed an average hardness (Table 5). The average *Hd* of plantain in simple-type irrigation is 0.4160 mm/5 sec, semi-technical 0.3093 mm/5 sec and technical 0.3053 mm/5 sec. This difference in Hd value occurs due to the different levels of efficiency and water flow control in each type of irrigation. Simple systems have the greatest energy loss due to uncontrolled channel conditions, while technical systems are most efficient in maintaining water pressure and flow, resulting in the lowest Hd values. The decrease in Hd along with the improvement of irrigation technology indicates an increase in efficiency in delivering water to plantain plants.

Table 5. Average Hardness Based on Type of Irrigation.

Day	Type of irrigation	The Part of plantain			Average	Hardness (mm/5 sec)
		Stem	Flesh	Tip		
0	Simple	2	0.6	4.2	2.2667	0.4533
	Semi-technical	n.a.	n.a.	n.a.	0.0000	0.0000
	Technical	n.a.	n.a.	n.a.	0.0000	0.0000
1	Simple	1.9	2.4	3.1	2.4667	0.4933
	Semi-technical	2.8	2.8	3.2	2.9333	0.5867
	Technical	2.2	1.4	3.9	2.5000	0.5000
2	Simple	1.9	1.6	2.1	1.8667	0.3733
	Semi-technical	3.3	2.1	3	2.8000	0.5600
	Technical	1.4	0.8	1.4	1.2000	0.2400
3	Simple	1.4	1.1	1.8	1.4333	0.2867
	Semi-technical	1.2	1.3	1.6	1.3667	0.2733
	Technical	2	3.6	2.1	2.5667	0.5133
4	Simple	2.1	2.2	2.8	2.3667	0.4733
	Semi-technical	0.8	0.8	0.3	0.6333	0.1267
	Technical	2.1	0.7	1.3	1.3667	0.2733

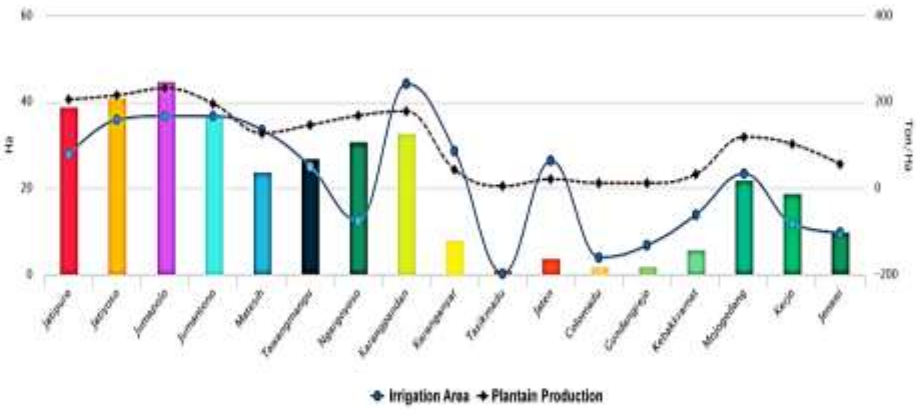


Figure 5. Irrigation area in Karanganyar, Indonesia. Source : Modified from Perceka and Aditya (2021).

3.3 Weight Loss Based on Irrigation Type

The number of samples is 7 for each type of irrigation. We took samples from 21 locations that we had previously mapped spatially. Table 6 shows the average weight of plantain during observation. We use Equation (1) to calculate the weight loss percentage to obtain the weight loss for plantains (Table 7). After we averaged, the highest weight loss occurred for simple irrigation at 7.32%, semi-technical irrigation at 1.21% and technical irrigation at 0.25%. The highest weight loss of 7.32% in the simple irrigation system was caused by the instability and limited water supply received by the plants. This system generally relies solely on rainfall or open water flow without controlled regulation, so plants often experience water stress, especially during the dry season. Lack of water causes the stomata to close to reduce transpiration, which leads to disruption of photosynthesis, suboptimal fruit growth, and a drastic drop in fruit moisture content during post-harvest.

