Agricultural Engineering
UNIVERSITY OF LAMPUNG

Vol. 14, No. 1 (2025): 182 - 193 http://dx.doi.org/10.23960/jtep-l.v14i1.182-193

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Principal Component Analysis in the Animal Products Precooling Process Using Compressive Type Plate Cooler

Surya Muttalib[1], Nursigit Bintoro[1,✉], Joko Nugroho Karyadi[1], Arifin Dwi Saputro[1]

[1] Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, University of Gadjah Mada, Yogyakarta, INDONESIA

Article History:

Received : 08 October 2024
Revised : 11 December 2024
Accepted : 12 December 2024

Keywords:

Animal product,
Cooling medium,
Force compression,
P recooling,
PCA.

Corresponding Author:
✉ nursigit@ugm.ac.id
(Nursigit Bintoro)

ABSTRACT

Precooling is a critical process in the post-harvest activities of vegetable and animal products. This research aimed to evaluate the relationship between animal products' physical, mechanical, and chemical parameters and their relationship with the treatment combination of compressive force, cooling media, and type of animal product samples using a compressive type plate cooler. The research was carried out with three types of meat (beef, chicken, and fish), three compressive forces (0, 100, and 200 kg), and two types of cooling medium (ice cubes and dry ice). The results showed that PCA using XLSTAT could be used to reduce the number of parameters to two main components which could explain 75% of the total variation in the data set. PCA was able to group precooling treatments with cooling media based on the physical, chemical, and mechanical properties. Treatments using ice media for all types of meat and compressive forces were grouped in quadrants I and II, while those using dry ice media were grouped in quadrants III and IV. Based on the type of meat sample, the results of PCA were able to group beef and chicken samples in quadrants I and IV, while tuna fish samples were in quadrants II and III.

1. INTRODUCTION

Animal products, especially meat and fish, have a high risk of damage because protein and fat are easily damaged physiologically and enzymatically. In addition, high water content in products increases the risk of microorganism growth (Wang, 2000; Rahman, 2007; Zambrano *et al*., 2019). Precooling after slaughter has become an important operational part before meat enters the cold chain (Ren *et al*., 2023). Precooling is basically a cooling process, however, it is different from the cooling that occurs in a cold storage room, because in precooling the process of cooling or reducing the temperature of the material is carried out quickly, whereas in a cold storage room the temperature decrease occurs slowly. The aim of precooling is to remove the heat content from the material as quickly as possible, so that the temperature of the material immediately drops to cold storage temperature (Karel *et al*., 1975).

From various references it can be seen that the precooling media for animal products that are widely used are liquid cooling, slurry ice cooling, combined blast and contact cooling, water precooling, vacuum precooling, and forced air precooling (Giannoglou *et al*., 2016; Sun & Hu, 2003; Valtýsdóttir *et al*., 2010; Wang *et al*., 2024). Cooling media that are often used in society are ice cubes (Jain *et al*., 2005) and dry ice (Bao *et al*., 2007; Bita *et al*., 2015; Costantini *et al*., 2016; Sasi, 2000; Jeyasekaran *et al*., 2004). Precooling is often carried out using cold air, a vacuum chamber, water, ice, and a mixture of ice and water using various equipment. One precooling method that is cheap, easy to implement, and does not require complex equipment is to use ice as a medium, either ice cubes or dry ice. Precooling using ice as a medium is often done by placing the material to be cooled on top of ice chips or covering it with ice chips. Using ice as a medium for cooling fish has big advantages because it is harmless, portable and cheap. And for its weight and volume, ice has a very large cooling capacity (Jain *et al*., 2005).

In pressure plate type cooling equipment, increasing the rate of decrease in product temperature in the precooling process can be done by applying pressure to the cooling medium in the form of ice to increase the intensity of contact between the cooling medium and the product being cooled. The principle of using pressure in the freezing process is that the transfer of energy in the form of heat can be increased by adding pressure to the existing temperature difference (Beier, 2006). Muttalib *et al*. (2024) apply external compressive forces by developing cooling equipment and supporting equipment. The research results show that the compressive force can increase the temperature drop during the cooling process. However, it is necessary to study in more depth the factors or parameters that simultaneously influence the physical, mechanical and chemical properties of the material being cooled.

Gao (2007), stated that during the precooling process there are many factors that influence the process of reducing the temperature of agricultural products, including product characteristics such as shape, size, surface to volume ratio, porosity, internal structure, density, thermal properties, and heat transfer rate. Brosnan & Sun (2001) stated that temperature is an important factor that influences the preservation of agricultural products. In addition, the relative humidity of the surrounding environment is another main factor that has the potential to influence the precooling process (Valtýsdóttir *et al*., 2010). Further analysis is needed regarding the effect of applying compressive force on the physical, chemical and mechanical parameters of the equipment being developed.

