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Influence of Acoustic Waves on the Shelf Life Quality of White Oyster Mushroom (*Pleurotus Florida*)

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Abstract*— Mushrooms are seasonal and highly perishable crops and contain about 90% (w.b) moisture. The moisture content of fresh mushrooms is 70 – 95% (w.b), depending upon the harvest time and environmental conditions, while that of dried mushrooms is close to 10% (w.b). Due to their high moisture content, they cannot be stored for more than 24 hours at ambient conditions. Hence, they need to be preserved by some methods. Moisture transportation and distribution in products are key factors for the development of the product quality. To control quality development, an understanding of the moisture content at a certain time of the product is required. The objective of the study was to extend the shelf life of fresh harvest of White oyster mushroom without compromising the quality by applying the acoustic wave with various exposure time. White oyster mushroom samples were exposed to acoustic waves (1kHz, 100 dB) inside a soundproof chamber at three levels of exposure time (1, 2, 3) hours. Subsequently, white oyster mushrooms sample stored in a refrigerator at 10 ^{o}C. The effects of acoustic waves application were determined by measuring the surface color, flesh firmness, and shelf-life extension every other day at cold storage. Results of the study indicated that white oyster mushroom samples exposed to acoustic waves for 2 hours exhibited the slowest to effect change in surface color for 13 days compared to 1 hour and 3 hours of exposure time at 11 and 12 days, respectively. Moreover, flesh firmness of white oyster mushroom samples exposed to acoustic waves for 2 hours was proved to exhibits the slowest to effect change for 13 days compared to 1 hour and 3 hours of exposure time at 11 and 12 days, respectively. The acoustic waves have a potential benefit of extending the shelf life of white oyster mushroom up to 13 days at 10 ^{o}C without altering the quality.

***Keywords*— mushroom; acoustic wave; shelf-life; quality; storage.**

I. INTRODUCTION

The mushrooms of the *Pleurotus genus* are more dedicated and sensitive than the *Agaricus genus* and they start deteriorating immediately within one day after harvesting due to its high moisture content and delicate nature [1]. Given their highly perishable nature, the fresh mushrooms must be processed to extend their shelf life for off-season use [2]. White oyster mushroom is a highly perishable mushroom with a reasonable shelf-life of 1 to 3 days at ambient temperature during marketing [3]. They must be either marketed soon after harvesting or preserved with exceptional care using processes such as storing in cold environment storage [4]. Mushrooms are 85 – 95% water. There are no barriers to water loss from their surface. When mushrooms wilt and shrivel, the quality of fresh mushrooms is lowered. Cooling the fresh mushrooms can be an alternative way to increase their shelf life thereby increasing their distribution and sale time [5].

Mushrooms are of commercial importance since their nutritional and medicinal value [6]. The annual average volume of mushroom production in the Philippines for the past four years (2010 – 2014) is about 510.8 MT wherein the annual average decrease is about 4.23% of the total production [7]. It is not enough to supply the country, even though some provinces are offering mushroom production training. Planting two mushroom beds a day for a total of 44 beds in a 22-day production cycle would give an income of Php1500.00 to Php2000.00 (US$205 to $273) per month. The Philippines ranks 60th among the producers of mushrooms in the world.

Mushrooms are seasonal and highly perishable crops and contain about 90% (w.b) moisture [8]. The moisture content of fresh mushrooms is 70 – 95% (w.b), depending upon the harvest time and environmental conditions, while that of dried mushrooms is close to 10% (w.b) [4]. Due to their high moisture content, they cannot be stored for more than 24 hours at ambient conditions. Hence, they need to be preserved by some method.

Moisture transportation and distribution in products are key factors for the development of the product quality. To control the quality development, understanding of the moisture content at a certain time of the product is required [9]. The application of acoustic waves in agriculture is an innovation arising nowadays, specifically in the growth of plants. The sound is an oscillation of waves of pressure transmitted through gases, liquids or solids. Plants are frequently exposed to abiotic and biotic environmental stresses. Stress signals are transmitted to cells, where they activate various stress response mechanisms. The mechanisms by which plants recognize external signals and then alter the expression of genes to affect physiological and/or metabolic processes are complex [10].

