POSTHARVEST QUALITY AND SHELF LIFE OF RASPBERRY AND STRAWBERRY AS AFFECTED BY DIFFERENT PACKAGES

Chandima Ekanayake
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University of Helsinki
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Strawberries and raspberries have high demand in Europe and mostly consumed as fresh. Berries are highly perishable and so, their postharvest physiology and shelf life are important. Packaging is needed to keep the berries in good quality during the time in storage. Plastic clamshells are the commonly used type of packages for the berries but there are environmental concerns due to the heavy disposal of plastics. To overcome this problem, a fiber package is going to be introduced. It is biodegradable, biobased, made with renewable raw material and the final product is recyclable. This research focused on the mentioned fiber package and its functionality as a berry package and as possible replacement for plastic (RPET) clamshells. Homogenous batches of raspberries (*Rubus idaeus*) and strawberries (*Fragaria* × *ananassa*) were stored in plastic packages and fiber packages at two different temperatures (+3 °C and +17 °C/+16 °C). Decay incidence, weight loss, surface area of the berry, color, firmness, total soluble solid concentration, acidity, and package staining were measured over the storage period. Results showed that berries stored in fiber packages at +3 °C had higher soluble solid concentrations than the berries stored in plastic packages at the same temperature. Berries stored in fiber packages at both temperatures showed higher weight losses. Fiber packages absorbed more moisture from raspberries and strawberries than plastic packages. However, raspberries can be kept upto 8 days and strawberries can be kept upto 5 days under the marketable condition in fiber packages at +3 °C.

Avainsanat — Nyckelord — Keywords

Packages, Raspberry, Strawberry, Postharvest Physiology, Shelf life, Temperature

Säilytyspaikka — Förvaringsställe — Where deposited Department of Agricultural Sciences

Muita tietoja — Övriga uppgifter — Further information

Pauliina Palonen, Hanna Koivula

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Abbreviations and Concepts

CRD	Complete Randomized Design
CIE	Commission Internationale d’Eclairage
L*, a*, b*	L* indicates lightness, a* and b* are color directions: +a is red direction, -a is green direction, +b is yellow direction and -b is blue direction.
MAP	Modified Atmospheric Package
NaPPi	National Plant Phenotyping Infrastructure
RGB	Red, Green, Blue
RH	Relative Humidity
RPET	Recycled Polyethylene Terephthalate
TA	Titratable Acidity
TSS	Total Soluble Solids
VPD	Vapour Pressure Deficit

1 Introduction

Berries are naturally enriched with many nutritive and bioactive compounds which are important in human diet (Mezetti 2013). They are in high demand in Europe and their production has increased in recent times. Strawberry (*Fragaria* × *ananassa*), which is mostly consumed as fresh, deteriorates quickly and is susceptible to physical abuse, water loss and microbiological decay (Nunes et al. 1995, Fan et al. 2009). High perishability of strawberries has resulted in short shelf life (Caner et al. 2008). The postharvest life of red raspberries (*Rubus idaeus*) is generally 2–3 days from picking, since its susceptibility to fruit rot and due to the loss of firmness (Khanizadeh et al. 2009). Raspberries are also highly consumed as fresh in Europe and the long shelf life is important (Palonen et al. 2017, Palonen and Weber 2019).

The physicochemical parameters including size, full color, glossiness, firmess and crisp texture, absence of decay, bruises, a balance between sweetness and acidity, green sepals and aroma are important in the acceptability of fruits to the market. Weight loss, presence of bruises and cuts, mold and decay symptoms, color changes, juice leakage, and sepal wilt are reasons for rejections and losses at the market (Horvitz 2017).

With the high perishability, it is obvious, that proper packaging is crucial to keep the berries in consumable condition after harvesting. Packaging protects the products from damage, making them convenient to handle, efficient in transportation and make the products prolong in shelf life (Petersen et al. 1999, Seglina et al. 2010). Packaging is also important in managing the moisture losses since moisture loss deteriorates the appearance of the product and reduces its weight (Hadadinejad et al. 2018).

Commonly used containers for berries are plastic clamshells of various sizes including 250 g, 500 g, 1000 g and 2000 g (Horvitz 2017). The main disadvantage of plastic packages is its disposal. It is estimated that global emissions of plastic waste to rivers, lakes, and the ocean range from 9 to 23 million metric tons and to terrestrial areas from 13 to 25 million metric tons per year in 2016 (Macleod et al. 2021). And estimations say it will approximately double by 2025. Concerns for the environment has led its way to sustainable packaging. Molded fiber package is one kind of sustainable package which has become more popular due to its renewability, recyclability, sustainability, and biodegradability (Zhang et al. 2022a). Most recent information claims that the members of the European parliament have proposed packaging, to reduce waste and to use the recycled content (Environment Committee, European Parliament 2023). They have also proposed to reduce the plastic packaging from 10 % in Europe by the year 2030. Currently, a European company is developing and potentially investing in wood-based packaging solution, and fresh berry segment is one of the potential application areas for the innovation. The aim of this study is to get more information on the functionality of one of their wood fiber packages (will be addressed as ‘fiber packages’ later in the thesis) as berry packages and as possible replacement for plastic (RPET) clamshells.

2 Background

At the post-harvest stage, the fruit is detached from the plant, but it continues its metabolism (Petersen et al. 1999, Forney 2009). Berries are harvested at the ready for consumption level which makes them especially vulnerable to deterioration. Fruits respirate and transpire even after harvesting and with a higher respiration rate, the shelf life becomes shorter. By reducing respiration and transpiration rates, shelf life can be increased. Postharvest storage technologies - controlling temperature, relative humidity, gas composition (ethylene, O_2 and CO_2), light, reducing mechanical/physical damage by applying food additives and treatments such as sorting, waxing, and irradiation are used for extending the shelf life and increase the quality of the product.

In berries including strawberry and raspberry, color, appearance (size, shape, and absence of defects), firmness, flavor (soluble solids, titratable acidity, and flavor volatiles), and nutritional value (vitamin C) are important characteristics that must be considered in deciding the quality (Horvitz 2017). Losses of weight rapidly after harvesting, getting easily crushed due to the cavity in the center of the fruit and susceptible to gray mold (*Botrytis cinerea*) are challenges in the commercial market of raspberry fruit (Funt and Hall 2013). The strawberry fruit undergoes changes in texture, color, flavour and nutritional content during storage and these changes are crucial for the determination of fruit quality and consumer’s acceptability (Goulas and Manganaris 2011). Moreover, deterioration, in off odor, browning on the sepals, dark bruises, surface unevenness, are reasons for the lower acceptance of strawberries (Jouquand et al. 2008).

2.1 Temperature

Temperature is one of the main factors affecting the storage shelf-life and quality of fruit and vegetables since it regulates the rate of all the metabolic processes. Therefore, temperature management is crucial to extend the postharvest life of berries (Horvitz 2017). For example, low temperatures slow the metabolism showing effect on the respiratory metabolism of berries and reducing the rate of decay (Giacalone and Chiabrando et al. 2012).