Referring to the number of variables that influence during the precooling process, it is possible for multicollinearity to occur in the measured parameters. Multicollinearity is a condition where there is a correlation between independent variables or between independent variables that are not independent of each other (Sriningsih *et al*., 2018). To overcome this problem, an analysis is needed that is able to reduce variables that have collinearity during testing. The method used is Principal Component Analysis (PCA), which is a multivariate statistical technique used to change a set of original variables that are correlated with each other into a new set of uncorrelated variables, known as principal components. Vidal *et al*. (2020) found that PCA was able to evaluate the effect of unfiltered beer-based marination on volatile terpenes and thiols, and sensory attributes of grilled ruminant meat and reduced the data to 2 components for 90.47% of the research data set. PCA analysis was able to identify 45% of the folate attributes that influence the taste of sea cucumbers (Li *et al*., 2024). In the context of the precooling process, this research aims to evaluate the relationship between the physical, mechanical and chemical parameters of animal products and their relationship with the combination of pressure treatment, cooling media and type of animal product samples in the precooling process using a pressure plate type cooler by applying Principal Component Analysis.

2. RESEARCH MATERIALS AND METHODS

2.1. Tools and Materials

In general, research materials can be separated into two, namely materials for constructing plate type cooling apparatus and sample materials for testing the pre-cooling process. The equipment is a plate construction that can exert a compressive force on samples of the material being cooled, especially meat or fish. This pressure plate type cooling equipment has total dimensions of 77.34 x 45 x 37.5 cm, threaded shaft diameter 1.2 cm made of iron rod, stainless steel pressure plate 10 x 10 cm, electric motor (DC 12 Volt, 2A, 400 rpm, torque 6.5 kg.cm, length 5 cm, diameter 2.5 cm, and weight 0.2 kg), 2 aluminum pulleys with a diameter of 8 and 12 cm, V-Belt diameter 25.8 cm; wooden box measuring 12 x 12 x 12 cm, load cell (capacity 500 kg, input impedance 401 +/-10 ohm, output impedance 350 +/-5 ohm, voltage 10-15V DC), relay, and computer for monitoring and storage test result data. This equipment is equipped with a compression force control system and a temperature monitoring system during the cooling process. The materials for making this control device include an Analog Digital Converter (ADC) with an ATM Mega Arduino uno Microcontroller (ATmega328 SMD, 5V), HX711 driver module, LCD screen, power supply (12 Volt, 10A), 4 sensor probe units type K thermocouple (cable length 1 m, model TP-01), 4-unit AD8495 driver and actuator as amplifier and current stabilizer. K-type thermocouples are used to measure the temperature of material samples and cooling medium. Figure 1 shows the construction of the pressure plate type cooling equipment constructed and used in this research.

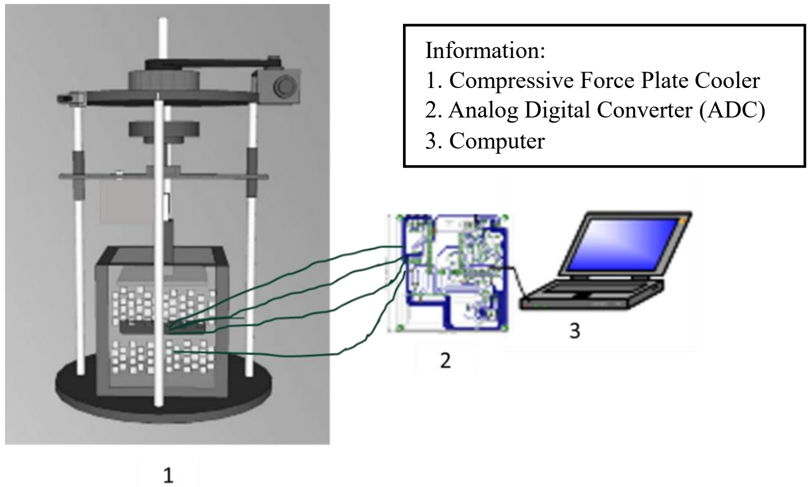

Figure 1. Pressure plate type cooling equipment constructed in the research

The sample ingredients in this research were beef tenderloin (M1), chicken breast (M2) and tuna fillet (M3). All of these samples were purchased from traditional markets in Yogyakarta. The beef and chicken meat samples had a compact texture, normal bright color, fresh condition, and no fishy smell which is a sign of spoilage. The tuna samples are fish fillets with fresh condition, firm flesh, red gills, bright eyes, bright fish scales (skin) and not easily peeled. The samples were brought to the laboratory in a tightly closed styrofoam box where the distance from the market to the laboratory was only about 15 minutes. Upon arrival at the laboratory, the three materials were cut into blocks with dimensions of 3 x 3 x 2 cm to be used as research samples.

As a cooling agent in this study, ice cubes (R1) and dry ice (R2) were used. Ice cubes were obtained from PT. Astra Ice Tube, Sleman, Yogyakarta, while dry ice was obtained from PT. Industrial Gas Samator, Semarang. The ice cubes and dry ice are then crushed manually to a size range of 1-5 mm before being used in the cooling process.

