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A REVIEW: THE EFFECTIVENESS OF EDIBLE COATING INCORPORATED WITH RED MACROALGAE (*Kappaphycus alvarezii*) EXTRACT ON THE POST HARVEST QUALITY OF FRUITS

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Abstract: Fruits and vegetables are the main fresh produce that receive high demand among consumers because of the nutritional properties to boost the human health. However, not all fruits and vegetables are durable due to the ongoing release of ethylene even when harvested. Damaged produce will not be accepted by the customer and will cause post-harvest losses. It was estimated that about 30% of fruits and vegetables are damaged or affected by microorganisms, insects, pre- and post-harvest conditions during transportation and improper storage conditions. Edible coating is an effective approach for fruit preservation. It provides good barrier properties towards carbon dioxide, oxygen, and moisture vapor and at the same time beneficial for the environment and human health. The aim of this review is to investigate the potential of red macroalgae (*Kappaphycus alvarezii*) as an edible fruit coating. This edible red macroalgae abundant in Sabah is widespread around the world due to their carrageenan properties. Carrageenan is normally used as the main edible coating material due to its thickening stability and natural antioxidant. The carrageenan film from these algae is able to replace synthetic packaging and is more environmentally friendly. The abundant source of this algae in Sabah will ensure sustainability and cost effectiveness besides increasing the socio-economy of the local community. Red macroalgae has potential to be used as a bio preservative in fresh produce as it shows better quality characteristics in physicochemical properties of fruits such as weight loss, colour and firmness.

Keywords: Edible coating, red macroalgae, post-harvest quality, fruits.

Introduction

Fruits and vegetables contain a lot of beneficial nutrients for human health as they contain 80% to 90% water content by weight. Some of the fruits and vegetables are very sensitive after being harvested and must be consumed or processed in a very short time to avoid the loss of nutritional content in the fresh produce. Major losses in quality and quantity of fresh fruits occur between harvest and minimally processed to be consumed by the consumers. Fruits and vegetables still remain physiologically active and continue their metabolic process which can easily be exposed by improper handling, inadequate storage temperature and transportation (Li *et al.,* 2017). After the fruit is harvested, the metabolism process will occur with the change of gaseous balance between the usage of oxygen and the production of carbon dioxide in the fruit. The loss of reserved substrates in the fresh fruits and vegetables will fasten the process of natural senescence as the source of energy to prolong the shelf life of the fresh produce is decreased (Mahajan *et al.,* 2014). This senescence phase will reduce the quality of the fresh produce in terms of nutritional content, flavor attributes, physical damage, unattractive color that will be rejected by consumers and cause post-harvest losses (Chakraborty *et al.,* 2018). Thus, edible coating is highly needed as it has a function as a protective natural barrier that uses natural ingredients which can be eaten together with the fruits as well as minimizing the physiological disorder (Galgano, 2015; Raghav *et al.,* 2016; Hassan *et al.,* 2018). Edible coating such as red macroalgae (*Kappaphycus alverazii*) is one of methods which can be used as a coating to the fruits to extend the shelf life to meet the postharvest quality required by consumers. Edible coating is an alternative method to extend the post-harvest life of fresh produce and minimally processed fruits and vegetables (Ochoa-Reyes *et al.,* 2019). Generally, the properties of edible coatings consist of hydrophobic group, such as hydrocolloids or hydrophilic group, lipid-based or waxes, protein-based or combination of both groups to improve function of edible coating (Pascall & Lin, 2013). Red macroalgae is one of the sources rich in carrageenan properties such as sulphated polysaccharide extracted from the cell wall of different red macroalgae from the family of Rhodophyceae (Karbowiak *et al.,* 2007). Moreover**,** it is a good source of compounds with potential application in food industry because it is known for their high polysaccharide, protein, mineral and vitamin contents, low lipid content and for the presence of antioxidants as one of bioactive compounds (Haddar *et al.,* 2012). This treatment can maintain or slower the deterioration process of colour oxidation, maturity stage and firmness as it acts as barrier that is able to decrease moisture, weight loss and prevent microorganism penetration (Hamzah *et al.,* 2013; Augusto *et al.,* 2016; de Oliviera *et al.,* 2018; Ramani & Aswini, 2020). The purpose of this study is to review the efficiency of red macroalgae extract as edible coating as protective layer on the post-harvest quality of fruits.