Storage temperature is a key factor that influences the stability of phenolic antioxidants in fruit during postharvest storage. Higher antioxidant capacity values are maintained in fruits stored at 4 °C, instead of 25 °C (Piljac-Žegarac and Šamec 2011). According to Kalt (1999), anthocyanin content and antioxidant capacity of strawberry (*Fragaria* × *ananassa* Duch., cv. Kent), and phenolics and anthocyanins of raspberry (*Rubus idaeus Michx*., cv. Nova) increase over the storage time related to the temperature. Therefore, keeping the fruits under refrigerated storage can be recommended.

Low temperatures, and high relative humidity, reduce the water loss rate, by decreasing the vapour pressure difference between the fruit and the surrounding air. Also, cold storage affects the rate of the growth and spread of pathogens including some fungi, slowing down the metabolism of the pathogens (Horvitz 2017). Temperatures around 0 °C are considered the best for strawberries to maintain the quality. But in the market condition the temperatures are higher than that, affecting strawberry shelf-life, and nutritional value including soluble sugars and vitamin C (Cordenunsi et al. 2005). Raspberries are also preferable to store at a temperature near 0 °C or with a combination of low temperature and modified atmospheres to avoid their high respiration rate, loss of firmness and freshness, susceptibility to fruit rot and darkening (Krüger et al. 2011).

2.2 Relative Humidity

The relative humidity (RH) of the storage environment is significant in fruit quality and storage life. High RH (around 95 %), minimizes the vapour pressure deficit (VPD) of air and fruit transpiration. When VPD between the fruit surface and the surrounding air is reduced, water loss and fruit shrivelling are reduced too (Forney 2009). If the relative humidity is higher than 95 %, it is favourable to the growth of fungi and bacteria (Wills et al. 2007). Only a few fungi can grow at the relative humidity level of 85 %. Relative humidity of 90 % is the best compromise to store fruits.

2.3 Properties and materials of berry packaging

In food packaging, tensile and thermal properties and barrier properties are essential requirements (Zhang et al. 2022). Barrier properties help in reducing the water vapor and gas exchange between food and the surrounding environment. For the horticultural products such as berries, the role of the packaging material includes maintaining freshness, prevention of mechanical damages that occur during handling and minimizing the weight loss and shrinkage (Robertson 2013). Some research claim that applying edible coating for freshly harvested berries (for example chitosan coating in strawberries), extends the shelf life and the freshness (Wang & Gao 2013).

However, packaging is now seen not only as a purpose of containment and protection by retailers and brand owners but also as a potential platform for communication with consumers. Environmental sustainability has an impact on the customer’s expectations regarding retail products and their packaging (Koutsimanis et al. 2012). Furthermore, package designs are affected by the cultural, social, personal and psychological characteristics of individuals (Girgenti et al. 2016).

2.3.1 Plastic

Wide, shallow containers are preferable for berries since it is not recommended to store many layers of berries inside one package (Horvitz 2017). Otherwise, the fruits can get crushed. Plastic clamshells are most used at supermarkets for berry packaging, and they show some benefits like, lower price, solid nature giving protection to fruits from mechanical damage, not staining and consumers can observe the berries inside, since they are transparent.

2.3.2 Modified Atmospheric Packaging (MAP)

Modified atmospheric packaging is based on balancing the respiration rate of the product and the gas transmission rate of the package (Leet et al. 1996). It creates and maintains the required CO_2 and O_2 levels under steady-state conditions in the package. The exact steady-state values of O_2 and CO_2 depend on gas exchange capacity and the respiration rate of the product.

Initially after harvest, the respiration rate of the product is high. It decreases with storage time and reaches a steady-state level (with the influence of storage temperature and the atmospheric composition). In MAP, a condition is created where CO_2 produced by the harvested product at steady state is transferred to the external atmosphere, while the O_2 consumed by the product is supplied by the atmosphere. To design efficient MAP, it is important to obtain reliable information on respiration (of berries) and permeability values (of packaging material) for both CO_2 and O_2.

2.3.3 Biobased packages

Western consumers are increasingly aware of environmental issues and pay attention for the disposal of the food packaging (Petersen 1999). For instance, a survey done in Denmark shows that the consumers are willing to pay more for food packaged in biobased materials which are more environmentally friendly (Thøgersen 1999). A study done with sweet cherry (*Prunus avium*) to evaluate the purchase decisions of consumers showed that the successful commercialization of fresh berries can be expected if the berries are packed in containers made from bio-based materials (Koutsimanis et al. 2012). Results show that consumers are concerned about the impact of food packaging to the environment.

When producing the biobased packaging, attention should be paid to any changes in mechanical properties during storage, potential for microbial growth, and release of harmful compounds into the packaged food product (Petersen 1999). Bio packaging should also meet the requirements of the individual food product. Environmental factors, such as temperature, relative humidity, and light intensity, to which the product is exposed during storage and distribution, are also evaluated when selecting packaging materials.

Molded fiber packages are one type of bio packages and good alternatives to plastic packages when produced with increased flexibility, rigidity, water resistance, air permeability and hydroscopic ability (Zhang et al. 2022a). They are prepared using renewable and biodegradable lignocellulosic fibers under a series of processing. These fiber based packages are also available for berry packaging, but they tend to stain easily and are more expensive (Horvitz 2017).

2.3.4 Other types of berry packages

There are some places in the world where baskets or buckets are used for berry packaging. Consumers can pay for the bucket when they buy it for the first time and later, they can reuse it. But this is less hygienic since the bucket, or the basket can collect fungal spores and the bottom layers of the fruits get crushed. Instead of baskets, cartons with clamshells or cardboard boxes are more suitable for berry packaging especially for retail (Horvitz 2017).

3 Research Objectives

The aim of this study was to get more information on the functionality of fiber products (fiber packages) as berry packages and as possible replacement for plastic (RPET) clamshells.

3.1 Package effect for postharvest quality of raspberries and strawberries

(H0): There is not any significant difference in post-harvest quality of raspberries or strawberries between plastic and fiber packaging.

(H1): There is a significant difference in post-harvest quality of raspberries or strawberries between plastic and fiber packaging.

3.2 Storage time effect for postharvest quality of raspberries and strawberries

(H0): There is not any significant difference in post-harvest quality of raspberries over the time in storage.

(H1): There is a significant difference in post-harvest quality of raspberries over the time in storage.

(H0): There is not any significant difference in post-harvest quality of strawberries over the time in storage.

(H1): There is a significant difference in post-harvest quality of strawberries over the time in storage.

3.3 Interaction effect of storage time and package type

(H0): There is not any interaction effect between the storage time and the package type for the postharvest quality of raspberries or strawberries.

(H1): There is an interaction effect between the storage time and the package type for the postharvest quality of raspberries or strawberries.

4 Materials and Methods

4.1 Materials and storage treatments

Experiment was conducted during June and July 2023 at Vikki campus premises, University of Helsinki, Finland.

