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Application of Room Cooling and Thermal Insulation Materials to Maintain Quality of Okra during Storage and Transportation

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Abstract: A combination of room cooling and the use of thermal insulation materials to maintain okra quality under simulated storage and transportation was evaluated. Okra pods were packed in plastic baskets and either cooled at 18 °C or not cooled in a room for 2 h. After either room cooling or no cooling, the okra pods were covered with three different materials: (1) perforated linear low-density polyethylene (P-LLDPE), (2) two layers of heat-reflective sheet with thin nonwoven (HRS+TNNW), and (3) metalized foam sheet (MFS). Typical handling (TP) without cooling and covering with P-LLDPE was used as the control. The six treatments were conducted during simulated storage (18 °C for 48 h) and transportation (30 °C for 15 h). Results showed that MFS gave the best insulation properties (Q_x and R-values), followed by HRS and TNNW. After room cooling, both HRS+TNNW and MFS materials delayed the time for pulp temperature to reach 18 °C (10 h), compared to P-LLDPE (2 h). TP presented the highest mass loss (17.8%) throughout simulated conditions, followed by cooling plus P-LLDPE (15.2%) and either of the thermal insulation materials with or without room cooling (3.6% to 5.2%), respectively. TP, cooling plus P-LLDPE, and no cooling plus MFS (44% to 56%) showed the highest percentage of decay, while cooling combined with both HRS+TNNW and MFS gave the lowest decay incidence (11–21%). Findings demonstrated that room cooling combined with HRS+TNNW had the highest efficiency for preserving cool temperature and reducing decay, compared to TP and room cooling plus MFS.

Keywords: decay; covering; nonwoven; mass loss; metalized foam sheet

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1. Introduction

Okra (*Abelmoschus esculentus* L.) is an economic vegetable crop widely grown in tropical and sub-tropical global regions. Okra pods are harvested when immature and eaten as vegetables [1]. Okra is an export vegetable crop of Thailand, with the Japanese market accounting for 83.3% of the total exported okra volume. The main growing areas are the central and northern areas of Thailand [2]. A decline in the quality of okra is attributable to various issues, including techniques for determining okra fruit quality, poor harvesting methods, okra harvester training levels, lack of good vehicles, terrible roads, and insufficient pre-cooling facilities [3]. High respiration rate and rapid deterioration causes heat build-up and leads to pod blackening as well as a rapid increase in okra water loss after harvesting [4,5].

Temperature and relative humidity are the most important factors affecting the shelf life of okra [6]. The optimal storage temperature of okra ranged from 7 to 10 °C, and the pods can be stored satisfactorily for 7–10 days [7]. Fresh okra pods exhibited extremely short shelf life due to high water loss or transpiration rates. Storage of okra at 25 °C resulted in a higher mass loss (14%) compared to a lower temperature of 4 °C after 5 days due to wilting, yellowing, and decay [8]. Storage at low temperatures led to a reduction of respiration rate, transpiration, and ethylene production [9]. At high temperatures, okra is highly susceptible to water loss, color fading, and decay, becoming squashy with a loss of commercial value and not easy to consume when fresh [10].

Heat generation, specifically known as 'Vital heat' in fresh produce, is produced as a by-product, primarily through the respiration process. Okra is classified at a very high respiration level, with a respiration rate of 40–60 mg CO_2 kg^{-1} h^{-1} and vital heat ranging from 427 to 640 J kg^{-1} h^{-1} at 5 °C [9]. Consequently, a cooling process should be taken into consideration when the storage room is designed as well as during transportation [11]. Cooling as quickly as possible after harvesting is critical to remove heat from the fresh produce and is a very important requirement for maintaining optimal product quality, especially for merchandise with naturally high respiration rates [12]. Forced-air cooling has been used for the export of okra received directly from the field [13]. In India, room cooling at 15 °C before storage at 8 °C is used for the export of okra [14]. The procedure of no cooling resulted in decreased fruit quality and increased fruit decay. Post-harvest loss of commercial fruits and vegetables increased by 25–30% when no cooling was employed through the whole storing and transporting chain, while it was only 5–10% when a cooling step at 8 °C was practiced [15]. Wang et al. [16] showed that room cooling at 2 °C reduced changes in the physiological quality of button mushroom (*Agaricus bisporus*). However, scant research has reported on cooling conditions and the efficiency of cooling processes to reduce heat generation in okra to extend storage or shelf life.

Thermal insulation materials are defined as materials or combinations of materials that retard the flow of heat to prevent or minimize temperature changes in the system or space [17]. Thermal insulation materials are normally used as pallet covering, combined with other materials, to protect fresh produce during transportation [18]. Thermal insulation material testing evaluates whether a packaging design succeeds in maintaining a temperature-sensitive product within its appropriate temperature range when exposed to ambient conditions [19]. The main thermal insulation properties are measured as thermal heat transfer and R-value. Heat transfer is the mechanism of energy movement due to temperature differences between two sources [20]. A low rate of heat transfer implies better insulation of the materials via reduction of conductive heat loss [21]. The resistance to heat flow through an insulation material, known as the R-value, is determined by ice-melt processing [22]. A higher R-value presents a better performance of thermal insulation materials [19].

Pallet cover is an alternative method used as packaging technology to reduce waste from food spoilage by minimizing temperature and humidity change during the transportation of fresh produce [18,23,24]. Research on packaging for vegetables revealed that covering the pallet side and bottom with insulated pallet cover (Reflectix™) resulted in a reduction of mass loss and wilting in amaranth and preserved a desirable dark green color. Use of pallet cover for amaranth gave a high score in overall quality, with improvement on no cover [18]. Liu [25] reported the use of an insulated cover to keep pre-chilled lettuce at low temperatures. The insulated cover was also suitable for low-temperature phosphine fumigation to control western flower thrips on harvested lettuce. Chaiwong and Bishop [23] reported on lightweight insulation bags. Results showed that insulated bags provided cool temperature management and reduced the cool chain breakdown of strawberries from the supermarket to domestic refrigerators. The insulated pallet covers also gave better temperature preservation compared to no cover, and temperature changes occurred more slowly in chard, cucumber, and carrot [18,23,24]. However, very few studies exist about the use of thermal insulation cover to prevent post-harvest losses of okra under different temperature conditions.

The main post-harvest problems of okra during domestic transportation are temperature and relative humidity fluctuation. These lead to physiological damages such as wilting and fruit rot before the freeze-drying process. Cooling treatment could delay the deterioration of okra quality, whereas thermal insulation covering could improve controlling temperature and humidity fluctuations under typical truck transportation. In this study, the efficiency of room cooling and thermal insulation materials in controlling cool temperature and okra quality under simulated storage and transportation were evaluated.

2. Materials and Methods

2.1. Materials Properties

Thermal heat energy was determined according to the procedure of Harvey [21], using an expanded polystyrene box with dimensions (75 × 38 × 38.5 cm^3) with two sections (Figure 1). The material sample was taped on a hole (C) 10 cm × 10 cm to allow heat from the heated copper coil (E) at temperature 45 °C in section 1 (A) to pass through the material sample and enter section 2 (B). Temperature data loggers (Tinytag Talk 2: TK-4014-PK, Gemini Data Loggers, West Sussex, UK) were used to monitor the temperature change between the two sections (section 1 (I) and section 2 (J)) of the box for 3 h until a constant temperature was recorded. The rate of transfer of thermal heat energy (Q_x) in J s^{-1} was calculated.

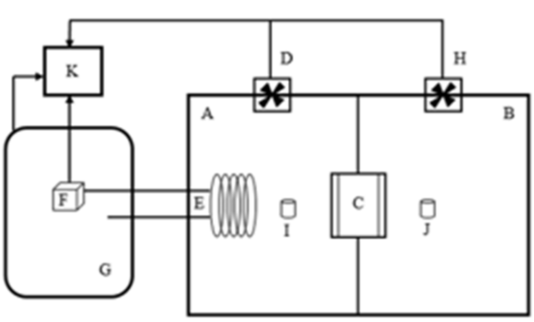

Figure 1. Schematic diagram for heat transfer test through material covers at the laboratory.

