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MINI REVIEW

A review: nutrition quality and processing of Malaysian strawberries

[1,*]Rosnah, S., [2]Hamzah, H.Z., [3]Shuso, K., [4]Yasunaga, E. and [5]Mahat, F.

[1]*Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[2]*Department of Economics, Faculty of Economics and Management, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[3]*Laboratory of Agricultural and Food Process Engineering, Graduate School of Agricultural Science, Hokkaido University, Kita 8, Nishi 5, Kita-ku, Sapporo, Hokkaido, 060-0808 Japan.*

[4]*Graduate School of Agricultural and Life Sciences, The University of Tokyo 1-Chome-1-1 Yayoi, Bunkyo City, Tokyo 113-0032, Japan*

[5]*Department of Management, Faculty of Economics and Management, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

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Abstract

Malaysian strawberries planted in the Cameron Highlands region are mostly done by small-scale farmers and often face post-harvest losses due to the highly perishable nature of strawberries and lack of information on available processing technologies. This review intended to give an overview of the nutritional quality of strawberries, post-harvest factors that contribute to quality decrement and processing practices done to reduce losses as well as increase the shelf-life of strawberries. Literature comparison between Malaysia and other countries was done on available prior studies and written reports. The review revealed that strawberries are rich in anthocyanin (which contributes to its red colour and flavour) and vitamin C, high in moisture content (up to 92% at ripening stage), have an acidic pH (ranging from 3.39 to 3.8 upon ripening) and sweet in taste (glucose, fructose and sucrose are the major soluble sugars available in strawberries). Several factors contributed to strawberry fruits losses and deterioration including the effect of improper handling, storage condition and pathogen bacteria attack. Drying and pasteurisation processes are the most common practices done in strawberry processing due to the effectiveness of the treatments in extending their shelf-life.

1. Introduction

Strawberries or scientifically known as *Fragaria × ananassa* are popular among consumers due to their unique taste, vibrant colour and appealing visual. Strawberries are non-climacteric fruits (Bhat and Stamminger, 2014) belonging to the "Rosaceae" family which have over six hundred varieties planted (Zeb *et al*., 2015). Strawberries can be planted either in seasonal or tropical climate areas. However, differences in climate do affect the overall quality and taste of strawberries. Cultivation and growing conditions, genotype and cultivars contribute to the diversity of the nutritional composition of strawberries which then relatively affects its flavour (Aaby *et al*., 2012).

Strawberries in Malaysia are planted in the highland regions with Cameron Highlands, one of the famous strawberries planting areas. Cameron Highlands is well known as an agro-tourism area in Malaysia, in which 90.18% of its land is forested area and 8.32% are agriculture land (include plantation of vegetables, tea and strawberries) (Leh *et al.,* 2017). The environmental temperature of Cameron Highlands which is less than 25°C provides an optimum condition for strawberries cultivation (Eisakhani and Malakahmad, 2009). Strawberries are known as an iconic crop of Cameron Highlands and chosen as a product in the "one district, one industry" campaign by the Malaysian government. Camarosa and Camaroga *cvs*. cultivar are among the popular varieties planted in Cameron Highlands (Isma *et al*., 2012) alongside the Festival, Camariosa, Montere, Sweet sensation, Winter star and Albion varieties in which most of these hybrids were bought from California, the United States of America. The production

*Corresponding author.
Email: *rosnahs@upm.edu.my*

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of strawberries in Malaysia is rather low due to the country's tropical climate with humidity in the planting area of approximately more than 90%. Rainy weather also contributes to low pollen germination as the bees' pollination activities are limited (Isma *et al*., 2012). Strawberries in Malaysia are best enjoyed fresh during the period between May till August as the weather condition at that period is ideal for the growth of strawberries with less rainfall (Ramachandran *et al.,* 2015).

Cultivation of strawberries in Cameron Highlands, Malaysia mostly uses hydroponic methods planted in greenhouses to ease the control of an ideal environment condition for strawberries growth. Temperature and humidity of the greenhouse are often maintained at 20°C and 70% humidity (Ramachandran *et al.,* 2015). Fresh strawberries have a short life; thus, the unsold ones are often utilised into other products such as jams, pickles, biscuits and confectioneries. The utilisation of strawberry into strawberry-based products in Malaysia is still minimal as it is done by small and medium scale manufacturers and processors. Thus, the factors contributing to the losses of post-harvest strawberries, the post-harvest practices to overcome the losses and processing of strawberries into valuable products are intended to be discussed in this present review.

