BANANA STORAGE PERFORMANCE IN A REFRIGERATION SYSTEM WITH R404A REFRIGERANT AT DIFFERENT PRESSURES

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***Abstract*— In this study, the storage performance of banana fruits in a refrigeration system at different pressures (950, 1050 and 1150 kPa) with R404A gas refrigerant was investigated. The trials lasted about 10 days. Weight loss (%), color changes, energy consumption and temperature values were determined. Total soluble solids (SSC), pH and total acidity (TA) of the fruits were also analyzed. The weight loss at the experiments was measured as %1.32 at 950 kPa pressure, %1.08 at 1050 kPa pressure and %1.30 at 1150 kPa pressure. Change in fruit surface areas throughout the storage period was determined with the aid of an image processing software. As compared to fresh fruits, SSC, pH and TA of the fruits were best-preserved at 950 kPa pressure. Therefore, 950 kPa pressure was recommended for R404A refrigerant in cold storage of banana fruits.**

***Keywords*— Food quality, Gas performance, Image processing, Preservation, Quality**

I. INTRODUCTION

Banana is among the leading fruits consumed worldwide. Besides nutritive values, banana fruits are also rich in vitamins, protein and minerals. With a rich content of phenolics, carotenoids, biogenic amine and various other bioactive compounds, banana fruits have several health benefits, thus play a key role in human nutrition. Majority of these compounds have antioxidant characteristics and able to prevent human body from oxidative stress conditions (Singh *et al*., 2016).

Banana has a significant place in fruit production of both Turkey and the world. World annual banana production is about 101 million tons. According to FAO data of the year 2017, annual banana production of Turkey was 369.211 tons (TUIK, 2019). The preservation of a fruit with such a large production and consumption demand is also very important. Banana fruits could be stored at 13°C for 1-2 weeks. Fruits are brought to appropriate storage conditions instantly to prolong post-harvest life of the fruits. Cold storages are used to provide appropriate storage conditions. (Boz, 2016).

Besides heating technologies, mankind always needs cooling technologies to sustain daily life. During the early periods of cooling industry emerged in the second half of the 19th century, water, air, carbon dioxide and ammonia have been used as refrigerants. Later on, several alternatives of these substances were developed, and researches are still ongoing about potential refrigerants (Koyun *et al*., 2005). Refrigerants are generally used in acclimatization, heat pumps and cold storage systems.

Majority of present cold storage facilities of Turkey are not fully integrated with newly developed technologies. After all, there are serious losses experienced throughout the post-harvest processes applied from the harvest to tables and such losses generate significant damages on national economy. Previous research indicated that Turkey lost about 10 million tons of annual fruit/vegetable production (40 million tons) and such a loss corresponded to a sum of 20 billion livres (about 3 billion dollars). It is possible to minimize these losses with urgent measures to be taken (Türk and Karaca, 2015).

To minimize these losses and to provide longer shelf life, cold storage systems are used. However, the damages of the refrigerants used in some of these systems are increasing day by day. Rapidly developing technology increased the quantities of refrigerants with serious negative impacts on ozone layer and global warming (Onat *et al.*, 2004). Greenhouse gases are the primary actors of global warming and fossil fuel-burning energy transformation systems and heating/cooling systems are the primary source of these greenhouse gasses (Çakır and Çomaklı, 2011). Chlorofluorocarbon (CFC) and hydrochlorofluorocarbons (HCFC), also known as refrigerants, are released to atmosphere in time, accumulate or reach to large quantities in atmosphere and finally end up with greenhouse effect. The ozone layer, preventing living creatures from the harmful effects of solar rays, is destructed through the fracture of weak ozone molecules by freed bromine and chlorine atoms of refrigerants. Therefore, refrigerants of cooling systems should be so selected as to maximize energy efficiency and to minimize global warming impacts of these systems (Yakut, 2013).

Refrigerant selection has become a significant issue just because of the above-mentioned reasons. Several factors are effective in refrigerant selection and such factors include ozone depletion potential (ODP) of the refrigerant, energy efficiency, global warming potential (GWP), safety and economics. A perfect refrigerant meeting all these criteria has not be identified or developed, yet (Koyun *et al*., 2005). However, some refrigerants with the least damage, which have been used recently and whose researches continue, are used. One of these refrigerants is R404A gas.