Acoustic waves are the pattern of disturbance caused by the movement of energy traveling through a medium (such as air, water, or any other liquid or solid matter) as it propagates away from the source of the sound. The source is some object that causes a vibration, such as a ringing telephone or a person's vocal cords. The vibration disturbs the particles in the surrounding medium; those particles disturb those next to them, and so on. The pattern of the disturbance creates outward movement in a wave pattern, like waves of seawater on the ocean. The wave carries the sound energy through the medium, usually in all directions and less intense as it moves farther from the source.

Acoustic waves can be classified into three groups according to their frequency ranges, - Infrasound consists of frequencies below 20 Hz, audible sound consists of frequencies between 20 Hz and 20,000 Hz (20 kilohertz), and ultrasound consists of frequencies over 20 kHz [11]. It is longitudinal waves where particles of the medium are temporarily displaced in a direction parallel to energy traveling and then return to their original position. The vibration in a medium produces alternative waves of relatively dense and sparse particles which are termed as compression and refraction, respectively.

Regulation of tomato fruit ripening may help extend fruit shelf life and prevent losses due to spoilage. In line with this, acoustic waves proved that it can delay the ripening of tomato by exposing it to a 1kHz acoustic waves for 6 hours and then monitored various characteristics of the fruit over 14-days at 23 ±1 C. Seven days after the treatment, 85% of the treated fruit was green, versus fewer than 50% of the non-treated fruit. Most of the tomato fruit had transitioned to the red ripening stage by 14 days after treatment. Moreover, changes in surface color and flesh firmness were delayed in the treated fruit [5].

Some researchers state also that, to extend the shelf life of fresh-cut products without compromising the nutritional quality, many methods have been proposed. Recently, a great deal of interest has been shown in the potential benefits of ultrasound, which has attracted considerable interest in food science and technology due to its promising effects in food processing and preservation [12]. Though lots of works have been done on the application of ultrasound during food processing and preservation, little information is known about the effects of ultrasound treatment on decay incidence and quality of vegetables and fruit after harvest [13].

Ultrasound (ultrasonic) is also one of the newest non-thermal methods to extend the shelf life of fresh fruits during storage. Peach (*Prunus persica [L.] Batsch)* is a perishable product and its storage period may be extended by using different postharvest methods. For this purpose, peaches harvested at the commercial ripening stage were treated with individual and combined effects of putrescine (1 mm) and ultrasonic treatment (32 kHz for 10 min); postharvest storage quality of peach fruit was evaluated during storage at 0-1 °C for 28 days. The result showed that individual and combined effects of putrescine and ultrasonic treatment, when compared to control fruits, could increase peach fruit postharvest life by inducing resistance to different diseases and chilling injury with no noticeable effect on fruit quality attributes such as weight loss, total soluble solids, and total sugar. At the same time, a combined putrescine and ultrasound treatment was found to be more effective than other treatments in decreasing respiration rate and maintaining firmness and acidity. Peach storability could be extended with a combined putrescine and ultrasound treatment because it delays the ripening processes [14].

Many studies proved that acoustic waves are an external factor that has a great impact on the biological index of plants and can either promote or suppress growth [15]. On the other hand, only a few studies were made regarding the application of acoustic waves in the storage of the perishable crops. This study aimed to extend the shelf life of fresh harvest of white oyster mushroom *(Pleurotus florida)* without compromising the quality by application of acoustic waves with various exposure time.

II. Materials and Method

Nowadays, one of the increasing phenomena in our agricultural sector is post-harvest losses due to storage. Inadequate storage facilities and technologies will give unsatisfactory quality to the crops and will decrease the crops' shelf-life condition. This study leads to an emphasis on developing technology for increasing the shelf-life condition of the white oyster mushroom.

A. White Oyster Mushroom

Approximately five-hundred (500) grams were used in the study. Samples were free from physical injuries and other external factors that may lead to early deterioration. It was placed in a plastic bag then to the cooler during transport to avoid the rapid decrease in the moisture that may be caused by the change in the environmental temperature.

B. Preparation of the Set-Up

Placing the transducer at the front of the white oyster mushrooms were made so that there was an equal distribution of acoustic waves inside the soundproof chamber. After exposing the white oyster mushroom to 1 kHz 100 dB acoustic waves, it was stored in a refrigerator with a temperature of 10^oC.