This decrease in moisture content causes greater weight loss during storage. In contrast, the semi-technical irrigation system showed a lower weight loss of 1.21%. This is because these systems have started to use more regular channels and are sometimes equipped with water distribution controls, although they are not fully automated or scheduled. The water supply is more stable than the simple system, allowing the plants to grow more optimally and maintain the moisture content in the fruit better. Meanwhile, technical irrigation showed the lowest weight loss, at only 0.25 per cent. This is due to systems that have utilised efficient and controlled irrigation management technologies, such as drip irrigation or automatic sprinklers, which ensure plants receive the water they need consistently. Optimal water availability supports plant metabolism, enhances the synthesis of bioactive compounds, maintains fruit moisture balance, and minimises postharvest respiration and transpiration. As a result, weight loss during storage is minimal.

Table 6. Average Weight of Plantain Based on Type of Irrigation.

Type of Irrigation/Sample		Days (g)				
		0	1	2	3	4
Simple	1	96.96	92.95	91.26	89.72	85.7
	2	109.84	104.72	102.99	101.16	94.72
	3	102.44	97.18	95.67	93.78	88.51
	4	83.47	80.31	79.13	77.76	72.52
	5	85.91	83.3	82.44	81.42	78.38
	6	82.99	78.92	77.6	76.2	70.82
	7	91.25	88.06	86.71	85.5	81.69
Semi-Technical	8	82.91	82.21	82.06	81.95	81.69
	9	97.91	97.69	97.52	97.35	97.01
	10	73.41	73.21	73.08	72.86	72.57
	11	81.18	80.98	80.85	80.7	80.47
	12	70.69	70.53	70.31	70.04	69.64
	13	80.34	80.18	79.99	79.62	79.31
	14	77.8	77.14	76.96	76.79	76.47
Technical	15	86.04	85.95	85.91	85.86	85.64
	16	78.91	78.69	78.63	78.58	78.41
	17	82.73	82.7	82.59	82.55	82.41
	18	82.09	81.86	81.74	81.7	81.64
	19	81.93	81.86	81.89	81.9	81.61
	20	84.27	84.22	84.16	84.22	83.96
	21	88.15	88.07	88.04	88.03	87.86

Table 7. The Weight Loss Percentage Based on Type of Irrigation.

Type of Irrigation /Sample		Days (%)				Average (%)
		1	2	3	4	
Simple	1	4.1357	5.8787	7.4670	11.6130	7.2736
	2	4.6613	6.2363	7.9024	13.7655	8.1414
	3	5.1347	6.6087	8.4537	13.5982	8.4488
	4	3.7858	5.1995	6.8408	13.1185	7.2362
	5	3.0381	4.0391	5.2264	8.7650	5.2672
	6	4.9042	6.4948	8.1817	14.6644	8.5613
	7	3.4959	4.9753	6.3014	10.4767	6.3123
Semi-Technical	8	0.8443	1.0252	1.1579	1.4715	1.1247
	9	0.2247	0.3983	0.5720	0.9192	0.5286
	10	0.2724	0.4495	0.7492	1.1443	0.6539
	11	0.2464	0.4065	0.5913	0.8746	0.5297
	12	0.2263	0.5376	0.9195	1.4854	0.7922
	13	0.1992	0.4356	0.8962	1.2821	0.7033
	14	0.8483	1.0797	1.2982	1.7095	4.1549
Technical	15	0.1046	0.1511	0.2092	0.4649	0.2325
	16	0.2788	0.3548	0.4182	0.6336	0.4214
	17	0.0363	0.1692	0.2176	0.3868	0.2025
	18	0.2802	0.4264	0.4751	0.5482	0.4325
	19	0.0854	0.0488	0.0366	0.3906	0.1404
	20	0.0593	0.1305	0.0593	0.3679	0.1543
	21	0.0908	0.1248	0.1361	0.3290	0.1702

Table 8. Zero-Order Reaction Kinetics in Simple Irrigation.

