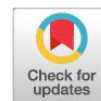


Research Article



Effect of Different Heating Temperatures and Acetic Acid Concentrations on Physical Quality of Curd as an Ingredient for Milk Nuggets

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Abstract | Diversification of milk products is essential to increase milk consumption and prolong the shelf life of milk without losing its highly nutritious content. This study aims to understand the effect of different heating temperatures and acetic acid concentrations in curd-making as a basis for producing milk nuggets. A 3 x 3 factorial Completely Randomized Design was used, with heating temperatures of 75°C, 80°C, and 85°C, and acetic acid concentrations of 0.2 M, 0.4 M, and 0.6 M. Five parameters (amount of whey, yield, pH, texture, and whiteness index) were observed as physical characteristics of the curd. The results showed that the different heating temperatures only affected the yield produced. Meanwhile, the varying acetic acid concentrations affected all parameters except the pH value. The combination of 85°C heating temperature and 0.6 M acetic acid concentration produced the highest values in all parameters. In conclusion, adding 0.6 M acetic acid at an 85°C heating temperature may produce the best curd for milk nuggets. Future research should explore the sensory evaluation and shelf-life stability of milk nuggets produced from curds to ensure consumer acceptability and market potential.

Keywords | Curd, Milk nuggets, Temperature, Acetic acid, Concentration, Physical characteristics

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INTRODUCTION

Milk contains a comprehensive nutritional profile, including fat, protein, lactose, salts, and vitamins (Thorning *et al.*, 2016). However, its high water content (>80%) makes it susceptible to spoilage, creating an ideal environment for microbial growth (Chinparast *et al.*, 2015). In Indonesia, fresh milk production reached 837,223 liters in 2023 (Central Bureau of Statistics, 2024). Despite this significant production, preserving milk and extending its shelf life remain challenging. To address this, it is crucial to

develop innovative milk-based products that retain milk's nutritional benefits while improving its acceptability and shelf life.

One such product is milk nuggets, which offer a versatile and nutritious alternative to traditional milk products. While nuggets are typically associated with meat, milk protein can also be used to create these products (Devi *et al.*, 2021). Milk nuggets are suitable as snacks or complementary meal components, boasting a longer shelf life when stored under refrigeration or freezing conditions.

Sandra *et al.* (2021) highlighted milk's potential for being processed into nugget-like products due to its soft yet solid texture. Diversifying milk-based products like nuggets broadens milk's utility beyond cheese and promotes processed milk consumption among Indonesians.

Coagulation is the critical step in producing milk nuggets, which separates milk into curds and whey. The curds are then used as the primary ingredient for milk nuggets. Various factors, including the type of milk, coagulation method, temperature, and heating conditions, significantly influence the curd-making process. Protein coagulation is achieved by adding a coagulant agent (Farkye, 2017), an acid, enzyme, or lactic acid bacterial starter (Bonfatti *et al.*, 2014; Panthi *et al.*, 2019). Each method has specific advantages and limitations.

Acid coagulation, often performed using acetic acid, is a common and cost-effective method (Awad *et al.*, 2012; Husnaeni *et al.*, 2019; Purwadi, 2009). The success of this process depends on critical parameters such as temperature and acid concentration (Bukhari *et al.*, 2013; Setiawan *et al.*, 2021; Sulejmani and Hayaloglu, 2016). These factors not only influence the coagulation process but also determine the texture and flavor of the final product. For instance, higher temperatures and appropriate acid levels promote syneresis (whey separation), leading to firmer curds. Milk coagulated at 32°C tends to form stronger cross-links, resulting in thicker bonds, larger pores, and increased syneresis (Tarapata *et al.*, 2021). Therefore, this study aims to investigate the effects of different heating temperatures and acetic acid concentrations on the coagulation of cow's milk to optimize curd production for high-quality milk nuggets.

MATERIAL AND METHODS

EXPERIMENTAL SITE AND RESEARCH MATERIALS

The research was done in the Laboratory of Animal Products Technology, Faculty of Animal Science, Universitas Brawijaya. In this study, we used fresh milk collected from the local dairy farm in Malang Regency and 100% glacial acetic acid (Supelco® Solution, Germany). We used a thermometer, water bath, scales, measuring cylinder, and pH meter to conduct the experiment.

RESEARCH DESIGN

A 3 x 3 factorial completely randomized design (CRD) was applied for this research. The first treatment was temperatures 75 °C, 80 °C, and 85 °C. The second treatment was acetic acid concentration of 0.2 M, 0.4 M, and 0.6 M. Every treatment using 1000 mL milk was repeated 3 times.