C. Sound-proof Chamber

The chamber itself was assembled using ¾" plywood and the soundproofing material called acoustical foam sound-proof insulation was used for this experiment (Figure 1). The acoustical foam sound-proof insulation was set up in the walls of the chamber with a dimension of 30in (length) x 30in (width) x 18in (height). It was installed to ensure that there is no extraneous noise to prevent a transfer of vibrations and sounds from outside during the acoustic wave treatments. A sound level meter was used to measure the sound inside the chamber to determine if it is soundproof. The produced 1 kHz, 100 dB acoustic waves were measured by a sound level meter at a distance from the transducer where the crop was positioned. Acoustic waves at 1 kHz, 100 dB was produced using a tone generator software and sound transducer.

Fig. 1 Soundproof chamber

D. Storage of White Oyster Mushrooms

Treated and non-treated white oyster mushrooms were directly put in the refrigerator where the temperature is at 10^{o}C. The temperature and relative humidity of the storage chamber were monitored daily.

E. Flesh Firmness

The data for flesh firmness of all samples were measured by using Shimadzu Table Top Type Tester EZTest Series available at PhilMech. Flesh firmness was measured based on the known force that being penetrate to the mushroom cap which was set in 4.00mm deep. The readings were expressed in Newton (N). The flesh firmness of the white oyster mushroom during the experiment was measured every two days. Flesh firmness measurement was done at the mushroom cap. Prior to storage, flesh firmness was recorded. The data were used for the comparison during the analysis of the results.

F. Surface Color

The data for surface color of all samples were measured using Chromameter (CR-400/410) Konica Minolta available at PhilMech. Surface color was measured on the basis of L value lightness of color from {zero (black)} to {100 (white)}; a^* value degree of {redness (0 to 60)} or {greenness (0 to -60)} and b^* value degree of {yellowness (0 to 60)} or {blueness (0 to -60)} from stored white oyster mushrooms.

The surface color of the white oyster mushroom during the experiment was measured every two days. Prior to storage, the surface color was recorded. The data were used for the comparison during the analysis of the results.

G. Shelf life

The shelf life of white oyster mushrooms was determined by counting the number of days from freshly harvested until they reached the unmarketable quality condition. It was determined whether acoustic waves will extend the shelf-life quality of the white oyster mushroom. White oyster mushroom considers a rating of 3 as the limit of acceptability for sale as shown in Table 1. Unclean and other discoloration factors on the white oyster mushroom were considered unmarketable. The data for the shelf life of white oyster mushroom was determined when it reached the stage of 4 where its quality is poor and the marketing condition is unsaleable [13].

TABLE I
DESCRIPTION OF NUMERICAL RATINGS FOR WHITE OYSTER MUSHROOM QUALITY [13]

Trait	Description of rating				
	1	2	3	4	5
Color	white	fair white	light brown	brown	dark brown
Surface glossiness	very smooth	smooth	slightly smooth	moderately smooth	uneven surface
Market quality	very good	good	fair but saleable	poor and unsaleable	severe unusable

H. Statistical Analysis and Experimental Design

In this study, the white oyster mushroom was exposed to 1 kHz at 100 dB acoustic waves prior to storage. There will be four treatments, Treatment 1 – zero exposure time, treatment 2–1 hour exposure time, treatment 3 – 2 hours exposure time, and treatment 4 – 3 hours exposure time. Consequently, white oyster mushroom samples were stored in a refrigerator at 10 ^{o}C. During the cold storage, measuring and monitoring of the surface color and flesh firmness were collected every two days until the crop reached unmarketable condition. At the end of the study, the number of exposure hours that would give the best shelf life quality on the white oyster mushroom was determined. Completely Randomized Design (CRD) was used to analyze the data collected. Analysis of Variance (ANOVA) was used to determine the level of significance among treatments. A comparison among means was done using Duncan’s Multiple Range Test (DMRT). A 5% level of significance was used.

III. Results and Discussion

A. *Surface Color*

Table 2 shows the change in color (ΔE) occurred in every treatment in this study. Results showed that zero application of acoustic waves had the highest mean in terms of change in surface color (43.13) compared with samples that were exposed to acoustic waves after 10 days of cold storage. While the least mean in the change in surface color was exhibited by the white oyster mushroom samples exposed in acoustic waves for 2 hours (26.35). The color is the most obvious indicator of the quality of mushrooms because it is the first parameter that consumers encounter. The whiteness is one of the most important quality factors associated with white oyster mushrooms [13].