2. Physical, chemical and nutritional characteristics

Strawberries are characterised as herbaceous plants with fibrous roots and basal leaves that arise from the crown (Kuchi and Sharavani, 2019). Figure 1 shows the cross-section of a strawberry fruit which consists of the flesh (pulp) with a lighter colour at the core centre, either light pink or white in colour, and the outer part of the fruit is covered with achenes (or seeds).

Figure 1. Cross section of strawberry fruit (*Fragaria* × *ananassa).* Adapted from Muthukumaran *et al.* (2017)

The chemical composition of strawberries changes during the ripening process. The total soluble solids (TSS) and pH of strawberries increase from 6.6% to 9.0% and from pH 3.39 to pH 3.80 respectively, but the moisture content (ranging from 91.9±0.4% to 92.5±0.8%) remains insignificantly different during the ripening stages 1 to 6 (Ornelas-Pas *et al.,* 2013). Glucose, fructose and sucrose are the major soluble sugars in strawberries in which glucose (1.4 to 3.1% fresh weight) and fructose (1.7 to 3.5% fresh weight) increase during the development of the fruit whereas sucrose increases during the maturity process (Kuchi and Sharavani, 2019). Citrate is the main organic acid in strawberries which relatively affects the overall flavour and taste of the strawberries. Asparagine, glutamine and alanine also contribute to the sensory sensation of strawberries. Anthocyanins with an approximate content of 0.5 to 1.5 mg/g fruit weight are the major component in strawberries which contributes to their colour and taste, whereas ascorbic acid (0.3 to 1.2 mg/g fruit weight) is the main amino acids with nutritional benefits. Ascorbic acid or the vitamin C content in strawberries is higher than oranges with added vitamin K, vitamin B5, vitamin B6, manganese, magnesium, copper, potassium and omega 3 fatty acid (Hakkinen and Torronen, 2000). Strawberries are believed to have an anti-cancer effect due to the high nutritional contents of folates, minerals, vitamins and phenolic constituents (Giampieri *et al.,* 2013).

3. Postharvest factors affecting strawberry fruits quality

Fruits will undergo a postharvest system after harvesting before they reach the end consumer and prevent losses. From 2011 to 2013, the postharvest losses of fruits in Malaysia have increased each year from 1,622,603 to 1,658,332 to 1,765,828 metric tonnes in which attitudes and infrastructure are the two main causes identified (Tengku Mohamed, 2017). According to Osman (2011), there are several factors that contribute to the quality of fruits during the postharvest process which include temperature, chilling injuries (CI), green ripening, loss of texture, browning of peel and pulp, relative humidity, loss of weight, shrinkage of fruit peel, peeling difficulty disorder (PDD), gases composition of storage atmosphere, mechanical damage and pathogen (Osman, 2011).

Strawberries are highly perishable fruits in which improper handling during postharvest may affect their overall quality. Hailu (2005) stated that the production of fresh products is complex due to their perish-ability and mass quantity, highlighting a need to be managed with care during the postharvest period. The ideal harvesting period of strawberries is 3 to 4 months after planting in which bruising of the fruit could Literature happen as ripening strawberries are soft in nature (Kuchi and Sharavani, 2019). The bruises may be due to the mechanical impact during picking, storage and transportation.

Temperature, gas composition of storage atmosphere and relative humidity are among the main contributing factors in retaining strawberry fruit quality, especially during storage. Fresh strawberries are recommended to be cooled to a temperature near 0°C within 1 hour after harvesting to preserve their freshness. Storage condition plays an important role to maintain strawberries' quality after harvesting. Modified atmosphere (MA) storage condition is able to retain the freshness of strawberries during post-harvest. Alterations of carbon dioxide (CO_2) and oxygen (O_2) level during storage of 10% CO_2 and 11% O_2 efficiently reduce the decay rate of fresh strawberries and maintain their quality (Almenar *et al*, 2006; Riad and Breacht, 2005).