The water vapor permeability (WVP) through different materials was determined using the desiccant in cup method. Following ASTM E96 [26], the specimen or cover material was sealed on the open mouth of a test dish containing a desiccant, and the test dish was placed in a constant climate chamber (KBF-115, Binder, Tuttlingen, Germany) at 25 °C and 50% relative humidity (RH). Water vapor permeability was then calculated as rate of water vapor transmission in g h^{-1} m^{-2}.

Air permeability was determined using an air permeability tester (FX 3300 LabAir IV, Textest Instruments, Schwerzenbach, Switzerland) according to ASTM D737-04 [27]. Thermal insulation materials were cut into square pieces of 20 × 20 cm and measured for air permeability (l m^{-2} s^{-1}). The R-value was determined as resistance to heat flow through the thermal insulation material using the ice-melt test, following Singh et al. [19]. In this method, 2000 g of ice were placed in a non-metallic bucket, which was then positioned in the center of a basket inside thermal insulation bags and wrapped tightly with tape. The package was stored on a shelf at ambient temperature (25 °C) for 12 h. At the end of the test, the thermally insulated containers were opened, and water was collected from the buckets. The weight of water was recorded to calculate the melt rate (m^2 °C W^{-1}). Five samples (replications) in each material were tested.

2.2. Plant Materials

'Lady Finger' okra pods from Green Global Seeds Company Limited, Thailand, were planted with the spacing between plant and row of 50 and 100 cm, respectively, with sprinkler irrigation. The okra pods were harvested 45 days after planting, or 6 days after flowering from an okra plantation (20°13′27.2″ N 99°50′05.2″ E), in Mae Chan district, Chiang Rai Province. The pods were transported from the farm to the Postharvest Laboratory at Mae Fah Luang University within 30 min. After arrival at the laboratory, the okra pods were graded to uniform size of pod length 7–11 cm (the specific size for okra processing), with minimum requirements being green in color, free of distinct signs of bruising and disease, and a clean-cut peduncle.

2.3. Experimental Treatments and Heat from Respiration Rate (RR)

The research study was divided into two experiments.

2.3.1. Handling Procedures

Six treatments were studied. The control, as typical handling (TP) of the Phayao community enterprise (without room cooling and covered with perforated linear low-density polyethylene (P-LLDPE)) was compared with developing handling (DH), comprising room cooling, covered by two thermal insulation materials (heat-reflective sheet (HRS) + thin nonwoven (TNNW)), which were polypropylene (PP)-based spunbond nonwoven, and metalized foam sheet (MFS)), as shown in Table 1. It is noted that the HRS material was evenly perforated and distributed with a pin of diameter 0.55 mm for a total perforation area of 0.09 cm^2.

Table 1. Six treatments (with or without room cooling) using different material covers.

Treatment	Description
TP (Control)	No room cooling with P-LLDPE covering
DH1	Room cooling with P-LLDPE covering
DH2	No room cooling with HRS+TNNW covering
DH3	No room cooling with MFS covering
DH4	Room cooling with HRS+TNNW covering
DH5	Room cooling with MFS covering

For each treatment, 1500 g of okra pods were packed in a plastic basket (five replications). Initial temperature at the core of the okra pods was approximately 30 °C. Room cooling treatments (DH1, DH4 and DH5) were performed by setting the cooling medium at 0 °C for 2 h, compared with a cool room at 18 °C (no room cooling) (TP, DH2, and DH3) for 2 h as the 7/8 cooling time. Pulp temperature of the okra was monitored by a multichannel data logger (Hioki, LR8431, Nagano, Japan) connected with a type-K thermocouple for 10 channels. Five baskets each room cooling at 0 °C or at 18 °C were allocated for temperature monitor. After room cooling, the okra pods were covered with different thermal insulation materials, except for TP and DH1. Storage and transportation conditions of okra to simulate commercial practice before processing comprised storage at 18 °C for 48 h and transfer at 30 °C for 15 h.

2.3.2. Determination of Respiration Rate

Respiration rate of okra was determined under three storage conditions (10, 20, 30 °C) for 2 and 3 days. Okra pods (150 g) were packed in a plastic food container (8400 mL) (Figure 2). Respiration rate testing was conducted in a closed system for 2 h. A gas sample of 5000 µL was drawn from each container at daily intervals for gas chromatography (GC) analysis. A gas chromatograph (7890A, Agilent Technologies, California, USA) equipped with a thermal conductivity detector (TCD) and HayeSep Q column (80/100 mesh, 3.05-m long) was used to analyze the gas samples. Nitrogen was used as the carrier gas at a flow rate of 52.2 mL min^{-1} with split mode. Injector, oven, and detector temperature conditions were 150, 60, and 275 °C, respectively. The respiration rate (R_{CO2}) was determined on days 2 and 3 for the three storage conditions and calculated by the following Formula (1) [11];

$$R_{CO2}\ (\mathrm{mg\ CO_2\ kg^{-1}\ h^{-1}}) = \frac{(\mathrm{CO_2\ (\%)} \times \text{volume of container (mL)})}{100 \times (\text{fruit weight (kg)}) \times (\text{closing time (h)})} \quad (1)$$

Figure 2. Okra pods packed in a plastic food container for respiration rate measurement by a closed system.

The respiration rate (R_{CO2}) of okra pods in each closed system storage condition was calculated as the temperature coefficient (Q_{10}) value by Formula (2):

$$Q_{10} = (R_2 R_1)^{10/(T_2 - T_1)} \tag{2}$$

where R_2 and R_1 are the respiration rate at temperature T_2 and T_1, respectively [28].

The Q_{10} values on day 2 (48 h) and day 3 (72 h) were used to estimate the respiration rate of okra pods (R_C) in different air temperature levels using a temperature data logger (Tinytag Talk 2: TK-4014-PK, Gemini Data Loggers, West Sussex, UK). This depended on the thermal insulation cover treatments under simulated storage (18 °C for 48 h) and transportation (30 °C for 15 h), respectively. The air temperature for estimation of okra respiration rate (R_C) in each cover treatment was determined from the final air temperature level before simulated storage (R_{C1}) and transportation conditions (R_{C2}). Respiration rates of okra pods in each cover material were converted into vital heat by Formula (3) [29]:

$$\text{Vital heat (J kg}^{-1}\text{ h}^{-1}) = R_C \times 10.7 \tag{3}$$

where R_C = respiration rate of okra pods in each cover treatment.

2.4. Temperature and Relative Humidity Monitoring

Air temperatures inside the covering and pulp temperatures at the core of the okra pods were measured using a temperature data logger for air temperature (Tinytag Talk 2: TK-4014-PK, Gemini Data Loggers, West Sussex, UK) with three replications and pulp temperature (Tinytag Talk 2: TK-4023-PK, Gemini Data Loggers, West Sussex, UK) with four replications. Relative humidity inside the covering was recorded using a temperature and relative humidity data logger (Tinytag Ultra 2: TGU-4500, Gemini Data Loggers, West Sussex, UK) at 30 s intervals. Pulp temperature was analyzed using temperature profile and boxplot at 12 h after simulated storage with stable temperature level. After simulated transportation at 30 °C for 15 h, air and pulp temperature levels were analyzed using a boxplot at 1 h 30 min (air temperature of TP at 25 °C) and 15 h after simulation, and the rate of change during temperature rise after simulated transportation was calculated. Data analysis of both air and pulp temperature focused on the data point at 25 °C and temperature range from 25 °C to 30 °C. Furthermore, heatmap analysis represented pulp temperature levels after simulated storage and transportation for 12 h. Python 3.6.9 was used to create the heatmap chart. The packages Seaborn version 0.11.1, Pandas version 1.1.5, and Matplotlib version 3.2.2 were all required by heatmap. The profile of relative humidity throughout the experiment was also investigated.