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Figure 1. Manufactured cooling system

The R404A refrigerant is widely used around the world. In addition, many studies have been carried out in recent years to determine the performance of this refrigerant (Sun *et al*., 2016; Islam and Singh 2019; Jeon, 2021; Widodo *et al*., 2021). R404A gas was used as refrigerant. R404A gas has a low global warming potential (GWP) and has “0” ozone depletion potential (ODP). The gas has a quite well heat transfer capacity and it is a refrigerant with the greatest condenser heat capacity. Therefore, it was selected as a refrigerant with a slight impact on global warming.

In this study, ın a refrigeration system using R404A gas the effects of different pressure values (950, 1050, 1150 kPa) on the storage life of the banana were investigated in terms of color, modeling, energy consumption and chemical analysis.

II. METHODS

A. Refrigeration system components and refrigerant

A refrigeration system using R404A gas as the refrigerant was manufactured in this study (Fig. 1).

Following the selection of refrigerant, Coolpack (Version 1.49) software was used for refrigeration calculations. The software was offered to use free of charge by Denmark Technical University (Bulgurcu, 2001; Anonymous, 2013). The software was also used in selection of pressure levels. Refrigerator is basically composed of a compressor, condenser, evaporator, refrigerant, copper conveyance pipes and capillary pipe sections.

B. Storage experiments

Experiments were conducted in manufactured refrigeration system at 3 different pressures (950, 1050 and 1150 kPa). The reason for choosing these pressure values is because they gave optimum results in preliminary studies. Enthalpies, refrigerant quantities to be used and reachable refrigerant quantities at each pressure level were calculated with the aid of Coolpack software. A high- and low-pressure indicator was placed over the system and pressures were instantly recorded with the aid of these indicators. The indicators is double manifold and is a Universal product.

Room temperature was measured at one-hour intervals during the experiments. During the experiments, the ambient temperature was determined at an average of 22±1° C degrees.

There were 4 temperature sensors placed over the manufactured refrigeration system. Universal boiler pass brand NTC 1/2 model temperature sensor is used. Sensors were placed at the input and outputs of compressor and evaporator. Temperature data were sent via Arduino IDE serial communication network and recorded to database with LABWIEV software. Throughout the experiments, temperature data were recorded daily with the aid of a software package. Whether the sensor temperatures are changed based on gas pressure was monitored. Obtained images were processed in LABWIEV VISION Software.

Banana fruits were placed in boxes and they were photographed daily under the same conditinos (at the same light intensity and ambient). The reason why banana fruits are put in boxes is to prevent the repetitions from mixing with each other and to facilitate the photographing process. The boxes are breathable plastic containers with holes at the bottom and sides. Resultant images were processed with an image processing software to determine daily changes in fruit colors and areas.

Fruit mass was measured daily with a precise balance (±0.01 g) (ANDGF300 model) throughout 10 days of storage.

Fruit skin color parameters (L, a, b) were measured with the aid of Minolta CR-300 model color meter.

The a indicates redness value. Negative a values indicate green color and positive a values indicate redness. The b indicates yellowness value. Negative b values indicate blueness and positive b values indicate yellowness. Zero crossing point ($a = 0$ and $b = 0$) indicates achromaticity, in other words greyness. The L values indicate color lightness and vary between 0 – 100 with L 0 indicating black color without any reflection and L 100 indicating white color with full reflection (McGuire, 1992).

Chroma indicates color saturation. Vivid colors have high chroma values and dull colors have low chroma values. Chroma (C) and hue angle (h°) values were calculated with the aid of the following equations:

$$C = (a^2 + b^2)^{1/2} \tag{1}$$

$$h^{\circ} = \tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{2}$$

Total color change (ΔE) was used to indicate total color difference at different storage conditions as compared to color values of fresh product. The following equations were used to determine total color difference values (Çelen *et al*., 2016).

$$\Delta L = L_{fresh} - L \tag{3}$$

$$\Delta a = a_{fresh} - a \tag{4}$$

$$\Delta b = b_{fresh} - b \tag{5}$$

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{6}$$

A constant coefficient is determined by using L, a and b values in the calculation of the browning index value. This constant value is used in a second equation to calculate the browning index (Plou *et al*., 1999).