The curd-making process was as follows: 1) heating the milk at a specified heating temperature, 2) after reaching the specified temperature, the acetic acid with concentra-

tion according to treatment was added as much as 5% from the total volume of milk, 3) stir the milk until curd was formed, and lastly the curd formed is filtered with a muslin cloth. After filtering, the curd could then be used for physical parameter analysis.

PARAMETERS STUDIED

The parameters observed were the amount of whey and yield (Adrianto *et al.*, 2020), pH value (AOAC, 2005), texture (Indiarto *et al.*, 2012), and whiteness index (Kamal-Eldin *et al.*, 2020). The detailed analysis conducted was as follows:

YIELD: Yield is a percentage of the ratio between the weight of the portion of the material used and the total weight of the material. The formula used to calculate the yield is:

$$\text{Yield (\%)} = \frac{\text{weight of formed curd}}{\text{weight of the milk used}} \times 100$$

pH VALUE: The pH value was measured using a pH meter (Hanna Instrument, USA) and calibrated with a buffer solution with pH values of 4 and 7. The pH meter cathode was inserted into the sample that had been mixed with aquatics in a ratio of 1:1 and left until the number indicated on the digital measurement did not change again. The pH meter cathode was rinsed with an aquabidest and dried before using again.

TEXTURE: Testing was carried out with the TA-XT2i tool. The curd sample was shaped and uniform in size. The variable measured was the hardness of the curd determined from the maximum force (peak value) at the first pressure or compression. It was done using Texture Expert with a Windows computer program.

COLOR: Curd color was measured by the CIE (International Commission on Illumination) color scale using the color reader tool. The measurement stage begins by turning on the color reader and pressing the on button. The sensor of the color reader was attached to the surface of the cheese, and the test button was pressed. The L* (dark to bright value), a* (red to green value), and b* (yellow to blue value) displayed on the monitor screen were recorded. The whiteness index was calculated using the results of color measurements (L*, a*, and b* values) with the formula Kamaleldin *et al.* (2020) as follows:

$$\text{Whiteness Index (WI)} = \sqrt{((100 - L^*)^2) + a^{*2} + b^{*2}}$$

DATA ANALYSIS

The research data were tabulated in the Excel program. The physical characteristics of the curd were analyzed using

Table 1: Physical characteristics of curd with heating temperature and acetic acid concentration treatments.

Parameter	Heating Temperature	Acetic Acid Concentration			Average
		0.2 M	0.4 M	0.6 M	
Whey (ml)	75 °C	845.04±13.75	812.67±16.62	789.67±3.21	815.78±26.43
	80 °C	856.33±35.02	787.67±18.61	792.33±21.13	812.11±40.11
	85 °C	807.33±20.60	793.04±21.02	793.67±11.50	798.05±17.28
	Average	836.22±30.88 ^b	797.78±19.90 ^a	791.89±12.26 ^a	
Yield (g)	75 °C	112.90±7.65	146.63±5.35	179.13±3.17	146.22±29.10 ^a
	80 °C	134.67±7.94	174.07±5.60	180.30±5.61	163.01±22.15 ^b
	85 °C	140.33±9.95	179.87±3.75	185.04±4.22	168.40±21.93 ^b
	Average	129.30±14.57 ^a	166.86±15.96 ^b	181.48±4.70 ^c	
Curd's pH	75 °C	5.50±0.07	5.52±0.06	5.55±0.07	5.52±0.06
	80 °C	5.68±0.11	5.56±0.07	5.56±0.08	5.60±0.10
	85 °C	5.64±0.08	5.64±0.13	5.58±0.17	5.62±0.12
	Average	5.61±0.11	5.57±0.10	5.56±0.10	
Curd's Texture	75 °C	3.03±0.21	4.57±0.50	5.97±0.67	4.52±1.34
	80 °C	3.23±0.65	5.40±0.10	5.60±0.46	4.74±1.21
	85 °C	3.67±0.15	5.83±0.71	6.10±0.30	5.20±1.22
	Average	3.31±0.45 ^a	5.27±0.71 ^b	5.89±0.49 ^b	
Curd's Whiteness Index	75 °C	87.88±1.10	86.72±0.84	85.51±1.17	86.70±1.37
	80 °C	86.67±0.76	86.38±0.51	85.19±0.99	86.08±0.96
	85 °C	86.27±0.67	85.60±0.34	85.03±0.89	85.63±0.79
	Average	86.94±1.04 ^b	86.23±0.72 ^b	85.24±0.91 ^a	

* Different superscripts within the same row or column showed significant differences between factor ($p<0.01$).

analysis of variance (ANOVA). If there is a significant test, results from treatments were followed with the Duncan Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Testing the curd's quality with different heating temperatures and acetic acid concentrations determines the quality of milk nuggets. The results of the curd's physical characteristics treated with different heating temperatures and acetic acid concentrations are presented in Table 1. It was shown that the different heating temperatures significantly affect ($p<0.01$) the amount of yield produced. Meanwhile, the acetic acid concentration significantly affects ($p<0.01$) all parameters except pH. No interaction ($p>0.05$) was found between the two treatments in the physical quality of the curd.

