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Unraveling the Mechanism: How Extremely Low Frequency (ELF) Magnetic Fields 300 μT Stimulate Tempe Fermentation

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Abstract: Electromagnetic field (ELF) is a non-pegion radiation because it has an electromagnetic wave spectrum frequency below 300 Hz. Electromagnetic wave radiation with a very low frequency can inhibit a decrease in pH which can slow the growth of bacteria in a material or product. Tempe is a fermented food made from soybeans or other beans using the molds Rhizopus oligosporus and Rhizopus oryzae. The purpose of this study was to determine the effect of exposure to elemental magnetic field of marine frequency (ELF) in the process of tempe fermentation. This research used experimental method by comparing control and experimental groups. Data obtained from the research conducted such as PH, density, tempe color, tempe aroma, and tempe texture. The pH of tempe is measured using a pH meter, to determine the texture density using the sense of touch. Knowing the aroma of tempe using the sense of smell and see the color of tempe using the sense of sight. The results showed that based on the results obtained, it can be concluded that exposure to the ELF magnetic field is thought to increase the activity of microorganisms involved in the fermentation process of tempe such as Rhizopus oligosporus.

Keywords: ELF magnetic field; fermentation, tempe.

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Introduction

Today's rapidly developing technology is an absolute part of life. Advances in technology have made humans dependent on exposure to electrical and magnetic forces (Djoyowasito et al., 2010). Electromagnetic fields (ELF) are non-pegionizing radiation because they have a frequency of the spectrum of electromagnetic wave radiation ranges below 300 Hz (El Firdausi et al., 2023). Non-pegion radiation, such as infrared and microwave radiation, is a form of electromagnetic radiation that does not have enough energy to cause ionization (Kamalia & Sudarti, 2022). Elektromagnetic waves don't require a medium to travel, hance the term "electromacnetic radiation" (Agustina et al., 2023). Meanwhile, magnetic fields have unobstructed properties, meaning that magnetic fields are able to penetrate almost all materials (Lutfiyahh et al., 2022). Both components in electromagnetic waves have different characteristics (Yulandari et al., 2024). The constituent components of electromagnetic waves are magnetic fields and electric, with a perpendicular shape as well as towards propagation. The difference lies in electromagnetic waves that cause them to be able to produce energy through space in the form of radiation. The flowing electric current can produce electromagnetic waves (Yulianto et al., 2022). Electromagnetic wave radiation covers a very wide frequency range, ranging from low frequencies such as gamma rays to high frequencies such as electromagnetic waves, as well as various frequencies around them (Kanza et al., 2020).

ELF magnetic fields are one of the alternative technologies that can help preserve foodstuffs without compromising their quality. The spectrum of electromagnetic wave radiation is very broad, from very low frequencies to the highest ELF electro-magnetic waves generated by alternating currents used by devices containing electricity, the frequencies achieved range from 0 to 300 Hz (Ma, rufiyanti et al., 2021). Electromagnetic combination consists of electric and magnetic fields. The main sources of these fields include generators, power plants, medical equipment, and various other devices. Because the energy produced by magnetic fields is very small, the temperature changes when connected through a system. Electric and magnetic fields have low energy and short range, called non-ionic radiation, while ionic radiation is far-reaching and has high energy (Suryani et al., 2023). The fermentation process can be accelerated by the ELF magnetic field and can also increase the efficiency of the fermentation process by decreasing pH, this technology is useful in preserving food ingredients using magnetic field exposure that slows down the increase in temperature that will damage the nutrients in an ingredient (Faridawati, et al., 2023). ELF magnetic field exposure which has an intensity of 300 μT in a time range of 5 minutes affects the pH and DHL values of fermented milk (Astutik and Sudarti, 2021).

