Effect of plasma activated water (PAW) in maintaining the quality of cherry tomatoes

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Abstract
Recently consumer demand of fresh fruits has been increased because public are more aware with their health. Fruits are often consumed raw, and that increase the chances of people being infected by pathogenic bacteria. This problem encourages the need to find new methods to maintain the quality and hygiene of fruits. Preservation methods that are often used today have many disadvantages, for example the use of temperature-based method that could possibly damage the texture and nutrient of the fruits. In this study, the use of Plasma Activated Water (PAW) on cherry tomatoes was proven to be able to maintain fruit quality for 2 days longer. This is because PAW has a higher oxidation reduction potential (ORP) compared to ordinary water. The higher the ORP is shown to have a better ability to inactivate the microorganisms attached to the fruit surface.

1. Introduction
Nowadays public awareness of the importance of health is increasing. This causes the public's demand of fresh fruit to increase. As we know fruits provide many health benefits because they contain nutrients that are very important for human body. Fruits are often consumed raw, causing people to have a greater chance of being infected by pathogenic bacteria if they are not cleaned or stored properly. One type of tomato that is popular among the public is the cherry tomato. Cherry tomatoes (Lycopersicon esculentum) are small, round tomatoes with a bright red color. This tomato is a type of tomato that is popular among the public because it has abundant nutrition and delicious taste because it is sweeter than other types of tomatoes [1]. This type of tomato is also easier to serve because it has a small size. Like other types of tomatoes, cherry tomatoes are also very healthy because they have a complete nutritional composition such as vitamin A, vitamin C, potassium, and even lycopene which is a natural antioxidant [2]. Tomatoes are usually consumed uncooked so that the chances of being infected by pathogenic bacteria are higher because pathogenic bacteria can contaminate fruits and vegetables through many media such as irrigation water, animal manure, and fertilizers [3]. Currently, the hygiene of the fruit has received special attention, because there are many cases of food poisoning contaminated by pathogenic
bacteria. In addition, bacteria on the fruit are also one of the factors that cause rot in the fruit. The method of preservation or storage is very important in maintaining the quality of the fruit that will be consumed. Preservation is an action taken to extend the shelf life of food by maintaining the properties that exist in food, both physical and chemical properties [4]. Preservation methods that are generally used is based on low temperature method with the intention it cannot affect the nutritional content, shape and taste of food. One example is storing food at temperatures below 5°C. This method is successful because by storing food at low temperature, it can reduce the number of microbial growths so that spoilage will be inhibited.

At this time many technologies have been developed and many new preservation methods are being developed. One popular method is by using non-thermal plasma technique. Basically, plasma is an ionized gas so that the electrons in the gas separate and cause the gas to have reactive properties. This can occur because the gas is heated causing the atoms in the gas to react with each other, therefore Plasma is also called the "fourth state of matter". By reacting water with plasma, water will contain the active composition of non-thermal plasma. Water containing the active composition of non-thermal plasma is also known as Plasma Activated Water (PAW). PAW has proven to have anti-bacterial properties because it has a high oxidation reduction potential (ORP) so it could possibly be applied as a food preservation method using the inactivation method because it can deactivate microorganisms which causes spoilage of food. Some studies have also shown that non-thermal plasma can maintain the fruit quality of Chinese bayberries [5].

This research was conducted to determine the ability of PAW in maintaining the quality of cherry tomatoes. In this study, the quality of the cherry tomatoes will be measured through indicators of texture and change of its color through observation method. After soaking the cherry tomatoes using PAW, research data will begin to be collected every day for a full week. The ability of PAW to maintain the quality of cherry tomatoes.

2. Literature Review
2.1. Tomato
Tomato (Solanum lycopersicum) is a fruit that contains very complete nutrients for the human body. Tomatoes contain carbohydrates, protein, and fat which are building blocks and a source of energy. Tomato fruit also contains vitamins and minerals that are essential for the health of the human body. These things make tomatoes a very promising agricultural commodity. Tomato fruit is also often found on healthy diet menus. This is because Tomato fruit has an attractive appearance and good taste, besides that tomato fruit is also easy to get because it has good market prospects, Tomato fruit is also very healthy because it has a complete nutritional composition such as vitamin A, vitamin C which are very helpful in curing mouth sores, inflammation of the tongue; phosphorus and potassium which play an important role in the formation of bones and teeth in living things and even lycopene which is a natural antioxidant. Based on the shape, size and color, tomatoes can be divided into 5 types [1]:

a. Tomato Beefsteak
It is a tomato that has a large size and is flat. This tomato has a bright red color and has a thin skin. This tomato weighs about 450 grams.

