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STUDY OF TEMPERATURE AND AIRFLOW RATE EFFECT ON ARTIFICIAL RIPENING PROCESS OF BANANA

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ABSTRACT

The present research was carried out in one of commercial refrigerators for ripening bananas (Musa Sapientium), which is located in Kafr El-Sheikh Governorate, Egypt. This investigation was conducted during the season of 2006/2007. The current study was essentially carried out to investigate the behavior of banana fruits during its ripening process under various values of temperatures and airflow rates. Both of temperature and airflow rate were controlled and adjusted inside ripening room, before loading bananas, by designing an adequate air distribution duct which, in turn, will enhance air temperature uniformity in both the vertical and horizontal dimensions of ripening room. As well as, to specify and determine the most important changes in some physical properties of banana fruits occurring during its ripening process.

*The experimental results showed that, the deviations of ripening room temperatures about their mean values were less with the existing of air distribution duct, than that of without one. Air distribution duct enhanced the uniformity of air distribution inside ripening room and increased its effectiveness by 458.62% at ripening room temperature of 21^{o}C***. The shortest periods of banana ripening (shelf-life) for stage of banana ripeness were obtained at ripening room temperature of 21^{o}C and airflow rate of 0.3m^{3}/s.kg. At airflow rate of 0.3 m^{3}/s.kg, the shelf-life of banana fruits was increased from 12 to 25 days by decreasing ripening room temperature from 21 to 15^{o}C. The optimum conditions for banana ripening were obtained at airflow rate of 0.3m^{3}/s.kg and at all the ripening room temperatures under study.*

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*** ^{o}C=K-273.

Generally, it was noticed that, at constant airflow rate, the ripening room temperature of 21^{o}C can be used to achieve a high rate of banana ripening. On the other hand, the ripening room temperatures of 18 and 15^{o}C can be used to achieve moderate and slow rate of banana ripening respectively. Therefore, shelf-life of banana fruits can be considered as a function of storage period for marketing or processing. Some physical properties such as ripening stage, mass loss percentage, pulp-to-peel ratio, pulp texture, pulp moisture content and pulp temperature were noticeably changed as the ripening process of banana fruits was proceeded.

INTRODUCTION

In Egypt, the growing area from banana fruits is annually about 50.24 thousand fed (21.10 thousand ha). Its productivity is about 875.1Gg and production rate is 17.43Mg/fed (41.49Mg/ha) *(Annual report in Arabic, 2006).* The design of a ventilation duct of constant cross-section is the discharge air from the duct be distributed uniformly along the duct's length. Uniformity of air discharge can be achieved by reducing the ratio of effective discharge area to duct cross-sectional area. Air temperature uniformity in both the vertical and horizontal dimensions may be considered a parameter in determining effectiveness of air distribution. Hot or cold spots within the building are also indicators of poor air temperature uniformity *(Hellickson and Walker, 1983).* Ripening involves a number of physical changes that occur in fruit. The most obvious change in many fruits during ripening is their external colour. The primary requirements for ripening rooms are that they should have a good temperature control system, good and effective air circulation, be gas tight, and a good system for introducing fresh air. If rooms are not frequently ventilated ripening can be delayed, or abnormal ripening can occur *(Thompson, 2003).* Banana is one of the important fruits in the world. Due to its high carbohydrate content, it considers a good source of energy. Because it is a climacteric fruit, it exhibits a well defined preclimacteric period after harvesting. During this period the fruit remain unripe due to its low respiration rate and also to small level of ethylene production *(Marriott, 1980)*. This period can extend with decreasing temperature between 40-15°C. *(Mootoo, 1990)*. After this period, the fruit respiratory rate increases. This increase is closely synchronized with ethylene evolution, peel chlorophyll breakdown, starch to sugar conversion, and pulp softening *(Aked and Kyamuhongire, 1996)*. Ripening at low temperature (15°C) doubles the shelf-life of banana fruits and extends their utilization period for processing *(Naser et al., 2001)*. Ripening of bananas is represented by a sequence of changes in the colour of the peel from green to yellow and the texture of the pulp. The duration of the shelf-life corresponds to the phase of development of the colour from stage No. 4 (more yellow than green) to stage No. 7 (yellow flecked with brown). It is a function of the storage conditions, principally the temperature. The rapidity of ripening increases as the temperature is raised. The fruits are maintained at the required ripening temperature, which is generally between 16 and 18°C *(Gowen, 1995)*. The bananas ripening rooms are subjected to intermediate temperatures, usually 18-20°C and high humidity. In ripening stage the skin colour changes from dark to light green and greenish yellow to bright yellow. Meanwhile the pulp softens outwards from the core and from the tip to stalk. The quality of bananas is improved if they are ripened properly at the right temperature and humidity *(Samson, 1986)*. To ripen banana fruits, specially constructed ripening rooms are used where temperature, humidity as well as airflow rates are controlled. The storage temperature in a ripening room is maintained around 15 to 21°C, with a relative humidity of 85%. The use of opened flame for heating should be avoided because carbon dioxide emitted during the combustion process will interfere with the ripening process. With bananas, as the ripening process proceeds, the rate of heat removal increases five or six times that of the initial rate. The refrigeration system for such products must be properly designed to remove the extra heat generated within the room. Therefore, high airflow rates are necessary for removal of heat given off by the product due to the respiration process. Other changes during ripening of bananas include change of skin colour from green to yellow, ease of peeling, increase in pulp-to-peel ratio, conversion of starch to sugar and softening of the pulp (*Amalendu and paul, 2001)*. Temperatures lower than 11.5^{o}C lead to symptoms of cold damage. Above 35^{o}C the development of the peel and of the pulp is desynchronized, with softening of the pulp proceeding faster than the colouring of the peel. This results in fruit with a soft pulp but a green peel. A reduction in relative humidity dose not alter the respiratory rate, but shows changes in the mass relationship between pulp to peel, in the peel colour, and in pulp softening *(Gowen, 1995)*. The maximum shelf-life (ripening period) of bananas is obtained by slow ripening at range of 16-17^{o}C *(Marriott and Lancaster, 1983)*. Bananas can be harvested unripe and ripened artificially at a later stage. During ripening, its respiration rate increases dramatically over a short period of time. Also, fruit colour is a strong indicator of shelf-life *(Jongen, 2002)*. The duration of "shelf-life" depends on storage temperature. To be assured of a firm pulp texture and bright yellow peel colour, green fruit must be ripened artificially at controlled temperatures. If initial ripening temperatures are too high (>25^{o}C), the fruit develops a soft, ripe pulp while the skin colour is only greenish yellow. Conversely, temperatures below 13^{o}C cause chilling *(Robinson, 1996)*. The movement of water from peel to pulp of bananas during ripening causes an increase in mass of the pulp *(Wills et al., 1984)*.

The essential aim of the study is to investigate the possibility of utilizing an air distribution duct inside ripening room of bananas. Also, to investigate the behavior of ripening process for bananas at various values of temperatures and airflow rates inside a modified ripening room with the existing of air distribution duct. The specific objective of the investigation was to identify and suggest the most important physical properties of bananas which can be changed during its ripening process.

MATERIALS AND METHODS

The experimental part of research work was carried out in a commercial refrigerator for bananas ripening. The experimental unit is located in Kafr

El-Sheikh city. The main parts of the modified commercial refrigerator were: ripening room, suction fan, air conditioning unit and air distribution duct.

AIR CONDITIONING UNIT:

The unit of conditioning air was divided into three essential components. These components are: indoor unit, outdoor unit, and the operating board. The air conditioning unit was adjusted in such a way to get three different levels of air velocity. As well as, using the operating board, both of ripening room temperature and relative humidity were controlled at the required levels in the experiment. The suction fan was mainly constructed in such a way that, when ripening room temperature is raised over the allowable level, then it must be operated automatically to keep the ripening room temperature at the required level throughout the experimental period. The technical specifications of air conditioning unit are listed in Table 1. Sketch of the experimental unit is shown in Fig. 1.