Fresh raspberries (R*ubus idaeus* cv. Vajolet) and fresh strawberries (*Fragaria* × *ananassa* cv. Malling Centennary) were obtained from producers in Finland. Berries were harvested at commercial maturity stage. Samples were qualitatively selected based on color, size, and absence of defects to obtain a homogenous batch. Raspberries were packed manually in wood fibre packages (118*141*35 mm) and plastic packages /RPET (121*142*26 mm) (ILIP S.r.l.,Castelfranco,Italy). Sixty packages from each plastic and wood fibre were prepared including 11-17 berries in each package. There was not any lid produced for the fiber packages. So, the same lids which came for the plastic packages were used for the fiber packages too. To make the perforation ratio equal in plastic and fiber packages, some holes were drilled in the lids of the fiber packages (Figure 1). Plastic and wood fibre packages with raspberries were stored in dark at two different temperatures (+17 °C and +3 °C).

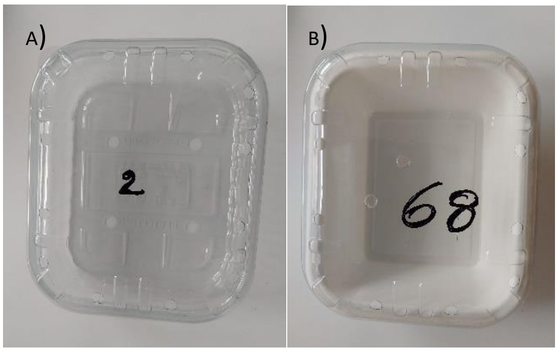

Figure 1. A - Plastic package used to pack raspberries, B - fiber package used to pack both raspberries and strawberries with two extra holes drilled on the lid.

Strawberries were packed manually in wood fibre packages (118*141*35 mm) and standard clamshells /RPET (124*95*76 mm) (Hankkija, Hyvinkää, Finland) and in each package there were 4-6 berries. To make the perforation ratio equal in fiber and plastic packages for strawberries, drilling holes in fiber packages was done and some taping was done in the plastic packages (near the lid and at the bottom of the package) (Figure 2).

Strawberries were stored in dark at +16 °C and +3 °C. Forty-eight packages from each plastic and wood fibre were stored in those two temperatures.

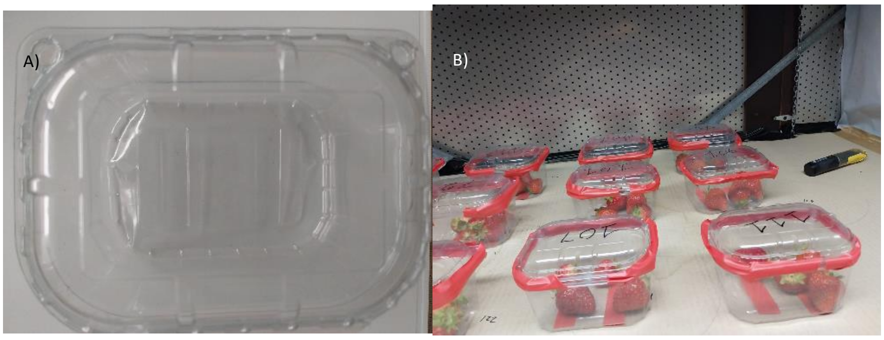

Figure 2. Plastic package used to pack strawberries. A – before the modifications, B- After the modifications were done.

4.2 Methods

Complete Randomized Design (CRD) experimental design was used for the study. Five replicates from each plastic and fiber packages from each day at each temperature were used in raspberry experiment. For raspberry at +3 °C sampling was done every three days until the 12th day and after that the last sample was taken on the 21st day. For raspberry at +17 °C, sampling was done every day until the 5th day and then the final sample was taken on the 7th day. For strawberry at +3 °C sampling was done in every three days until the 15th day and at +16 °C it was done every day for five days.

After the sample packages were taken out, they were weighed using an electronic balance (Mettler Toledo, Switzerland). When carrying the berries from place to place for different measurements, styrofoam cooler boxes were used. Decay incidence of berries was observed after weighing. Next step was to take the berry packages for NaPPi (National Plant Phenotyping Infrastructure) analysis. After NaPPi imaging, they were taken for texture analysing. These measurements were done at scheduled times on each measurement day. When the texture analysis was done, the remaining berries were taken out from the packages and put into plastic bags and taken to the freezer (-18 °C) to be used for the further laboratory analyses (total soluble solid content and acidity). After all the berries were taken out, the empty packages were weighed (Mettler Toledo, Switzerland). Empty packages were then carried to be photographed (Canon, EOS 760D, Tokyo, Japan).

4.2.1 Decay Incidence

Decay incidence was assessed visually for the occurrence of fungal growth (rotting at least 5mm in diameter) and any other means of decay. The proportion of the decayed area of the berry out of the total berry was visually estimated. Then the total decayed areas of all the berries were calculated as a percentage of the total berries in packages.

4.2.2 Weight Loss

First, package weight with berries before storage (W1) was measured for all the packages. Then the package weight with berries was measured when they were taken out from the storage (W2). An electronic balance was used to measure weight (Mettler Toledo, Switzerland). Weight loss was calculated as a percentage using those values (1).

$$(W1-W2)/W1\times 100\% \qquad (1)$$

4.2.3 Texture

Texture was analysed using a Stable Micro Systems Texture Analyser (TA. XT plus 100, Stable Micro Systems, England). For raspberry 36 mm (diameter) probe and 20 g of contact force were used (pre-test speed 2 mm/sec, test speed 5 mm/sec, post-test speed 5 mm/sec). Two representative raspberries from each replicate package were used for texture analysis. Raspberry texture was measured as ‘hardness’ or the ‘firmness’ using the probe to compress the berry.

For strawberry a puncture method was used to measure the skin strength of strawberry (pre-test speed 1.5 mm/sec, test speed 1.00 mm/sec, post-test speed 10 mm/sec). The (maximum) force at which the puncture happens was measured using a 2 mm probe. The contact force was 20 g. One representative strawberry from each replicate package was used for the measurement.

4.2.4 Color and the surface area of the berry

Five raspberries from each replicate package and one strawberry from each replicate package were used. Raspberries were placed on imaging trays with blue background (Figure 3) to take images. For strawberries, berries were dissected before keeping on the imaging trays (Figure 3). Berry imaging was performed with the PlantScreenTM Compact system at the National Plant Phenotyping Infrastructure, University of Helsinki. Top view images were obtained with RGB camera GigE uEye model UI-5580SE-C/M (IDS GmbH, Obersulm, Germany) equipped with 1/2” CMOS sensors (Aptina Imaging, San Jose, CA, USA). Surface area of the image of the berry (initially measured in pixels and later converted to square millimitres) and color hues were derived from RGB images after image prosessing for background exclusion and color segmentation using the MorphoAnalysis v.

1.0.9.8. software (Photon Systems Instruments, Drásov, Czech Republic). Surface area of the berry image was a 2D indicator of the size of the berry. L*, a*, and b* values of color were obtained converting the RGB values to determine the color. Delta e (ΔE) value of the color was calculated using the L*, a*, b* values with the equation below (2).