2.5. Mass Loss Determination

Mass loss of the okra pods was determined using an electric weighing balance (Pioneer^{TM}, Ohaus, NJ, USA). Percentage mass loss (%) was calculated on the basis of initial weight (IW) before cooling and final weight (FW) at the end of simulated storage and transportation, using WL (%) = [(IW − FW/IW] × 100 [30].

2.6. Determination of Decay Incidence

The first sign of okra deterioration was observed as a small wet lesion on pod, and then the entire pod coated with a grayish-white mass of mold. The okra pods were evaluated when incidence of decay occurred, calculated based on weight of pods showing symptoms of decay (D), and classified into four categories, including <10% of decay occurrence, 10–25% of decay occurrence, 25–50% of decay occurrence, and >50% of decay occurrence. Percentage decay (%) was calculated on the basis of total weight of pods per plastic basket (TW), using D (%) = [(D/TW) ×100] [30]. Incidence of decay was determined at the end of simulated storage and transportation.

2.7. Statistical Analysis

SPSS for Windows version 20 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. Data analysis for the estimated respiration rate with three replicates, averaged pulp temperature in heatmap chart with four replicates as well as material properties, mass loss, and incidence of decay with five replicates compared by mean at a significant level of 0.05 using Tukey's HSD post hoc test.

3. Results and Discussion

3.1. Materials Properties

The properties of the thermal insulation materials, including thickness, thermal heat energy, WVP, air permeability, and R-value, are shown in Table 2. Temperature transfer through the material was studied in terms of the heat transfer processes. Heat transfer is the process of energy movement caused by temperature differences [20]. Lower thermal heat energy (Q_x) value shows a lower heat transfer rate (good insulator) through the substance layer, while higher Q_x shows a higher heat transfer rate (poor insulator) through the layer [21]. In this study, results indicated that MFS with a thickness of 3.1 mm gave the lowest heat transfer property (Q_x = 1.53 J s^{-1}), compared to the other three materials, while P-LLDPE (0.120 mm) had the highest Q_x value (3.85 J s^{-1}). A combination of HRS (1.450 mm) (2.57 J s^{-1}) and TNNW (0.270 mm) (3.23 J s^{-1}) showed improved insulation property and potential for prototype development for covering material in the future. The high insulation properties of MFS and HRS materials may be partly due to greater thickness. Material with lower thermal heat energy (Q_x) also tends to have a higher R-value. MFS had the highest R-value (0.225 m^2 °C W^{-1}), followed by HRS (0.211 m^2 °C W^{-1}), TNNW (0.187 m^2 °C W^{-1}), and P-LLDPE (0.153 m^2 °C W^{-1}), respectively (Table 2). Results showed that MFS and HRS preserved cool temperatures better than the other materials (Figure 3).

Table 2. Covering material properties (thickness, thermal heat energy, WVP, R-value and air permeability).

Material	Thickness (mm)	Thermal Heat Energy ($Q_x \times 10^{-4}$) (J s^{-1})	R-Value (m^2 °C W^{-1})	Water Vapor Permeability (g h^{-1} m^{-2})	Air Permeability (l m^{-2} s^{-1})
P-LLDPE	0.120 ± 0.03 ^{d}	3.85 ± 0.06 ^{a}	0.153 ± 0.01 ^{d}	0.325 ± 0.04 ^{a}	172.80 ± 12.05 ^{b}
TNNW	0.270 ± 0.20 ^{c}	3.23 ± 0.07 ^{b}	0.187 ± 0.01 ^{c}	0.450 ± 0.05 ^{a}	945.60 ± 43.21 ^{a}
HRS	1.450 ± 0.43 ^{b}	2.57 ± 0.12 ^{c}	0.211 ± 0.02 ^{b}	0.000003 ± 0.00 ^{b}	0.59 ± 0.01 ^{d}
MFS	3.100 ± 0.08 ^{a}	1.53 ± 0.06 ^{d}	0.225 ± 0.01 ^{a}	0.000012 ± 0.00 ^{b}	49.42 ± 0.21 ^{c}

Note: Different letters for different mean levels in each parameter for Tukey's HSD post hoc test indicate significant differences at $p < 0.05$. Values are mean ± S.E. from five replicates. Four materials were perforated linear low-density polyethylene (P-LLDPE), heat-reflective sheet (HRS), thin nonwoven (TNNW), and metalized foam sheet (MFS).

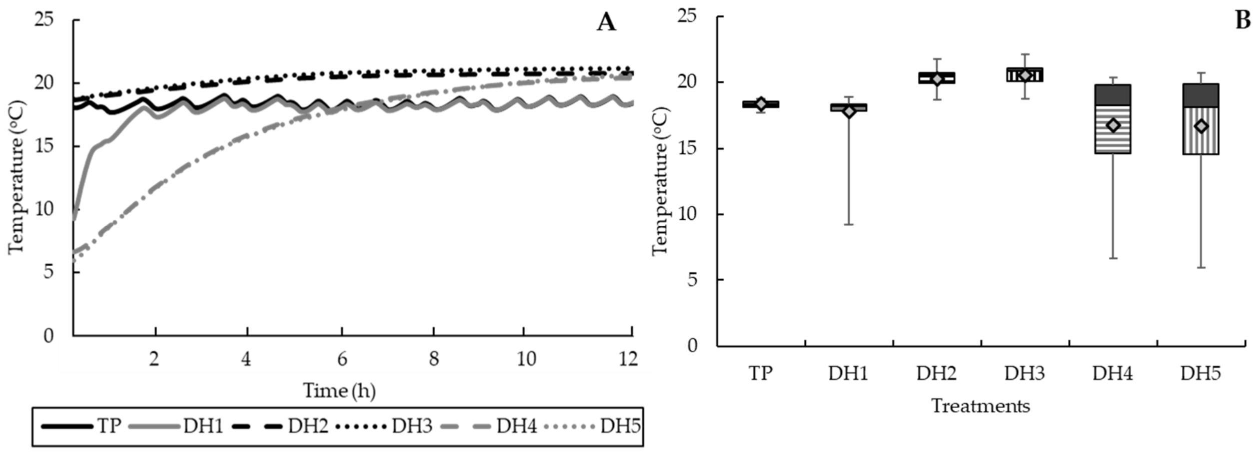

Figure 3. Pulp temperature profiles during simulated storage at 18 °C for 12 h (**A**) and boxplot of pulp temperature profiles during simulated storage at 18 °C for 12 h (**B**). Boxes indicate the lower and upper quartile. The horizontal line in each box represents the median temperature. Mean temperature for each treatment is indicated by ♦. Vertical lines extending above and below each box represent minimum and maximum temperature recorded. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

For water vapor permeability (WVP), a partial pressure difference between the inside and outside of the test material affects the gain or loss of moisture in the product [31]. In this study, TNNW and P-LLDPE showed higher WVP than MFS and HRS, and would be suitable for highly breathable fruits (Table 2). High WVP material had the potential to eliminate vapor condensation, thus inhibiting microbial activity [31]. On the other hand, both MFS and HRS materials had lower WVP values and air permeability, which may cause vapor condensation inside the covering (Table 2). Interestingly, a combination of HRS and TNNW showed good performance in terms of insulation and water and air permeability properties, with the potential to maintain cool temperatures and protect condensation inside the package or cover.