The results of the research showed that the higher concentration of acetic acid (0.6 M) would reduce the amount of whey, pH, and whiteness index as well as increase the yield and texture of the curd with values for each parameter, 791.89±12.26 ml; 5.56±0.10; 85.24±0.91; 181.48±4.70 g and 5.89±0.49, respectively. The heating temperature (85 °C) in making curd will increase the yield (168.40±21.93 g) and curd texture (5.20±1.22) and reduce the amount of

whey produced (798.05±17.28 ml). The texture of curd of all groups in show in Figure 1.

Curd quality should be considered because it is the most essential ingredient in milk nugget production. Prastujati *et al.* (2018) stated that adding proteolytic enzymes and acids to milk will cause the coagulation process of milk proteins, which then form curd and whey. In this study, it was found that whey production tended to decrease with increasing acetic acid concentration. Adding acetic acid reduces milk's pH (Panthi *et al.*, 2017). As the concentration of acetic acid increases, the pH of the milk drops lower, thereby accelerating and strengthening the coagulation process of casein protein. With more casein coagulating, the amount of yield/curd produced increases. These results followed the opinion of Pawlos *et al.* (2023) that a high acid concentration and a fast and efficient casein precipitation process produce a denser and drier curd. The amount of whey in this study ranged from 78-86%, almost the same as research by Bintsis and Papademas (2023), which revealed that whey from cheese making ranged from 80-90% of the total weight of milk used.

Another factor that causes high or low levels of curd produced was the protein and fat content of the milk used. At a constant level of water content, the higher the fat

and protein content of milk, the higher the yield obtained (Musra *et al.*, 2021; Vasbinder *et al.*, 2003). Furthermore, Alpay and Uygun (2015) reported that adding agglomerates also caused more total solids to be produced. However, the resulting curd breaks easily and has small lumps, so it dissolves easily with the whey when filtered. This can cause a decrease in the yield percentage produced. Pardede and Arreneuz (2013) explained that the more concentration of coagulating agent added, the higher the acidity level and the higher the proteolysis that occurs so that the protein dissolves in the whey.

In this research, a heating temperature of 85 °C and an acetic acid concentration of 0.6 M obtained the highest average yield value. The heating temperature and high acetic acid concentration together increase the coagulation efficiency of casein, resulting in a more prosperous and denser curd. High heating temperatures can accelerate protein reactions and denaturation, while acetic acid accelerates casein coagulation by drastically lowering the pH and producing high curd yields. At a pH of about 4.6, casein reaches the isoelectric point, where the surface charge of the protein is neutral, and the casein protein becomes insoluble. High levels of acetic acid accelerate the attainment of this pH, accelerating casein coagulation. Casein coagulates as curd at its isoelectric point, namely at pH 4.6 (Chinprahast *et al.*, 2015). Casein coagulation cannot be done at the isoelectric point, but the yield will decrease because coagulation above the isoelectric point will result in the remaining casein charge. Hovjecki *et al.* (2022) and Amaro-Hernández *et al.* (2020) explain that a decreased pH will cause the milk coagulation process not to run perfectly to form curd.

The pH (potential hydrogen) value is the free hydrogen ion found in the product. The pH value can reflect the concentration of free hydrogen ions (Misbachudin *et al.*, 2014). The statistical analysis showed that the heating temperature and acetic acid concentration did not affect the pH of the curd ($p > 0.05$). Likewise, the interaction of heating temperature and papain concentration did not show a significant effect on Danke's pH ($P < 0.05$) (Pulungan *et al.*, 2020). The pH value of this curd is still classified as alkaline because no curing process was carried out. Fox *et al.* (2004) stated that a too-low or too-high pH would make the resulting curd soft and brittle so that the fat and casein are lost with the whey. The pH value dramatically influences enzyme activity. Changes in pH cause changes in the charge of amino acid residues, especially those that make up the active center of enzymes (Kusumadjaja and Dewi, 2010).