$$X = \frac{a+(1,75\ L)}{[(5,645\ L)+(a-(3,012\ b))]} \quad (7)$$

$$BI = \frac{[100(X-0,31)]}{0,17} \quad (8)$$

C. Chemical Analyses

The acidity of the fruit was expressed as citric acid by using the titration acidity method. 5 g of homogenized fruit samples were weighed, 95 ml of distilled water was added, and the pH value was measured with the help of a pH meter (HANNA brand H1 2211 model). Then, 0.1 N sodium hydroxide (NaOH) was added until the pH value reached 8.1. Soluble solids content (SSC) was measured by using the digital refractrometer (PAL-1, McCormic, USA) (Aglar *et al*., 2019).

D. Mathematical Modeling

Models are used to model moisture variation during the cold storage of agricultural commodities with the aid of the relationships between the actual values and estimated values Coefficients of refrigerated storage curves, R and p values of these curves were determined with the aid of SigmaPlot 10.0 software.

Equations of three best fitting models were selected and comparisons were made among them.

The equations used for mathematical modeling are given below. The following equations were used for modelling in similar refrigerant performance tests (Qiu *et al.*, 2021; Xu *et al*., 2022).

Exponential Decay; Single,2

$$f = k\ \exp(-hx) \quad (9)$$

Polynomial; Quad

$$f = y0 + k\ x + h\ x^2 \quad (10)$$

Polynomial; Cubic

$$f = y0 + k\ x + h\ x^2 + j\ x^3 \quad (11)$$

E. Materials used in experiments

Following the manufacture of refrigeration system, banana fruits were stored at 3 different pressure levels for 10-day durations.

III. RESULTS AND DISCUSSION

A. Weight loss

Experiments were conducted at 3 different pressure levels as of 950, 1050 and 1150 kPa. Each pressure value was assayed in 3 parallels. The processes lasted about 10 At the end of the experiments, weight loss in banana fruits was measured as % 1.32 at 950 kPa, %1.08 at 1050 kPa and %1.30 at 1150 kPa pressure.

Table 1 Weight losses of banana fruit at different pressures

Pressures (kPa)	Weight loss (%)
950	1.32[a]
1050	1.08[b]
1150	1.30[a]

The differences of the data were determined according to the significance level in the SPSS program ($P<0.05$)

B. Color values

Average manual and computer-aided image processing measured and calculated color values for fresh and cold-stored banana fruits are provided in Table 2.

As compared to fresh products, significant differences were observed in L, a and b values of cold-stored fruits at different pressures.

As compared to the fresh products, decreases were observed in L (lightness) and b (yellowness/blueness) and increases were observed in a (redness/greenness) values at all pressure levels.

Yıldız *et al.* (2015) reported L, a and b values of bananas respectively as 73.84, -1.22 and 21.20. Present findings comply with those earlier ones.

The chroma (color saturation) value of the fresh product was identified as 28.90 (Table 1). The lowest value (9.59) was observed at 950 kPa pressure and the greatest value (12.05) was observed at 1050 kPa. The closest value to the fresh product was observed at 1050 kPa pressure.

The hue angle of the fresh product was measured as 64.60. The lowest hue angle (19.21) was observed at 950 kPa pressure and the greatest hue angle (24.50) was observed at 1050 kPa pressure.

The lowest BI (browning index) (39.59) was observed at 950 kPa pressure and the greatest value (50.47) was observed at 1050 kPa pressure.

The greatest total color difference (ΔE) (31.20) was observed at 1050 kPa pressure and the lowest value (24.48) was observed at 950 kPa pressure.

As can be inferred from Table 1 to computer-aided image processing measured and calculated, significant differences were observed in L, a and b values of the fresh and cold-stored products at all pressure levels.