2.2. Method

First, the cooling medium in the form of ice chips is put into a wooden box on the pressing equipment with a thickness of 3 cm, then the meat sample is placed on top, then the ice chips are added again until they fill the wooden box. Two thermocouples were attached to the meat sample, one each at the center and surface of the material. Likewise, a thermocouple is also installed in the cooling medium. The wooden box is then positioned directly under the pressure plate of the precooling equipment, then the pressure plate is lowered to provide a certain predetermined pressure to the upper surface of the cooling ice medium. The compressive forces used in this study were 0 kg (P0), 100 kg (P100), and 200 kg (P200). After the pressing force is reached, the pressing equipment is stopped, the amount of temperature drop of the sample and cooling medium, and the pressing force are continuously monitored until the sample temperature reaches a constant condition or around 600 seconds.

2.3. Test Parameters

2.3.1. Temperature

During the precooling process, the temperature is measured using a K-type thermocouple sensor device (cable length 1 m, model TP-01) equipped with an AD8495 driver connected to a computer via an Analog Digital Converter (ADC). The sample temperature is measured at the center of the material (Tc) and the surface of the material (Ts) during the precooling process. In addition to the sample temperature, the temperature of the cooling ice medium was also measured during the precooling process. The temperature data for the material and cooling medium is measured until the material temperature is more or less constant, which takes around 600 seconds. For analysis purposes, the values of Tc, Ts, and the temperature of the cooling medium at the end of the precooling process are used.

2.3.2. Change in thickness

As a result of the application of compressive forces during the precooling process, changes in sample thickness need to be known. The thickness of the sample before and after the cooling process was measured using digital calipers (type: 1108-150 with resolution: 0.01mm/0005). Thickness changes are calculated using equation 1.

$$\Delta t = \frac{t_o - t_1}{t_o} x\ 100\% \tag{1}$$

where Δt is the change in sample thickness (%), t_o is the initial sample thickness (mm), and t_1 is the final sample thickness (mm)

2.3.3. Color

The color of the sample was measured both before and after the cooling process using a TES-135A colorimeter and expressed in CIElab color standards, namely L, a^*, and b^* (colorimeter calibration using the white reference method (Choudhury, 2014). Measurements were carried out in three positions, namely the top surface, the side and inner surfaces of the sample. To measure the color of the inner sample, the sample is cut horizontally using a sharp knife. The color measurement results from the three positions are then averaged and used to calculate ΔE using Equation (2).

$$\Delta E = \sqrt{(L - L_0)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \tag{2}$$

where ΔE is color difference, and L, a^*, and b^* are respectively lightness, redness and yellowness.

2.3.4. Water Content

The sample water content was measured both before and after the cooling process. Water content measurements were carried out by thermogravimetry following the AOAC method, 2005 expressed as a percentage of wet weight using equation 6 (AOAC International, 2006).

$$K_a\ (\%wb) = \frac{W_0 - W_1}{W_0} x\ 100\% \tag{3}$$

where K_a is the water content of the sample (%wb), W_0 is the initial weight of the sample (g), W_1 is the dry weight of the sample (g)

2.3.5. Proximate Analysis

The proximate content of the samples was measured both before and after the cooling process. Protein, determined using the Kjeldahl method based on AOAC 2005 (AOAC International, 2006). Fat content was determined using the Soxhlet AOCS Ba 3-38 method (AOCS, 1998) using petroleum ether (boiling point 40–60 °C) for extraction. Carbohydrates and ash were determined following AOAC 2005. Equations (4–8) were used to approximate the values for the samples tested.

$$\%N = \frac{(V_a - V_b)\ HCl \times N\ HCl}{W \times 1000} \times 100\% \tag{4}$$

$$K_p = \%N \times 6.25 \tag{5}$$

$$K_l = \frac{w_{extraction}}{W} \times\ 100\% \tag{6}$$

$$K_{ash} = \frac{W_1}{W_0} \times\ 100\% \tag{7}$$

$$K_k = 100\% - K_a - K_l - K_p - K_{ash} \tag{8}$$

where V_a is the titration volume (mL), V_b is the blank volume (mL), $\%N$ is nitrogen content (%), W is the mass of the titration sample (g), K_p is protein content (g), K_{ash} is the ash content (%), W_0 is the weight before ashing (g), W_1 is the weight after ashing (g), K_l is fat content (%), K_k is carbohydrate content (%), and 6.25 is conversion factor.

2.3.6. Total volatile base

Total volatile base (*TVB*) is determined using the AOAC 999.01 method. The work procedure for measuring TVB is divided into 3 stages as follows: (1) Extraction stage, the sample is weighed 25 grams using a beaker glass. Then 75 mL of 7.5% perchloric acid (PCA) was added to the sample and homogenized with a homogenizer for 2 min. The solution is then filtered with coarse filter paper and a filtrate is produced which will be used in the next stage. (2) In the distillation stage, 1 mL of the filtrate sample is put into the outer chamber on the left of the Conway cup, then 1 mL of K_2CO_3 is put into the outer chamber on the right of the Conway cup. 1 mL of 3% boric acid was put into the inner chamber of the Conway cup, then the Conway cup was closed tightly and then incubated for 2 h at 35°C. (3). In the titration stage, the borate solution is titrated in the inner chamber with 0.02 N HCl solution. The end point of the titration is indicated by the formation of a green color. The *TVB* content was calculated using Equation (9).

$$TVB = \frac{(V_c - V_b) \times N\ HCl \times F \times 100}{Bs} \tag{9}$$

where V_c is the volume of HCl solution for titration (mL), V_b is the volume of HCl solution in the blank titration (mL), *N* is the atomic weight of nitrogen (14.007 g/mol), *F* is the dilution factor, and *Bs* is the sample weight (mg).