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \qquad (2)$$

L^*_1 = L* value of the berries on 0 day

L^*_2 = L* value of the berries on consequent days

a^*_1= a* value of the berries on 0 day

a^*_2= a* value of the berries on the consequent days

b^*_1= b* value of the berries on 0 day

b^*_2= b* value of the berries on the consequent days

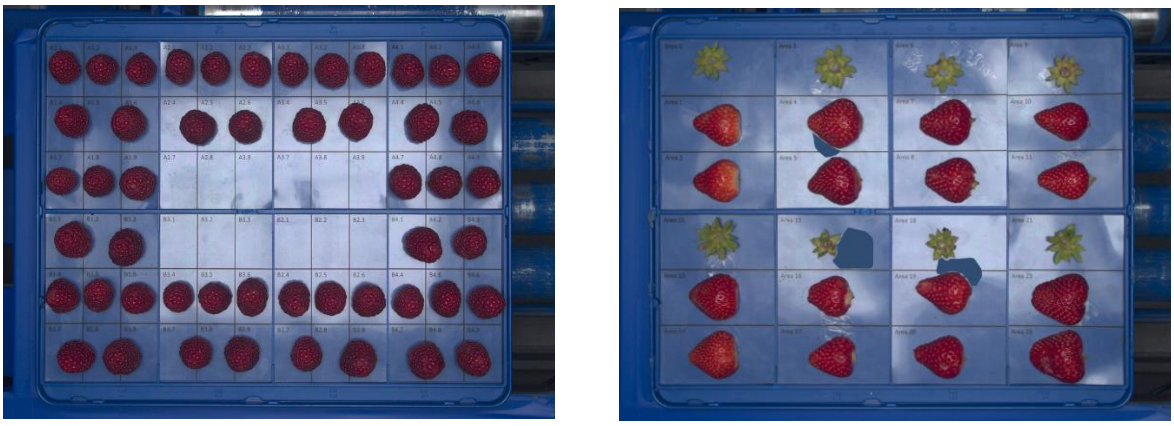

Figure 3. Raspberries and strawberries placed on the trays with blue color background for imaging.

4.2.5 Total soluble solids (TSS), titratable acidity (TA)

Berry samples stored at -18 °C were thawed (5 to 6 raspberries from one replicate and 2 to 3 strawberries from one replicate) at room temperature and homogenized (Vevor, High Speed

Homogeniser FSH-2A, Shanghai, China). The homogenate was centrifuged at 7000 rpm at 18 °C for 15 minutes in 50 ml plastic tubes. The collected supernatant was filtered through a Whatman filter paper to remove the remaining particles from the berry juice and 15 ml plastic tubes were used to collect the juice. Five ml from each sample was pipetted into test tubes. Fifteen millilitres of milli-Q water were added to the same test tube with a laboratory doser and mixed by shaking. Out from the diluted juice, three samples of 5 ml were pipetted into three sample cups. Then, 60 ml of milli-Q water was added to the sample cups with a doser, and 1.25 ml of berry juice was titrated to an end point of pH 8.1 with 0.1 N NaOH using an automated titrator (Metrohom Ti Touch, 800 Dosino). The mean value of three samples prepared from each berry package was calculated.

At the same time TSS was measured two to three times per one replicate berry package, using an Atago refractometer PAL-1 (Atago, Tokyo, Japan). If the first two measurements were not the same a third measurement was taken.

4.2.6 Package staining and absorption of juice

Surface area of the package covered with juice leaked from the berries was observed visually. If there were any stains in the wood fibre package, a representative stain was selected, and a cross section was cut using a blade to see how deep (in micrometres) the juice penetrated. Stains of the wood fibre package were observed using a stereomicroscope (Leica M205 FCA). Images were taken using a software (LAS X). For fiber packages with strawberry, the amount of juice absorbed by the packages was calculated as a percentage using the initial weight of the empty package (W1) and the weight of the empty package after removing the berries (W2). This was calculated as a percentage of the initial weight of the fiber package, for the purpose of identifying how much moisture content that the fiber package can absorb (3).

$$(W2-W1)/W1\times100\% \qquad (3).$$

4.3 Statistical Analysis

The significance of the main effects of package type, duration of storage as well as their interaction were statistically tested using two-way ANOVA in IBM® SPSS® software platform, version 28 (International Business Machines Corporation, USA). Treatment means were separated using Tukey’s test at a significant level of $P \leq 0.05$.

5 Results

5.1 Raspberry

5.1.1 Weight loss and surface area of the berry.

Weight loss of raspberry increased over time at both storage temperatures (Figure 4). It reached close to 10 % in both plastic and fiber packages at +17 °C. At +3 °C weight loss of berries was 13 % in plastic, while it was 17 % in the fiber packages on the last day. At both storage temperatures raspberry weight loss was affected by both the time in storage (P<0.001) and by the type of package (P<0.001). There was an interaction effect between time in storage and the type of package at +3 °C (P<0.001). The fiber package showed higher weight loss percentage of raspberry than in the plastic package over the time.

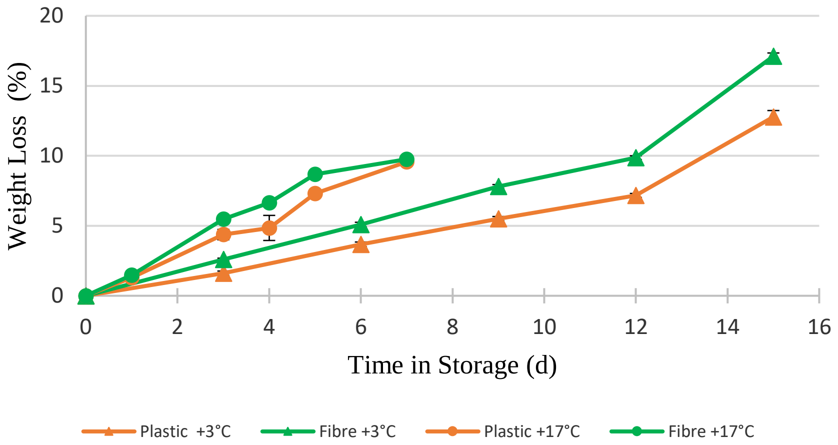

Figure 4. Mean values of the weight loss percentage in raspberry stored at +17 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5).

At both storage temperatures, surface area of the berry changed significantly over time (P=0.006 in +17 °C and P<0.001 in +3 °C) (Figure 5). The effect of package type was not significant at +17 °C but it was significant at +3 °C (P<0.001). On the 21st day at +3 °C , the mean surface area of the berries in plastic packages was 474 mm^2 while it was 444 mm^2 in fiber packages.