Pathogen is another factor that affects the quality of strawberries, either fresh or processed into products. Pathogens are relatively affected by environmental and storage conditions. Post-harvest losses of strawberries often happened due to bacterial infection from the effect of environmental and storage conditions (Salami *et al*., 2010). Strawberries are strongly affected by diseases and pests, especially with unfavourable weather conditions throughout the vegetation season and harvest (Sojka *et al*., 2015); thus, strawberries are processed into other valuable products to increase their shelf-life. Figure 2 shows the condition of strawberry fruits after harvesting which have been affected by moulds due to improper handling and storage conditions during postharvest. Strawberries in Malaysia are mainly managed by small-scale farmers and marketed locally. Small-scale farmers often face multiple problems during the pre and postharvest periods due to insects, diseases, weeds and droughts. Cameron Highlands is well known as strawberries plantation area in Malaysia facing the issues mentioned due to its geographical factors which are sensitive towards any ecosystem changes (Rahim *et al*., 2016). Besides, the trend of the strawberry market at Cameron Highlands depends on the visitors where during the holiday periods in Malaysia, the strawberries are high in demand while during the regular working days, farmers experience losses as the strawberries are over-ripening which consequently leads to dumping.

Figure 2. Strawberry infected by *Botrytis cinera* disease. Adapted from Salami *et al*. (2010)

4. Postharvest processing and products

4.1 Sanitisation of postharvest strawberries

Pesticides are often used by farmers to increase productivity and product yields. However, such practices cause later effects of bio-accumulation of pesticides through the food chain (Kin and Huat, 2010); thus, the sanitisation process is needed upon harvesting to get rid of any pesticides residue. Contamination of fresh strawberries may happen due to insects, soil, water or improper handling, either during the pre-harvest or post-harvest stages, thus sanitisation is a crucial first approach for inactive spoilage bacteria to preserve the freshness of products (Nicolau-Lapena *et al*., 2019). A prior study by Kin and Huat (2010) on sanitisation of strawberry fruits collected at the Malaysian Agricultural Research and Development Institute (MARDI), Cameron Highlands with different sanitising solutions of acetic acid, sodium carbonate, sodium chloride and solely tap water showed that acidic solutions of 5 to 10% acetic acid in tap water removed around 44 to 70% pesticide residues in strawberries after soaking for 10 to 30 minutes and dried overnight. Later in 2019, Nicolau-Lapena *et al*. (2019) proved that acidic solution was able to disinfect spoilage microorganism in fresh strawberries, whereas washing with only water will cause cross-contamination and increase the microbial load in fresh strawberries. Fresh strawberries inoculated with *Listeria Innocua* at concentrations of peracetic acid of 20 to 80 ppm in tap water experienced up to 4 log reduction without significant alterations of the physicochemical and antioxidant properties of strawberries (Nicolau-Lapena *et al*., 2019).

4.2 Storage of fresh strawberries

Storage of fresh strawberries is crucial to maintain their freshness and acceptability before they meet the end consumers for direct consumption or for further processing into products. Fresh strawberry fruits need to be stored at lower temperatures to retard microbial growth and to preserve the nutritional contents. Octavia and Choo (2017) studied the effect of storage on the quality of fresh Camarosa strawberries from Cameron Highlands refrigerated at 4ºC which resulted in the degradation of nutritional and bioactive compounds due to the effect of storage time. 88.1%, 55.5% and 93.2% of anthocyanin, ascorbic acid and folate contents were lost after 6 days of storage, thus it was recommended that fresh strawberries be consumed within 2 days for the best quality and nutritional contents.