The smallest difference in chroma values of the fresh and cold-stored products was observed at 950 kPa pres-

Table 2 Manual and computer-aided image processing-measured and calculated color values of banana fruit

			L	a	b	C	H°	ΔE	BI
Manual measured and calculated	**Fresh**		60.54[a]	1.13[c]	28.88[a]	28.90	64.60	-	-
	950 kPa		29.94[bc]	6.74[b]	6.82[c]	9.59	19.21	24.48	39.59
	1050 kPa		31.27[b]	7.94[a]	9.07[b]	12.05	24.50	31.20	50.47
	1150 kPa		29.14[c]	7.42[a]	6.57[c]	9.91	19.52	24.91	40.28
Computer-aided image processing measured and calculated	**950 kPa**	**Fresh**	60.07[a]	-4.65[b]	48.76[a]	48.96	109.29	-	-
		Stored	24.08[b]	3.19[a]	13.31[b]	14.10	30.84	39.06	63.26
	1050 kPa	**Fresh**	60.19[a]	-6.36[c]	49.15[a]	49.33	110.15	-	-
		Stored	23.21[b]	3.58[a]	11.42[b]	13.01	27.65	35.09	56.82
	1150 kPa	**Fresh**	57.62[a]	-4.62[b]	49.19[a]	49.44	110.33	-	-
		Stored	23.74[b]	3.53[a]	14.03[b]	11.43	25.36	32.10	52.00

The differences of the data were determined according to the significance level in the SPSS program ($P<0.05$)

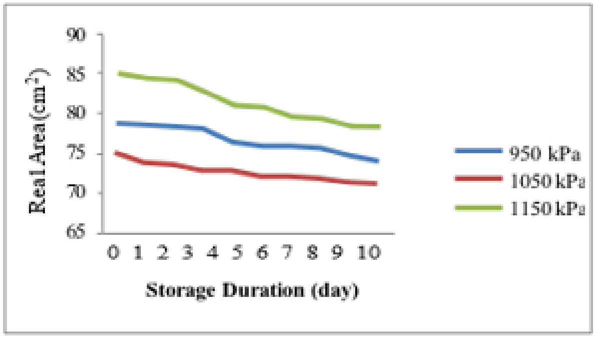

Figure 2. Changes in areas of banana fruits

Table 3. Chemical analysis results of banana fruits

	SSC (%)	pH	TA (%)
Fresh	23.50[a]	6.01[b]	2.60[a]
950 kPa	22.85[b]	6.14[b]	2.35[b]
1050 kPa	21.35[c]	6.34[a]	2.00[c]
1150 kPa	19.35[d]	6.15[b]	2.15[bc]

The differences of the data were determined according to the significance level in the SPSS program (P<0.05).

sure. Thus, this treatment was identified as the most appropriate method for chroma criterion.

The smallest difference in hue angle values of the fresh and cold-stored products was observed at 950 kPa pressure.

C. Image processing

Image of banana fruits were taken daily throughout the storage duration to determine the changes in fruit areas.

Image processing was done through the labwiev program. There were not any problems experienced in image processing of banana fruits. Changes in fruit areas throughout the storage period are presented in Fig. 2. Surface area decreased at all pressures and such changes were different from each other at different pressures. The greatest area loss was observed at 1150 kPa pressure.

D. Chemical analyses

The pH, SSC and TA values of fresh and cold-stored fruits at different pressures are provided in Table 3.

As compared to fresh fruits, decreasing SSC values were observed with increasing pressures. Besides, as compared to the fresh fruits, at 1050 kPa pressure, pH value was greater than the pH values at the other pressures and level. It is thought that the reason for the decrease in the TA value was lower than the TA values at the other pressures. The SSC and TA values at all pressures were significantly different from the values of fresh fruits at 5% SSC value at different refrigerant pressure values is that the sugar in the banana is slightly fermented.

While there were significant differences in pH values of the fresh and cold-stored fruits at 1050 kPa pressure, differences at the other pressures were not found to be significant. Considering the present chemical analysis, the most appropriate pressure for cold storage of banana fruits was identified as 950 kPa. Sönmezdağ *et al*. (2012) reported SSC, pH and TA values of banana fruits respectively as 21.3±0.9, 4.85±0.03 and 5.3±0.04. Present findings comply with those earlier ones.

E. Mathematical modeling data

Numerical values for the parameters of Exponential Decay; Single 2, Polynomial; Quad and Polynomial; Cubic equations and model "R²" and "p" values are provided in Table 3. Exponential Decay equations for the greatest R^2 value (0.9998) was obtained from 950 kPa pressure and the lowest value (0.9960) was obtained from 1150 kPa pressure. Polynomial; Quad equation for the greatest R^2 value (0.9999) was obtained from 950 kPa pressure and the lowest value (0.9976) was obtained from 1050 kPa pressure. Polynomial; Cubic equation for the greatest R^2 value (0.9999) was obtained from 950 kPa pressure and the lowest value (0.9976) was obtained from 1050 kPa pressure.