Day	ΔE	$Q_t = Q_0 - kt$
0	0.00	0.00
1	2.09	-22.93
2	89.41	-45.86
3	94.83	-68.80
4	68.29	-91.73

3.4 Zero Order Reaction Model Kinetics

Quality reduction based on zero reaction order is a constant quality reduction. A chemical reaction is said to have zero order if the concentration of the reactants does not influence the response rate. No matter how much the reactant concentration increases, it will not affect the magnitude of the response. Based on Equation (5), zero-order reaction kinetics measurements were obtained on days 0 to 4 (Table 8). We then made a graph of stem plantain observations on simple irrigation using the Sigma Plot tool (Figure 6). We obtained Y = 22.932 X – 17.872 with R^2 = 0.6052. The value of gradient value (a) = 22.932 means that every 1 unit increase in X will be followed by a 22.932 unit increase in Y. This indicates a positive relationship between X and Y. In the same way, we obtain a graph of flesh plantain observations on simple irrigation (Figure 7), we obtained Y = 4.7220 X – 7.8325 with R^2 = 0.7771 and value a = 4.7220. We obtain a graph of tip plantain observations on simple irrigation (Figure 8). We obtained Y = 6.3000 X – 9.6378 with R^2 = 0.8037 and value a = 6.3000. Zero-order reaction kinetics per section on plantain fruit as in Table 9.

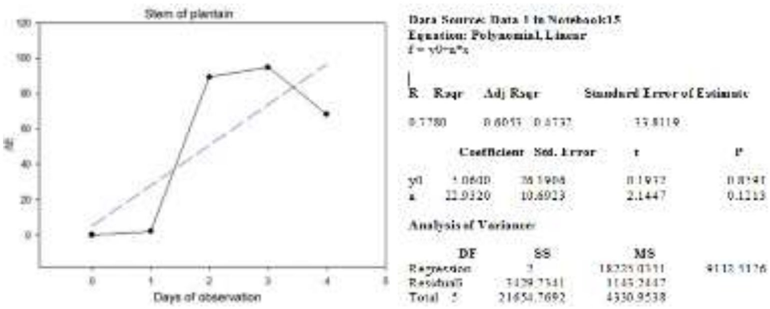


Figure 6. Growth Chart of Plantain Stems under Simple Irrigation.

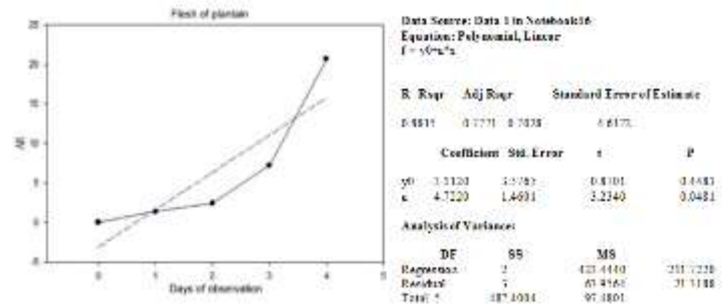


Figure 7. Growth Chart of Plantain Flesh under Simple Irrigation.

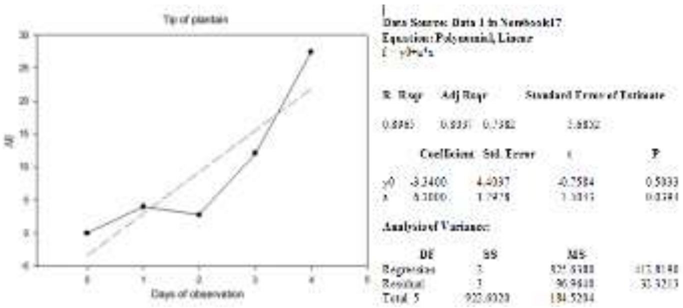


Figure 8. Growth Chart of Plantain Tip under Simple Irrigation.