Table 1: Technical specifications of air conditioning unit.

Unit	Model and value
Indoor unit (cooling only) Indoor unit (heat pump) Outdoor unit (cooling only) Outdoor unit (heat pump)	G+ITWG 024U G+IHWG 024U G+OTS 025 G+OHS 025
Cooling capacity, kW	7.03
Heating capacity, kW	7.03
Cooling power consumption, W	2700
Heating power consumption, W	2500
Power supply, V/Ph/Hz	220-240/1/50
Refrigerant type	R22
Net mass, kg: Indoor unit Outdoor unit	 12.5 64.5

AIR DISTRIBUTION DUCT:

For the purpose of the uniformity of distributing air temperature inside ripening room and, in turn, rising the effectiveness of ripening process for bananas, a proper circular duct was designed and fixed with the indoor

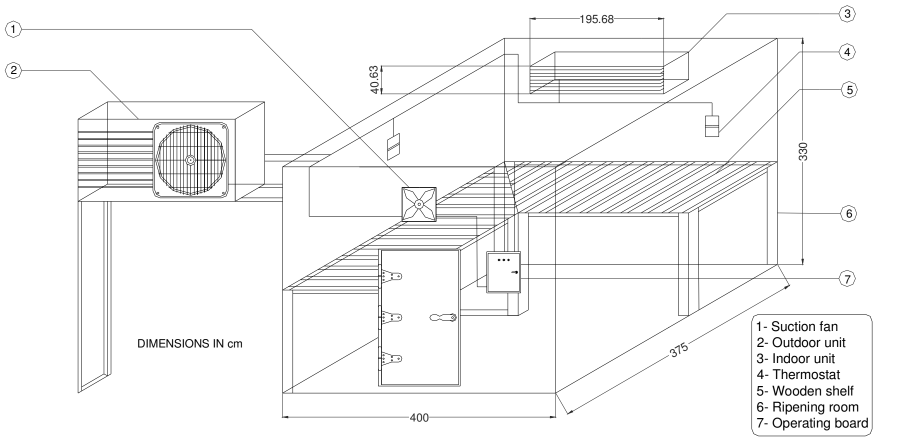

Fig. 1: Schematic diagram of the commercial refrigerator used for banana ripening.

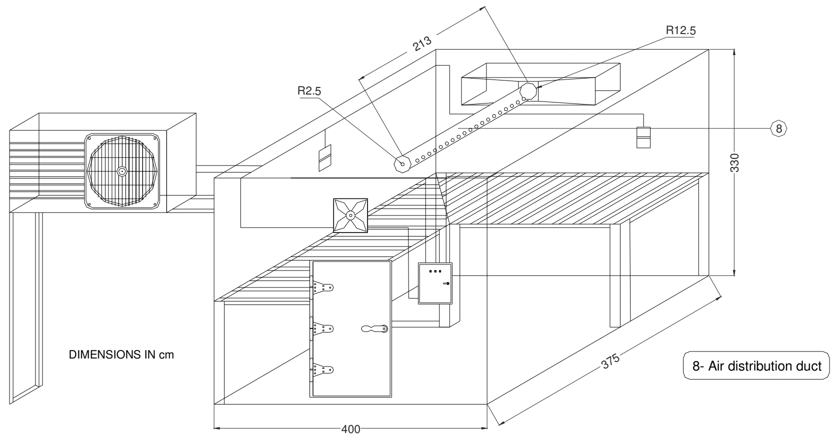

Fig. 2: Schematic diagram of the modified commercial refrigerator with an air distribution duct.

BANANA FRUITS:

Quantity of bananas inside the ripening room was always variable. Therefore, it was massed at each treatment throughout the period of experiment. Hence, the required airflow rate was estimated in relative to each kilogram of bananas. The samples of bananas were transported, after each ripening stage, to Meet El-Deeba village. The physical properties of bananas were tested and identified at laboratory of process engineering and handling, Rice Mechanization Center, Meet El-Deeba village, Kafr El-Sheikh Governorate. At the initiation of banana ripening, pulp-to-peel ratio, pulp texture and pulp moisture content were estimated. Their averaged values were as: 1.57±0.02, 10.75±0.87 N/cm^2 and 63.36±0.29% w.b. successively.

INVESTIGATED VARIABLES:

Three different levels of airflow rate were designed as: 0.1, 0.3 and $0.5 m^3/s.kg$. The ripening room temperatures were selected within the recommended range for banana ripening as: 21, 18 and 15^oC. The relative humidity of ripening room was kept steady all the period of study to be equal to 80±3%. Some physical properties of bananas were studied during its ripening process. Those properties such as ripening stage, mass loss percentage, pulp-to-peel ratio, pulp texture, pulp moisture content and pulp temperature. The influence of ripening room temperature and airflow rate on ripening rate was investigated.

MEASUREMENTS:

Before loading banana fruits to the ripening room (ripening room without bananas), air temperature was measured inside ripening room with and without the air distribution duct Twenty-seven thermocouples were accurately distributed along the vertical and horizontal directions of the ripening room (Fig. 3). J-type thermocouples and a digital thermometer (Model HH-26J-USA) with a wide range of -80 to 760^oC, were used for recording air temperature inside ripening room at the designed ripening room temperatures of 21, 18 and 15^oC. Temperature measurements, at every sensor from twenty-seven sensors, were replicated three times and the averaged values were taken. The standard deviation of those averaged values was calculated at every level of ripening room temperature under study. The designed airflow rates were obtained when the cross-sectional area of the indoor unit was automatically changed. Then, the required airflow rate can be calculated by multiplying both of the cross-sectional area of air distribution duct and the measured air velocity. A digital fan anemometer (Model: BR-B) was used for measuring the velocity of air.

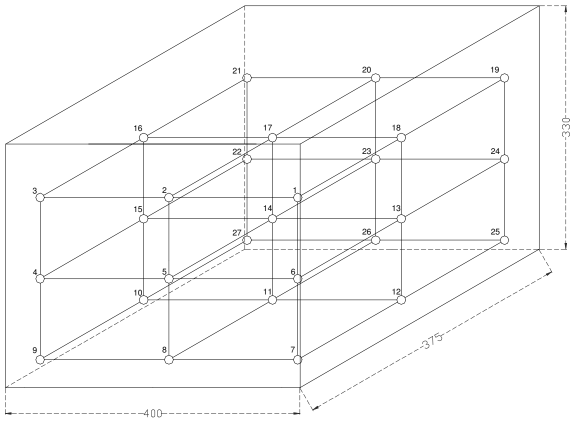

Fig. 3: Sensors for temperature recording along the length, width and height of ripening room.

Stage of banana ripeness were visually determined by a sequence of changes in banana peel colour. These changes were classified according to *Ochse et al., 1961*, Which are prepared for commercial use. This classification includes eight stages of peel colour and were translated to numerical scale. The ripening stages of bananas in respect with peel colour, were as: 1=green; 2=green trace of yellow; 3=more green than yellow; 4=more yellow than green; 5=green tip; 6=all yellow; 7=yellow flecked with brown and 8=yellow with large brown areas.

Mass loss percentage of bananas was calculated using the following formula:

$$m = \frac{M_1 - M_2}{M_1} x100 \quad \text{...} \quad 1$$

Where:

m mass loss percentage, %;

M_1 mass of bananas bunch before each ripening stage, kg and

M_2 mass of bananas bunch after each ripening stage, kg.