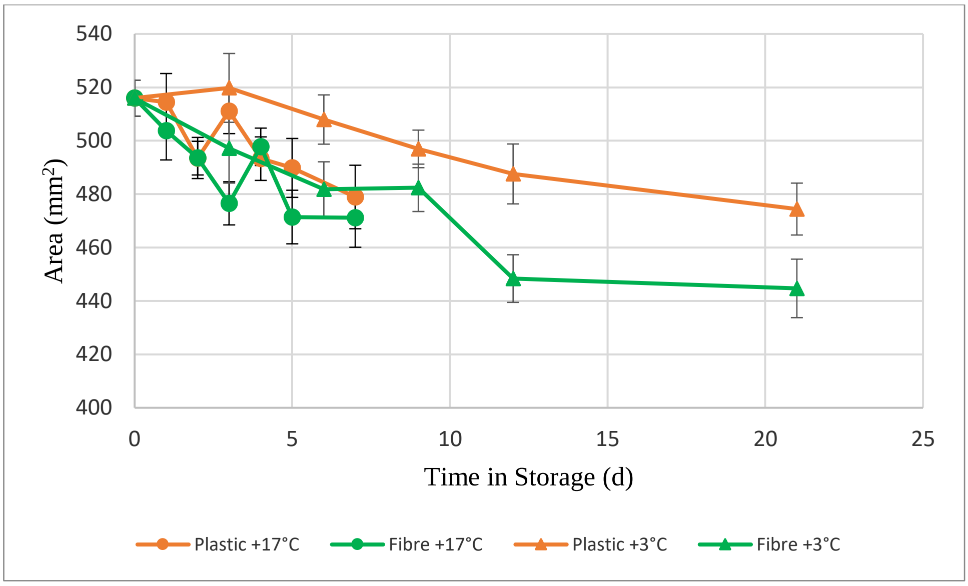

Figure 5. Mean values of the surface area of the raspberry stored at +17 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5).

5.1.2 Decay and firmness

Decay of raspberry increased over the time (Figure 6). The proportion of decayed surface area ranged between 0 to 4 % at +17 °C and between 0 to14 % at +3 °C. At both temperatures decay was affected by the time in storage (P<0.001), but not by the type of package. There was an interaction effect between the time in storage and the type of package at +17 °C (P=0.002).

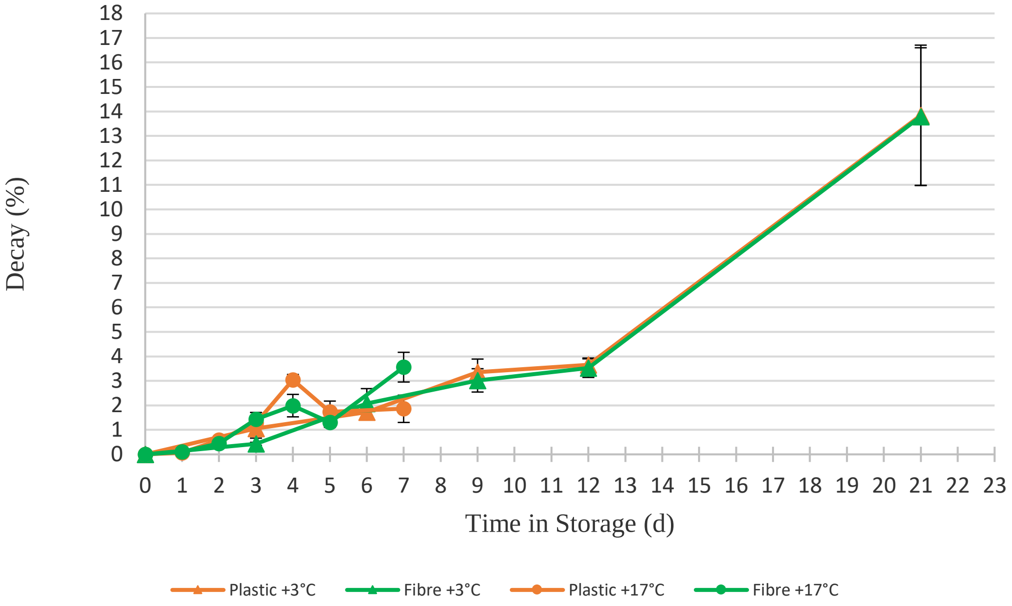

Figure 6. Mean values of the percentage of decayed surface area in raspberry stored at +17 °C and +3 °C in either plastic or fiber packages. Vertical bars show ± standard error of mean (n=5).

Firmness of raspberry decreased over the time (Figure 7). In the beginning of the experiment, the mean value of the force to compress the raspberry was 300 g and it decreased to 100 g over the time. Firmness of raspberry at both storage temperatures was affected by the time of storage ($P<0.001$). At +17 °C, it was affected by the type of package ($P=0.042$). At +3 °C firmness was not affected by the type of package. There was an interaction effect between the time in storage and the type of package at +17 °C ($P=0.040$). The raspberries in the fiber package showed a lesser firmness than the raspberries in the plastic package on the 3rd day.

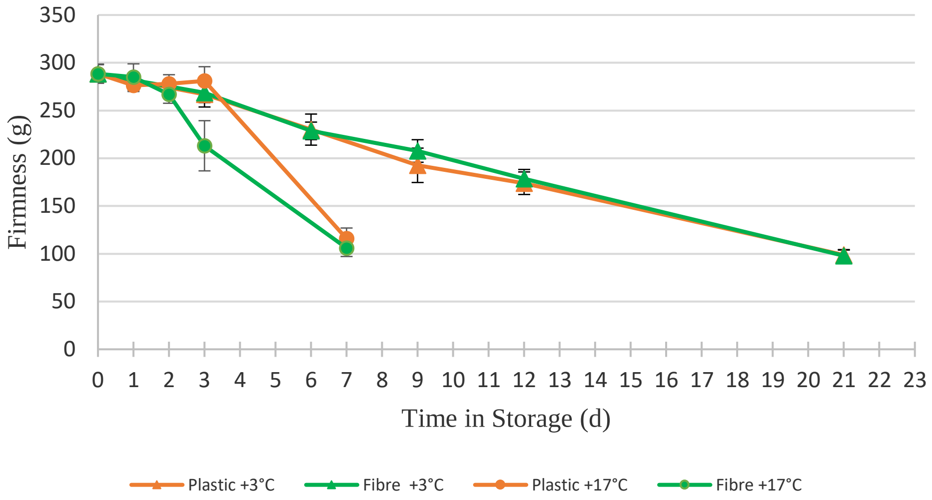

Figure 7. Mean values of the firmness in raspberr y stored at two different temperatures at +17 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5).

5.1.3 Color

The raspberries turned darker and more bluish color as they aged (Appendix 4). Mean values of L*(Lightness) of raspberry color at both temperatures decreased over time (Figure 8). There was a significant difference of time of storage for L* at both +16 °C (P<0.004) and +3 °C (P<0.002). Mean values of raspberry a* (indicates red color) and mean values of raspberry b* (indicates blue color) also had a significant difference at both temperatures (P<0.001) over the storage time. There was not any significant difference of package type for L*, a*, b* at both the temperatures. There was an interaction effect of time in storage and the type of package at +3 °C for a* value (P=0.017).