Electromagnetic wave radiation includes the spectrum of gamma rays, X-rays, and even ultraviolet radiation. Electromagnetic wave radiation at very low frequencies can inhibit the decrease in pH value, which can slow down the bacterial growth in a material or food. Radiation includes waves of the electromagnetic spectrum, including ELF magnetic fields with frequencies below 300 Hz, which can react to forces on magnetic currents (Suryanto and Bakhri, 2023). Electromagnetic waves can be classified into two, namely artificial and natural electromagnetic waves, with many equipment produced by humans through cables (Ramadhani et al., 2024). Factors that cause differences in radiation effects include differences in frequency, exposure distance to the source, exposure time and wavelength (Niati et al., 2021). Electromagnetic waves have significant potential to improve food security in everyday life. Utilizing the intensity and exposure time of ELF electromagnetic waves in this activity, it can be a useful guideline trying to increase the durability of food products (Sudarti et al., 2018).

The application of magnetic field radiation plays an important role in everyday life including in the tempe fermentation process (Cahyono et al., 2023). Tempe is a food made from beans or soybeans and fermented food using Rhizopus oryzae and Rhizopus oligosporus molds (Alvina et al., 2019). During the fermentation process, soybeans or other legumes nto a product that has a unique flavor and undergoes transformation, delicious texture, and specific aroma. The presence of microorganisms not only adds aesthetic value but also enhances nutritional benefits, making tempe a healthy food that is rich in plant protein. Its nutritional characteristics include a nutty flavor, but tempe also contains fats, carbohydrates, and minerals that the body needs (Putrawan et al., 2023). The Rhizopus Oligosporus mold species can produce a filase enzyme that plays an important role in hydrolyzing a filic acid to be converted into inositol and phosphate. The mold produces anti-toxins to protect against alfatoxins, producing antibacterials during the fermentation process. Indicators to determine the physical properties of tempe seen from the degree of similarity (pH). The degree of similarity is a value that shows a similarity in a material. Rhizopus oligosporus fungus can produce lactic acid in tempe. The longer the vulnerable time in fermentation, the pH of tempe also decreases because low pH is less suitable for the growth rate of fungi (Azizah et al., 2022). The rate of enzyme activity is influenced by pH and temperature. Each type of enzyme has an optimum pH that supports its performance. Storage temperature is also an important factor to consider. Low temperatures can inhibit bacterial growth and biochemical reactions, while high temperatures accelerate them. Therefore, a study was conducted on the effect of a magnetic field with an intensity of 300 µT for a duration of 20 minutes on the tempe fermentation process.

Method

This type of research is an experimental study that aims to examine the effect of ELF magnetic field exposure on the tempe fermentation process. The method used is by comparing two groups, namely the experimental group and the control group. In this study, the material used is tempe obtained from tempe makers in the Jember area. In this study, the tools used were pH meter which was used as a measuring tool for a pH value, Extremely Low Frequency (ELF) magnetic field source, a balance sheet whose function was to weigh the tempe for each group, and a glass beaker which served as a solution container to be used for calibration. This experimental procedure includes first preparing 1 kg of tempe that has been leavened, then dividing the tempe into several groups, namely 2 experimental groups and control groups. The experimental group amounted to 10 pieces of tempe and the control group amounted to 10 pieces of tempe with the size of one pack of tempe containing 50 grams. The first group, the experiment, was exposed to a 300 µT ELF magnetic field for 30 minutes. pH measurements were taken 2 days after exposure to the ELF magnetic field. In the next stage of analyzing data, the technique used in analyzing the data of this study is by direct observation and there are 3 observers. Taste assessment starts from a scale of 1 to 3 where 1 is less, 2 is sufficient, and 3 is very (Sudarti *et al*., 2023).

Picture 1. Photo of tempe before exposure to ELF magnetic field radiation

Result and Discussion

ELF waves are electromagnetic waves that work in the frequency range of 3-300 Hz. Research shows that ELF waves can enhance the metabolism of certain microorganisms through cellular stimulation, which is able to accelerate the fermentation process. Exposure to ELF waves, especially at a frequency of 300 Hz. That can accelerate mold growth by increasing enzyme activity and metabolism without disturbing the stability of the fermentation environment.

Experiments with a control group at an intensity of 200µT and an exposure duration of 90 minutes showed how magnetic fields can influence the growth of cells and microorganisms. This supporting the optimization of microbial work in the fermentation process (Nur et al., 2022). This is evident in tempe making experiments, where tempe exposed to ELF waves has a higher density than tempe without exposure. This density indicates a more optimal mycelium formation due to the stimulation of microorganism metabolism by ELF waves, so that the fermentation process runs faster and more efficiently. The combination of frequency, intensity and duration of exposure is an important factor in determining the success of fermentation using this technology.