Pulp-to-peel ratio was determined by the following relation:

$$P = \frac{P_1}{P_2} \quad \text{...} \quad 2$$

Where:

P pulp-to-peel ratio, dimensionless;

P_1 mass of fruits pulp after each ripening stage, kg and

P_2 mass of fruits peel after each ripening stage, kg.

To estimate the moisture content of fruits pulp, using a vacuum oven at 70°C to constant mass according to *AOAC, 1985*, the following equation was used:

$$MC = \frac{W_1 - W_2}{W_1} X 100 \quad \cdots\cdots\cdots\cdots \quad 3$$

Where:

MC pulp moisture content, %w.b.;

W_1 mass of fruits pulp before each ripening stage, kg and

W_2 mass of fruits pulp after each ripening stage, kg.

A Japanese texture meter, (M-T-140) with a plunger of 8mm in diameter, was used to measure changes in pulp texture during ripening process and it was expressed in terms of N/mm^2.

The pulp temperature was measured by using the same apparatus, which was described above for measuring ripening room temperatures. At each ripening stage, five thermocouples were constructed in the ripening room and the mean values of pulp temperature were considered.

A multiple regression analysis was done and regression equations of two independent variables were developed for some physical characteristics of bananas during its ripening process.

RESULTS AND DISCUSSION

AIR DISTRIBUTION EFFECTIVENESS:

Effectiveness of air distribution inside ripening room was highly influenced with the air distribution duct. As indicated in Fig. 4, the mean values of ripening room temperature were of 14.93 and 14.21°C, 17.93 and 17.19°C, and 20.94 and 20.18°C inside ripening room with and without the air distribution duct respectively at the investigated temperatures of 15, 18 and 21°C successively. It is obvious that the deviations of temperatures about their mean values were less with the air distribution duct, than that of without one. This means that the air distribution duct raised the effectiveness of air distribution inside ripening room, and hence, ripening rate of bananas can be improved and accelerated. As shown in Fig. 4, the air distribution duct raised the

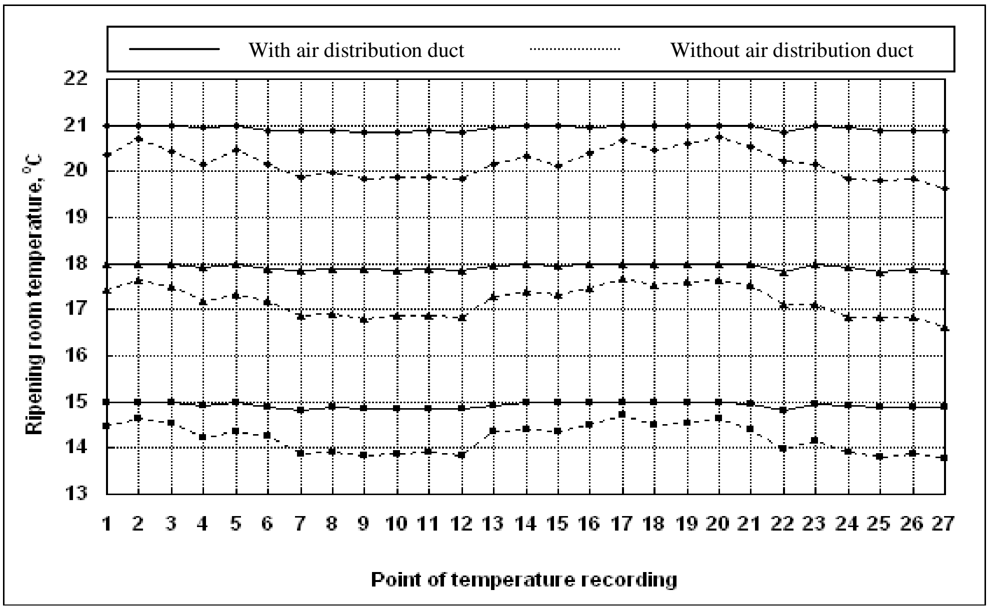

Fig. 4: Distributing air temperature along the vertical and horizontal directions of ripening room with and without the air distribution

uniformity effectiveness of air distribution inside ripening room by 395.24, 406.25 and 458.62% at ripening room temperatures of 15, 18 and 21°C successively. This, in turn, will enhance the uniformity of air distribution for each finger of bananas and therefore maintain its quality to be ready in use after that for processing or marketing. From the mentioned results beforehand, it can be recommended that the air distribution duct must be designed and fixed with the indoor unit and then banana fruits can be loaded and ripened under the modified conditions with the existing of air distribution duct.

RIPENING STAGE:

As shown in Fig. 5, the full ripening stage of bananas was at stage No. 8. It is clear that, as the ripening room temperature decreased from 21 to 15°C, the ripening period was expanded from 12 to 25 days at constant airflow rate of 0.3m^3/s.kg. Meanwhile, the ripening period (shelf-life) of bananas was shortened by increasing airflow rate. It is noticed that, at ripening room temperature of 21°C, the shelf-life was shortened from 14 to 13 days as the airflow rate increased from 0.1 to 0.5m^3/s.kg. The shortest period of ripening bananas was found 12 days at airflow rate of $0.3m^3$/s.kg and ripening room temperature of 21°C. This means that, to obtain a quick ripening of bananas, then $0.3m^3$/s.kg and 21°C can be used to fulfill this process.

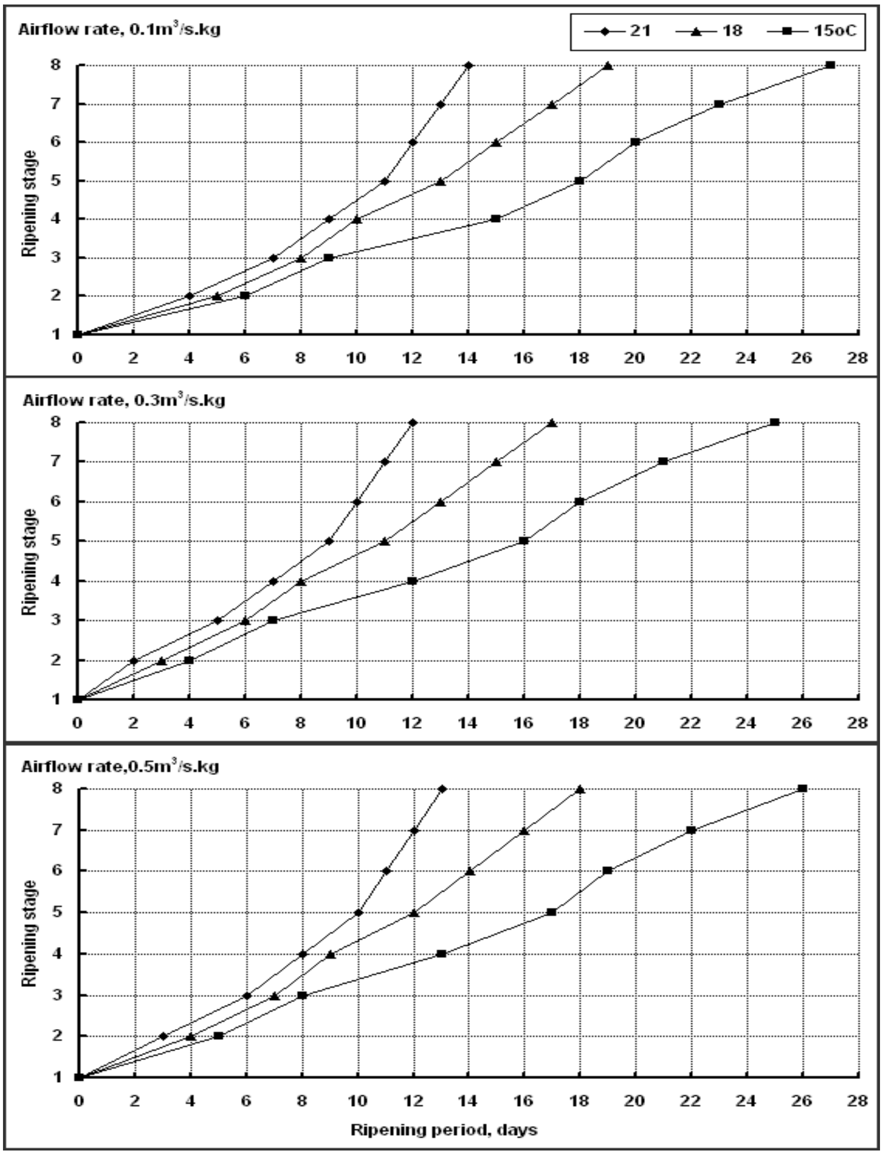

Fig. 5: Influence of ripening room temperature on ripening stage at different airflow rates