Red Macroalgae (*Kappaphycus alvarezii*)

Red macroalgae, *Kappaphycuss alvarezii* is one of the marine algae that is important and highly demanded for its cell wall polysaccharide and carrageenan, thus making it the most important carrageenophyte in the world (Bindu & Levine, 2011). Red macroalgae is from Primoplantae clade and is included in a group of non-vascular plants consisting of 6100 species of wide variety of size and shape (Cian *et al.,* 2015). It has many abnormal morphology and mode of reproduction (Usov, 1992). Red macroalgae is wild aquatic plant that is abundant on the coast especially in coral reefs and protected beaches (Figure 1). Seaweed is one type of algae and can be recognized by different pigment colours such as red, green and brown (Gupta & Abu-Ghannam, 2011). Seaweed comes from the large plant size called macroalgae which is classified into three major groups based on pigmentation: red seaweeds (*Rhodophyceae*), green seaweeds (*Chlorophyceae*) and brown seaweeds (*Phaephyceae*) (Samarakoon & Jeon, 2012). Moreover, various products have been produced, both food and non-food (Ghadiryanfar *et al.,* 2016).

Figure 1: The red macroalgae variety of *K. alvarezii*

Red macroalgae are one of the largest groups of algae for consumption worldwide, containing a good source of Ƙ-carrageenan which is a major component of dietary fibre (Jumaidin *et al.,* 2017). Carrageenan also plays a big role for gelling, stabilizing properties and thickening agents for pharmaceutical industries and food (Lahaye & Kaeffer, 1997; Mustapha *et al.,* 2011; Ramani & Aswini, 2020). Hence, red macroalgae play a large role of functional properties such as thermal stability, gelling ability and potential against health risk because they consist of bountiful polysaccharides as a biodegrade polymer (Thakur *et al.,* 2017). Red macroalgae are sustainable natural resources that have higher industrial potential and not fully utilized. The largest production of seaweed is in Sabah, Malaysia with the total production of 15,000 MT in 2010 and it is expected to increase over times (Tan *et al.*, 2011), (Mustapha *et al.,* 2011; Ramani & Aswini, 2020).

Processing of Red Macroalgae

Red macroalgae are ready to be harvested within two months. There are some areas in certain villages in Semporna that have shorter cultivation period, between one to 1.5 months. Red macroalgae need to be dried to increase the shelf life before further use. There are two types of drying methods *viz.* drying on the platform and hanging method. Basically, the drying process usually takes time from three to five days and up to seven days depending on the weather condition (Sade & Ariff, 2006).

The optimum moisture content in dried red macroalgae ranges from 25% to 30% (Goh & Lee, 2010). Due to the slow drying rate of hanging method, this method is less popular to be used among the local farmers. Transparent plastic is usually used to cover the seaweed throughout the drying process (Sade & Ariff, 2006).

Properties of Red Macroalgae

In general, red macroalgae are photosynthetic containing chlorophyll a and d, inadequacy of flagella, and consist of carotenoids and phycobiliproteins (allophycocyanin, phycoerythrin and phycocyanin) as accessory pigments (Denis *et al.,* 2009). Basically, Rhodophyta which has presence of accessory pigments can grow up at 200 m deep with the ability to survive at the great depth (Lee, 2008). Moreover, red macroalgae (i.e. Rhodopyta) have attracted food and pharmaceutical industry for the search of new natural nutrients and bioactive compounds (Ficko-Blean *et al.,* 2017). On the other hand, among seaweeds, the red algae contain high amount of carbohydrate and minerals (Masarin *et al.,* 2016). Moreover, specific functional properties have been attributed to rhodophyta proteins or peptides and polysaccharides because of their unique composition (Urbano & Goni, 2002). These polysaccharides have chemical structures and physicochemical properties that differ substantially from those of land plants (Soares *et al.,* 2016). Furthermore, red seaweeds have a unique polysaccharide composition and as there is no starch in chloroplasts, using floridean starch from cytoplasm as the food reserve (Yu *et al.,* 2002).