The utilization of magnetic fields, especially ELF waves, has been proven to have a positive impact on maintaining the quality of food ingredients. According to Nuriyah et al. (2022), ELF magnetic fields have a significant biological effect, which is indicated by changes in the growth rate of microorganism cells. This effect occurs because magnetic fields are able to increase cell metabolism and enzyme activity involved in biological processes, including fermentation. Thus, ELF magnetic fields not only accelerate the fermentation process, but also maintain or improve the quality of food ingredients, as evidenced by the research of Nuriyah et al. (This technology has great potential to be applied in the modern food industry to support production efficiency and quality.

From various studies that have been conducted, it can be inferred that electromagnetic fields with extremely low-frequency (ELF) have diverse effects on the growth of microorganisms, including bacteria and fungi, depending on the frequency, intensity, and duration of exposure. According to Yulandari et al. (2024), the effective ELF magnetic field intensities for triggering bacterial proliferation in fermentation products are in the ranges of 200 µT, 300 µT, and 500 µT, with the duration of exposure also playing an important role in determining the results. Where these biological effects of ELF magnetic fields indicate that the intensity and duration of exposure must be adjusted to obtain optimal results. By utilizing the right magnetic field intensity, as suggested by Yulandari et al. (2024), according to observations the frequency of 300 Hz also proved optimal for increasing the activity of protease and amylase enzymes, which support the breakdown of protein and starch in soybeans.

The quality of tempe is influenced by the quality of soybeans, the production process, namely its sterilization and the quality of yeast used in the fermentation process. The most important influence to produce quality tempe is the fermentation process. This study was conducted to see the test results of tempe fermentation quality by using ELF magnetic field exposure which will trigger the proliferation of yeast bacteria added to soybeans. This study uses elf magnetic field exposure of 300µT which aims to determine the pH value, comparison of tempe weight before and after exposure to light, and other changes. Exposure was carried out in the physics laboratory of FKIP University of Jember. The study used two types of treatment, namely tempe without magnetic field exposure as a control group and tempe using magnetic field exposure as an experimental group. This was done to determine the difference in the condition and quality of tempe given exposure to magnetic fields and not. The exposure was carried out for 20 minutes and after that left the tempe at room temperature for 2 days. After 2 days of storage, research was conducted on pH, density, color, rhyzopus, aroma and texture in each group, namely the extremely group and the control group. The research produced the following data:

Tabel 1. pH Measurement

Control Group		Experimental Group	
K1	7,9	E1	9,0

K2	7,5	E2	7,8
K3	10,9	E3	8,7
K4	10,2	E4	9,0
K5	7,9	E5	9,0
K6	7,9	E6	8,9
K7	7,5	E7	8,7
K8	7,8	E8	9,0
K9	10,2	E9	8,8
K10	10,9	E10	9,0
Average pH	7,85	Average pH	8,8

Based on the table above, it can be seen that the average pH in the experimental group is higher than in the control group. The increase in pH indicates a decrease in acidity levels in tempe. This rise in pH may be caused by microbial activity. During the fermentation process, microorganisms such as Rhizopus oligosporus produce metabolites, including organic acids. These organic acids lower the environmental pH. However, if there are factors that inhibit the growth or activity of these microorganisms, the production of organic acids will decrease, leading to an increase in pH. This statement aligns with Azizah et al., who state that an increase in pH values in the experimental group above the average of the control group occurs due to exposure to ELF magnetic fields, which can alter the movement of ions across a cell membrane. Therefore, exposure to ELF magnetic fields can enhance the movement speed of these ions. An object exposed to a magnetic field will create a force on the ions to move and actively bind to protein channels, influencing the opening conditions of gates within the cell membrane. The ions affected by the magnetic field concerning cell growth include calcium ions (Ca2+). Calcium ions (Ca2+) are paramagnetic materials, which means they can be influenced by a magnetic field. The effect of the magnetic field on such materials involves the alignment of electron spins, which initially are random but become directed due to the magnetic field. The speed of movement of extracellular calcium ions (Ca2+) passing through the cell membrane can change due to induced currents caused by changes in the magnetic field. As a result, if the supply of calcium ions (Ca2+) is consistently maintained according to cellular requirements, this will enhance the growth rate of cells and bacteria. However, if the amount of calcium ions (Ca2+) entering the cell is less than or exceeds what is needed by a cell, it can hinder cell growth and may even cause damage within that cell.