MASS LOSS PERCENTAGE:

As shown in Fig. 6, the mass loss percentage increased gradually as the ripening process was proceeded for all stages of banana ripeness. At ripening stage No. 8 of full banana ripeness, as airflow rate increased from 0.1 to $0.3m^3/s.kg$, values of mass loss percentage decreased from 8.48 to 6.98% at ripening room temperature of 21^oC. At constant airflow rate of $0.3m^3/s.kg$, it was found that as the ripening room temperature decreased from 21 to 15^oC, the reduction of mass loss percentage was 43.58%. It is noticed that, the lowest values of mass loss percentage were found at airflow rate of $0.3m^3/s.kg$ at all values of investigated ripening room temperatures.

PULP-TO-PEEL RATIO:

The effect of ripening room temperature on pulp-to-peel ratio was investigated as shown in Fig. 7. It is noticed that, at constant airflow rate of $0.3m^3/s.kg$, the pulp-to-peel ratio increased from 2.34 to 3.79 while the ripening room temperature increased from 15 to 21^oC. Also, it was indicated that, when both of airflow rate and ripening room temperature were constant, pulp-to-peel ratio was gradually increased during ripening of bananas according to *Wills et al., 1984 and Amalendu and paul, 2001*. Meanwhile, as the ripening room temperature was constant at 21^oC the pulp-to-peel ratio was increased from 2.01 to 3.79 as airflow rate increased from 0.1 to $0.3m^3/s.kg$.

PULP TEXTURE:

Pulp texture of bananas was highly affected by ripening room temperature and airflow rate as shown in Fig. 8. Pulp texture of bananas was strongly decreased from 10.75 to $0.48N/cm^2$, at ripening room temperature of 21^oC and airflow rate of $0.3m^3/s.kg$, as bananas was ripened from stage No. 1 to stage No. 8 according to *Amalendu and paul, 2001*. Whereas the ripening room temperature was raised from 15 to 21^oC, at constant airflow rate of $0.3m^3/s.kg$, the bananas pulp texture was lowered from 0.98 to $0.48N/cm^2$. Meanwhile, values of pulp texture were decreased from 0.97 to $0.72N/cm^2$, at constant ripening room temperature of 18^oC, when airflow rate increased from 0.1 to $0.3m^3/s.kg$. It is noticed that, the lowest values of pulp texture of bananas were found at airflow of $0.3m^3/s.kg$ at all of ripening room temperatures.

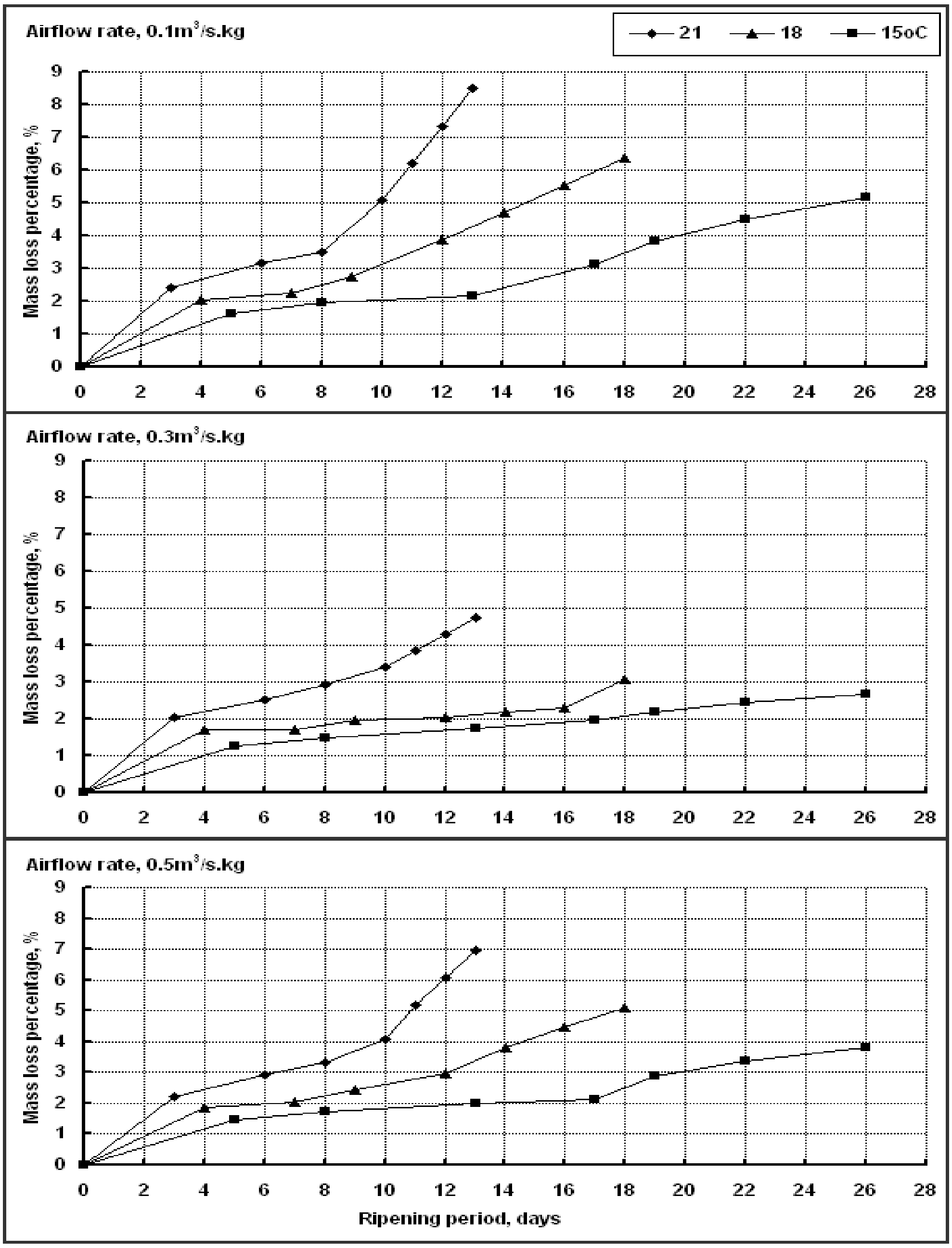

Fig. 6: Influence of ripening room temperature on mass loss percentage at different airflow rates.