3.2. Respiration Rate, Q_{10} Value, and Heat from Respiration Rate

An increase in storage temperature and time resulted in a rise in okra respiration rate. Respiration rate at three storage conditions (10, 20, 30 °C) for 2 days increased gradually from 186.39 (10 °C) to 355.44 (30 °C) mg CO_2 kg^{-1} h^{-1} as well as on day 3 (Table 3). Similarly, Hardenburg et al. [7] reported that higher storage temperature at 25–27 °C (328–362 mg CO_2 kg^{-1} h^{-1}) increased respiration rate compared to lower temperatures at 5 °C (59 mg CO_2 kg^{-1} h^{-1}) and 10 °C (86 to 95 mg CO_2 kg^{-1} h^{-1}). Furthermore, the widely used Q_{10} value represents an improvement in the rate of a process with a 10 °C increase in temperature [32]. In this study, the Q_{10} value of temperature range (10–20 °C) on days 2 and 3 increased from 1.17 to 1.87, while the Q_{10} value of temperature range (20–30 °C) decreased from 1.50 to 1.37 (Table 3). In lower temperature storage, Q_{10} value is typically less than 2.00 levels, whereas Q_{10} value gradually decreased in higher temperature conditions [33]. However, Q_{10} values of okra during different storage temperatures have never been reported. Yasunaga et al. [34] reported that Q_{10} value of cucumber at 10 to 20 °C was 4.37 and dramatically decreased to 1.89 with higher temperature storage at 20–30 °C. In this study, to estimate okra respiration rate under simulated storage (R_{C1}) and transportation (R_{C2}), the Q_{10} value was calculated for respiration rate in each cover treatment and converted to vital heat as shown in Tables 4 and 5, respectively.

Table 3. Rate of respiration of okra pods at different storage conditions (10, 20, 30 °C) for 2 and 3 days in a closed system.

Temperature (°C)	R_{CO2} (mg CO_2 kg^{-1} h^{-1})		Q_{10}	
	Day 2	Day 3	Day 2	Day 3
10	186.39	207.33		
			1.17	1.87
20	237.70	325.63		
			1.50	1.37
30	355.44	444.61		

Table 4. Estimated respiration rate (R_{C1}) and vital heat among the six treatments under simulated storage at 18 °C for 48 h.

Treatment	Rc_1 (mg CO_2 kg^{-1} h^{-1})	Vital Heat (J kg^{-1} h^{-1})
TP	329 ± 0.0 ^{a}	3522 ± 0.1 ^{a}
DH1	329 ± 0.0 ^{a}	3522 ± 0.1 ^{a}
DH2	330 ± 0.8 ^{a}	3529 ± 8.1 ^{a}
DH3	330 ± 0.9 ^{a}	3536 ± 9.3 ^{a}
DH4	214 ± 0.4 ^{b}	2288 ± 4.7 ^{b}
DH5	218 ± 1.9 ^{b}	2329 ± 20.1 ^{b}

Note: Different letters for different mean levels in each parameter for Tukey's HSD post hoc test indicate significant differences at $p < 0.05$. Values are mean ± S.E. from three replicates. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

Table 5. Estimated respiration rate (R_{C2}) and vital heat among the six treatments under simulated transportation at 30 °C for 1 h (air temperature of TP at 25 °C) and 15 h (the end of simulated transportation).

Treatment	Rc_2 (mg CO_2 kg^{-1} h^{-1}) at 1 h	Vital Heat (J kg^{-1} h^{-1}) at 1 h	Rc_2 (mg CO_2 kg^{-1} h^{-1}) at 15 h	Vital Heat (J kg^{-1} h^{-1}) at 15 h
TP	541 ± 4.7 ^{a}	5791 ± 49.0 ^{a}	640 ± 0.3	6853 ± 3.1
DH1	549 ± 2.6 ^{a}	5873 ± 28.5 ^{a}	646 ± 0.6	6914 ± 6.3
DH2	486 ± 6.1 ^{b}	5202 ± 66.3 ^{bc}	633 ± 4.0	6774 ± 42.5
DH3	483 ± 4.7 ^{b}	5167 ± 49.7 ^{bc}	629 ± 8.2	6732 ± 87.4
DH4	506 ± 2.7 ^{b}	5413 ± 28.0 ^{b}	632 ± 3.2	6768 ± 34.3
DH5	481 ± 8.4 ^{b}	5148 ± 88.4 ^{c}	645 ± 3.8	6900 ± 40.9

Note: Different letters for different mean levels in each parameter for Tukey's HSD post hoc test indicate significant differences at $p < 0.05$. Values are mean ± S.E. from three replicates. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

The efficiency of room cooling and thermal insulation materials under simulated storage and transportation conditions for respiration rate and heat from respiration (vital heat) was studied. Table 4 shows that respiration rates and vital heat levels in DH4 and DH5 were lower than in the other three treatments under simulated storage at 18 °C for 48 h. After room cooling at 0 °C for 2 h, the field heat and vital heat of okra were removed and reduced to around 20% of no room cooling before the cool storage condition. However, no difference was shown between no room cooling plus either P-LLDPE or insulated materials (HRS + TNNW, MFS), as well as room cooling with P-LLDPE. A decrease in vital heat in okra suggested that room cooling combined with insulated material cover should be employed. During simulated transportation at 30 °C for 1 h, the vital heat of DH2, DH3, and DH5 (5148–5202 J kg^{-1} h^{-1}) was lowest compared with TP and DH1, and DH4 treatments (5791–5873 J kg^{-1} h^{-1}). However, at a longer period of simulated transportation for 15 h, vital heat levels in all DH treatments were similar to TP. The efficiency of thermal insulation materials reduced the vital heat loss for a short period of around an hour. Either room cooling or no room cooling with thermal insulation material covering reduced heat from respiration under heat stress conditions over a short period (Table 5).

3.3. Air and Pulp Temperature Levels of Okra

Room cooling and thermal insulation materials showed efficient cooling under simulated storage and transportation. After simulated storage at 18 °C for 12 h, okra pulp temperature profiles of room cooling treatments (DH1, DH4, and DH5) maintained cool temperature for around 10 h, better than no room cooling treatments (TP, DH2, and DH3). The use of two thermal insulation materials (HRS and MFS) combined with room cooling (DH4 and DH5) maintained cool temperatures, compared to no cover. In addition, the combination of room cooling and thermal insulation as a covering material effectively maintained cool temperature (Figure 3A). Temperature control of cover treatments was presented as a boxplot (Figure 3B) which showed the mean (rhombuses), lowest (lower error bars), and highest temperature (upper error bars) levels. Okra pulp temperature in DH4 and DH5 had the lowest mean temperature (17 °C) compared to the other four treatments (19 °C for TP and DH1; 20 °C for DH2 and DH3). The use of thermal insulation materials without room cooling (DH2 and DH3) gave the significantly highest pulp temperature (highest upper error bars) as well as the warmest level (highest lower error bars) after simulated storage at 18 °C for 48 h. This was presented as a narrow range of cool temperature levels (a smaller boxplot) compared with room cooling (DH4 and DH5) (a larger boxplot).

To simulate actual transportation for 15 h, we designed an experiment to analyze when the air temperature of TP reached a constant level at 25 °C. Thermal insulation materials maintained a cool temperature (average and minimum temperature levels) better, compared to either no covering or covering with P-LLDPE (TP and DH1). However, thermal insulation materials tended to build up pulp temperature (Figure 4C,D). The minimum air and pulp temperatures inside thermal insulation materials were the lowest. (Figure 4A,B). As no published reports were available concerning the effect of room cooling combined with thermal insulation covering under storage and transportation conditions on the quality of okra, the results of this study were compared to published data for other fresh fruits and vegetables. Bollen et al. [35] used low-temperature cooling in combination with pallet covers for asparagus. They found that the use of covering with insulation materials reduced heat generated by fresh produce with high respiratory rates inside the covering. Long-term covering was recognized as a problem due to heat accumulation, leading to a higher temperature than no cover. Other studies reported that thermal insulation covers showed better temperature preservation than no cover, and temperature changes occurred more slowly than with no cover in amaranth [18], strawberries [23], and chard, cucumber, and carrot [24]. However, in this study, both temperature profiles increased to 30 °C within 15 h (Figure 4B,D). Covering with thermal insulation materials maintained cool temperature (<25 °C) under a high-temperature environment for less than 6 h. Additionally, the pulp temperature levels after simulated storage and transportation are presented in the heatmap chart (Figure 5) as a matrix of red–blue color tones with average temperature in each hour for 12 h. At the simulated storage (Figure 5A), DH4 and DH5 had a significantly low average of pulp temperature (blue color tone), while DH2 and DH3 had a significantly high average of pulp temperature (light orange color tone) that related to the highest pulp temperature profiles (Figure 3A) and the smallest boxplot size with the lowest pulp temperature profiles when compared among the five treatments (Figure 3B). Moreover, the heatmap chart during simulated transportation (Figure 5B) showed that the use of thermal insulation materials (DH2, DH3, DH4, and DH5) caused a heat accumulation (light orange color tone) within an hour, then there was no significant difference among all treatments after an hour. The combination of room cooling and thermal insulation materials (DH4 and

DH5) increased the efficiency of maintaining cool temperature more than using thermal insulation materials without room cooling (DH2 and DH3).