Red macroalgae have been recognized as one of the marine microorganisms and *K. alvarezii* is the macroalgae that composed of Ƙ-carrageenan. Due to the excellent properties of the carrageenan in red macroalgae (Table 1), it is suitable to be used in pharmaceuticals, food production and different application (Cian *et al.,* 2015). The most common polysaccharide that can be split out from the red macroalgae are agar, carrageenan and alginate that had been utilized as coating materials (Gade *et al.,* 2013). The carbohydrate polymers that can be extracted from the red macroalgae are alginates with the mannuronic-acid and guluronic-acid that are composed of polymers from the red macroalgae (Jard *et al.,* 2013). Secondly, agar that contain the D-galactose and anhydro-L-galactose containing polymers that can be isolated from the red macroalgae (Yun *et al.,* 2015). Thirdly, carrageenan that comes together with the pectin is the main natural gelling polysaccharide that can be extracted from the red macroalgae not including starch which receive a high demand between consumers as high-value food ingredient (Larotonda, 2007).

Table 1: Characteristics of carrageenan (Source: Tobacman, 2001)

Source	**Mostly from the Red Macroalgae of Euchema sp. and Kappaphycus alvarezii**
Chemical composition	α-D-1,3 and β-D-1,4 galactose residues that are sulfated up to 40% of the total weight found in the hydrocolloid, low positive charge over normal pH range, related with magnesium, potassium, calcium and sodium salts.
Solubility	ƙ is soluble in a hot solution and the treatment of aqueous solution with the potassium ion precipitates ƙ-carrageenan.
The formation of gel	ƙ-carrageenan gel can be formed by the reaction of potassium chloride.
Viscosity	Viscosity that ranges from 5 to 800 cps for 1.5% solution at 75°C and the food grade of carrageenan based on viscosity are not less than 5cps at 75°C for a 1.5% solution.
Properties	Milk proteins help to combine ƛ and ƙ carrageenan easily to enhance the texture and solubility. The main role is as thickening agent, stabilizer and emulsifier.
Synergic effects	Hydrocolloids may affect the gel strength and cohesiveness.
Concentration in food products	0.005 to 2.0% by weight.
Major uses	Pharmaceuticals, cosmetics, skin preparations and processed meats.

The Potential of Red Macroalgae (*Kappaphycus alvarezii*) Properties as Anti-microbial

Red macroalgae has carrageenan properties that function as antimicrobial agents (Ramani & Aswini, 2020). Antimicrobial food packaging and based film is one of the alternatives for the concepts of active packaging (Quattara *et al.,* 2000). The ideal of the biodegradable packaging and synthetic packaging consists of the film material which can prevent the spoilage of various microbial agents (Sung *et al.,* 2013). The innovation of technology especially in edible coating has a great impact towards the post-harvest quality of fresh produce (Dhall, 2013).

Ƙ-carrageenan based film has been approved as one of the anti-microbial agents that contains ovotransferrin which can prolong the shelf life of the fresh chicken breast (Seol *et al.,* 2009). The storage of fresh chicken breast can be prolonged at 5°C with slight antimicrobial activity especially *Escherichia coli* during seven days of storage. Besides, red macroalgae can inhibit *Bacillus subtilis, Staphylococcus aureus, Lactobacillus acidophilius, E. coli, Pseudomonas aeruginosa,* and *Proteus mirabilis* when treated as edible coating on the tomato with highest inhibition zone at 100 00 µg/mL concentration (Ramani & Aswini, 2020). This is because the application of carrageenan is beneficial towards fruit and meat due to the hydrocolloid property as functional food ingredient in edible coating formulation to improve the gelling effect, as micriobial inhibitor and prolong the shelf life (Masarin *et al*., 2016; Mohamed *et al*., 2020). Moreover, red macroalgae have ovotransferrin that can inhibit the microbial growth because it can isolate iron needed by microbes to survive (Pereira, 2017).