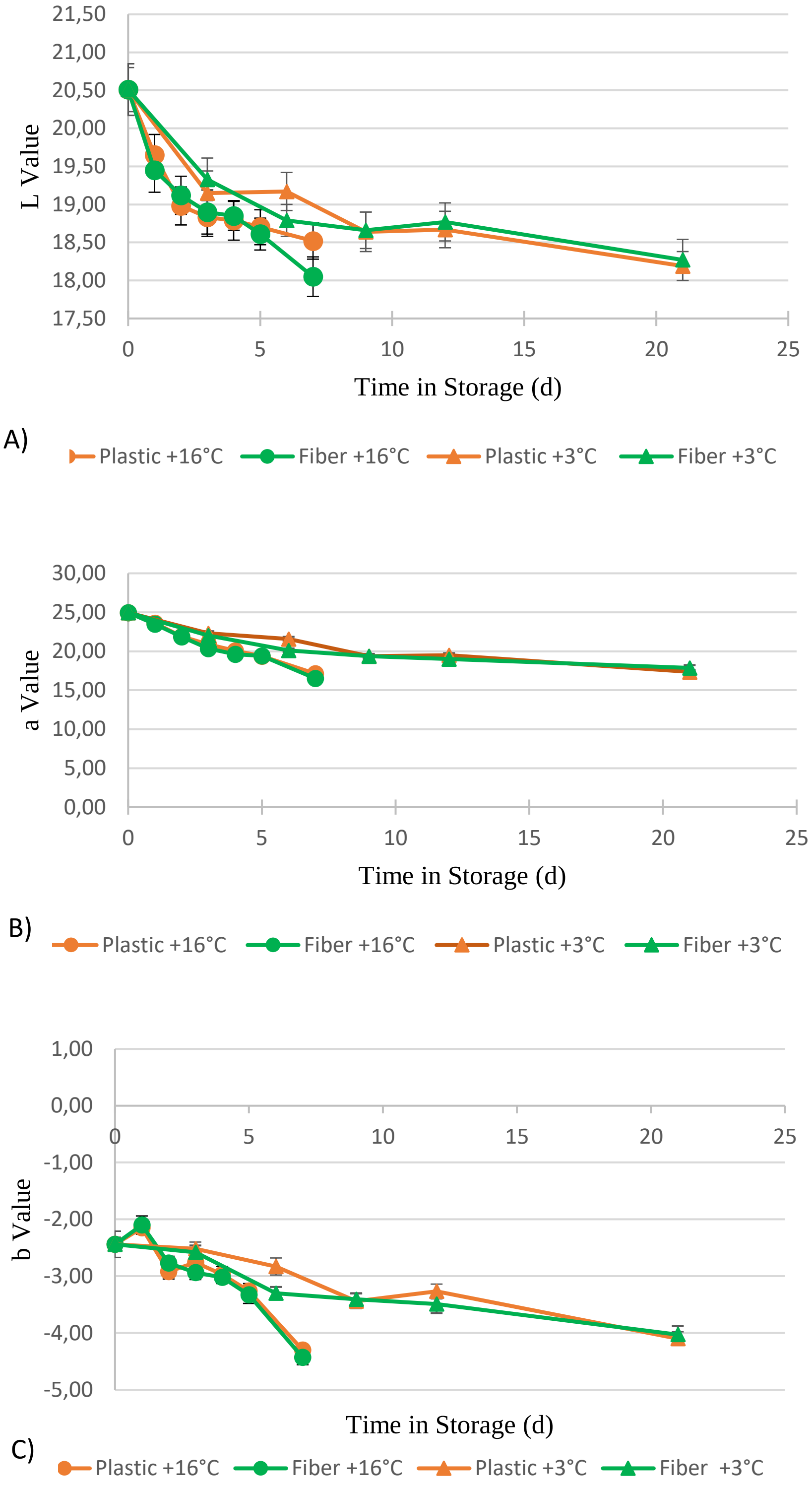

Figure 8. Mean values of the L*, a*, b* color values in raspberry stored at +17 °C and +3 °C in either plastic or fiber package. L* (A graph) indicates lightness, a* (B graph) and b* (C graph) are color directions: +a was the red direction, -a was the green direction, +b was the yellow direction and -b was the blue direction.

The Delta E values (Figure 9) highlighted the fact that the overall color difference (compared to the fresh berries) became more and more obvious as a function of time and was detectable by human eye starting from day 2 (delta values higher than 3 can be detected by human eyes in side-by-side comparison).

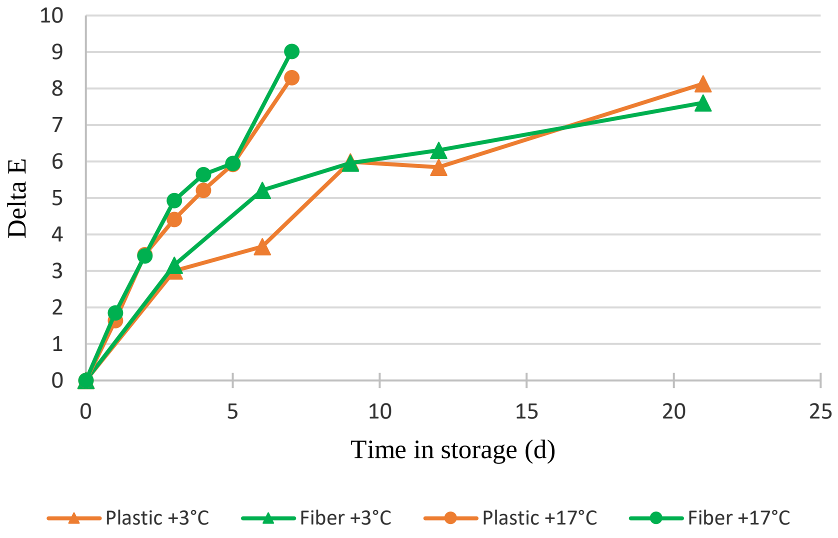

Figure 9. Delta E values of plastic and fiber packages at +17 °C and +3 °C derived from L*,a* and b* values of color.

5.1.4 Concentrations of total soluble solids (TSS) and titratable acidity (TA)

At +17 °C mean values of TSS in raspberries stored in both of plastic and fiber packages were more than 10 °Brix until the 5th day. TSS was not affected by the type of package or time of storage at +17 °C. At +3 °C, TSS was not affected by the time of storage, but there was a significant difference between the two types of packages ($P<0.001$), °Brix values being higher in fiber package (Figure 10).

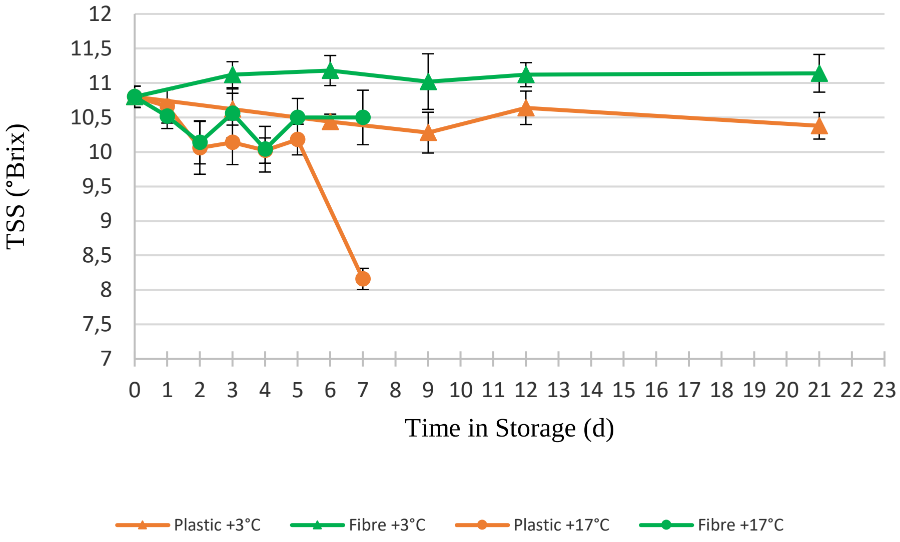

Figure 10. Mean values of the soluble solid content in raspberry stored at +17 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5).