F. Energy consumption

Experiments were conducted at 3 different pressure levels for 12 days. Total energy consumption values were calculated at the end of each pressure trial. Total energy consumption was calculated as 15.84 kWh at 950 kPa pressure, 15.64 kWh at 1050 kPa pressure and 15.32 kWh at 1150 kPa pressure.

According to these results, it is seen that the energy consumption decreases as the pressure value increases. It is thought that the reason for this is that the R404A refrigerant gives better performance at high pressures.

G. Measured temperature data

Temperature sensors were placed at 4 different locations as of the input and output of compressor and evaporator. Temperature data of the sensors were processed with the aid of Labview software. The averages of temperature values taken from the evaporator and compressor input and output are given in Table 5.

When Table 5 is examined, it has been determined that there is a residual in the inlet and outlet temperatures with the increase in pressure.

Table 4. Model parameters of all equations

Model equations	Pressures	k	h	R^2	p
Exponential Decay; Single,2	950 kPa	168.21	0.0053	0.9998	<0.0001
$(f = k\exp(-hx))$	1050 kPa	169.21	0.0044	0.9976	<0.0001
	1150 kPa	186.23	0.0049	0.9960	<0.0001
Polynomial; Quad	950 kPa	-0.8652	0.0004	0.9999	<0.0001
$(f = y0 + k\,x + h\,x^2)$	1050 kPa	-0.7463	0.0025	0.9976	<0.0001
	1150 kPa	-0.7279	-0.0157	0.9981	<0.0001
Polynomial; Cubic	950 kPa	-0.8554	-0.0019	0.9999	<0.0001
$(f=y_0+k.x+h.x^2+j.x^3)$	1050 kPa	-0.6946	-0.0098	0.9976	<0.0001
	1150 kPa	-0.4260	-0.0874	0.9988	<0.0001

f: Function of the model, k-h-x-y_o: Constant coefficients of the model, t: Time, R^2: Stability coefficient, p: Materiality level

Table 5. Temperature data taken in the experiment

Pressures (kPa)	Compressor input	Compressor output	Evaporator input	Evaporator output
950	26.00	20.75	1.58	-2.17
1050	26.11	24.72	1.78	-1.11
1150	28.61	26.56	1.87	-0.25

V. CONCLUSIONS

Post-harvest losses in agricultural commodities generate serious economic losses every year. Therefore, agricultural products are cold-stored to prevent such losses and prolong shelf life. Refrigerant selection is significant issue in cold storages. Present refrigerant, R404A, was selected since it has the least impacts on environment, and it was the most appropriate one. The manufactured refrigeration system was operated with R404A refrigerant at 3 different pressures (950-1050-1150 kPa) and the storage performance was assessed. Banana fruits were stored in manufactured refrigeration system for 10days. These values, the fruit is now seriously deteriorating.

Weight loss at the end of the experiments was measured as %1.32 at 950 kPa pressure, %1.08at 1050 kPa pressure and %1,30 at 1150 kPa pressure. The least weight loss was observed at 1050 kPa pressure. The weight loss values were fluctuating according to the pressures. The pressure value that best preserves the weight loss was determined as 1050 kPa. In terms of energy consumption, as pressure values increase, energy consumption decreases. According to the results obtained, the minimum energy consumption was determined as 1150 kPa pressure. The relationship between pressure values and temperature, on the other hand, increases as the pressure values increase, so does the temperature value.

As compared to the fresh fruits, the most optimum pressure value for SSC, pH and TA of banana fruits was identified as 950 kPa.

Among the equations used to model the change in fruit mass, Polynomial Quad equation yielded the best estimation and the most appropriate pressure was identified as 950 kPa.

It was concluded based on present findings that 950 kPa was the most appropriate pressure in refrigeration and cold storage of banana fruits. Therefore, 950 kPa pressure was recommended for R404A refrigerant in cold storage of banana fruits.

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