Red Macroalgae Extraction

Yield and gel strength of extracted carrageenan from macroalgae need to be analysed to determine the quality of carrageenan. The gel strength is important for stabilizing thickening agent in food products, cosmetics and pharmaceutical (Augusto *et al.,* 2016). There are many ways to collect carrageenan extraction from the red macroalgae. The collected red macroalgae need to be sun-dried on the side for three days before being processed in the laboratory. Then, the dried algae were washed and penetrated to remove the visible foreign materials such as stones and sand. Salt content that will affect the final gelling property in the red macroalgae must be reduced by further washing with running deionized water for five minutes. Then, the excess moisture of pretreated red macroalgae was removed by drying in the oven at 60°C until constant weight was achieved. The dried pretreated algae were kept clean prior to analysis.

Application of Red Macroalgae as Edible Coating

Red macroalgae containing carrageenan with pectin is the main natural gelling polysaccharide (Rudolph, 1986). Carrageenan is a generic name that can be found from a family of water soluble, natural and sulphated galactans (Rudolph, 1986; Ren, 1997). Moreover, carrageenan can act as one important factor for food and pharmaceutical industries such as thickening, gelling and stabilizing agents (Tavassoli-Kafrani *et al.,* 2016). All carrageenan properties are easily dissolved in water and hardly dissolved in organic solvents, fats and oils (Campo *et al.,* 2009). The main cations obtained in carrageenan are potassium, calcium, magnesium, sodium and other ions but at lower frequency (Ortiz-Tafoya *et al.,* 2018). The gels formed from carrageenan have the viscosity solutions that can be determined from the equilibrium of cations in the water solution and the proportion of sulphate fractions (Siah & Ishak, 2015).

Moreover, polysaccharide is a good barrier against gaseous such as oxygen, ethylene and carbon dioxide that can be found in one of the carrageenan properties split from the red macroalgae (Lacroix & Tien, 2005). Furthermore, carrageenan application as a natural edible coating on papaya was able to lower oxygen permeability and able to reduce moisture loss from the thickening of carrageenan coating that soon will be dehydrated as a sacrificing agent (Hamzah *et al.,* 2013). This can be proven by using carrageenan as an alternative coating on papaya which shows a positive effect from a combination of 0.78% (w/v) carrageenan with 0.85% (w/v) glycerol for a carrageenan-based coating. This treatment was effective as a physical barrier and reduced the weight loss and lowered the decay rate during post-harvest storage. Furthermore, red macroalgae are also used as edible film through casting technique. The ideal of innovated based film must be sealable, transparent and has good mechanical strength to withstand the pressure during handling throughout the post-harvest operation (Siah *et al.,* 2015). Seaweed edible film had oxygen permeability rate of 18.54 $cm^3 \mu m/m^2$ day that shows excellent barrier properties than wheat gluten films. In another case study, the potential application of using seaweed extracts as post-harvest treatment, minimally processed in Fuji apples, has shown a positive result that this extraction is able to retard the enzyme activities and reduce browning index when compared with citric acid dipping treatment (Augusto *et al.,* 2016).