Table 9. Zero-Order Reaction Kinetics per Section on Plantain Fruit

Day	Q_t Stem	Q_t Flesh	Q_t Tip
0	0.00	0.00	0.00
1	-22.93	-4.72	-6.30
2	-45.86	-9.44	-12.60
3	-68.80	-14.17	-18.90
4	-91.73	-18.89	-25.20

Using the Sigma Plot tool, we created a zero-order graph for simple irrigation (Figure 9). In the same way, we obtain zero-order graphs for semi-technical and technical irrigation using the Sigma Plot tool (Figure 10). Based on calculations using the Sigma Plot tool, it shows that the three environmental variables of temperature, humidity, and soil water content have a significant relationship with the physical factors of hardness, weight loss, and discolouration. The correlation coefficient for the water temperature variable is 0.81, humidity 0.82, and soil water content 0.65 so that the average of the three variables is a correlation coefficient of 0.76.

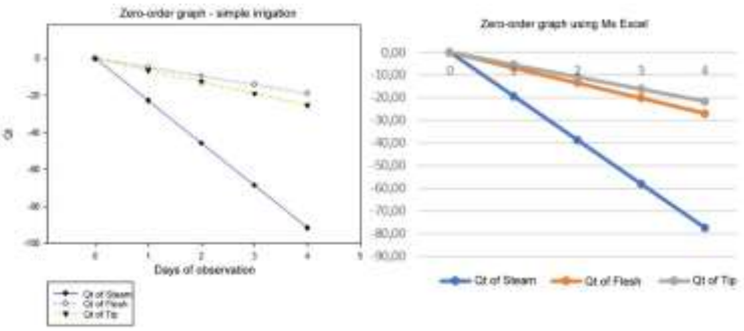
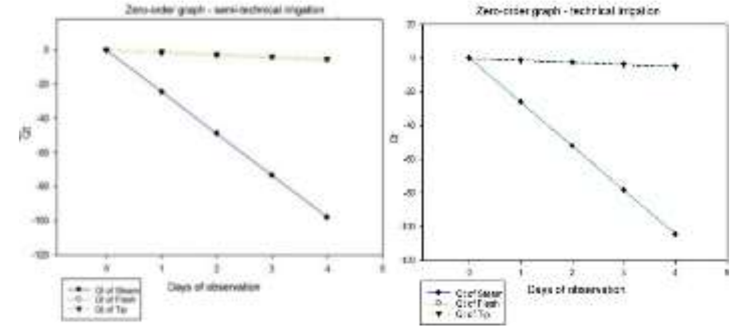


Figure 9. A zero-order graph for simple irrigation.



(a) (b)

Figure 10. (a) A zero-order graph for semi-technical irrigation, (b) technical irrigation.

Table 10. Stem Plantains in Simple Irrigation With First-Order Kinetics.

Day	ΔE	Kt	ln kt	$Q_t = Q_0 - kt$
0	0.00	0	n.a.	n.a.
1	2.09	22.932	-3.13	-6.54
2	89.41	45.864	-3.83	-342.07
3	94.83	68.796	-4.23	-401.25
4	68.29	91.728	-4.52	-308.59

3.5 Kinetics of First Order Reaction Models

At this stage, we calculate plantains in simple irrigation with first-order kinetics in the stem, flesh, and tip sections. Then, we compared semi-technical and technical irrigation, and finally, we made a first-order kinetics graph for each type of irrigation. Stem plantains in simple irrigation with first-order kinetics as in Table 10. We also calculated the first-order kinetics for the flesh and tip in simple irrigation to construct a first-order graph (Figure 11). In the same way, we obtain First-Order Graphs for semi-technical and technical irrigation using the Sigma Plot tool (Figure 12).

Based on data from observations with three treatments, namely simple, semi-technical, and technical irrigation, weight loss has occurred, with the highest weight loss of plantain fruits was under simple irrigation, followed by semi-technical and technical irrigation, followed by semi-technical and technical irrigation. The results of this research are in line with research by Mekonnen *et al.,* (2022) which indicated that technical irrigation results in lower weight loss of agroindustry commodities. Also, Ahmed (2022) research states that technical-type of irrigation reduces the weight loss of agricultural commodities. For hardness, simple irrigation treatment shows faster softening occurs quicker than semi-technical and technical. According to the statements of Kumari *et al.,* (2023) and Magda *et al.,* (2022) technical irrigation can extend the shelf life of agricultural commodities. In all types of irrigation, we obtained an average colour ^{0}hue value of 54^0, meaning that the color changed from yellow to red and yellow.