For a longer storage period of Malaysian strawberries, other factors than temperature need to be take into consideration as mentioned earlier (Section 3); gas composition, atmosphere and relative humidity are crucial in controlling the quality of freshly harvested strawberries. Jadhav and Gurav (2018) found that the Sweet Charlie variety of strawberries (originated from India) stored at a cold storage of 4ºC at 95% relative humidity (RH) had greater quality than strawberries stored at room temperature (RT) with a longer shelf-life of 4 days compared to 2 days of RT storage. Controlled RH showed better preservation effects on the strawberry fruits. Higher weight loss was found in RT (6.18%) stored strawberries than cold storage (3.10%) after 3 days of storage, with lower ascorbic acid content. The firmness of strawberries during RT storage also decreased with a higher total soluble solid content. The increase in total soluble solids during storage may be due to sugar decomposition which later contributed to microbial growth. Similarly, Yang *et al.* (2018) found that the total soluble solid of the Sweet Charlie variety (originated from Hubei province, China) increased as the temperature of storage increased from 15 to 35ºC during 12 days of storage. On the 8th day of storage, there were 11.12±1.0%, 28.38±2.22% and 45.88±2.63/% weight loss at storage temperatures of 15, 25 and 35ºC respectively, with greater degradations of anthocyanins and ascorbic acid content at increasing storage temperatures.

Since Malaysia has a tropical climate with higher RH which contributes to microorganism growth in strawberries, modified atmosphere storage may be implemented to extend the shelf-life of fresh strawberries. The Charlotte variety of strawberries (originated from Geongsang province, Republic of Korea) stored in an acrylic chamber (90 x 60 x 60 cm) at 4ºC for 10 days were injected with 30 kPa CO_2 for 1 and 3 hr; 50 kPa for 1 and 3 hr; 70 kPa for for 1 and 3 hr. Colour properties of lightness (L*) and redness (a*) did not significantly change after injected with CO_2 at all treatment conditions. Injection of higher concentrations of CO_2 from 30 kPa to 70kPa increased the firmness of strawberries compared to the controlled ones with increasing pH value from 3.35 to an average of 3.76 after 10 days of storage. Total anthocyanin content (TAC) decreased after CO_2 treatment for all conditions and increased in value during storage but was lower than the controlled sample which may be due to the delayed accumulation of TAC. Meanwhile, the total phenolic content (TPC) increased during storage of all samples with the highest increment of TPC shown in the controlled untreated sample. Despite lower bioactive values during storage, the microbial load of the modified atmosphere storage and the total aerobic bacteria decreased after CO_2 treatment at all treatment conditions with lower counts at higher concentrations of CO_2, 70 kPa throughout storage of 10 days. Thus, lower storage temperature, with proper gas composition and relative humidity can positively improve the freshness of strawberry fruits intended for fresh consumption.

4.3 Postharvest processing

Preservation is crucial for fresh strawberries, either intended for fresh consumption or further processing as fresh strawberries have a short shelf life and easily spoiled. Freezing is one of the most used physical treatments on strawberries to preserve their nutritional quality for later use and processing. Freezing is regarded as a conventional physical treatment in which the water content of food is reduced below its freezing point and experiences a state of change to form ice crystals (Fellow, 2002). The Festival variety of strawberries packed in a polyethylene bag and freeze at -27ºC using a commercial freezer (Arcelik, 2572D) were able to retain ascorbic acid loss below 50% up to 13 weeks of storage (42% loss) from the initial value of 38 mg/100 g, with minimal decrement of colour properties of L* and a* and unnoticeable colour changes ($\Delta E<1.5$). Nurzahida, Sakinah and Abdullah (2010) studied the effect of freezing as one of the preservation techniques on the ice crystal formation of local strawberries from Cameron Highlands. Based on the study, frozen strawberries were able to preserve their appearance, colour and texture with the moisture content of fresh and dried strawberries at 89.6 and 10.8% respectively after the blast freezing process at -40°C for 120 minutes and at a constant pressure of 0.1 Torr for 72 hours.

Table 1 summarises the recent research done on the preservation of fresh strawberries planted in other regions and countries. Treatments with gamma radiation, pulsed light and edible coating have been used to preserve the strawberries, whereas such practices are still uncommon for fresh strawberries preservation in Malaysia. The Camarosa variety is one of the most planted varieties in Malaysia. Based on Table 1, Camarosa strawberries from Aizawl, India preserved by coating with edible oil before storage and refrigerated at 4ºC showed that the sensory and colour properties were not relatively affected with better retention of ascorbic acid and anthocyanins content throughout 16 days of storage (Hazarika *et al.* 2019). The similar variety from Spain was used in a study by Avalos-Llano *et al.* (2018) on the effect of pulsed light on strawberries quality attributes. Before undergoing treatment with pulsed light, freshly harvested Camarosa strawberries were sanitised by immersing into 200µL/L sodium hypochlorite for 1 min and rinsing with tap water to inhibit fungal occurrence for a longer time. Pulsed light at doses of 4, 8, 12 and 16 J/cm² reduced browning in strawberries due to enzymatic activity. However, redness of strawberries treated at 16 J/cm² showed greater decrement which may