Texture is one of the consumer assessments because it determines the quality of food products and has parameters

that can be directly observed. This was supported by the opinion that reducing the product percentage can affect the elasticity of milk nuggets. In this study, texture was measured based on hardness value. The average hardness value in the acetic acid concentration treatment increases the hardness value as the acetic acid concentration increases. The texture of curd as a result of the treatments can be shown in Figure 1. This is because coagulation occurs more quickly, producing a harder curd with a denser and more compact structure. After all, the curd lumps are smaller and denser. A denser, more compact curd can hold less whey, resulting in a drier curd. The concentration of acetic acid plays a vital role in determining the final texture of the curd produced. Higher concentrations tend to produce curds that settle more quickly, are denser, and drier, while lower concentrations produce softer, looser, and moister curds. Choosing the right acetic acid concentration is crucial in cheese-making to achieve the desired texture and characteristics (Seth and Bajwa, 2015; Sulejmani *et al.*, 2014).

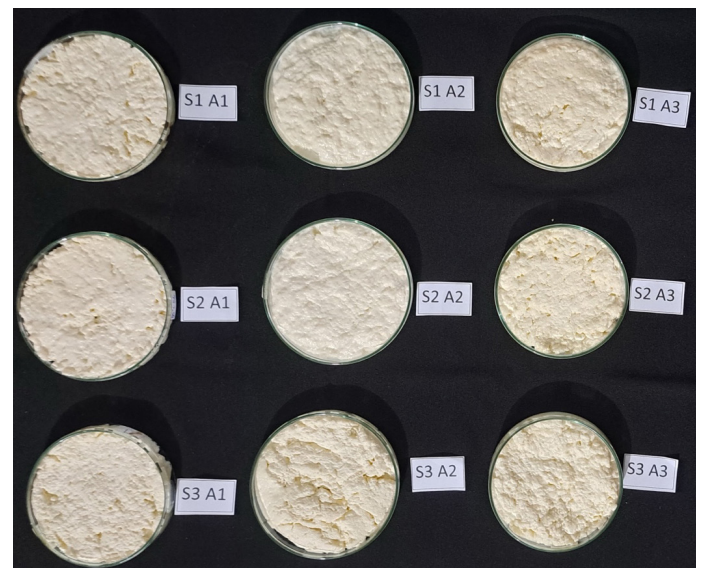


Figure 1: The texture of the curd with the treatment of heating temperatures and acetic acid concentrations (S1= 75 °C; S2= 80 °C; S3= 85 °C; A1= 0.2 M; A2= 0.4 M; A3= 0.6 M).

The texture of the curd is essential in determining the final moisture of the milk nuggets. At very low pH (due to high acetic acid concentrations), casein protein will coagulate more strongly. This lower pH produces a more rigid and stiffer curd (Mahomud *et al.*, 2021; Wardhani *et al.*, 2018). The research results of Anggraini *et al.* (2013) added that the greater the level of coagulating materials in a product tends to reduce elasticity, or the texture becomes softer due to increased proteolytic activity. According to Winarno (2004), the physical properties of curd, such as texture compactness, are influenced by protein compounds, which consist of 70% globulin, which can be coagulated by acid and heat at a temperature of 85 °C.

The color characteristics of curd are important because they are closely related to human sensory assessment as consumers. The analysis results in this study showed that increasing the concentration of acetic acid affected ($p < 0.05$) the whiteness index of curd. Increasing the concentration of acetic acid tends to reduce the Whiteness Index of the curd produced. This is caused by accelerated Maillard reactions, non-enzymatic browning, and changes in the curd microstructure. Panthi *et al.* (2017) reported that high concentrations of acetic acid caused faster and stronger coagulation of casein, which could result in changes in the microstructure of curd. These changes may affect the reflection of light from the surface of the curd, making it appear less white. Tamanna and Mahmood (2015) added that the Maillard reaction can occur more quickly and intensely at higher concentrations of acetic acid. This reaction involves interactions between reducing sugars and amino acids, producing a brown product that lowers the Whiteness Index.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results, it can be concluded that the yield quantity is the only factor affected by the varying heating temperatures. All metrics were influenced by the varying concentrations of acetic acid, except for pH. The best quality curd for making milk nuggets, based on physical tests of yield and texture, was achieved at a temperature of 85°C with an acetic acid concentration of 0.6 M. Further research is needed to assess the economic value of this process for producing milk nuggets.

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NOVELTY STATEMENT

This study is the first one to test the effect of different heating temperatures and acetic acid concentrations in curd-making on the production of milk nuggets.

AUTHOR'S CONTRIBUTIONS

All authors contributed equally to the manuscript.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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