2.3.7. Compressive Strength

In this research, during the precooling process, pressure is applied to the cooling medium and meat samples, therefore it is necessary to know the changes in sample hardness after the cooling process. The hardness value is measured using pressure testing equipment that is integrated with the developed cooling equipment, both before and after the cooling process. Hardness measurements are carried out by placing a sample measuring 1 x 1 x 1 cm on the base of the pressing equipment and then pressing until the maximum compressive force value is reached. The hardness value is expressed in stress and calculated using Equation (10).

$$KT = \frac{F_{max}}{A} \tag{10}$$

where *KT* is hardness (kg/cm²), F_{max} is the maximum pressing force (kg), and *A* is the surface area of the sample (cm²).

2.4. Data Analysis

In this study there was a combination of compressive force treatments of 0 kg (P0), 100 kg (P100), and 200 kg (P200), cooling media of ice cubes (R1) and dry ice (R2), and the type of meat, namely beef tenderloin (M1), chicken breast (M2), and tuna fillet (M3). So, based on the treatment given, 18 treatment units were produced, each of which was coded P0R1M1, P100R1M1, P200R1M1, P0R2M1, P100R2M1, P200R2M1, P0R1M2, P100R1M2, P200R1M2, P0R2M2, P100R2M2, P200R2M2, P0R1M3, P100R1M3, P200R1M3, P0R2M3, P100R2M3, and P200R2M3. The measurement data were analyzed using Principal Component Analysis of the XLSTAT program. The PCA algorithm used in this research uses the nonlinear iterative PLS (NIPALS) method, due to the ease and simplicity of the analysis process (Stott *et al*., 2017). Data correlation was validated using Chi-square (Observed value), Chi-square (Critical value), *p*-value test at the 5% significance level and Kaiser-Meyer-Olkin. Before carrying out the data analysis process using PCA, the data from the measured parameters is standardized into standard normal form (*Z*-score) as follows.

$$Z_i = \frac{x_i - \bar{X}}{\sigma} \tag{11}$$

where Z_i is the i^{th} data standardization value, x_i is the ith data value, $\bar{X}$ is the average value of the data, and σ is the standard deviation value of the data

3. RESULTS AND DISCUSSION

3.1. Description of Research Data

In this study there were 14 parameters consisting of *Tc*, *Ts*, Δ*t*, *L*, *a**, *b**, Δ*E*, K_a, K_p, K_l, K_k, K_{ash}, *TVB*, and *KT*. Because PCA is sensitive to the variance of the initial parameters, where parameters with a larger range will dominate parameters with a small range, this will result in bias in the PCA analysis. To overcome this problem, all measured parameters undergo a standardization process first before carrying out PCA analysis. Data standardization is used as a transformation process to eliminate the influence of differences in scale, so that it becomes more rational to compare (Anwar, 2018). Table 1 summarizes 14 data parameters measured in this study before and after the standardization.

The results of parameter measurements show that there are very large differences in the range of values between these parameters. There are test parameters with a very small range of values such as the *Ts* value (-7.35 to 11.16), whereas there are parameters with a very large range of values such as *KT* (954.95 ± 938.61). Therefore, these parameter data need to be standardized to eliminate bias influenced by differences in scale. Data standardization was carried out using Equation 10, resulting in more comparable parameter values, where the standard deviation value of these parameters was the same, namely 1.03. From the results of this standardization, there are no parameters that are more dominant than others. This can be seen, for example, the maximum value of ΔE which was originally 361.80 changed to 2.36 which is comparable to the other parameter values.

After the data standardization process, validation was then carried out using chi-square, significance test (*p*-value <0.05) and Keiser-Meyer-Olkin (KMO>0.5). The results of the data validation test obtained a chi-square value of 185.82, *p*-value <0.0001, and a KMO value of 0.68. The KMO value is greater than 0.5 indicating that the data is valid to be tested using PCA. In the initial stage of PCA analysis, there were parameters with KMO values <0.5, namely the variables ΔE, b^*, and K_{ash}, so these three parameters were excluded and could not be included in the PCA analysis. So the parameter that meet the criteria for PCA analysis are *Tc*, *Ts*, Δt, *L*, a^*, K_a, K_p, K_l, K_k, *TVB*, and *KT*.