Table 1. Physical treatments on fresh strawberries

Strawberry variety/ origin	Physical treatment and parameter	Quality assessment	References
Camarosa from Aizawl, India	Edible coating: 100 % coconut oil Strawberry fruit firstly dipped into 2% chitosan, 1% acetic acid solution and left for 12 hr for bubble removal before dipped into coating solution, glycerol then added as a plasticiser.	Coconut oil edible coated strawberry lowest in physiological weight loss (17.57%), greater texture (3.85N) after 16 days refrigerated storage 4ºC compared to uncoated (25.27%, 2.58N) with excellent retention of ascorbic acid (65.74 mg/100 mL juice) and anthocyanin content (33.38%). Overall acceptability of appearance, flavour, taste shown coconut oil coating scored the highest likeability.	Hazarika *et al.* (2019)
Camino from Brazil	Gamma radiation: 1.0, 2.0, 3.0 and 4.0 kGy at 8±1ºC with Cobalt 60 source Category II Panoramic Multipurpose Radiator (MDS Nordion, Canada)	No significant change of firmness at all treatment condition. Significant loss ($p<0.05$) in strawberry weight at lower dose, shorter storage time, with no significant colour changes after treatments (at all dosage induce). Ascorbic acid at 3.0 kGy retains higher value (65.71±11.76 mg/100 g fruit) compared to other doses after treatment.	Filho *et al.* (2018)
Camarosa from Spain	Pulsed light: Doses of 4, 8, 12 and 16 J/cm² per side using pulsed UV system Model XeMaticA-2 L (360º sample illumination)(SteriBeam System GmbH, Kehl, Germany)	No sign of browning shown at all treatment condition after 10 days. Redness (a*) decrease at lower dosage during storage but more prominent decrement shown at 16 J/cm². Pulsed light able to retain firmness of strawberries after treatment at all dosage. Higher dosage affects the antioxidant, ascorbic acid and phenolic content during storage at 5ºC for 14 days in darkness but still maintain higher value compared to untreated sample.	Avalos-Llano *et al.* (2018)

be due to the anthocyanin colour pigment degradation. Higher dose induced relatively affected the anthocyanins and ascorbic acid content in fresh strawberries; however, such loss was still lower than the untreated sample. An alternative non-thermal treatment used for strawberries was gamma radiation which also showed promising results of extending the strawberries' shelf-life without severely affecting the nutritional and sensory properties (Filho *et al.* 2018). Pulsed light treatment implies short time pulse at wavelength between 100 to 1100 nm, whereas gamma radiation is an ionising radiation in which both cause DNA damage of microorganisms and relatively kill them as they are unable to replicate.

Utilisation of fresh strawberries into other products is one of the best methods to improve their marketability as well as increase the strawberries' shelf-life. Dried strawberries, jams, juices and beverages are the most popular strawberry-based products in Malaysia. Among the processing techniques, processing using heat is the most commonly used by manufacturers, either in Malaysia or worldwide due to its widely known effectiveness in microbial inactivation and shelf-life extension. However, due to massive degradation of nutritional and antioxidant quality, researchers had shifted their interest towards alternative physical treatments such as pulsed light, sonication and high-pressure processing (HPP). Table 2 summarises, in brief, some of the physical treatments used in the processing of dried strawberries.