Effect of Red Macroalgae as Edible Coating on the Physico-chemical Properties of Fruit

Weight Loss

Fruits and vegetables deteriorate easily as their metabolic process continues after harvest. The process will increase the weight loss due to loss of carbon reserves and transpiration (Mbele, 2017). Red macroalgae have potential as a good oxygen barrier that helps to prevent the weight loss of fruits (banana) contributed by the properties of polysaccharide (de Oliviera *et al.,* 2018). Red macroalgae could retain the water in banana up to 95% at 25°C ± 2°C for 10 days (de Oliviera *et al.,* 2018). Relative humidity also influences the oxygen barrier that will increase the oxygen permeability due to the swelling of hydrophilic films (Laufer *et al.,* 2013). Other than that, comparing edible coating from two different species of macroalgae, *K. alvarezii* and *Sargassum tenerrimum,* shows that *K. alvarezii* was more effective in maintaining the weight loss of tomato by 6.33% than when treated with *Sargassum tenerrimum* by 16.16% and the control 19.64% after 28 days of storage at ambient temperature (Ramini and Aswini, 2020). *K. alvarezii* as edible coating is effective as a good barrier to the carbon dioxide and oxygen and helps to lower the moisture loss (Augusto *et al.,* 2016).

Colour

The quality of the colour is the one that will affect consumers acceptance (Yousuf *et al.,* 2018). The green colour is due to the presence of chlorophyll, which is magnesium-organic complex and this colour is easily lost due to the degradation of the chlorophyll structure (Nauyoma, 2015). The loss of green colour is one of the valuable guides to maturity. A study was conducted using *Eksotika* papaya that was coated with carrageenan and stored in 26°C ± 2°C for five days at ambient condition. Both of the linear terms of carrageenan as edible coating on the surface of papaya show that significant difference ($p < 0.1$) especially on the changes of the color components with the addition of glycerol give more positive effect on the appearance of the fruit. The values of L*, a* and b* are 31.5667, -68.7 and -44.2333 respectively. Generally, the *Eksotika* papaya is able to maintain closer to the ground colour which is green, the increase of a value indicates the peel colour tends to the read and the increase of b value tends to be the yellow color.

The application of red macroalgae extracts treatment for minimally processed of Fuji apples shows a good positive effect by an increase of a*, b* and decrease of L* value with the hue angle (Augusto *et al.,* 2016). The enzymatic activity increases which leads to the tissues softening that promotes the enzyme substrate and causes the changes of browning for control. The minimally processed Fuji apples treated with red macroalgae extracts have an ideal protective effect that had lower significant changes ($p < 0.05$) than the control.

Firmness

Postharvest quality of fruit can be observed through the changes in firmness caused by the ripening process (Galgano, 2015). Soft texture on the fruits is a sign of the reduction of firmness that occurred due to the breakdown of the polymeric substances. It usually happened during ripening process which affects the strength of the cell wall (Falguera *et al.,* 2011). Basically, the loss of fruit firmness might be due to the low protection against transmission of water vapor that causes less cell tugor (Oms-Oliu *et al.,* 2008). The application of carrageenan from the red macroalgae extraction as an edible coating on the fruits can reduce the oxygen permeability and reduce the respiration rate (Hamzah *et al.,* 2013; Augusto *et al.,* 2016).

Carrageenan was found to extend the shelf life of *Eksotika* papaya at ambient conditions (Hamzah *et al.,* 2013). Next, seaweed extracts also play a big role on the post-harvest treatment for minimally processed Fuji apples (Augusto *et al.,* 2016). The minimally processed was applied with seaweed extraction of 0.5% and the effect on the post-harvest quality was observed for 20 days of storage at 4°C ± 2°C condition. The firmness results show that the changes associated with the change of temperature ($p < 0.05$) between the control and seaweed extracts of *bifurcaria.*

The application of carrageenan has the potential as an alternative coating as it reduces the fruit water loss (Pavlath & Orths, 2009). The increase of carrageenan concentration may create a thick protective coating layer around the external fruit surface that prevents the moisture content and subsequently protect the fruit (Vargas *et al.,* 2008).

Conclusion

Due to the high carrageenan content, red macroalgae have the potential to be used as edible coating to prolong the shelf life of fruit and vegetables. Application of this extract will be cost-effective source of natural antioxidants and can be used as an alternative method to synthetic coating of fruit. The application of this extract can also extend the ripening, reserve the nutritional content and good barrier properties against bacterial infection.

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