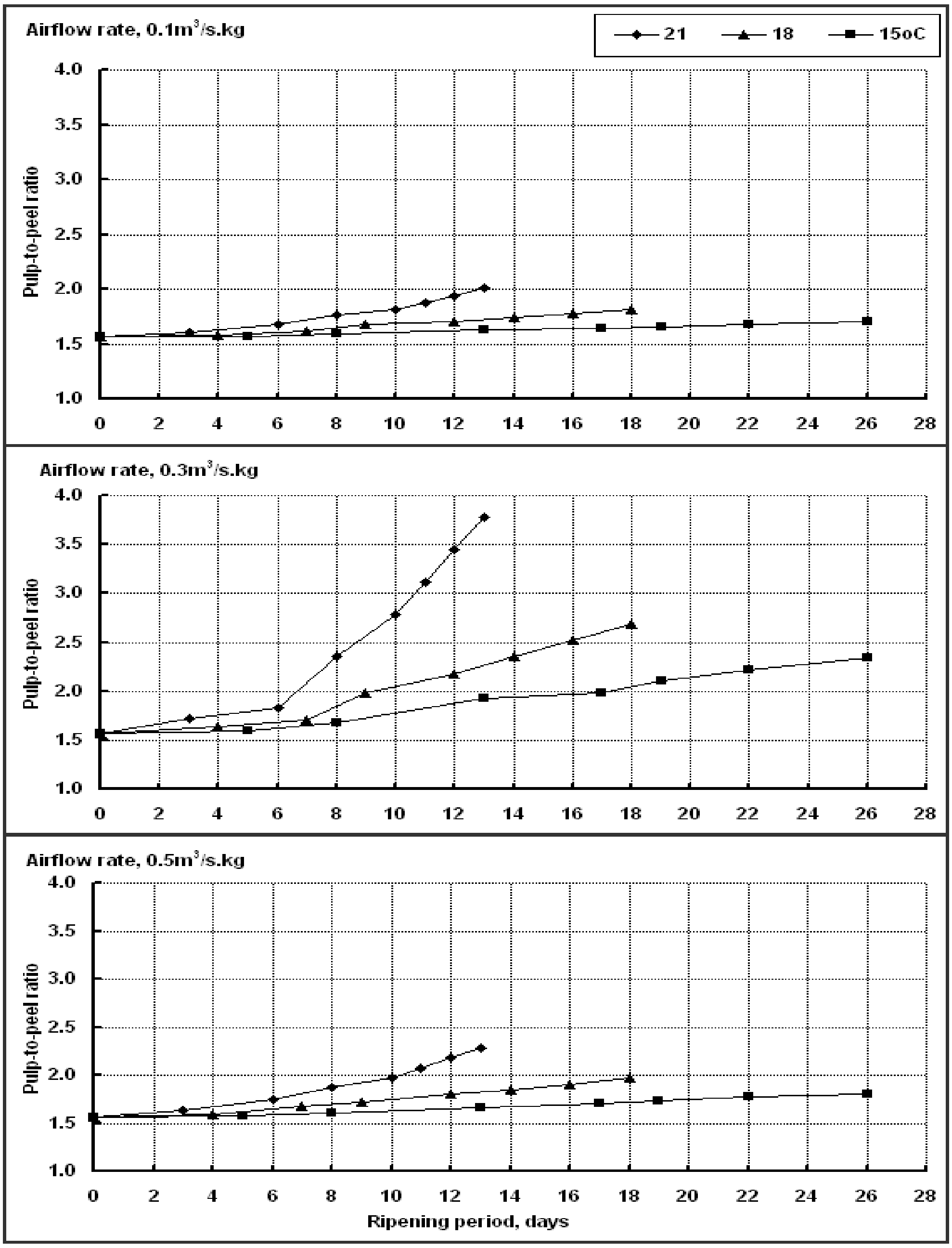

Fig. 7: Influence of ripening room temperature on pulp-to-peel ratio at different airflow rates.

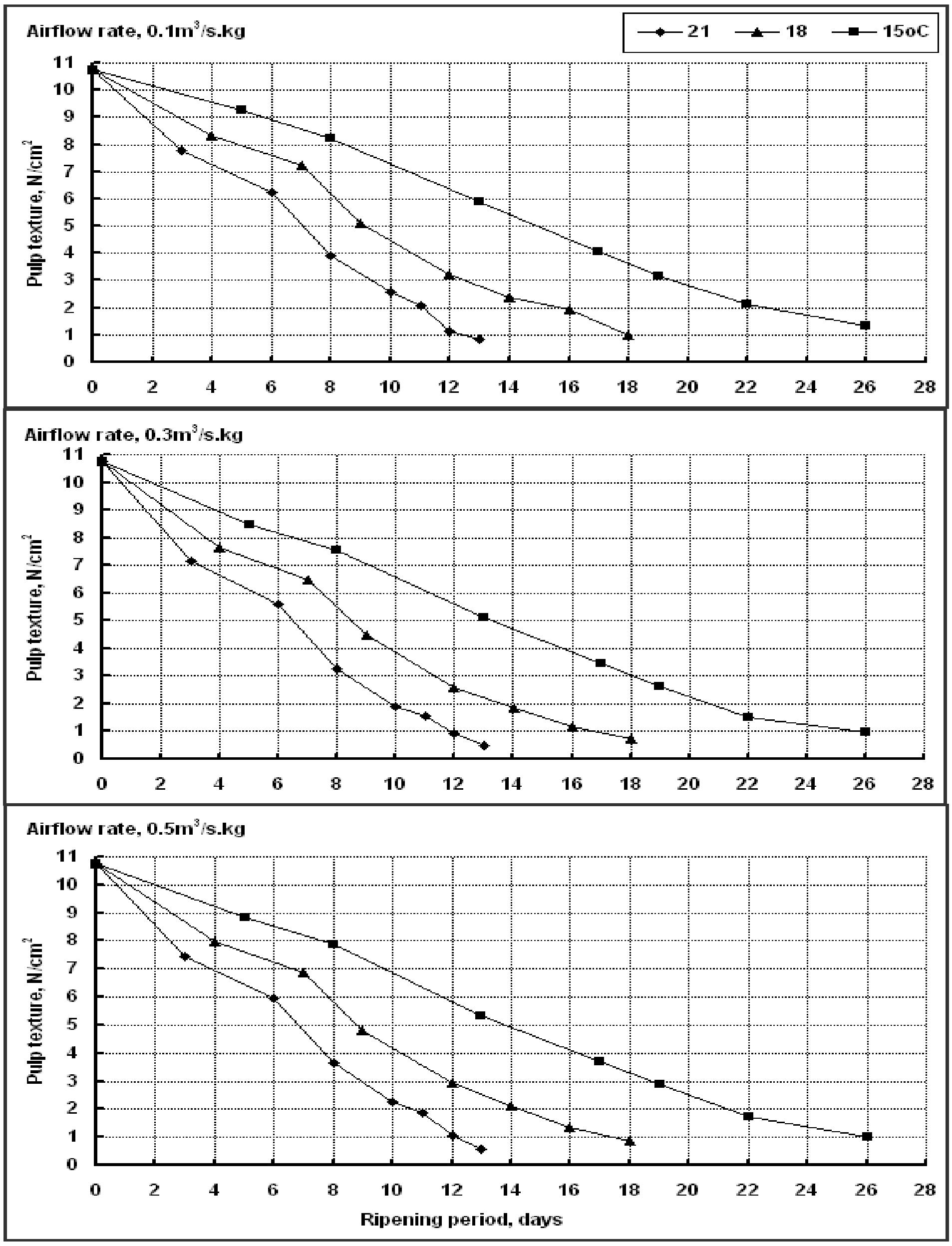

Fig. 8: Influence of ripening room temperature on pulp texture at different airflow rates.