Concentration of titratable acids of raspberry was between 1.2 % and 1.9 % and decreased over the time at both storage temperatures (P<0.001) (Figure 11). The type of package had a significant effect on acidity at +3 °C (P<0.001), but not at +17 °C.

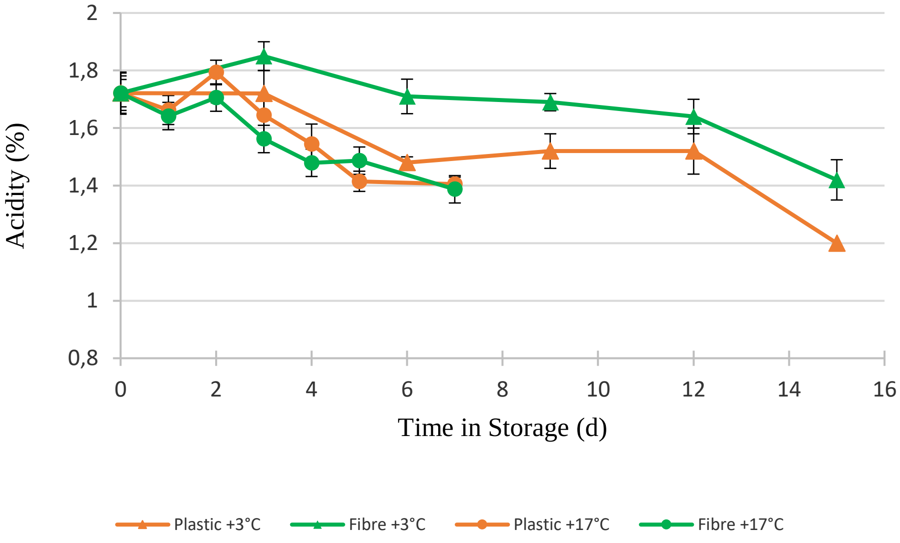

Figure 11. Mean values of the acidity in raspberry stored at +17 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5).

TSS/TA of raspberry at +3 °C was between 6 and 9 and increased over the time (P<0.001) (Figure 12). The type of package had a significant effect on TSS/TA at +3 °C (P=0.043), but there was not any interaction effect between the type of package and time in storage.

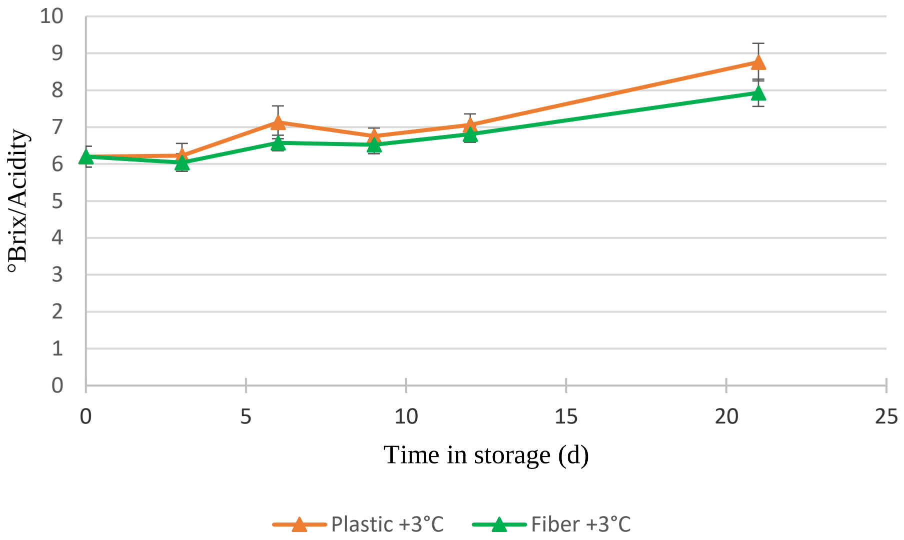

Figure 12. A shows TSS/TA ratio (sugar/acid ratio) of raspberries at +3 °C when stored in plastic and fiber packages (n=5).

5.1.5 Package staining

Area stained by raspberry juice in fiber packages having a white surface was more visible than in plastic packages (Figure 13). Microscopic images showed that juice did not penetrate through the outside of the package but stopped in an inside layer of the package (Figure 14). Staining was observed as increasing with the time in storage. However, shaking of the packages while carrying them was also a reason for the stains. On some days when more shaking happened, more stains were visible on the packages (Appendix 1).

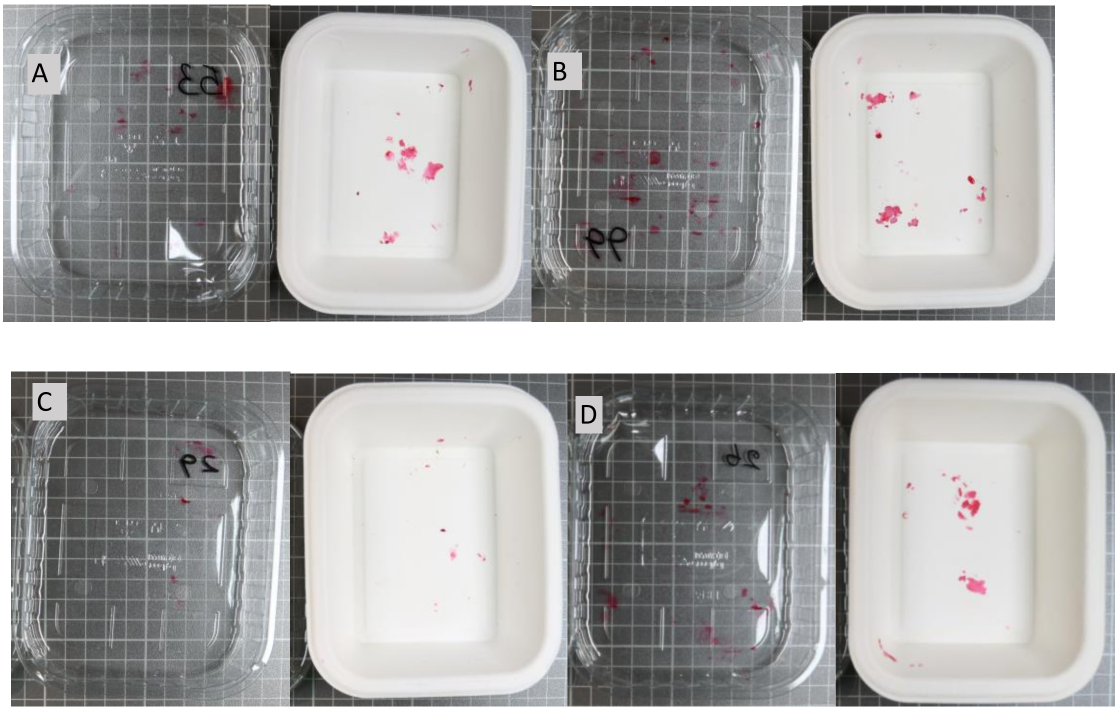

Figure 13. Photographs of representative fiber and plastic packages with staining (A -One plastic package and fiber package on the 3rd day at +17 °C, B- on the 4th day at +17 °C and C- on the 6th day and D- on the 9th day at +3 °C).