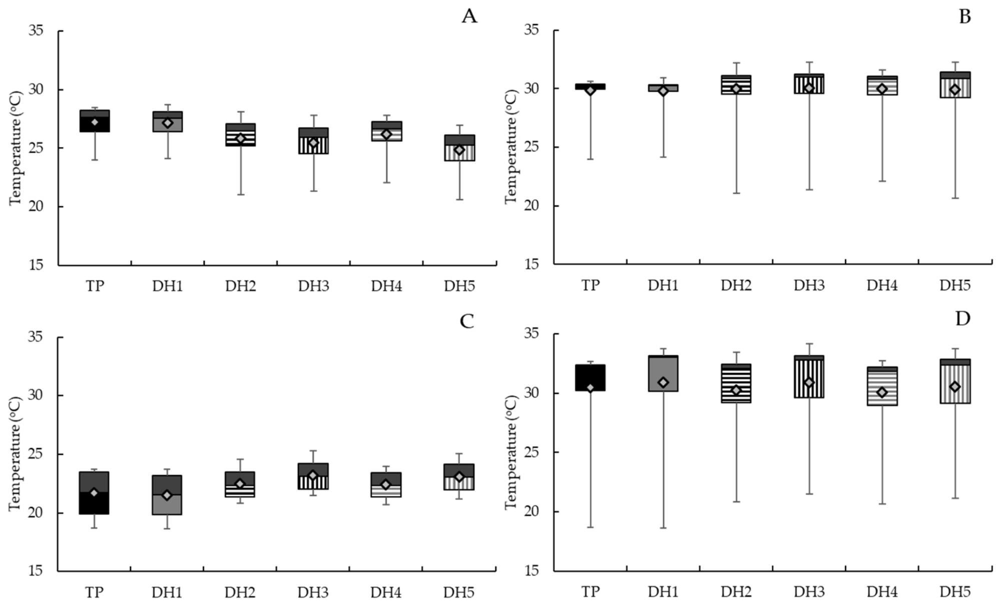

Figure 4. Air temperature profile after 1 h 30 min (**A**) and 15 h (**B**), pulp temperature profile after 1 h 30 min (**C**) and 15 h (**D**) during simulated transportation at 30 °C. An interpretation of the box plot graph is presented as a caption in Figure 3. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

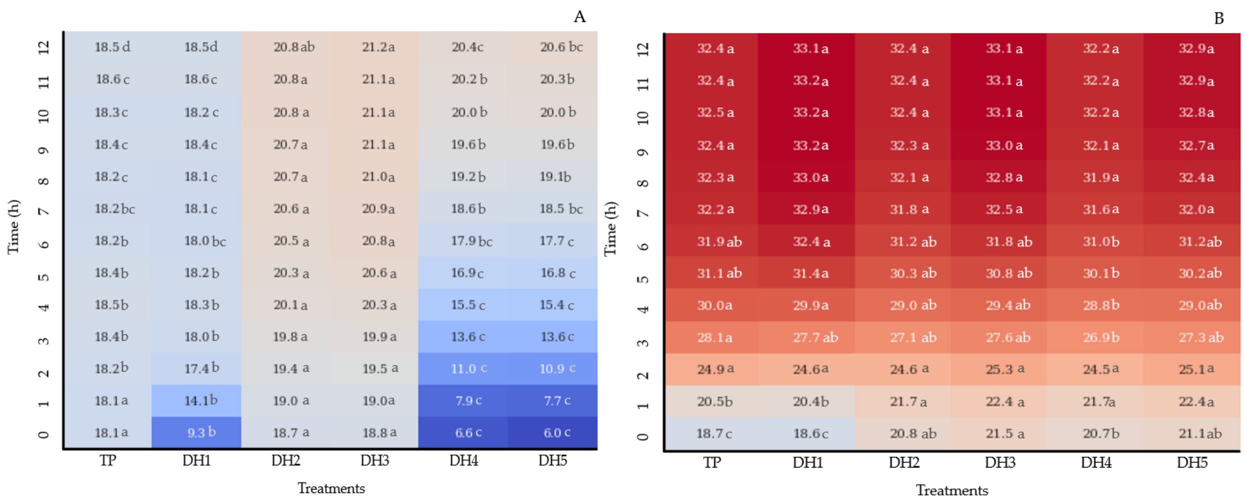

Figure 5. Heatmap chart of pulp temperature profiles during simulated storage at 18 °C for 12 h (**A**) and simulated transportation at 30 °C for 12 h (**B**). Different letters in each row indicate significant differences of mean temperature from four replicates for pulp temperature in each hour at $p < 0.05$. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

Table 6 compares the air temperature change rate inside the covering under simulated transportation testing. TP and DH1 showed the lowest rates of temperature change, whereas no cover in TP and DH1 treatments showed reduced control of cool temperature due to either high air ventilation through the plastic basket or no thermal insulation covering, respectively, indicating the highest thermal heat energy (Q_x) and lowest R-value of

P-LLPPE (Table 2). P-LLDPE gave poor preservation of cool temperature during simulation compared with the other materials. By contrast, low pulp temperature change rate showed high effectiveness of thermal insulation materials (TNNW, HRS, and MFS) for DH2 to DH5 by maintaining cool pulp temperature (Table 6). In previous studies, cardboard in combination with plastic foil of bottle beer gave control cold temperature than hard plastic crate under air temperature condition at 30 °C due to a reduction of the air movement and transferring contribution of the beer bottle as well as a reduction of vibration damping during transportation [36]. The efficiency of a base material nonwoven fabric on temperature-controlled deliveries was studied by Dieckmann et al. [37]. Nonwoven feather fiber composite isolation gave greater material performance aspects than EPS in terms of thermal insulation, and inexpensive, sustainable, and lightweight material. In this study, HRS and MFS-based aluminum foil material and nonwoven performed good thermal insulation. However, the browning incidence of okra pods also caused vibration damage during handling and transportation. Interestingly, further research should be conducted to investigate the combined effects of thermal insulation materials on cold temperature control and vibration damage reduction during transportation.

Table 6. Rate of changes in air and pulp temperature under simulated transportation at 30 °C for 15 h.