PULP MOISTURE CONTENT:

During ripening of bananas, form stage No. 1 to stage No. 8, the moisture was transferred from peel to pulp according to *Wills et al., 1984.*

Therefore, it is indicated from Table 2, as bananas were ripened from stage No. 1 to stage No. 8, the moisture content of pulp gradually increased at all of airflow rates and ripening room temperatures. As shown in Fig. 9, when airflow rate is constant at $0.3m^3/s.kg$, the moisture content of bananas pulp increased from 69.98 to 74.74% w.b. as the ripening room temperature also increased from 15 to 21°C. As well as, it is indicated that, at constant ripening room temperature of 15°C, the pulp moisture content increased from 67.11 to 69.25% w.b. as airflow rate raised from 0.1 to $0.5m^3/s.kg$. While, at constant airflow rate of $0.3m^3/s.kg$ and constant ripening room temperature of 21°C, the moisture content of bananas pulp gradually increased from 63.36 to 74.74% w.b. as bananas were ripened from stage No. 1 to stage No. 8. The highest values of pulp moisture content were noticed at airflow rate of $0.3m^3/s.kg$ at all of ripening room temperatures.

PULP TEMPERATURE:

As shown in Fig. 10 and Table 2, the pulp temperature of bananas dramatically increased until stage No. 6 of bananas ripening because bananas gained its maximum respiration rate at this stage. When the airflow rate and ripening room temperature were constant at $0.1m^3/s.kg$ and 21°C, the pulp temperature of bananas increased from 21.87 to 22.49°C, as the ripening process was proceeded from stage No. 2 to stage No. 8. It is revealed from Fig. 10 and Table 2, that the pulp temperature of bananas gradually increased by increasing the ripening room temperature and reducing airflow rate. At ripening room temperature of 21°C, the pulp temperature of bananas decreased from 22.49 to 21.56°C, at ripening stage No. 8, as airflow rate raised from 0.1 to $0.5m^3/s.kg$. Meanwhile, when airflow is constant at $0.3m^3/s.kg$ and at ripening stage No. 8, the pulp temperature increased from 16.06 to 22.16°C by rising the ripening room temperature from 15 to 21°C. the lowest values of pulp temperature were found at airflow rate of $0.5m^3/s.kg$ at all of ripening room temperatures.

Table 2: Changes in physical properties of bananas during its ripening process as affected by both of ripening room temperature and airflow rate.

Property	Airflow rate, $m^3/s.kg$	Ripening room temperature, °C	Ripening stages, (1=green, 2=green trace of yellow, 3=more green than yellow, 4=more yellow than green, 5=green tip, 6=all yellow, 7=yellow flecked with brown and 8=yellow with large brown areas, *Ochse et al., 1961*)							
			1	2	3	4	5	6	7	8
Ripening period, days	0.1	21	0.0	4	7	9	11	12	13	14
		18	0.0	5	8	10	13	15	17	19
		15	0.0	6	9	15	18	20	23	27
	0.3	21	0.0	2	5	7	9	10	11	12
		18	0.0	3	6	8	11	13	15	17
		15	0.0	4	7	12	16	18	21	25
	0.5	21	0.0	3	6	8	10	11	12	13
		18	0.0	4	7	9	12	14	16	18
		15	0.0	5	8	13	17	19	22	26
Mass loss percentage, %	0.1	21	0.0	2.41	3.17	3.51	5.10	6.22	7.35	8.48
		18	0.0	2.05	2.23	2.74	3.86	4.70	5.54	6.38
		15	0.0	1.63	1.94	2.17	3.14	3.82	4.50	5.19
	0.3	21	0.0	2.03	2.53	2.93	3.40	3.85	4.30	4.75
		18	0.0	1.69	1.72	1.95	2.05	2.18	2.31	3.08
		15	0.0	1.25	1.47	1.73	1.96	2.20	2.44	2.68
	0.5	21	0.0	2.21	2.94	3.32	4.06	5.18	6.08	6.98
		18	0.0	1.86	2.03	2.46	2.97	3.81	4.47	5.12
		15	0.0	1.45	1.75	1.98	2.11	2.88	3.36	3.83
Pulp-to-peel ratio, dimensionless	0.1	21	1.57	1.61	1.68	1.76	1.82	1.88	1.94	2.01
		18	1.57	1.58	1.62	1.68	1.71	1.74	1.78	1.82
		15	1.57	1.57	1.59	1.63	1.64	1.66	1.68	1.70
	0.3	21	1.57	1.72	1.83	2.35	2.78	3.12	3.45	3.79
		18	1.57	1.63	1.71	1.98	2.18	2.35	2.52	2.69
		15	1.57	1.59	1.68	1.93	1.99	2.10	2.22	2.34
	0.5	21	1.57	1.63	1.75	1.88	1.97	2.08	2.18	2.29
		18	1.57	1.59	1.67	1.72	1.80	1.85	1.91	1.97
		15	1.57	1.58	1.61	1.66	1.71	1.73	1.77	1.81
Pulp texture, N/cm^2	0.1	21	10.75	7.78	6.26	3.91	2.58	2.08	1.16	0.83
		18	10.75	8.34	7.21	5.12	3.24	2.38	1.93	0.97
		15	10.75	9.27	8.25	5.89	4.07	3.16	2.11	1.35
	0.3	21	10.75	7.17	5.62	3.25	1.89	1.57	0.93	0.48
		18	10.75	7.62	6.49	4.48	2.59	1.86	1.18	0.72
		15	10.75	8.47	7.54	5.11	3.48	2.65	1.49	0.98
	0.5	21	10.75	7.45	5.95	3.63	2.28	1.86	1.05	0.59
		18	10.75	7.95	6.88	4.81	2.91	2.12	1.33	0.86
		15	10.75	8.86	7.87	5.32	3.68	2.87	1.75	1.02
Pulp moisture content, % w.b.	0.1	21	63.36	64.41	65.93	67.46	68.78	70.18	71.59	72.99
		18	63.36	63.95	64.97	66.35	67.78	68.21	69.23	70.25
		15	63.36	63.21	64.46	64.79	65.38	65.95	66.53	67.11
	0.3	21	63.36	65.19	66.59	68.28	69.89	71.51	73.12	74.74
		18	63.36	64.61	65.68	66.87	68.03	69.19	70.88	71.51
		15	63.36	64.28	65.11	66.21	66.88	67.75	68.63	69.98
	0.5	21	63.36	64.78	66.21	67.87	69.35	70.88	72.40	73.94
		18	63.36	64.28	65.35	66.78	67.83	68.99	70.16	71.32
		15	63.36	63.93	64.83	65.18	65.97	67.31	68.13	69.25
Pulp temperature, °C	0.1	21	-	21.87	22.68	23.52	24.05	23.41	22.68	22.49
		18	-	18.73	19.59	20.25	20.84	20.37	19.52	19.39
		15	-	15.72	16.56	17.24	17.82	17.33	16.49	16.34
	0.3	21	-	21.31	22.25	22.71	23.52	22.98	22.35	22.16
		18	-	18.22	19.43	19.62	20.31	19.95	19.25	19.11
		15	-	15.21	16.4	16.61	17.29	16.91	16.22	16.06
	0.5	21	-	21.12	21.91	22.43	22.93	22.56	21.94	21.56
		18	-	18.11	18.75	19.23	19.87	19.42	18.78	18.26
		15	-	15.1	15.72	16.22	16.85	16.38	15.75	15.21