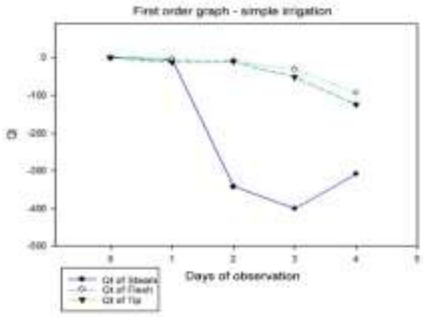
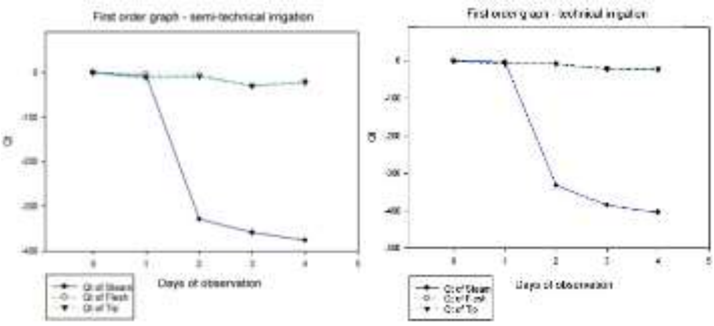


Figure 11. The first-order kinetics in simple irrigation.



(a) (b)

Figure 12. (a) The first-order kinetics in semi-technical irrigation, (b) technical irrigation.

Meanwhile, all kinds of irrigation produce relatively similar kinetic models for zero-order and first-order reactions. The results of this research are in line with Zhao *et al*., (2023) and Setyadjit *et al.,* (2017) which indicated that kinetic models for both zero-order and first-order reactions for horticultural food commodities have relatively similar graphs. These findings can contribute significantly to agricultural research and inspire further exploration and innovation, farmers can implement innovations in IoT-based smart irrigation, renewable energy-based modular technical irrigation and AI-based prediction and monitoring systems.

4. CONSLUSIONS

The results showed that all environmental variables had a considerable relationship with physical factors, where the correlation coefficient for the water temperature variable was 0.81, humidity 0.82, and soil moisture content 0.65 so that the average of all these variables had a correlation coefficient of 0.76. It includes hardness index, weight loss, and color change. The average hardness in simple-type irrigation is 0.4160 mm/5 sec, semi-technical 0.3093 mm/5 sec and technical 0.3053 mm/5 sec. The highest weight loss occurred for simple irrigation at 7.32%, semi-technical at 1.21%, and technical at 0.25%. On average, for all types of irrigation, the color changes from yellow to red. Our study also concluded that technical irrigation is the most suitable for plantain cultivation. These findings can contribute significantly to agricultural research and inspire further exploration and innovation, farmers can implement innovations in IoT-based smart irrigation, renewable energy-based modular technical irrigation and AI-based prediction and monitoring systems.

5. REFERENCES

Adi, D.D., I.N. Oduro, & C. Tortoe. 2019. Physicochemical changes in plantain during normal storage ripening. *Scientific African Elsevier B.V.* 6(1): 1–12.

Ahmed, M.H. 2022. Impact of irrigation on farm household diet quality: Evidence from Ethiopia. *Irrigation and Drainage.* 71(4): 1089–1106.

Andreux, F. 1996. Humic substances in terrestrial ecosystems. in: *Humic Substances In Terrestrial Ecosystems.* pp. 45–100.

Arbat, G., & D. Masseroni. 2024. The use and management of agricultural irrigation systems and technologies. *Agriculture (Switzerland).* 14(2): 1–5.

Ayeh, E.S., E. Asiamah, A.A. Boakye, F.D. Wireko-Manu, E. Aryeetey, & I.N. Oduro. 2023. Effects of ripening stages and thermal treatment on quality characteristics of the overripe plantain puree. *Journal of Agriculture and Food Research Elsevier B.V.* 14(6): 1–6.