Drying is one of the common physical treatments to preserve the quality of food and not limited to only fruits. Drying is done to reduce the water content in food to inhibit the growth of microorganisms for the later purposes of marketing, storage and processing (Misha *et al.*, 2013). Dried strawberry products are a healthier choice of snacking as the basic nutritional content is better preserved compared to processed junk food (Kowalska *et al.*, 2017). Based on Table 2, De Brujin and Börques (2014) found that a combined treatment of osmotic dehydration and vacuum microwave drying was able to remove water efficiently with improved firmness and better colour and nutritional qualities compared to conventional air-drying. Later in 2017, Adak *et al.* (2017) studied the effect of infrared drying on the Camarosa variety from Turkey in which the colour properties and anthocyanin content of dried strawberries were well retained at air velocity of 1 m/s, 200 W at 80ºC. Nazmer *et al.* (2018) then compared the quality of freeze-dried strawberries with strawberries dried with a hot-air dryer. Freeze-dried strawberries resulted in better nutritional retentions of anthocyanins, ascorbic acids, total phenolic and total antioxidant content with less

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Table 2. Processing of dried strawberries

Strawberry variety/ origin	Product	Physical treatment and parameter	Quality assessment	References
San Andreas (Chile)	Dried strawberries	Air drying : 70ºC, 10 hours in Proctor-0.62 tray dyer (Proctor and Schwartz Corp, Philadelphia, USA)	Osmotic dehydration-vacuum microwave drying was able to create the highest water flux out of product with improved mechanical resistance, slight colour loss and acceptable rehydration performance.	De Brujin and Bórquez (2014)
		Vacuum microwave drying : 50 ºC and air velocity 1.0 m/s in the mechanical heating oven (Binder FD 53, Tuttlingen, Germany) and air heating with electrical resistance of 1200W with 3 trays as closed circuit		
		Osmotic dehydration-vacuum microwave drying: 70 mm Hg absolute pressure, 10 min of vacuum pulse for 4 hr followed with mixed into 60% sucrose solution shaken at 140rpm (orbital shaker, Ilshin Lab Co. Ltd, South Korea)		
Camarosa (Turkey)	Dried strawberry	Infrared drying: Power 200–300 W, 60–100 ºC and air velocity 1–1.5 m/s with automatic drying system (Zenittel Automation Technology System, Turkey)	Air velocity 1 m/s at 200W of T 80 ºC yield greater colour properties L*, a*, b*, chroma, hue angle and colour difference (ΔE<1.5) (less noticeable) with the highest content of anthocyanins.	Adak *et al.* (2017)
From Maule (Chile)	Dried strawberry	Freeze dry: -20ºC, 0.5 mHg absolute pressure for 24 hr using Vacudyne Pilot Freeze Dier (Vacudyne Inc., Chicago, Heights, USA)	Better anthocyanin, total phenolic, ascorbic acid and total antioxidant better retain after freeze-dried. Minimal colour changes observed after both treatments.	Nezmer *et al.* (2018)
		Hot-air drying: Pilot air dryer (Wenger Drying Technology, Inc., Sabetha, KS, USA) at parallel airflow 70ºC and 0.76 m/s velocity for 16 hr		

noticeable colour changes (ΔE<1.5). Among the dehydration or drying techniques, freeze-drying is one of the best methods for strawberry processing as it retained most of the quality attributes (Shishehgarha *et al.,* 2002). Kowalska *et al*. (2017) supported that the antioxidant content of freeze-dried strawberries resulted in well-retained vitamin C and polyphenolic content with acceptable sensory attributes of flavour and texture compared to the microwave-oven drying technique. The study by Shishehgarha *et al.* (2002) also agreed that freeze-drying below 50°C retained the appearance of strawberries well, with no significant difference in the colour properties. Thus, the application of the above mentioned technologies can be considered to be applied in Malaysia for processing of premium quality products with excellent nutritional values.

Besides dried strawberries, jams and spread are other popular strawberry-based products in Cameron Highlands. According to Market Insight: Malaysia (2014), strawberry jam is one of the popular flavours of jam in Malaysia alongside pineapple, grape, blackcurrant and mixed fruits jam. Jam-type spread products are mainly produced in small scale by the farmers themselves; however, no published study has described in details the processing of the products done in Cameron Highlands. The general jam processing is fruits mixed with sugar at the same ratio and cooked using thermal treatment (Naem *et al*., 2015) According to Holzwarth *et al*. (2012), strawberry jam is produced by mixing strawberry fruit, sucrose, isoglucose, and water in which the raw ingredients are heated at 90°C until the ºBrix reading is approximately 63°Brix, where the pH of the jam then adjusted to 2.9 by adding citric acid. The processing of strawberry jam involves heat treatment or pasteurisation process to reduce the water activities of strawberry jam which relatively promotes a longer shelf life and retain the anthocyanin colour pigments during storage at 4°C. Naem *et al*. (2015) studied on the nutritional composition of commercialised strawberry jam in Malaysia and found that local strawberry jams provide a decent source of energy and carbohydrate with exceptionally lower fatty acids level. Besides, although the level of vitamin C content in jam is low due to the effect of heat processing, the strawberry jam has a higher vitamin C content than grape and apricot jams.