b. Globe Tomatoes
This tomato is the most popular tomato among the public because it is usually used insalads. These tomatoes are round in shape, and have smooth skin. This tomato weighs about 70-100 grams.

c. Plum Tomatoes
This tomato has an oval shape with the thickest skin when compared to other tomato varieties. These tomatoes also have less water content so they are better able to retain their shape when in a can. This tomato is perfect for making a sauce because it has a denser flesh than other types of tomatoes.
d. Cherry Tomatoes
Cherry tomatoes are small, round tomatoes with a bright red color. This tomato is a type of tomato that is popular among the public because it has abundant nutrition and a delicious taste because cherry tomatoes are sweeter than other types of tomatoes because of their higher sugar content. Unfortunately, cherry tomatoes are highly susceptible to pathogenic fungal infections, not only infected in the growing environment, but also in storage sites [6].

e. Heirloom tomatoes
These tomatoes have a unique shape, color and taste. Unlike other types of tomatoes, these tomatoes come in various shapes and colors including green, yellow, purple and even maroon. Tomatoes are usually consumed uncooked so that the chances of being infected by pathogenic bacteria are higher because pathogenic bacteria can contaminate fruits and vegetables through many media such as irrigation water, animal manure, and fertilizers. Currently, the cleanliness of the fruit has received special attention, because there have been many cases of food poisoning contaminated by pathogenic bacteria. In addition, bacteria on the fruit are also one of the factors that cause rot in the fruit.

2.2. Food Preservation
Preservation is an action taken to extend the shelf life of food by maintaining the properties that exist in food, both physical and chemical properties. Food preservation is applied to overcome problems in improper agricultural planning, so that food ingredients will be easier to find throughout the year because properly stored food has a long durability. In addition, food preservation is also applied to solve public health problems because poor quality food has the potential to cause health problems for consumers. Until now, there have been many ways of preserving food. Based on the techniques used, food preservation can be divided into 3 categories:

1. Inhibition
The concept in this method is to control variables that affect food quality, for example, temperature, microstructural and pH. The most popular method is to store food at temperatures below 5°C. This method is successful because by storing food at low temperature, it can reduce the number of microbial growths so that spoilage process can be inhibited.

2. Inactivation
The concept in this method is to deactivate the variables that cause spoilage in food. The most popular method is to utilize thermal energy. This method is quite popular because this method is a relatively safe method because it is safe from chemical substances. Unfortunately, this method has the disadvantage of changing the taste and texture of food.

3. Indirect Approach
Apart from using a direct approach, preserving food can also be carried out by an indirect approach. This concept aims to prevent preserved food from being contaminated with the variables that cause food spoilage. This concept has an important role in producing good quality food. The application of this concept can be done by packaging techniques, for example, antimicrobials in food packaging.

2.3. Non-thermal Plasma
Basically, plasma is an ionized gas so that the electrons in the gas separate and cause the gas to have reactive properties. This can happen because the gas is heated causing the atoms in the gas to react with each other, therefore, Plasma is also called the "fourth state of matter".

Based on the temperature, the plasma can be divided into 2 types, namely: thermal plasma and non-thermal plasma. Thermal plasma has a temperature that can reach several thousand degrees Kelvin. Thermal plasma can be used for various things such as metallurgy, especially for melting, besides that
thermal plasma is also used to destroy hazardous waste materials [7].

Non-thermal plasma has its advantage in itself because the lower temperature allows non-thermal plasma to be used in several things that cannot be done using thermal plasma because the temperature is very high. For example, non-thermal plasma has also been used in the field of food sterilization [8]. In addition to the non-thermal plasma that generated in open air to treat many surface materials, the non-thermal plasma could also be generated to the water to make the such an activated water. The so-called plasma activated water (PAW) has been shown to have anti-bacterial properties due to it has a high value of oxidation-reduction potential (ORP) [5]. With the properties possessed, PAW can be developed as a method of preserving foods, including tomatoes as the fruit model in the present study. The process of the generation of PAW itself can be carried out either by irradiating the open-air plasma on the surface of the water with a distance of several millimeters or by generating the plasma underwater. In this study, we used the latter one to maximize the absorption of electrical energy transfer to the formation of more radical species in water, thus increasing the ORP values more effectively.