Bhuiyan, F.R., N.A. Campos, R. Swennen, & S. Carpentier. 2020. Characterizing fruit ripening in plantain and Cavendish bananas: a proteomics approach. *Journal of Proteomics* Elsevier 214(10): 1–11.

CIELAB. 2013. *Defining and Communicating Color : The CIELAB System.* Sappi Fine Paper North America.

Douville, H., S. Qasmi, A. Ribes, & O. Bock. 2022. Global warming at near-constant tropospheric relative humidity is supported by observations. *Communications Earth and Environment Springer US.* 3(1): 1–7.

Etefa, O.F., S.F. Forsido, M.T. Kebede. 2022. Postharvest loss, causes, and handling practices of fruits and vegetables in Ethiopia: scoping review. *Journal of Horticultural Research.* 30(1): 1–10.

Gabr, M.E., A. Awad, & H.N. Farres. 2024. Irrigation water management in a water-scarce environment in the context of climate change. *Water, Air, and Soil Pollution Springer International Publishing.* 235(2): 1–19.

Ghazzawy, H.S., N. Alqahtani, M. Munir, N.S. Alghanim, & M. Mohammed. 2023. Physicochemical properties of date palm fruits. *Plants.* 12(1003): 1–28.

Gidado, M.J., A.A.N. Gunny, S.C.B. Gopinath, A. Ali, C. Wongs-Aree, & N.H.M. Salleh. 2024. Challenges of postharvest water loss in fruits: Mechanisms, influencing factors, and effective control strategies – A comprehensive review. *Journal of Agriculture and Food Research Elsevier B.V.* 17(5): 1–13.

Hidayat, A., & D. Ferdina. 2020. Planning optimization planning irigation area of Solok Sumatera West Regency. *IJEEIT : International Journal of Electrical Engineering and Information Technology* 2(2): 41–60.

Kader, A.A., R.L. Cook, C.M. Bruhn, M.S. Reid, & J.F. Thompson. 2002. *Postharvest Technology of Horticulture Crops.* University of California. Agriculture and Natural Resources. 535 p.

Kim, J.B., S.H. Kim, & D.H. Bae. 2023. The impacts of global warming on arid climate and drought features. *Theoretical and Applied Climatology Springer Vienna.* 152(1–2): 693–708.

Kumari, P., Gaur, S. S., and Tiwari, R. K. 2023a. Banana and its by-products: a comprehensive review on its nutritional composition and pharmacological benefits. *EFood.* 4(5): 1–23.

Kumari, S., R. Kumar, Y.K. Singh, K. Karuna, S. Kumar, A.K. Rai, R. Kumar, K. Madhumala, K. Nandita, & R. Kumar. 2023b. Effect of different levels of irrigation on plant growth and yield of mango cv. Langra. *Current Journal of Applied Science and Technology.* 42(6): 19–25.

Lee, S.K., & A.A. Kader. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology.* 20(3): 207–220.

Liang, L., Y. Song, Z. Shao, C. Zheng, X. Liu, & Y. Li. 2024. Exploring the causal relationships and pathways between ecological environmental quality and influencing factors: a comprehensive analysis. *Ecological Indicators Elsevier Ltd.* 165(5): 1–14.

Liu, Z., X. Yan, P. Wang, Z. Liu, L. Sun, & X. Li. 2024. Changes in fruit texture and cell structure of different pumpkin varieties (lines) during storage. *Postharvest Biology and Technology Elsevier B.V.* 208(10): 1–11.

Magda, M., H. Zeinab, M. Hegazy, & M. Nagy. 2022. Saving irrigation water and its effect on thompson seedless grape productivity and fruit shelf life quality. *Journal of Sustainable Agricultural and Environmental Sciences.* 1(10): 195–209.

Markovic, I., J. Ilic, D. Markovic, V. Simonovic, & N. Kosanic. 2013. Color measurement of food products using CIE L * a * b * and RGB color space. *Journal of Hygienic Engineering and Design.* 4(1): 50–53.

Maseko, K.H., T. Regnier, B. Meiring, O.C. Wokadala, & T.A. Anyasi. 2024. Musa species variation, production, and the application of its processed flour: A review. *Scientia Horticulturae Elsevier B.V.* 325(8): 1–16.