TABLE II
CHANGE IN SURFACE COLOR OF WHITE OYSTER MUSHROOM AT 10 DAYS, (ΔE)

Treatment	Replicate			Mean
	I	II	III	
T1(0 hour)	43.33	43.84	42.22	43.13[a]
T2(1 hour)	28.24	42.31	45.55	38.70[ab]
T3(2 hours)	29.49	22.67	26.90	26.35[b]
T4(3 hours)	32.91	37.29	38.52	36.24[ab]

Means not sharing the letter in common differ significantly by Duncan's Multiple Range Test at 5% level of significance

Analysis of variance showed that acoustic waves had a significant effect on the change in color (ΔE) of white oyster mushroom.

B. *Color Development*

Color development and chart of white oyster mushroom samples at different levels of exposure time was presented in Figure 2, 3, 4, and 5. It was observed that white oyster mushrooms exposed to acoustic waves for two hours prior to storage took the longest time of storage period at around 14 days to reach the unmarketable color condition. An additional 4 marketable days was achieved as compared to zero hour of exposure time.

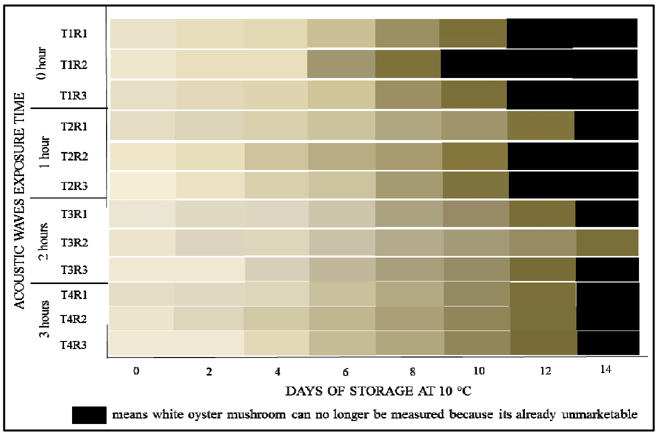

Fig. 2 Color development chart of white oyster mushroom

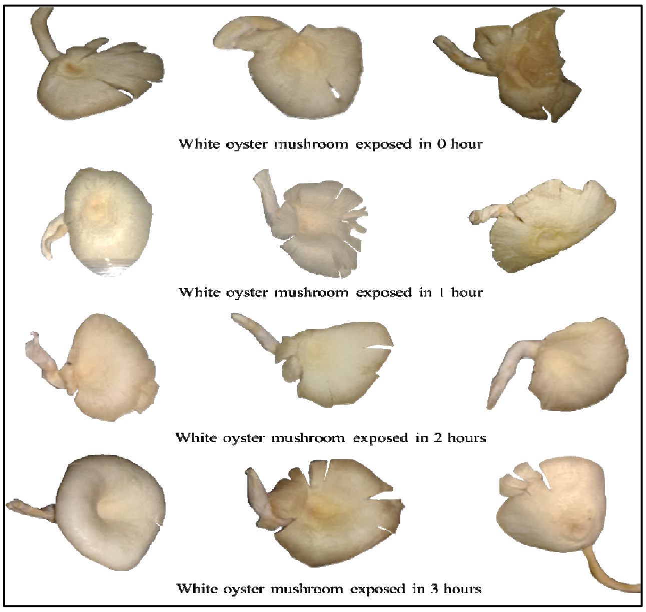

Fig. 2 Comparison of white oyster mushroom at 10 days

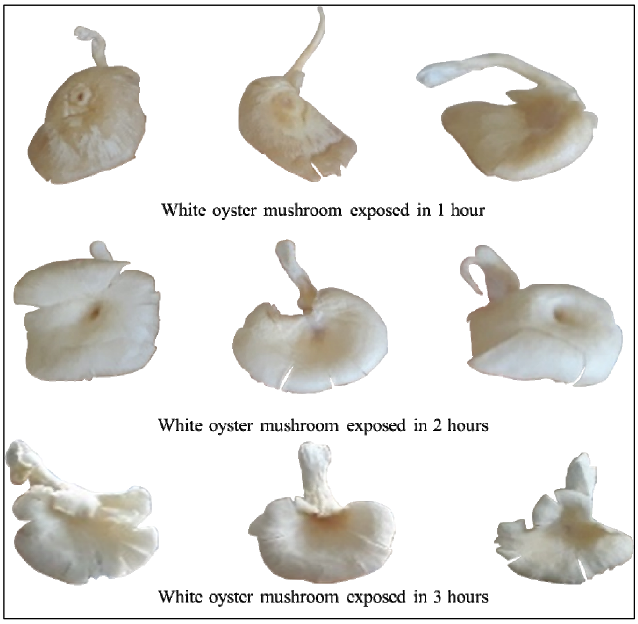

Fig. 3 Comparison of white oyster mushroom at 11 days

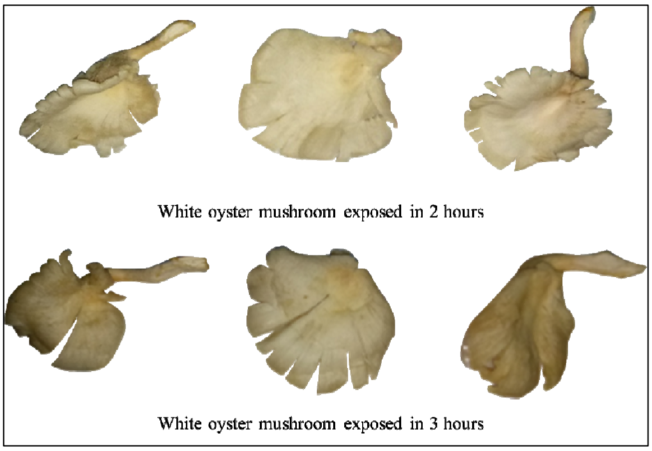

Fig. 4 Comparison of white oyster mushroom at 13 days

C. *Flesh Firmness*