Treatment	**Rate of Temperature Changes (°Ch^{-1})**			
	Air Temperature		**Pulp Temperature**	
	T_1–25 °C	**25–30 °C**	**T_1–25 °C**	**25–30 °C**
TP	7.54 ± 0.17 ^{b}	1.40 ± 0.02 ^{a}	4.26 ± 0.20 ^{a}	2.64 ± 0.15 ^{a}
DH1	7.34 ± 0.21 ^{b}	1.40 ± 0.01 ^{a}	4.00 ± 0.11 ^{a}	2.58 ± 0.02 ^{ab}
DH2	9.56 ± 0.47 ^{ab}	1.13 ± 0.04 ^{b}	2.55 ± 0.08 ^{b}	2.02 ± 0.05 ^{bc}
DH3	10.30 ± 1.41 ^{ab}	1.32 ± 0.05 ^{a}	2.50 ± 0.08 ^{b}	1.88 ± 0.15 ^{c}
DH4	11.69 ± 0.47 ^{a}	1.14 ± 0.03 ^{b}	2.59 ± 0.10 ^{b}	1.83 ± 0.08 ^{c}
DH5	9.25 ± 0.45 ^{ab}	1.08 ± 0.04 ^{b}	2.75 ± 0.18 ^{b}	1.75 ± 0.15 ^{c}

Note: T_1 is the temperature at the end of the simulated storage. Different letters in different mean levels of each parameter for Tukey's HSD post hoc test indicate significant differences at $p < 0.05$. Values are mean ± S.E. from five replicates. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

3.4. Relative Humidity inside Covering Materials

Relative humidity was monitored during simulated storage and transportation. Relative humidity of TP and DH1 as no covering (75%) (Figure 6A) was lower than all the other thermal insulation materials (100% RH) (Figure 6B,C) after storage for 48 h. This showed that the use of thermal insulation materials for covering preserved relative humidity fluctuation inside the covering was better than without covering (Figure 6B,C). Low relative humidity in TP and DH1 increased mass loss (>15%), while thermal insulation covers with 100%RH reduced mass loss (5%) throughout this simulation (Figure 7). The effect of relative humidity (RH) on the quality of 'Niitaka' pears was studied by Lim et al. [38] using two types of pallet covers made of polyethylene film to maintain high RH in commercial low-temperature storage rooms. Use of pallet covers increased RH from 83 to 87% or 93 to 95% for open and closed pallet covers, respectively. Moreover, using insulated material for covering preserved the relative humidity inside the covering and was better than no covering during shipping delays in amaranth [18]. Covering with thermal insulation materials maintained the highest RH level (100% RH) after 12 h, particularly HRS and MFS (Figure 6). This result related to the lowest WVP level of HRS and MFS materials, which preserved the relative humidity inside the covering (Table 2). On the other hand, low WVP of MFS caused condensation inside the covering and accelerated the activity of microorganisms with an increase of decay incidence (Figure 8).

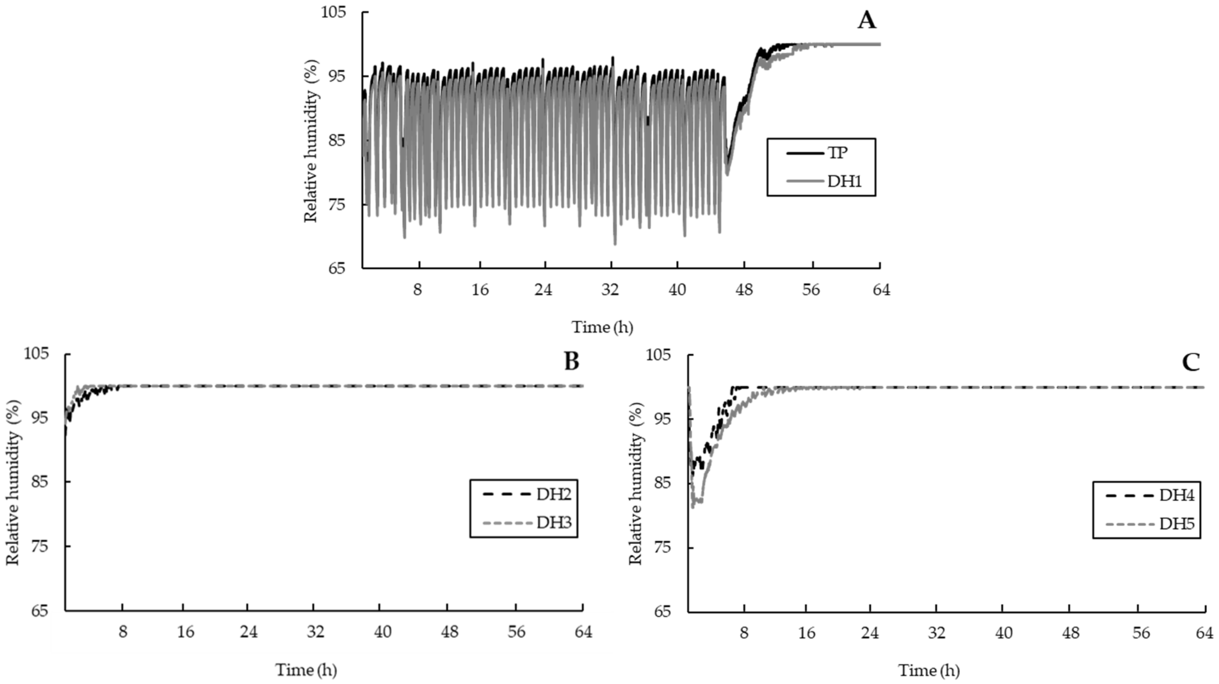

Figure 6. Relative humidity profiles among treatments, including TP and DH1 (**A**), DH2 and DH3 (**B**), DH4 and DH5 (**C**), after simulated storage at 18 °C for 48 h and simulated transportation at 30 °C for 15 h. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

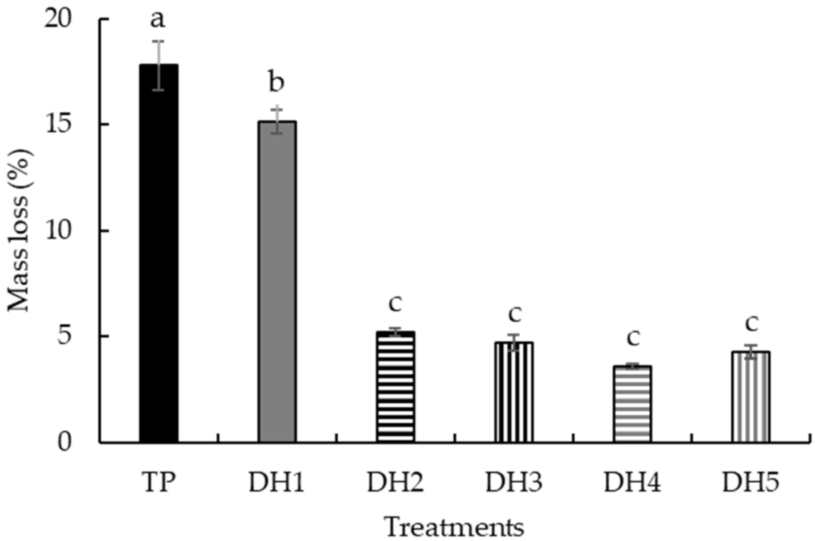

Figure 7. Mass loss (%) among the six treatments after simulated storage at 18 °C for 48 h and simulated transportation at 30 °C for 15 h. Different letters in different mean levels of each parameter for Tukey's HSD post hoc test indicate significant differences at $p < 0.05$. Values are mean ± S.E. from five replicates. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

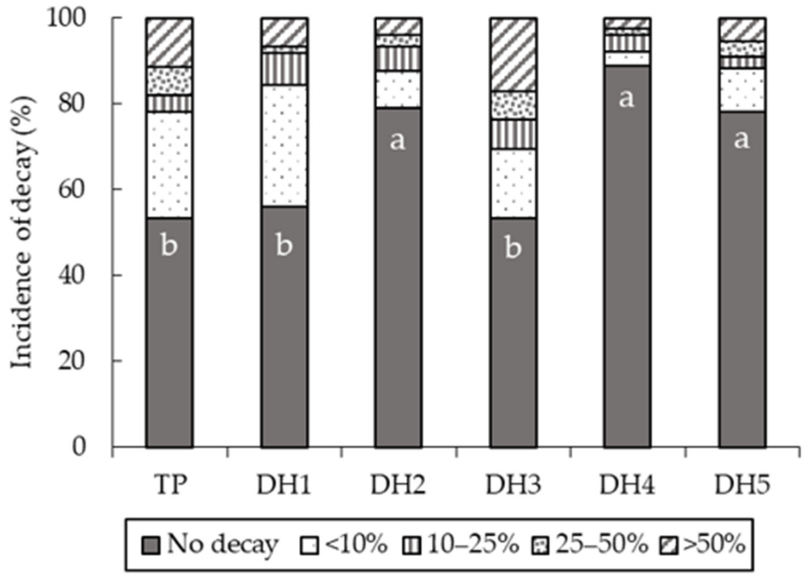

Figure 8. Incidence of decay (%) among the six okra treatments after simulated storage at 18 °C for 48 h and simulated transportation at 30 °C for 15 h. Different letters in different mean levels of each parameter for Tukey's HSD post hoc test indicate significant differences at $p < 0.05$. Values are mean ± S.E. from five replicates. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