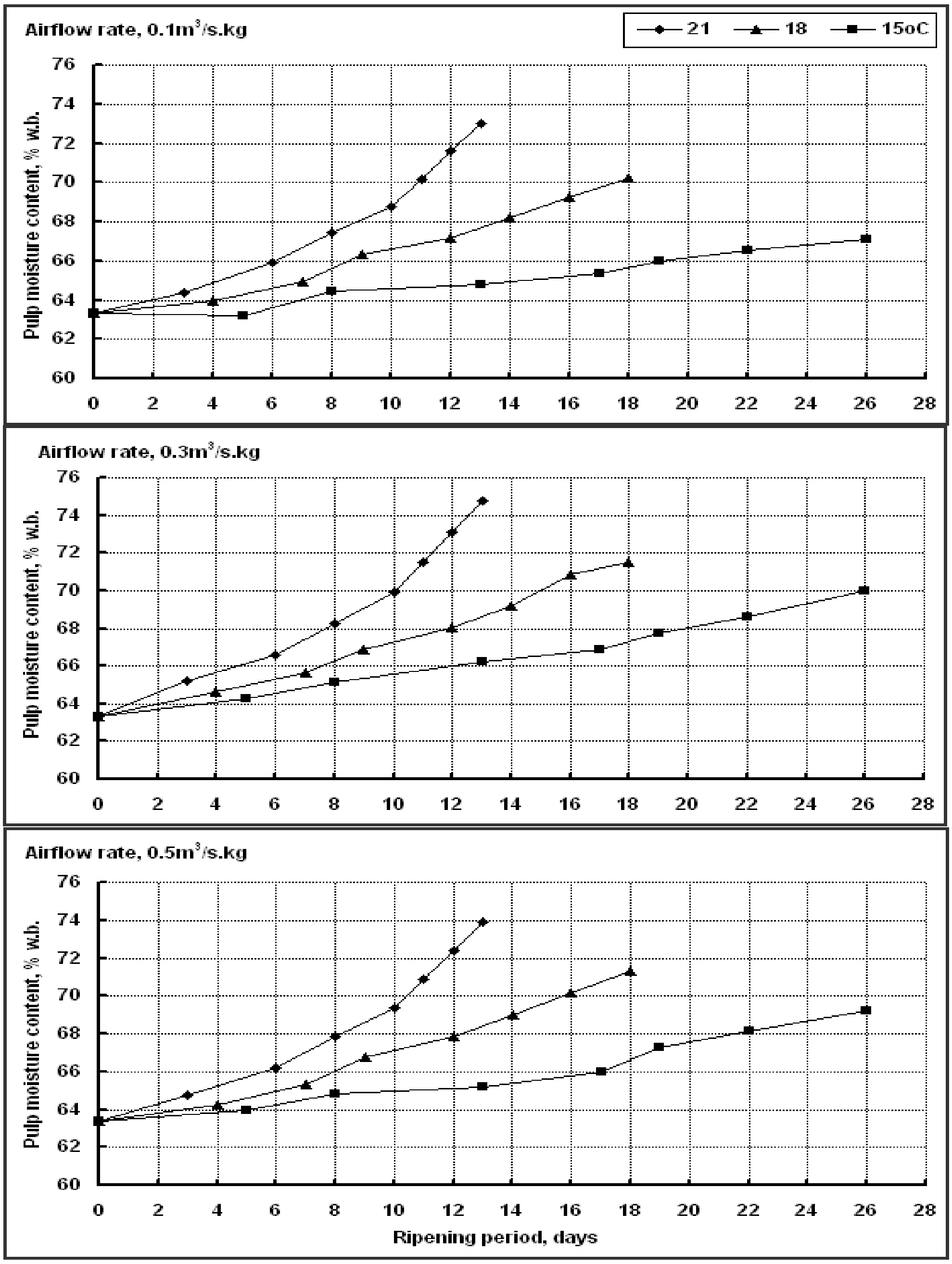

Fig. 9: Influence of ripening room temperature on pulp moisture content at different airflow rates.

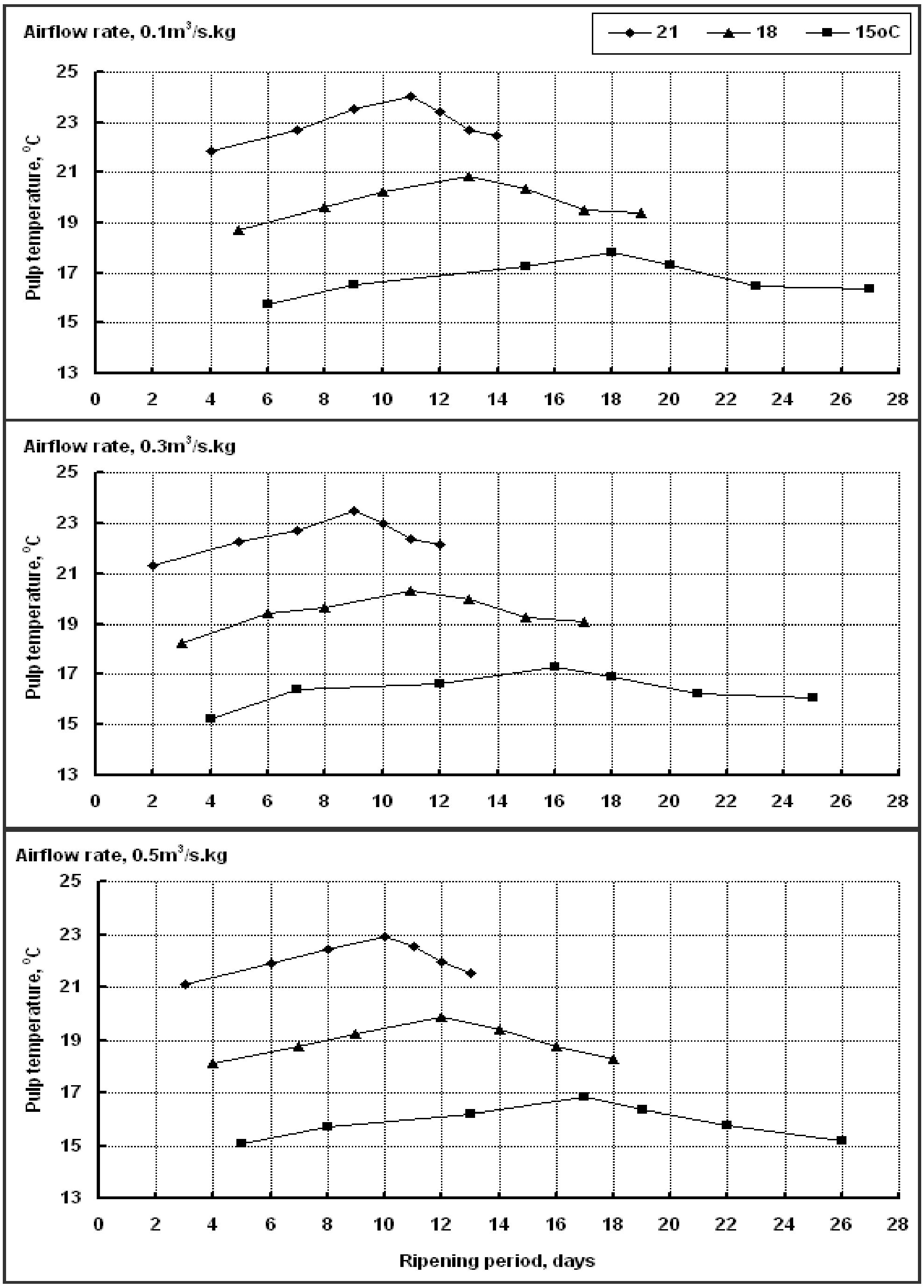

Fig. 10: Influence of ripening room temperature on pulp temperature at different airflow rates.

A regression analysis was done for the group of data which obtained through the experimental work. Multiple linear regression equations were derived for all of the physical properties of bananas for ripening stage No. 8. The values of regression coefficients and their corresponding values of determination coefficients are listed in Table 3. The ripening stage No. 8 was directly considered, for developing such linear regression equations, because bananas have been reached its maximum ripening rate and its ripening process of bananas has been accomplished at this stage. Similar regression coefficients could be attained for all of bananas properties at every stage of ripening and, hence, many multiple regression equations could be developed. In short, the ripening rate of bananas was highly and significantly affected by both of airflow rate and ripening room temperature at all of the ripening stages. The ripening process of bananas, at various indicators, was well described by the following general multiple linear regression equation:

$Y = a_o + b_1X_1 + b_2X_2$ ……………………………..……..… 4

Where:

Y indicator;

X_1 airflow rate, m^3/s.kg;

X_2 ripening room temperature, ^oC;

a_o Y-intercept and

b_1, b_2 regression coefficients.