Table 3 shows the change in flesh firmness occurred in every treatment in this study. Negative change values indicate that the white oyster mushroom samples attained higher value with respect to storage days. Subsequently, the higher the value of flesh firmness of white oyster mushroom the looser it becomes.

TABLE III
CHANGE IN FLESH FIRMNESS OF WHITE OYSTER MUSHROOM AT 10 DAYS, ΔF (-)

Treatment	Replicate			Mean
	I	II	III	
T1 (0 hour)	0.14	0.12	0.13	0.13^{b}
T2 (1 hour)	0.07	0.07	0.13	0.09^{a}
T3 (2 hours)	0.09	0.09	0.07	0.08^{a}
T4 (3 hours)	0.09	0.08	0.09	0.09^{a}

Means not sharing letter in common differ significantly by Duncan's Multiple Range Test at 5% level of significance

Results showed that zero application of acoustic waves had the highest mean in terms of change in flesh firmness (0.13) compared with samples that were exposed to acoustic waves after 10 days of cold storage. While the least mean in the change in flesh firmness was exhibited by the white oyster mushroom samples exposed in acoustic waves for 2 hours (0.08). The firmness of fresh produce crops is attributed to the physical anatomy of tissue, cell size, shape, cell wall strength, and intercellular adhesion. Mushrooms are the fruiting bodies of larger hidden structures called mycelia. Mycelia are made up of millions of cells and it would be impossible to count them all [16]. The textural changes in fruits and vegetables can be related to bacteria growth like Pseudomonas or to transformations in cell wall polymers due to enzymatic reactions [17]. This kind of bacterial-induced softening was proved but it was inhibited by acoustic waves application.