3. Experimental

3.1. PAW Preparation

In the present study, the PAW was prepared by generating plasma discharge underwater. Two stainless steel electrodes, arranged using a point-to-point geometry configuration with a distance of 2 mm were inserted into a beaker containing 200 ml of mineral water. The plasma discharge was performed by delivering electrical energy from a homemade AC high voltage power supply with applied voltage of 660 V p-p and 2.4 A amperages. The plasma exposure under water was carried out at different treatment time (60, 180 and 300 s). It is needed to mention that the temperature of the plasma treated water has reached more than 70°C, so it needs to be cooled first before the water characteristic changes was measured. The PAW physicochemical properties (pH, electrical conductivity, TDS and ORP) were measured after the water was cooled to the ambient temperature using a multiparameter device. The measurements were repeated three time for each sample.

3.2. Cherry Tomato Treatment

The second part of this study was to investigate the effect of PAW to maintain the quality of cherry tomato in regards to the extension of the fruit shelf life. Soon after the PAW temperature has reached the ambient and after measurement of PAW physicochemical properties, the PAW was utilized to treat tomatoes with immersed technique in 2 minutes using the same source of PAW. Then the cherry tomatoes will be stored at room temperature (28°C) for 5 days with 2 storage environments, in an open air and in a plastic zip lock. During 5 days observation, the changes experienced by the cherry tomato are recorded.

4. Results and Discussion

4.1 Physicochemical Properties of PAW

Many previous studies about developing PAW were using gas-phase plasma system to alter the water properties of the water, such as DBD plasma system [9, 10], gliding arc discharge at forward vortex flow reactor [11], plasma jet system [12] and any other types. In this study, we used submerged plasma with consideration that the power of delivered electrical energy will has a little energy loss, and lead to the highly efficient interaction between the plasma and the water, thus, accelerate the formation of more chemical species inside the water. In the present study, it was found that the amperage to sustain plasma underwater was achieved to 2.4 A, that high enough to transfer electrical energy from AC high voltage power supply to heating the water. Therefore, the temperature of the water was reached to 72.8°C from normal condition of 28°C after 1 min plasma activation. The figure of plasma underwater in action and the measured temperature by using thermal imaging camera FLIR TG-165 is depicted in Figure 1 below.
PAW has received significant consideration from researchers due to its non-toxic mode of action and becomes activated water due to the production of many types of reactive species that could react with the bacterial to inhibit its activity. It has been widely known that the inactivation activity by PAW relies on the existence of various reactive species, which are generally formed within the aqueous medium or at the gas-liquid interface. PAW with a longer plasma activation time has a higher antimicrobial efficacy, which can be due to the generation and accumulation of a higher amounts of reactive species in the PAW [13]. The characteristics of control water (without treatment) and the activated water after treated with different plasma treatment time are shown in Table 1 below:

Table 1. Comparison of physicochemical properties of control water and PAW after treated with different plasma treatment time.

| No | Treatment time (s) | pH  | EC (µS/cm) | TDS (ppm) | ORP (mV) | Temperature (°C) |
|----|--------------------|-----|------------|-----------|----------|-----------------|
| 1  | Control (0)        | 7.23| 213        | 123       | 211      | 29.4            |
| 2  | 60                 | 7.07| 230        | 140       | 243      | 73              |
| 3  | 180                | 6.98| 261        | 196       | 262      | 73.7            |
| 4  | 300                | 6.84| 287        | 278       | 276      | 74.9            |

The value of pH states the level of acidity or basicity in a solution by indicating the concentration of hydrogen ions in the solution. Some previous works [14, 15] have found that the reactive species and ions produced during plasma treatment leads to the acidic pH and the value of pH will continue to decrease extensively with increasing plasma treatment time, generally to the PAW preparation with gas-phase system. However, in the present study the trend of pH value of the PAW could be said not significantly decrease until 300 s of plasma discharge underwater. This may be happened due to the difficulty of nitrogen gas inclusion from ambient to the water, makes underwater plasma only slightly produce reactive nitrogen species (RNS), unlike in gas-phase systems where plasma has a free contact with ambient. The plasma that occurs underwater only slightly involves the dissolved nitrogen in the water to produce NO$_3^-$ and NO$_2^-$ ions and the subsequent production of NO$_3^-$ diffused into the water, thus even until 300 s plasma activation only result in small changes of pH value compared to the pH control water.