Juice processing in Malaysia still practises the conventional thermal pasteurisation as it is widely known for its efficiency in microbial inactivation and preventing deterioration of the product. However, no reported study was done in evaluating the quality of strawberry beverages and drinks in Malaysia as the market of such product is limited and manufactured in small and medium scale by the farmers to overcome the surplus of strawberries during off-peak seasons. The beverage industry in Malaysia has shown a significant increase over the past years with 15.8% contribution to the manufacturing industry in Malaysia and is normally operated by small and medium scale manufacturers (Rahim and Raman, 2015). Strawberry fruits are rich in anthocyanin pigments which contribute to the red colour of strawberry juice. Processing temperature above 80°C on strawberry juice relatively degrades the anthocyanin content, but the alteration of the juice pH to pH 2.0 is able to withstand the changes and results in stable colour properties (Wang *et al.,* 2015). The processing of strawberry juice can be done either using fresh or frozen strawberries. Klopotek *et al*. (2005) conducted a study using frozen strawberries (thawed overnight at 10°C) for juice production pasteurised at 85°C for 5 minutes and resulted in 35%, 27% and 6% of vitamin C, total phenolic content and anthocyanins loss respectively after processing. Due to the massive degradation of the nutritional content of fruit juice products after thermal pasteurisation, an alternative non-thermal technology is explored. High intensity pulsed electric field (HIPEF) treatment was used by researchers in Spain to study the effect of HIPEF on strawberry juice quality, in which the treatment was able to retain better aroma-related enzyme activities and better flavour and appearance of colour for 14 days compared to thermally pasteurised strawberry juice (Aguiló-Aguayo *et al*., 2009). Ripe strawberries from Auckland, New Zealand underwent high-pressure processing (HPP) for strawberry puree production and resulted in stable polyphenol oxidase (PPO) enzyme activity, and well retained antioxidant activity with no significant effect of pH and soluble solid of the end products (Sulaiman *et al.,* 2016). Later in 2018, Aaby *et al.* (2019) compared the quality of juice and puree of the Senga Sengana variety of strawberries from Norway processed by conventional heat pasteurisation and HPP. Both HPP (20ºC, 1 to 3 minutes, 400 to 600 MPa) and thermal pasteurisation (85ºC, 2 minutes in boiling water) were able to extend the shelf-life of strawberry juice up to 49 days of storage compared to the untreated sample. Despite the effectiveness in microbial inactivation, both processing techniques caused anthocyanin and ascorbic acid degradation, with browning effects more prominent in the HPP treated juice. Meanwhile, the same parameter of processing was used to treat strawberry puree and resulted in lower colour changes during 35 days storage after HPP and thermal pasteurisation, but HPP treated puree was closer to the fresh puree in sensory attributes. HPP (at 500 and 600 MPa) and thermally treated strawberry puree had a shelf-life of up to 46 days with heat treatment and a well-retained vitamin C of up to 48% of initial content compared to HPP (40 to 4% at 400 to 600 MPa). There is no implementation of non-thermal alternative juice processing in Malaysia in the juice and beverage manufacturing industry due to the lack of expertise and technology development. Besides, strawberry processing is done in small scales, causing dissemination of new technology a little harder as the market for strawberry-based products are limited and mostly focusing in the Cameron Highlands area.

5. Conclusion

Strawberries in Malaysia are regarded as a premium and exotic fruits as the plantation area are done on a medium-scale for local commercialisation in Cameron Highlands in the state of Pahang. The highly perishable characteristic of fresh strawberry fruits requires them to undergo proper handling process from the pre-harvesting, harvesting to postharvest periods until they meet the end consumers. The utilisation of strawberry-based products in Malaysia is done in small and medium scale due to the limitations of stock, technology and expertise.

Conflict of Interest

The authors declare no conflict of interest.

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