Mekonnen, D.K., J. Choufani, E. Bryan, B. Haile, & C. Ringler. 2022. Irrigation improves weight-for-height z-scores of children under five, and women's and household dietary diversity scores in Ethiopia and Tanzania. *Maternal and Child Nutrition.* 18(4): 1–11.

Nikolaou, G., D. Neocleous, A. Christou, E. Kitta, & N. Katsoulas. 2020. Implementing sustainable irrigation in water-scarce regions under the impact of climate change. *Agronomy*. 10(8): 1–33.

Ohno, Y. 2000. CIE Fundamentals for color measurements. in: *International Conference on Digital Printing Technologies.* pp. 540–545.

Pareek, S. 2016. *Nutritional and Biochemical Composition of Banana (Musa spp.) Cultivars*. *Nutritional Composition of Fruit Cultivars.* Elsevier Inc. 37 p.

Parthasarathi, T., S. Firdous, E.M. David, K. Lesharadevi, & M. Djanaguiraman. 2022. Effects of high temperature on crops. *Intech.* 11(1): 1–18.

Perceka, D.U., & T. Aditya. 2021. Pembuatan sistem informasi irigasi dan kebutuhan air dengan standard dan mekanisme akses berbasis infrastruktur data geospasial untuk irigasi pertanian di Kabupaten Karanganyar. *JGISE: Journal of Geospatial Information Science and Engineering* 4(1): 1–15.

Perez-Blanco, C.D., A. Hrast-Essenfelder, & C. Perry. 2020. Irrigation technology and water conservation: a review of the theory and evidence. *Review of Environmental Economics and Policy.* 14(2): 216–239.

Setyadjit, S., E. Sukasih, & A.B. Arif. 2017. Prediction of storage life of shallot powder by using acceleration method. *International Journal of Agriculture System.* 5(2): 140–153.

Singh, H., & H.S. Ramaswamy. 2023. Thermal processing of acidified vegetables: effect on process time-temperature, color and texture. *Processes.* 11(4): 1–14.

Sremac, A.F., B. Lalic, J. Cuxart, & M. Marcic. 2021. Maximum, minimum, and daily air temperature range in orchards: What do observations reveal?. *Atmosphere.* 12(10): 1–22.

Stathers, T., D. Holcroft, L. Kitinoja, B.M. Mvumi, A. English, O. Omotilewa, M. Kocher, J. Ault, & M. Torero. 2020. A scoping review of interventions for crop postharvest loss reduction in sub-Saharan Africa and South Asia. *Nature Sustainability Springer US.* 3(10): 821–835.

Tirtalistyani, R., M. Murtiningrum, & R.S. Kanwar. 2022. Indonesia rice irrigation system: time for innovation. *Sustainability (Switzerland).* 14(19): 1–19.

Vallance, C. 2024. Reaction kinetics. *Treatise on Process Metallurgy*. 1: 681-753.

Xu, H., X. Wang, C. Zhao, S. Shan, & J. Guo. 2021. Seasonal and aridity influences on the relationships between drought indices and hydrological variables over China. *Weather and Climate Extremes Elsevier B.V.* 34(1): 1–13.

Yin, Y., H. Ke, Y. Tu, X. Wang, Y. Chen, & S. Jiao. 2024. Changes of summer meteorological drought and their relationship with the dry and wet circulation patterns in the Huai River basin, China. *Journal of Hydrology: Regional Studies Elsevier B.V.* 52(2): 1–16.

Yusianto, R., G.F. Shidiq, H. Suprijono, & Marimin. 2023. Adaptive models for determining cropland suitability and total harvest prediction for potato using iot. *Potato Journal.* 50(1): 26–37.

Zhao, Y., L. Li, S. Gao, S. Wang, X. Li, & X. Xiong. 2023. Postharvest storage properties and quality kinetic models of cherry tomatoes treated by high-voltage electrostatic fields. *LWT - Food Science and Technology Elsevier Ltd.* 176(10): 1–11.