Table 1. Parameter values measured in the study before and after standardization

Variable	Obs	Mean	Before standardization			After standardization		
			Minimum	Maximum	Std. dev	Minimum	Maximum	Std. dev
Tc	18	3.31	-5.02	18.52	6.76	-1.27	2.32	1.03
Ts	18	-0.09	-7.35	11.16	5.50	-1.36	2.10	1.03
Δt	18	16.11	2.64	40.38	12.41	-1.12	2.01	1.03
L	18	50.55	7.32	70.69	15.36	-2.90	1.35	1.03
a^*	18	5.56	0.72	10.01	2.92	-1.71	1.57	1.03
b^*	18	9.14	3.00	25.59	5.10	-1.24	3.32	1.03
ΔE	18	81.65	0.84	361.80	122.00	-0.68	2.36	1.03
K_a	18	74.72	71.23	78.09	1.92	-1.87	1.81	1.03
K_p	18	21.98	20.14	23.51	1.17	-1.61	1.35	1.03
K_l	18	0.92	0.31	1.42	0.46	-1.38	1.13	1.03
K_k	18	1.45	0.26	2.81	1.02	-1.21	1.37	1.03
K_{ash}	18	1.24	1.00	1.51	0.19	-1.29	1.45	1.03
TVB	18	16.72	9.44	26.55	6.04	-1.24	1.67	1.03
KT	18	954.95	204.34	3,095.00	938.61	-0.82	2.35	1.03

3.2. Correlation between Parameters

PCA has the ability to extract and determine the relationship between parameters (Delsen *et al*., 2017). The correlation values between the parameters tested in this precooling research can be seen in Table 2. The results of this correlation test show a significant relationship at the 5% significance level. According to Schober *et al*. (2018) correlation values can be classified into 5 groups, where a correlation value of 0.00 – 0.10 indicates there is no correlation; 0.10 – 0.39 indicates a weak correlation; 0.40 – 0.69 indicates moderate correlation; 0.70 – 0.89 indicates a strong correlation; and 0.90 – 1.00 indicates a very strong correlation.

The Tc parameter is positively correlated with *Ts* with a correlation value of 0.914, which indicates a very strong relationship between the two parameters. This also means that a decrease in the surface temperature of the material will also be followed by a decrease in the central temperature of the material, and vice versa. However, this *Tc* parameter is negatively correlated with Δt with a value of -0.678. This shows a moderate correlation value, and also means that an increase in *Tc* will be followed by a decrease in Δt, and vice versa. It can also be observed that the *Ts* parameter has a moderate to very high correlation value, except with K_p, K_l, and K_k, and all of them are positive. This shows that *Ts* has a very large influence on most changes in the values of other material parameters measured in this

Table 2. Correlation values between parameters measured in the study

Variables	*Tc*	*Ts*	Δt	*L*	*a**	K_a	K_p	K_l	K_k	*TVB*	*KT*
Tc	1	0.914	–0.678	–0.661	–0.656	0.644	–0.199	0.064	–0.3	0.664	–0.661
Ts	0.914	1	–0.652	–0.707	–0.737	0.719	–0.19	0.077	–0.289	0.746	–0.669
Δt	–0.678	–0.652	1	0.22	0.744	–0.434	–0.105	0.067	0.147	–0.714	0.598
L	–0.661	–0.707	0.22	1	0.363	–0.734	0.407	–0.077	0.278	–0.454	0.58
*a**	–0.656	–0.737	0.744	0.363	1	–0.497	0.024	–0.189	0.309	–0.798	0.578
K_a	0.644	0.719	–0.434	–0.734	–0.497	1	–0.631	0.339	–0.422	0.495	–0.446
K_p	–0.199	–0.19	–0.105	0.407	0.024	–0.631	1	–0.667	0.524	0.234	–0.102
K_l	0.064	0.077	0.067	–0.077	–0.189	0.339	–0.667	1	–0.894	–0.159	–0.02
K_k	–0.3	–0.289	0.147	0.278	0.309	–0.422	0.524	–0.894	1	–0.08	0.414
TVB	0.664	0.746	–0.714	–0.454	–0.798	0.495	0.234	–0.159	–0.08	1	–0.725
KT	–0.661	–0.669	0.598	0.58	0.578	–0.446	–0.102	–0.02	0.414	–0.725	1

*) significance level (α) = 0.05

research. The decrease in the *Ts* value as a result of the precooling treatment will be followed by a decrease in the *Tc*, Δt, *a**, K_a, *TVB*, and *KT* values. This is in line with the research results of Tao *et al*. (2023) where temperature greatly influences the quality and structure of ingredients in super chilling pork.

Meanwhile, weak correlation generally occurs in the chemical property parameters K_p, K_l, and K_k, with the physical property parameters *Ts*, *Tc*, Δt, *L*, and *a**. This shows that these physical property parameters cannot be used as indicators of changes in the chemical properties of the sample material being tested. However, the chemical property parameters K_p, K_l, and K_k are correlated with each other at a moderate to high level, with a correlation value range of 0.524 – 0.894.