Electrical conductivity (EC) gives an idea of how many active ions are present in a solution. Based on research measurement, the longer the water is experienced with plasma underwater, the higher the EC in the solution. The water before the experiment had an EC value of 213 µS/cm. Water treated for 60 seconds had an EC of 230 µS/cm, water treated for 180 seconds had an EC of 261 µS/cm, and water treated for 300 seconds had an EC of 387 µS/cm. The formation of ions and reactive oxygen species (ROS) and their accumulation of their higher amounts with the plasma treatment time might be the...
plausible reason of the continuous increase of the EC values. Similar to the EC value, the corresponding total dissolved solid (TDS) value, which is an indicator that tells the weight of the particles in a solution also has an increase with the prolong of the plasma treatment time.

Oxidation Reduction Potential (ORP) is an indicator that shows how likely a solution is to become an oxidizing or deoxidizing agent. Based on the data in the table, it can be seen that the longer the plasma treatment was carried out, it would be followed by the increasing of ORP values of the water. Control water which has an ORP of 211 mV after was changed to ORP values of 243 mV, 262 mV and 276 mV after being treated with plasma for 60, 180 and 300 seconds respectively. ORP is one of the important factors affecting the ability of PAW as a disinfectant because high ORP inactivates the microorganism by damaging the membrane in the cell.

4.2. Effect of PAW on Shelf life of Cherry Tomatoes

Figure 2 shows the physical properties of cherry tomatoes that had immersed 2 minutes in PAW with different time activation as it was observed during the 5 days with two condition of storage environment. In general, tomatoes that treated with PAW has a better result in maintaining the fruit quality, and the tomatoes stored in a zip lock bag shows a better result of storage than the ones in open air condition and the control one. Direct contact with ambient temperature makes tomatoes stored in open air experience shrinking in volume and are susceptible to microorganism attacks to make tomatoes start to be spoiled, while tomatoes stored in zip lock bags are slightly protected from both of the above conditions. On the second day, the control tomatoes were dried and starting to lose some of their volume, while the tomatoes with PAW treatment looked a little less of its freshness but maintaining its color. At the third day, all tomatoes storage in open air have lose their volume, the quality was broken and only the tomatoes treated with 300 min PAW seems to be maintained its color and texture, in which the next day, they tend to be spoiled.

Since the higher amount of reactive oxygen species (ROS) generated in PAW is regarded mainly responsible to increase the value of ORP, and ORP has positive correlation with inactivation capability [15], therefore the PAW which has activated by 300 min plasma with the highest ORP value exhibits the most efficient activated liquid in this study to inhibit microorganisms to spoil the fruits. As a result, the shelf life of the tomatoes could keep maintain their quality in color and texture until three days with the help of zip lock bags.

| Day | Control | PAW 60 sec. | PAW 180 sec. | PAW 300 sec. |
|-----|---------|-------------|-------------|-------------|
|     | Open air | in zip lock | Open air | in zip lock | Open air | in zip lock |
| 1   | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) | ![Image](image4.png) |
| 2   | ![Image](image5.png) | ![Image](image6.png) | ![Image](image7.png) | ![Image](image8.png) |
| 3   | ![Image](image9.png) | ![Image](image10.png) | ![Image](image11.png) | ![Image](image12.png) |
| 4   | ![Image](image13.png) | ![Image](image14.png) | ![Image](image15.png) | ![Image](image16.png) |
| 5   | ![Image](image17.png) | ![Image](image18.png) | ![Image](image19.png) | ![Image](image20.png) |

**Figure 2.** Observation results on fresh cut cherry tomatoes after immersed 2 min in PAW with different plasma activation time.
5. Conclusion
The present study was conducted to assess the ability of PAW in maintaining the quality of cherry tomatoes. PAW itself was prepared by carried out plasma underwater in beaker containing 200 ml of mineral water using the AC high voltage power supply. A pair of stainless steel is used as an electrode and connected to the high voltage power supply for 60, 180, and 300 seconds of treatment. Based on research data, PAW is proven to have the ability to maintain the quality of the cherry tomato both in color and texture. The use of PAW on cherry tomato stored in an open space has a 1 day longer life span when compared to cherry tomato that are not applied with PAW. The longer the treatment time duration in making PAW will also have a better affect in maintaining the quality of the cherry tomato. This is because the longer the PAW treatment time, the ORP will increase. The highest measured of the ORP value (PAW that activated by 300 s plasma underwater) was proven to the most efficient liquid to maintain fruit quality by inactivating the microorganisms and capable to extend the shelf life of cherry tomatoes to the next two days.

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