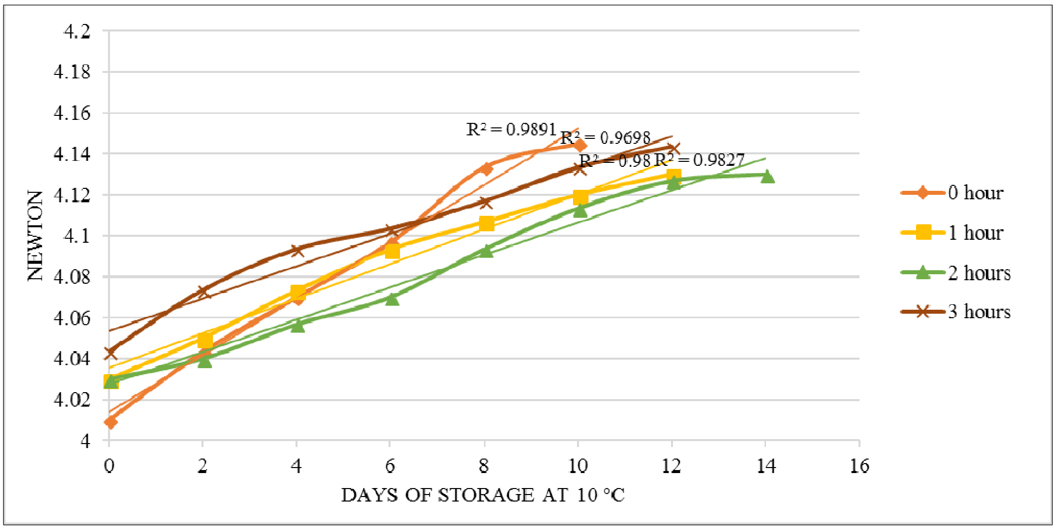

Fig. 5 Flesh firmness of white oyster mushroom with respect to storage days

Analysis of variance showed that acoustic waves had a significant effect on the change in flesh firmness (ΔF) of white oyster mushroom. The stored white oyster mushroom tends to loosen its firmness with respect in prolonging its storage days from 4.01 Newton to 4.15 Newton at zero hour application, 4.03 Newton to 4.13 Newton at 1 hour application, 4.03 Newton to 4.13 Newton at 2 hours application, and 4.04 Newton to 4.14 Newton at 3 hours as shown in Figure 5. But it was observed that zero-hour application exhibits a sudden change in firmness while 1 hour, 2 hours and 3 hours application gradually change its flesh firmness when stored at cold storage (10^{o}C) with an increase in the number of days of storage confirming a gradual reduction in mushroom firmness under refrigerated condition.

D. *Shelf Life*

The shelf life of white oyster mushroom as influenced by acoustic waves as shown in Table 4. White oyster mushroom exposed in acoustic waves for 2 hours had the highest shelf life among treatments with around 13 days followed by 1 hour-treated white oyster mushroom with around 11 days. Non-treated white oyster mushroom samples had the shortest shelf life days among treatments with around 10 days. Recently, a great deal of interest has been shown in the potential benefits of applying acoustic waves. Proven that, it is one of the newest non-thermal methods to extend the shelf life of fresh produce during storage [14].

TABLE IV
SHELF LIFE OF WHITE OYSTER MUSHROOM AS INFLUENCED BY ACOUSTIC WAVES WITH DIFFERENT EXPOSURE TIME, DAYS

Treatment	Replicate			Mean
	I	II	III	
T1 (0 hour)	10	8	10	9.33^{c}
T2 (1 hour)	12	10	10	10.67^{bc}
T3 (2 hours)	12	14	12	12.67^{a}
T4 (3 hours)	12	12	12	12^{ab}

Means not sharing letter in common differ significantly by Duncan's Multiple Range Test at 5% level of significance

Analysis of variance showed that acoustic waves had a significant effect on the shelf life of white oyster mushroom.

E. *Exposure Time*

The exposure of white oyster mushrooms in acoustic waves that gives the best shelf life quality was determined by analyzing the results of every parameter that were measured namely: surface color, flesh firmness, and shelf life. Based on the results, 2 hours of exposure to acoustic waves had the longest shelf life which lasted around 13 days of maintaining its marketable quality. The least number of days observed was around 11 days where white oyster mushroom samples were exposed to 1 hour of acoustic waves.

F. *Shelf Life Quality of Treated and Untreated White Oyster Mushrooms*

Comparison in the shelf-life quality of treated and untreated white oyster mushroom samples was done based on the result of data measurement in surface color, flesh firmness, and shelf life. Normally, the shelf life of white oyster mushrooms lasts 10 – 12 days under refrigerated storage of 10 °C [13]. A shelf life of white oyster mushroom treated with acoustic waves differs significantly compared to the untreated white oyster mushrooms in terms of surface color and flesh firmness. Acoustic waves treatment was able to extend the shelf-life quality of white oyster mushroom samples for a few days compared to zero application of acoustic waves. Therefore, the method of the present invention can be utilized in the freshness preservation and long-term storage of agricultural products after harvest [17].

IV. Conclusion

Based on the findings in this study, it can be concluded that acoustic waves can be an effective post-harvest treatment in prolonging the shelf life and marketable quality of white oyster mushroom compared to the untreated white oyster mushroom samples. Acoustic waves treatment had a positive effect in delaying color changes and flesh firmness of the white oyster mushroom samples. The shelf life and marketable quality of white oyster mushroom could be prolonged up to 14 days by exposing it to 1 kHz, 100 dB acoustic waves at 2 hours prior to storage at 10 °C.Non-treated white oyster mushroom samples exhibited the change in surface color and flesh firmness faster compared to the white oyster mushroom samples treated with acoustic waves. Application of acoustic waves can be a potential supplement to refrigerated storage to further extend the shelf-life quality of white oyster mushroom.

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