3.3. Interpretation and Visualization in PCA Analysis

The PCA method will form a new set of dimensions which are then ranked based on the data variance, thereby creating a data set with simpler features (Hediyati & Suartana, 2021). Meanwhile, Patel *et al*. (2022) stated that a scree plot is a graph that presents the sequence of eigenvalues from the largest to the smallest value. Figure 2 is a scree plot that shows the eigenvalues for each main component resulting from PCA analysis. A scree plot is a graph that displays the eigenvalue or variance of each main component on the ordinate against the main component number on the abscissa. Ledesma *et al*. (2015) stated that scree plots help visualize the optimal number of components by identifying points after small eigenvalues and similar sizes so that they can be used as a reference in analysis. F1 and F2 have the highest eigenvalues of 5.628 and 2.584 respectively. This shows that the main components F1 and F2 have eigenvalues that meet the PCA test standards where the standard eigenvalue of the main components have to be >1.

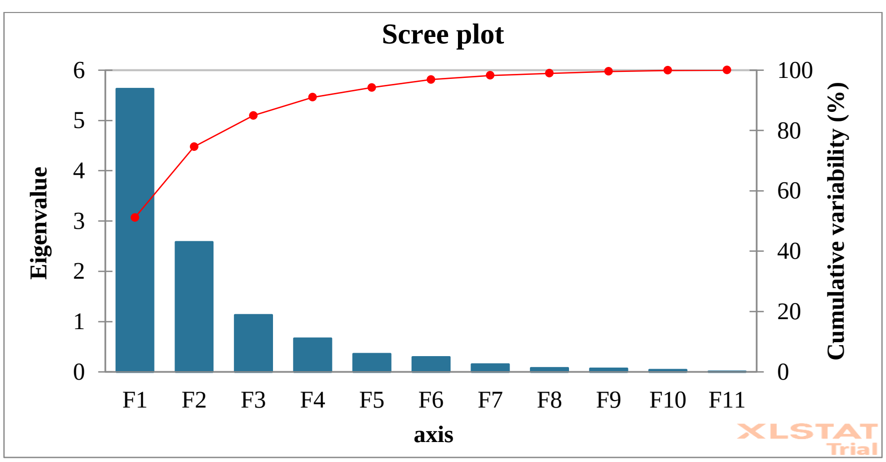

Figure 2. PCA scree plot in the precooling process using the press plate method

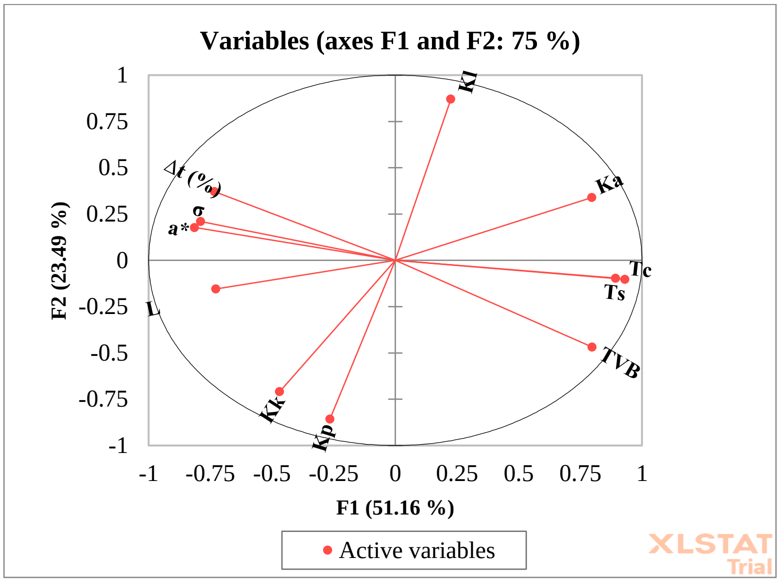

Figure 3. Biplot distribution of the contribution of the parameters tested in components F1 and F2

In this study, a set of data sets tested showed that the total variation in data from the two main components was 75% with details of F1 contributing 51.16% and F2 contributing 23.49% (Figure 3). The parameters *Tc*, *Ts*, *a**, *Ka*, *TVB* and *KT* make the largest contribution to the main component of F1 with percentages of 14.19%, 15.40%, 11.76%, 11.29%, 11.34%, and 11.05%. Meanwhile, for the main component F2, the largest contribution came from *L*, K_l, and *Kk*, respectively 26.78%, 15.04%, and 17.27%. The main components F1 and F2 produce a new combination that is able to reduce the number of parameters that must be tested.

According to Girgel *et al*. (2021), a biplot curve can be analyzed that there is a positive relationship between parameters that form narrow angles, for example in this study between *KT* and *a**, between *KT* and Δ*t*, between K_k and K_p, and so on. Parameters that form right angles show that they have no relationship with each other, for example between Δ*t* and K_p, between *Tc* and K_l, between *Ts* and K_k, and so on. Meanwhile, parameters that form large angles indicate a negative relationship with each other, for example between Tc and Δ*t*, *Tc* and Δ*t*, *KT* and K_a, and so on. These results can also be confirmed by the correlation values between parameters in Table 1. So by analyzing this biplot directly you can find out the closeness and direction of the relationship between the parameters being tested. Biplot can determine the relationship between parameters and their detailed explanation from a multivariate data set (Yan & Rajcan, 2002).