3.5. Mass Loss of Okra

Okra pods in TP and DH1 (no cover and P-LLDPE covering) lost a significant amount of fresh weight (around 15%) compared to thermal insulation material treatments (5%) (Figure 7). This corresponded to better performance in maintaining lower temperature and higher relative humidity by thermal insulation materials (Figures 3 and 6). There was no significant difference between room cooling or no cooling combined with thermal insulation materials (Figure 7). However, limited data exist comparing the efficiency of thermal insulation covering on mass loss of fresh produce. Wheeler et al. [18] reported that amaranth contained in uncovered pallets had more weight (11.0%) than in pellets covered with Reflectix^{TM} insulation material (2.0%) (bubble pack insulation consisted of reflective aluminum foil and heavy gauge polyethylene) over a 6 h storage cycle. Reflectix^{TM} cover effectively minimized the amount of moisture loss during amaranth storage. Macnish et al. [39] compared the performance of four propriety pallet cover systems (CO_2 West, PEAKfresh, PrimePro, and Tectrol) in maintaining the quality of strawberry fruit during transportation with a temperature at 20 °C. Results showed that pallet cover systems significantly reduced transport-related mass loss by less than 0.5%, compared to those with control or no cover material (0.8%). Similarly, Lim et al. [38] found that the use of pallet cover in pear storage for 7 days reduced mass loss compared to no pallet cover. The application of pallet cover is an alternative technique for controlling temperature and humidity fluctuation during transportation [40] as well as reducing the rate of mass loss [41]. In this study, low mass loss of okra in thermal insulation covers after simulation (Figure 7) was related to low levels of WVP (Table 2).

3.6. Incidence of Decay (ID)

Highly significant decay of okra at 50–80% was presented in no room cooling plus covering with either thermal insulation material or P-LLDPE. The okra pods turned black with mold infection. The DH4 and DH5 treatments had the lowest percentage of ID (<20%) compared to the other four treatments (Figures 8 and 9). Thermal insulation materials maintained cool temperature and relative humidity (Figures 3 and 6). This was related to a lower incidence of decay (Figure 8) and mass loss (Figure 7). Increasing efficiency of thermal insulation covers suggested application with room cooling to maintain a cool temperature under heat stress conditions. However, the application of MFS covering should be considered in case of a high-temperature condition (30 °C) over 15 h, which may lead to heat accumulation (Figure 4). Vapor condensation resulted in an increase of okra decay (Figure 8) due to low WVP (Table 2). Thermal insulation covers may be applied for a short journey (<6 h) for domestic transportation under ambient temperature (no refrigerated vehicle) to maintain cool temperature with less decay. HRS+TNNW covering with cooling technique showed high potential application for fresh produce with high respiration rates, such as asparagus, broccoli, mushroom, and sweet corn [29]. The overall post-harvest loss from mass loss and incidence of decay showed that TP was the highest post-harvest loss (65%), followed by DH1 (59%), DH3 (52%), DH5 (27%), DH2 (26%), and DH4 (15%), respectively (Figures 7 and 8).

Figure 9. Okra pictures from the six treatments including TP (**A**), DH1 (**B**), DH2 (**C**), DH3 (**D**), DH4 (**E**), and DH5 (**F**) after simulated storage at 18 °C for 48 h and simulated transportation at 30 °C for 15 h. Six treatments were no room cooling with P-LLDPE covering (TP as control), room cooling with P-LLDPE covering (DH1), no room cooling with HRS+TNNW covering (DH2), no room cooling with MFS covering (DH3), room cooling with HRS+TNNW covering (DH4), room cooling with MFS covering (DH5).

4. Conclusions

Room cooling with TNNW provided greater efficiency to preserve a cool temperature (2 °C) and reduce the decay of okra (10%), compared to TP (42%) and no room cooling plus MFS (48%) after simulated cool storage and high-temperature transportation conditions. Application of thermal insulation materials for covering reduced mass loss (5%), compared to either no cover or P-LLDPE throughout the simulation test (15–17%). Thus, the room cooling combined with HRS+TNNW (DH4) gave the lowest post-harvest loss (15%) as compared to TP, cooling plus P-LLDPE (DH1), and no cooling plus MFS (DH3) in a range of post-harvest loss (52% to 65%). Results showed that cooling was a very important step to apply in the post-harvest handling of okra before covering to remove both field heat and respiratory heat. Material properties, including low thermal heat energy (Q_x) level and high R-value and WVP value, should be considered for developing thermal insulation material for fresh produce. Future research should be conducted to assess the effect of room cooling and thermal insulation material for other fresh fruits and vegetables, particularly the high respiration rate group.

Author Contributions: J.R. conducted experiments, analyzed data, interpretated results, and assisted manuscript writing. R.S. co-investigated, interpretated results, and assisteddata analysis. C.P. co-investigated, supported cover materials, interpretated results in material analysis, and assisted manuscript writing. H.K. provided comments and suggestions for the final draft of the manuscript. S.C. was the principal investigator of the research, responsible for the overall research management,

interpretation of results, and manuscript writing. All authors have read and agreed to the published version of the manuscript.