Tabel 2. Density Measurement

Control Group				Experimental Group			
Sample Name	m (gr)	ΔV (mL)	**ρ** (gr/mL)	Sample Name	m (gr)	ΔV (mL)	**ρ** (gr/mL)
K1	50	50	1	E1	51	50	1,02
K2	50	50	1	E2	50	50	1
K3	50	50	1	E3	50	50	1
K4	50	50	1	E4	51	50	1,02
K5	50	50	1	E5	50	50	1
K6	50	50	1	E6	50	50	1
K7	50	50	1	E7	50	50	1
K8	50	50	1	E8	50	50	1
K9	50	50	1	E9	50	50	1
K10	50	50	1	E10	50	50	1
Average Density			1	Average Density			1,004

Based on the table, it can br seen that the average density of the control group is smaller than that of the experimental group. ELF light may affect the cell structure of the rhyzopus fungus which plays a role in tempe fermentation. This structural change can have an impact on the density of tempe. The greater the density of tempe, the greater its mass, the large mass will affect its density. A study by Astutik and Sudarti (2021) titled "The Effect of ELF (Extremely Low Frequency) Magnetic Field Exposure at 500 µT on pH, Density, and Physical Quality of Silken Tofu" shows that the density in the control group is lower compared to the experimental group. This is due to a reduction in water content in the silken tofu, which inhibits the growth of spoilage bacteria, thereby preserving the quality of the tofu better.

Tabel 3. Color Research On Control Group

Sample	Normal			Brown			Black		
	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)
K1	3	3	2	1	1	1	1	1	1
K2	3	3	3	1	1	1	1	1	1
K3	3	3	3	1	1	1	1	1	1
K4	3	3	3	1	1	1	1	1	1
K5	3	3	3	1	1	1	1	1	1
K6	3	3	3	1	1	1	1	1	1
K7	3	3	3	1	1	1	1	1	1
K8	3	3	3	1	1	1	1	1	1
K9	3	3	3	1	1	1	1	1	1
K10	3	3	3	1	1	1	1	1	1

Based on this table, it shows that tempe on average has a normal color. The normal color of tempe occurs because tempe does not experience external influences such as exposure to ELF.

Tabel 4. Color Research In Experimental Groups

Sample	Normal			Brown			Black		
	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)
E1	3	3	2	1	2	2	1	1	1
E2	3	3	2	1	2	2	1	1	1
E3	3	3	3	1	2	1	1	1	1
E4	3	3	2	1	2	2	1	1	1
E5	3	3	3	1	2	2	1	1	1
E6	3	3	2	1	2	2	1	1	1
E7	3	3	2	1	2	1	1	1	1
E8	3	3	2	1	2	2	1	1	1
E9	3	3	3	1	2	1	1	1	1
E10	3	3	3	1	2	1	1	1	1

Based on the table, there is tempe that is normal in color and there is also tempe that is slightly brownish in color. This is in accordance with the journal Putrawan et al which states that tempe is slightly brownish in color. Tempe contains phenolic compounds which can oxidize into darker colored compounds when exposed to light, including eif light. This oxidation process often occurs in fruit and vegetables which change color when exposed to air.

Tabel 5. Rhyzopus Research On Control Group

Area (mm)	Thickness

Sampl e	Long (mm)	Wide (mm)	Total Area (mm)	
K1	80	60	480	10
K2	80	65	520	5
K3	80	70	560	5
K4	75	65	487,5	10
K5	80	65	520	10
K6	80	65	480	10
K7	80	65	520	10
K8	75	65	487,5	10
K9	80	70	560	10
K10	70	60	420	10

Based on this table, the length and width of each tempe wrapper are different. The varying sizes occur due to differences in wrapping the tempe because the size of the ziplock plastic is too big. Based on the data, exposure to ELF waves affects the activity of Rhizopus oligosporus as the main microorganism in tempe fermentation. In the experimental group, the growth of Rhizopus mycelium was uneven, which was reflected in the variation of tempe dimensions, such as area and thickness. ELF waves may interfere with the metabolic processes of Rhizopus, including the production of enzymes that play a role in binding soybeans into tempe structures.