3.4. Component Grouping

One of the results of the PCA test is a diagram consisting of 4 quadrants which is able to explain in detail the grouping of data based on treatment as shown in Figure 4. The extraction results on the main components F1 and F2 show that PCA is able to group data based on treatment type. The compressive force treatment factors (P0, P100, and P200) are distributed evenly in all quadrants. This shows that the compressive force treatment has a strong influence on the main components F1 and F2 in almost all parameters studied. Meanwhile, the cooling media treatment is clearly depicted as a separate group between ice media (R1) and dry ice (R2). Treatment variations using ice cooling media were grouped in quadrants I and II, while treatment variations using dry ice cooling media were grouped in quadrants III and IV. This phenomenon shows that cooling media factors or precooling temperature differences can be identified and grouped separately. The treatment factor for the type of meat samples also provides separate groupings, where beef and chicken samples are grouped in quadrants I and IV, while tuna fish samples are in quadrants II and III. These results indicate that fish samples which physically and chemically have different properties from beef and chicken can be grouped in different quadrants. Based on the results of this analysis, overall it can be seen that the PCA analysis is able to group the treatment factors applied in this research.

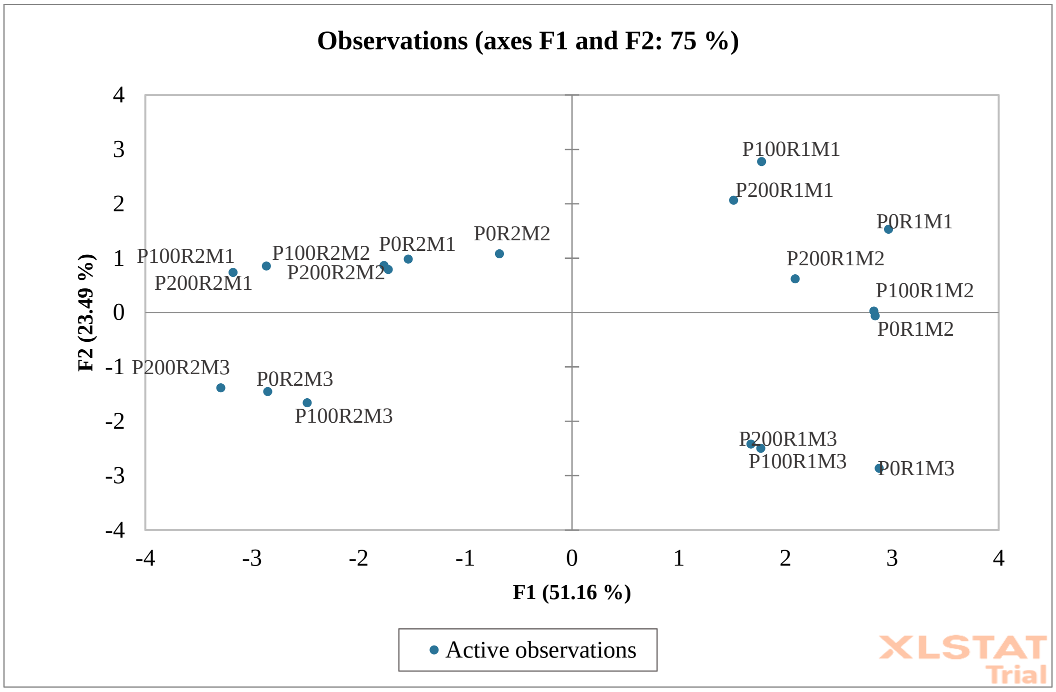

Figure 4. Value extraction and grouping based on main components

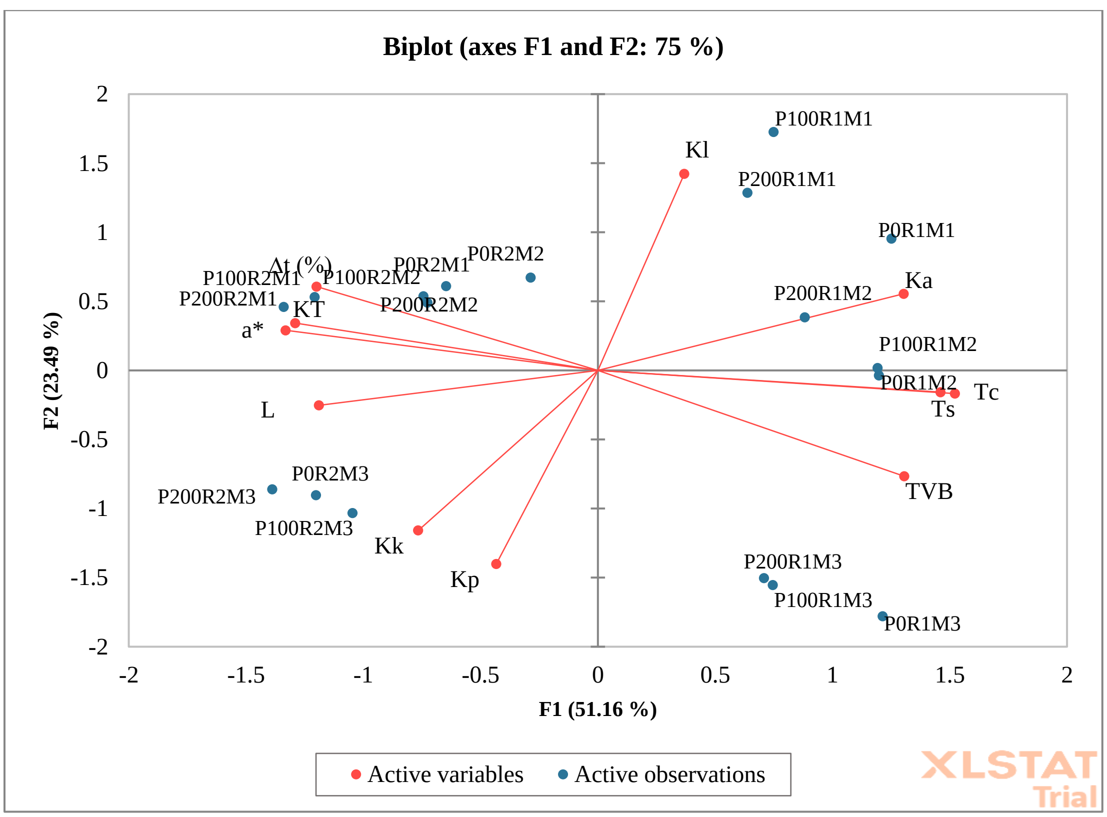

Figure 5. Biplot of PCA analysis results in the precooling process using the press plate method

Figure 5 shows the biplot of the results of grouping data based on treatment factors and test parameters simultaneously. This grouping can be used to relate the relationship between treatment factors and the parameters tested. The treatment factors in quadrant I are closely related to the K_a and K_l parameters; treatment factors in quadrant II are related to *TVB*, *Ts*, and *Tc*; treatment factors in quadrant III are related to *L*, K_k, and K_p; while the treatment factors in quadrant IV are related to *KT*, Δt and a^*. The treatment factor in quadrant I is the use of ice cooling media made from beef and chicken, characterized by high K_a and K_l parameters. This shows that precooling beef and chicken with ice medium will have a positive relationship or high value on the K_a and K_l parameters.