Table 3: Regression equation, describing the ripening process for bananas at ripening stage No. 8.

Indicator	Y-intercept	Regression coefficients		Determination coefficient (R^2)
	a_o	b_1	b_2	
Shelf-life, days	+58.750	-2.500	-2.167	0.966
Mass loss percentage, %	-2.274	-3.433	+0.473	0.555
Pulp-to-peel ratio, dimensionless	-0.106	+0.450	+0.124	0.261
Pulp texture, N/cm^2	+2.487	-0.567	-0.081	0.807
Pulp moisture content,% w.b.	+54.862	+3.467	+0.852	0.909
Pulp temperature, ^oC	+1.151	-2.658	+1.033	0.998

CONCLUSION

The essential points of the present investigation can be concluded as follows:

1. The existing of air distribution duct inside ripening room of bananas raised the uniformity effectiveness of air distribution by 395.24, 406.25 and 458.62% at ripening room temperatures of 15, 18 and 21^{o}C respectively.
2. Ripening period of bananas was shortened by 52% with increasing ripening room temperature from 15 to 21^{o}C, while by increasing airflow rate from 0.1 to 0.3m^3/s.kg, it was reduced only by 14.286%.
3. For achieving a quick ripening of bananas, airflow rate of 0.3m^3/s.kg and ripening room temperature of 21^{o}C could be recommended to accomplish this process successfully.
4. By proceeding ripening process of bananas from stage No. 1 to stage No. 8, mass loss percentage, pulp-to-peel ratio, pulp moisture content and pulp temperature gradually increased, while pulp texture was strongly decreased.
5. The lowest values of mass loss percentage and pulp texture were obtained at airflow rate of 0.3m^3/s.kg at all of ripening room temperatures. Conversely, the highest values of pulp moisture content were found at airflow rate of 0.3m^3/s.kg.
6. All of the physical properties of bananas were noticeably affected by changing both of airflow rate and ripening room temperature. From the above-mentioned results, it can be revealed that, at any airflow rate within the recommended range for ripening bananas, the ripening room temperatures of 21, 18 and 15^{o}C can be successfully used for achieving high, moderate and slow ripening rates successively.

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الملخص العربي

دراسة تأثير درجة الحرارة ومعدل سريان الهواء على عملية الإنضاج الصناعي للموز

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يعتبر الموز من الفاكهة التي تحتوي علي نسبة عالية من الكربوهيدرات ، لذا فهو مصدر هام للطاقة وتزرع مصر منه سنويا حوالي 50.24 ألف فدانا (21.1 ألف هكتار) وتبلغ إنتاجيته حوالي 875.1 جيجا جرام ومعدل الإنتاج هو 17.43 ميجا جرام/فدان (41.49 ميجا جرام/هكتار) (التقرير السنوي للزراعة المتوسطية ، 2006). وفى مصر يتم إنضاج الموز صناعيا بعد حصاده في غرف خاصة تعرف بغرف الإنضاج والتي غالبا ما تقع بالقرب من أسواق التوزيع. وهناك طرق عديدة تستخدم في عملية إنضاج الموز داخل هذه الغرف. ومن أهم هذه الطرق هو التحكم في الظروف الجوية داخل هذه الغرف من حيث التحكم في درجة حرارة غرفة الإنضاج وكذا معدل سريان الهواء داخل غرف الإنضاج مع المحافظة على رطوبة نسبية عالية تتراوح في المدى ما بين 80±3% عند جميع مراحل إنضاج الموز. لذلك كان الهدف الرئيسي من هذا البحث هو دراسة إمكانية استخدام ماسورة لتوزيع الهواء داخل غرفة الإنضاج حيث تم تصميم ماسورة لتوزيع الهواء بشكل منتظم قطرها 0.25م وطولها 2.13م ومثقبة من جانبيها وكذا السطح السفلي لها بثقوب قطر كل منها 0.05م وهذه الماسورة مصنوعة من البلاستيك. تم تركيب ماسورة توزيع الهواء في الوحدة الداخلية لوحدة تكييف الهواء مع خفض النسبة بين مساحة مقطع الماسورة إلى الوحدة الداخلية إلى 25%. تم تحميل غرفة الإنضاج بثمار الموز بعد إضافة ماسورة توزيع الهواء. تم أيضا دراسة تأثير كلا من درجة حرارة غرفة الإنضاج ومعدل سريان الهواء على بعض الخواص الطبيعية للموز أثناء مروره بجميع مراحل الإنضاج. تم اختبار ثلاثة مستويات من درجة حرارة غرفة الإنضاج وهى 21 ، 18 ، 15^{5}م ، وثلاثة مستويات من معدل سريان الهواء وهى 0.1 ، 0.3 ، 0.5 م^{3}/ث.كج ودراسة تأثيرهما على معدل إنضاج الموز داخل غرفة الإنضاج.

<u>ويمكن تلخيص النقاط الجوهرية في البحث كما يلي:</u>

1- بلغت قيم الانحراف القياسي لدرجات حرارة غرفة الإنضاج عن متوسطها الحسابي في وجود ماسورة توزيع الهواء 0.063، 0.064، 0.058 عند درجات الحرارة المدروسة 15، 18، 21^{5}م على الترتيب. بينما بلغت قيم الانحراف القياسي في حالة عدم وجود ماسورة توزيع الهواء 0.312، 0.324، 0.324 عند نفس درجات الحرارة تحت الدراسة على التوالي.

2- ازدادت فعالية انتظامية توزيع الهواء داخل غرفة الإنضاج في وجود ماسورة توزيع الهواء بنسبة 395.24، 406.25، 458.62% عند درجات الحرارة 15، 18، 21^{5}م على التوالي.

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3- بزيادة درجة حرارة غرفة الإنضاج من 15 إلى 21^{5}م ، انخفضت فترة إنضاج الموز بنسبة 52% ، بينما انخفضت هذه الفترة بنسبة 14.286% بزيادة معدل سريان الهواء من 0.1 إلى 0.3م^{3}/ث.كج.

4- لتحقيق إنضاج سريع للموز ، يوصى باستخدام درجة حرارة غرفة الإنضاج عند 21^{5}م ، وكذا معدل سريان الهواء عند 0.3م^{3}/ث.كج لإتمام هذه العملية.

5- بانقضاء عملية إنضاج الموز مرورا بالمرحلة الأولى وحتى المرحلة الثامنة ، تأثر كل من النسبة المئوية للفقد في الكتلة ، نسبة اللب إلى القشرة ، المحتوى الرطوبى للب ودرجة حرارة اللب بالزيادة (علاقة طردية) ، بينما تأثر قوام اللب بالنقصان (علاقة عكسية).

6- تم الحصول على اقل قيم لكلا من النسبة المئوية للفقد في الكتلة وكذا قوام اللب عند معدل سريان الهواء 0.3م^{3}/ث.كج عند جميع درجات حرارة غرفة الإنضاج. بينما وجد أن أعلى قيم للمحتوى الرطوبى للب تقع عند هذا المعدل.

7- تأثرت جميع الخصائص الطبيعية للموز بشكل ملحوظ عند تغير درجات حرارة غرفة الإنضاج وكذا معدلات سريان الهواء. اتضح أيضا ، عند أي معدل سريان هواء داخل المدى الموصى به ، فإنه يمكن إنجاز معدل إنضاج سريع ومتوسط وبطئ عند درجات حرارة غرفة الإنضاج 21 ، 18 ، 15^{5}م على الترتيب.