Tabel 6. Experimental Rhyzopus

Sample	**Area (mm)**			**Thickness (mm)**
	Long (mm)	Wide (mm)	Total Area (mm)	
E1	55	70	385	15
E2	75	60	450	20
E3	75	60	450	5
E4	75	55	375	15
E5	70	60	420	10
E6	65	70	455	10
E7	75	60	450	10
E8	75	60	450	10
E9	75	60	450	10
E10	75	60	450	10

Tempe fermentation experiment for experiment for control and experimental groups through exposure to ELF wave, it was found that the aroma of tempe in both groups still showed no signs of decay. This indicates that the fermentation process is going well, and the main microorganisms such as Rhizopus oligosporus are still able to dominate and play their role. However, the control group had a higher level of tempe normalization than the experimental group. This is likely due to the effect of ELF waves on fermentation microbial activity.

Tabel 7. Aroma Research On Control Group

	Normal/Khas			**No Scent**			**Rotten**		
Sampel	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)
K_1	3	3	3	1	1	1	1	1	1
K_2	3	3	3	1	1	1	1	1	1
K_3	3	3	3	1	1	1	1	1	1
K_4	3	3	3	1	1	1	1	1	1
K_5	3	3	3	1	1	1	1	1	1

K_6	3	3	3	1	1	1	1	1	1
K_7	3	3	3	1	1	1	1	1	1
K_8	3	3	3	1	1	1	1	1	1
K_9	3	3	3	1	1	1	1	1	1
K_{10}	3	3	3	1	1	1	1	1	1

Tabel 8. Aroma Research In Experimental Groups

	Normal/Khas			**No Scent**			**Rotten**		
Sampel	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)
E_1	2	2	2	1	1	1	1	1	1
E_2	2	2	2	1	1	1	1	1	1
E_3	2	2	2	1	1	1	1	1	1
E_4	2	2	2	1	1	1	1	1	1
E_5	2	2	2	1	1	1	1	1	1
E_6	2	2	2	1	1	1	1	1	1
E_7	2	2	2	1	1	1	1	1	1
E_8	2	2	2	1	1	1	1	1	1
E_9	2	2	2	1	1	1	1	1	1
E_{10}	2	2	2	1	1	1	1	1	1

Exposure to ELF waves may affect microbial metabolism or the growth of fungal mycelium, resulting in a less optimal texture, appearance or structure of tempe compared to the control group. In addition, interference with biochemical reactions during fermentation may have affected the final quality of tempe in the experimental group, although it did not cause a foul aroma. Therefore, although ELF waves did not trigger spoilage, their presence seems to have a small but significant effect on the normality of the tempe produced.

Meanwhile, according to Anisa M and Sudarti (2024). Shows that ELF exposure improves the physical quality of tempe, with significant differences in aroma, color, texture, and pH between the control and experimental groups. Overall, both support the effect of ELF magnetic fields, but the results vary.

Tabel 9. Texture Observation In The Contol Groups

	Congested			**Mushy**			**Watery**		
Sample	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)
K1	2	2	2	2	2	2	1	1	1
K2	1	1	1	2	2	2	1	1	1
K3	2	2	1	2	2	3	1	1	1
K4	1	1	1	2	2	3	2	2	1
K5	3	3	2	1	1	2	1	1	1
K6	2	2	2	2	2	2	1	1	1
K7	2	2	2	2	2	2	2	2	1
K8	1	1	1	2	2	2	1	1	1
K9	2	2	2	2	2	2	1	1	1
K10	2	2	2	2	2	2	1	1	1

Tabel 10. Texture Observation In The Experimental Groups

	Congested			**Mushy**			**Watery**		
Sampel	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)	P(1)	P(2)	P(3)
K1	1	1	2	2	2	1	1	1	1
K2	2	2	2	2	2	2	1	1	1