The treatment factor in quadrant II is the use of ice cooling media with tuna fish which has a positive relationship, especially with *TVB*. The treatment factor in quadrant III is the use of dry ice cooling media with tuna fish which has a positive relationship with *L*, K_k, and K_p. The treatment factor in quadrant IV is the use of dry ice cooling media made from beef and chicken which has a positive relationship with *KT*, Δt and a^*. Samples that are close to each other have the same description, while samples in opposite locations have different descriptions (Setyaningsih, *et al*., 2010).

Furthermore, a more detailed analysis can be carried out, that the parameters K_l, K_a, *Tc*, and *Ts* group samples of beef (M1) and chicken meat (M2) with ice cooling media (R1) at all compressive forces (P0, P100, and P200) in quadrant I, has values for these parameters that are greater than the other treatment combinations. On the other hand, the parameters Δt, *KT*, and a^* which group chicken meat (M2) with dry ice cooling media (R2) at all compressive forces in quadrant IV, have values for these three parameters that are greater than those in the same sample, namely chicken meat (M2) with ice cooling media which is located in quadrant I. Likewise, the parameter values *L*, K_k, and K_p in tuna fish samples (M3) with dry ice cooling medium (R2) which is located in quadrant III, are higher. Higher compared to other treatment combinations. Meanwhile, tuna fish samples (M3) with ice cooling media (R1) at all compressive forces were located in quadrant II, generally characterized by higher *TVB* values than other treatment combinations.

4. CONCLUSION

The results of the research can be concluded that PCA with XLSTAT can be used well to reduce the number of parameters into two main components which can explain 75% of the total variation in a data set of precooling results from research. PCA is able to group precooling treatments with ice and dry ice cooling media based on the physical, chemical and mechanical properties of the meat samples tested. Treatments using ice media for all types of meat and compressive forces were grouped in quadrants I and II, while those using dry ice media were grouped in quadrants III and IV. Based on the type of meat sample, the results of PCA analysis were able to group beef and chicken samples in quadrants I and IV, while tuna fish samples were in quadrants II and III. PCA can clearly be used to analyze the relationship between treatment and the parameters being tested.

ACKNOWLEDGEMENT

The author would like to express his deepest gratitude to the Ministry of Education, Culture, Research and Technology, Indonesia for the funding provided to carry out this research, as well as to Gadjah Mada University for trusting the author to carry out this research. This research was funded by the Ministry of Education, Culture, Research and Technology, through the Doctoral Dissertation Research (PDD) No. 2780/UN1/DITLIT/PT.01.03/2024, both for conducting research and publishing it.

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