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References

1. Tripathi, K.K.; Govila, O.P.; Warrier, R.; Ahuja, V. Biology of *Abelmoschus esculentus* L. (Okra). In *Series of Crop Specific Biology Documents*; Department of Biotechnology, Ministry of Science & Technology & Ministry of Environment and Forest, Govt. of India: New Delhi, India, 2011; 26p.
2. Thai Customs. Statistic Report 2020. 2020. Available online: http://www.customs.go.th/statistic_report.php?lang=en&tariff_code=07099990003 (accessed on 14 August 2020).
3. Tsado, E.K. Quality of postharvest handling of marketable okra fruits sold in Minna, Niger State, Nigeria. *Eur. J. Agric. For. Res.* **2015**, *3*, 33–45.
4. Okra: Postharvest Care and Market Preparation; Publications in the Postharvest Handling Technical Bulletin Series No.10. 2003. Available online: http://agriculture.gov.gy/wp-content/uploads/2016/01/Okra.pdf (accessed on 10 November 2020).
5. Perkins-Veazie, P.; Collins, J.K. Cultivar, packing and storage temperature differences in postharvest shelf life of okra. *HortTechnogy* **1992**, *2*, 350–352. [CrossRef]
6. Taain, D.A.; Jasim, A.M.; Al-Hij, M.J.H.H. A study of storage behavior of okra fruits (*Abelmoschus esculuntus* L. Moenth cv. Khnesri). *Int. J. Farming Allied Sci.* **2014**, *3*, 760–766.
7. Okra: The Commercial Storage of Fruits. Vegetables and Florist and Nursery Stocks. USDA-ARS Agriculture Handbook #66 (Revised). 2016. Available online: https://www.ars.usda.gov/arsuserfiles/oc/np/commercialstorage/commercialstorage.pdf (accessed on 10 November 2020).
8. Cheng, Z.; Gong, X.; Jing, W.; Peng, Z.; Li, J. Quality change of postharvest okra at different storage temperatures. *J. Food Eng. Technol.* **2018**, *7*, 43.
9. Kader, A.A. *Postharvest Technology of Horticultural Crops*, 3rd ed.; University of California Agriculture and Natural Resources: Davis, CA, USA, 2002; pp. 39–47.
10. Huang, S.; Li, T.; Jiang, G.; Xie, W.; Chang, S.; Jiang, Y.; Duan, X. 1-Methylcyclopropene reduces chilling injury of harvested okra (*Hibiscus esculentus* L.) pods. *Sci. Hortic.* **2012**, *141*, 42–46. [CrossRef]
11. Saltviet, M.E. Measuring Respiration. 2015. Available online: http://ucce.ucdavis.edu/files/datastore/234-20.pdf (accessed on 10 June 2020).
12. Kienholz, J.; Edeogu, I. *Fresh Fruit and Vegetable Pre-Cooling for Market Gardeners in Alberta*; Alberta Agriculture, Food and Rural Development: Edmonton, AB, Canada, 2002; pp. 1–4.
13. Food and Agriculture Organization of the United Nations (FAO). *Good Practice in the Design Management and Operation of a Fresh Produce Packing-House*; FAO Region Office for Asia and the Pacific: Bangkok, Thailand, 2012; pp. 44–47.
14. Dhall, R.K.; Sharma, S.R.; Mahajan, B.V.C. Development of post-harvest protocol of okra for export marketing. *J. Food Sci. Technol.* **2014**, *51*, 1622–1625. [CrossRef] [PubMed]
15. Yang, Z.; Ma, Z.; Zhao, C.; Chen, Y. Study on forced-air pre-cooling of Longan. In *2007 ASAE Annual Meeting 076267, Minneapolis, MN, 17–20 June 2007*; American Society of Agricultural and Biological Engineers: St. Joseph, MI, USA, 2007.
16. Wang, Z.; Chen, L.; Yang, H.; Wang, A. Effect of exogenous glycine betaine on qualities of button mushrooms (*Agaricus bisporus*) during postharvest storage. *Eur. Food Res. Technol.* **2015**, *240*, 41–48. [CrossRef]
17. Deshmukh, G.; Birwal, P.; Datir, R.; Patel, S. Thermal insulation materials: A tool for energy conservation. *J. Food Process Technol.* **2017**, *8*, 670. [CrossRef]
18. Wheeler, L.; Kitinoja, L.; Barrett, D. Use of insulated covers over product crates to reduce losses in amaranth during shipping delays. *Agriculture* **2015**, *5*, 1204–1223. [CrossRef]
19. Singh, S.P.; Burgess, G.; Singh, J. Performance comparison of thermal insulated packaging boxes, bags and refrigerants for single-parcel shipments. *Packag. Technol. Sci.* **2008**, *21*, 25–35. [CrossRef]
20. Harding, K.G. *Heat Transfer Introduction*; University of the Witwatersrand: Johannesburg, South Africa, 2018; pp. 1–62.

21. Harvey, B.V. Mild Chilling Injury of Banana (Cavendish cv. *Williams*) and Its Control in the Field. Ph.D. Thesis, The University of Adelaide, Adelaide, Australia, September 2005.
22. Desjarlais, A.O.; Zarr, R.R. (Eds.) *Insulation Materials, Testing and Applications, 4th Volume (Vol. 1426)*; ASTM International: West Conshohocken, PA, USA, 2002; 417p.
23. Chaiwong, S.; Bishop, C.F.H. Use of an insulated bag from the supermarket to maintain 'Elsanta' strawberry temperature to households. *Acta Hortic.* **2014**, *1079*, 187–192. [CrossRef]
24. Melis, R.B. New Techniques and Methods for Cold Chain Monitoring and Tracking in Perishable Products. Ph.D. Thesis, Universidad Politécnica de Madrid, Madrid, Spain, 2016; pp. 134–146.
25. Liu, Y.B. Low-temperature phosphine fumigation of chilled lettuce under insulated cover for postharvest control of western flower thrips, *Frankliniella occidentalis* (Pergande) (*Thysanoptera: Thripidae*). *J. Asia Pac. Entomol.* **2011**, *14*, 323–325. [CrossRef]
26. ASTM. *(96). Standard Test Methods for Water Vapor Transmission of Materials*; ASTM International: West Conshohocken, PA, USA, 2005.
27. ASTM. *Standard Test Method for Air Permeability of Textile Fabrics*; D737-96; ASTM International: West Conshohocken, PA, USA, 1996; pp. 230–234.
28. Kader, A.A.; Saltveit, M.E. Respiration and gas exchange. *Post. Physio. Patho. Veg.* **2003**, *2*, 7–29.
29. Patel, B.B.; Roy, F.S.; Saiyad, M.J.S.; Joshi, D.C. Respiration behaviour and heat of respiration of mango (cv. *Langdo*) under different storage conditions. *Int. J. Agric. Environ. Biotechnol.* **2016**, *9*, 855–859. [CrossRef]
30. Ngure, J.W.; Aguyoh, J.N.; Gaoquiong, L. Interactive effects of packaging and storage temperatures on the shelf-life of okra. *ARPN J. Agric. Biol. Sci.* **2009**, *4*, 43–52.
31. Mangaraj, S.; Goswami, T.K.; Panda, D.K. Modeling of gas transmission properties of polymeric films used for MA packaging of fruits. *J. Food Sci. Technol.* **2015**, *52*, 5456–5469. [CrossRef] [PubMed]
32. Tripathi, P.C.; Lawande, K.E. Temperature-related changes in respiration and Q_{10} coefficient in different varieties of onion. *Progress. Hortic.* **2010**, *42*, 88–90.
33. Murata, S.; Miyauchi, K.; Wang, Y. Measurement of respiration of fresh vegetables. *J. Jpn. Soc. Agric. Mach.* **1993**, *55*, 69–75.
34. Yasunaga, E.; Tomita, K.; Hamanaka, D.; Hu, W.; Uchino, T. Effect of temperature on the respiration rate of some vegetables. *IFAC Proc. Vol.* **2001**, *34*, 205–210.
35. Bollen, F.; Bycroft, B.L.; Brash, D.W. Using insulation and cooling to improve the asparagus cool chain. *Acta Hortic.* **1993**, *415*, 323–332.
36. Paternoster, A.; Van Camp, J.; Vanlanduit, S.; Weeren, A.; Springael, J.; Braet, J. The performance of beer packaging: Vibration damping and thermal insulation. *Food Packag. Shelf Life* **2017**, *11*, 91–97. [CrossRef]
37. Dieckmann, E.; Nagy, B.; Yiakoumetti, K.; Sheldrick, L.; Cheeseman, C. Thermal insulation packaging for cold-chain deliveries made from feathers. *Food Packag. Shelf Life* **2019**, *21*, 100360. [CrossRef]
38. Lim, B.S.; Lim, C.I.; Gross, K.C. High relative humidity under pallet coverage maintained 'Niitaka' pear fruit (*Pyruspyrifolia Nakai*) quality during low temperature storage. *Korean J. Hortic. Sci. Technol.* **2005**, *23*, 135–139.
39. Macnish, A.J.; Padda, M.S.; Pupin, F.; Tsouvaltzis, P.I.; Deltsidis, A.I.; Sims, C.A.; Brecht, J.K.; Mitcham, E.J. Comparison of pallet cover systems to maintain strawberry fruit quality during transport. *HortTechnology* **2012**, *22*, 493–501. [CrossRef]
40. Moureh, J.; Laguerre, O.; Flick, D.; Commere, B. Analysis of use of insulating pallet covers for shipping heat-sensitive foodstuffs in ambient conditions. *Comput. Electron. Agric.* **2002**, *34*, 89–109. [CrossRef]
41. Badia-Melis, R.; Mc Carthy, U.; Ruiz-Garcia, L.; Garcia-Hierro, J.; Villalba, J.R. New trends in cold chain monitoring applications-A review. *Food Control* **2018**, *86*, 170–182. [CrossRef]