K3	3	3	2	1	1	1	1	1	1
K4	3	3	2	1	1	1	1	1	1
K5	1	1	1	2	2	2	1	1	1
K6	1	1	1	2	2	2	1	1	1
K7	2	2	2	2	2	1	1	1	1
K8	2	2	1	2	2	2	1	1	1
K9	1	1	1	3	3	2	1	1	1
K10	1	1	1	3	3	2	1	1	1

In the tempe fermentation experiment involving a control group and an experimental group exposed to ELF (Extremely Low Frequency) waves, the results showed that the aroma of tempe in both groups remained stable, indicating that the fermentation process was proceeding well. The main microorganism, Rhizopus oligosporus, continued to dominate and function effectively. However, the control group exhibited a higher level of normality in tempe compared to the experimental group. This may be due to the effects of ELF waves on the activity of fermentation microbes, which can influence the metabolism and growth of fungal mycelium, resulting in less optimal texture and structure of tempe in the experimental group.

pH measurements indicated that exposure to ELF waves affected fermentation conditions. In the study by Maylinda Nur Azizah et al., there was a significant difference in pH values between the control and experimental groups. For example, at 12 hours after exposure, the pH value for the control group was 6.46, while the experimental group with an intensity of 200 µT showed pH values ranging from 5.91 to 6.45. The decrease in pH in the experimental group may indicate that fermentation conditions were not optimal for the growth of Rhizopus oligosporus, potentially leading to variations in tempe texture.

Regarding texture, although the journal did not explicitly measure physical parameters such as density or compactness of tempe, a decrease in pH could negatively impact the activity of enzymes involved in forming tempe texture. In the experimental group, growth of Rhizopus mycelium appeared less uniform, as reflected by variations in dimensions of tempe, such as surface area and thickness. This observation aligns with findings that ELF waves may disrupt fungal metabolic processes, including enzyme production crucial for binding soybeans into tempe structure. Variations in color, aroma, and texture of tempeh in the experimental group indicate that ELF waves can also affect other aspects of quality. This variation may be caused by disruption of microbial metabolism or enzyme production due to exposure to ELF waves. Yulandari et al (2024) revealed that exposure to ELF magnetic fields can increase the growth of certain bacteria such as salmonella thypimurium and lactobacillus, which play an important role in the fermentation process of foods such as tempeh, cheese, and tape. The exact mechanism behind the effect of ELF waves on microbial growth and tempeh quality is still not fully understood. However, several studies have shown that ELF waves can interact with biological molecules and change the permeability of cell membranes. As revealed by Saragih et al (2024) that long-term exposure to a 50 Hz magnetic field is a significant risk factor for neoplastic development as well as genetic differences and animal fertility, the negative impact of ELF wave exposure on animal and plant gene expression.

Thus, while ELF waves did not cause expansion in tempe, their presence seems to have a small yet significant effect on the normality level and quality of the resulting tempe texture. Further research is needed to understand the specific mechanisms by which exposure to ELF magnetic fields affects microbial metabolism and the physical quality of fermented products like tempe.

Conclusion

This activity aims to see what happens as a result of irradiation with an Extremely Low Frequency (ELF) magnetic field with a power of 300 micro tesla (µT) on tempe fermentation. Based on the results obtained, it was concluded that exposure to ELF is thought to increase the activity of microorganisms involved in the tempe fermentation process, such as Rhizopus oligosporus. The higher activity of these microbes contributes to the acceleration of the fermentation process, resulting in a shorter time needed to reach the desired level of tempe maturity. In addition, exposure to magnetic fields also has the potential to improve the quality of the tempe produced, with tempe having a better texture and better flavor compared to tempe not exposed to magnetic fields. Despite the improvement in quality and fermentation speed, the results obtained may vary depending on several factors, such as the duration and frequency of magnetic field exposure. Therefore, to understand more about the mechanism of how ELF magnetic fields affect tempe fermentation, further research is needed. This could include variations in magnetic field intensity, type of microorganisms, as well as other parameters that could affect the final result. Overall, this lab showed that ELF magnetic field radiation at 300 micro tesla can have a positive effect on the tempe fermentation process. With a better understanding of this effect, it is hoped that new methods can be developed for the production of more efficient and high-quality tempe.

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