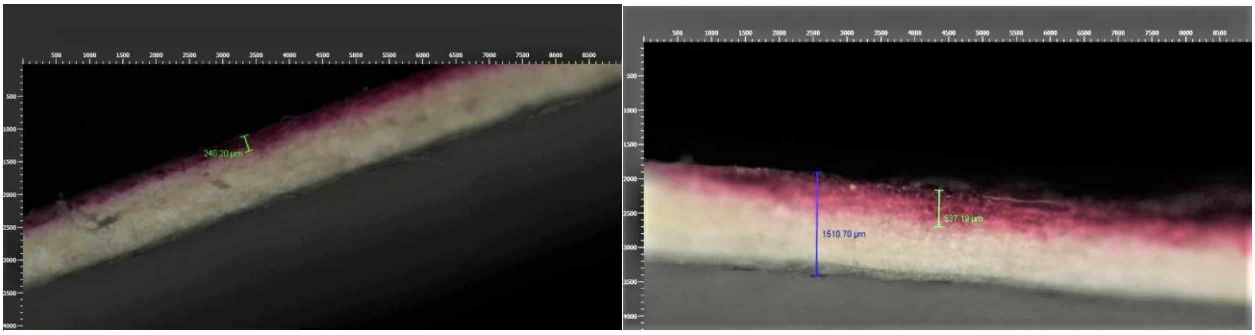

Figure 14. Microscopic images of cross sections of the stained areas of two representative fiber packages. The light red color layer shows the area stained with raspberry juice and the white color layer was the unstained fiber layer/layers of the package.

5. 2 Strawberry

5.2.1 Weight loss and surface area of the berry

Weight loss percentage of strawberry increased over the time (Figure 15). Weight loss reached 15 % in fiber and 12 % in plastic on the 5th day at +16 °C. On the 15th day at +3 °C, plastic package had a weight loss percentage of 18 % and fiber package had 28 %. Weight loss percentage of strawberry at both temperatures was affected by the time of storage (P<0.001) and by the type of package (P=0.005 at +16 °C and P<0.001at +3 °C).

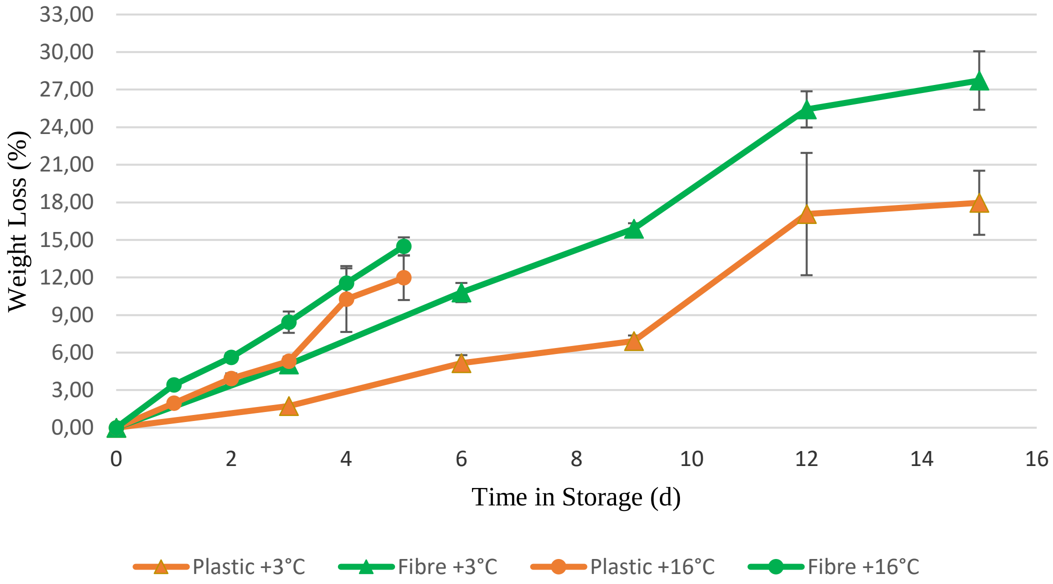

Figure 15. Mean values of the weight loss percentage in strawberry stored at +16 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5, except for the last sampling days n=4).

Mean values of the surface area of the strawberry when dissected to two halves, decreased over time (P<0.001) at both temperatures (Figure 16). There was a significant difference of the type of package at +16 °C (P=0.011) as well as at +3 °C (P=0.009). At +3 °C there was an interaction effect between the type of package and the time in storage and fiber package showed lower surface area values from day 3 to day 12 than the plastic package.

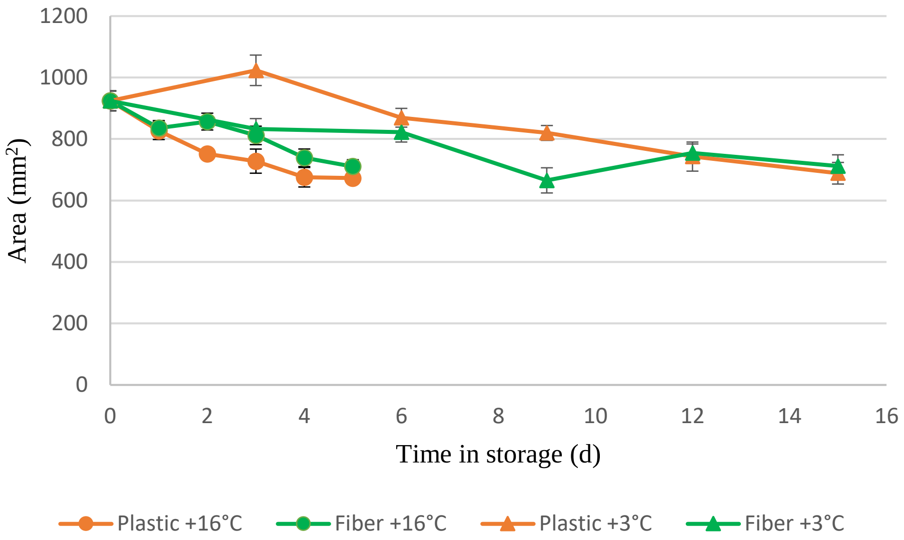

Figure 16. Mean values of the surface are of strawberry when dissected to two halves, stored at +16 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5 except for the last sampling days n=4).

5.2.2 Decay and Skin strength

Decay percentage reached 100 % in plastic packages at +16 °C (Figure 17). At both temperatures decay percentage was affected by the time of storage ($P<0.001$). At +16 °C it was also affected by the type of package ($P=0.007$) and at +3 °C it was not affected by the type of package.

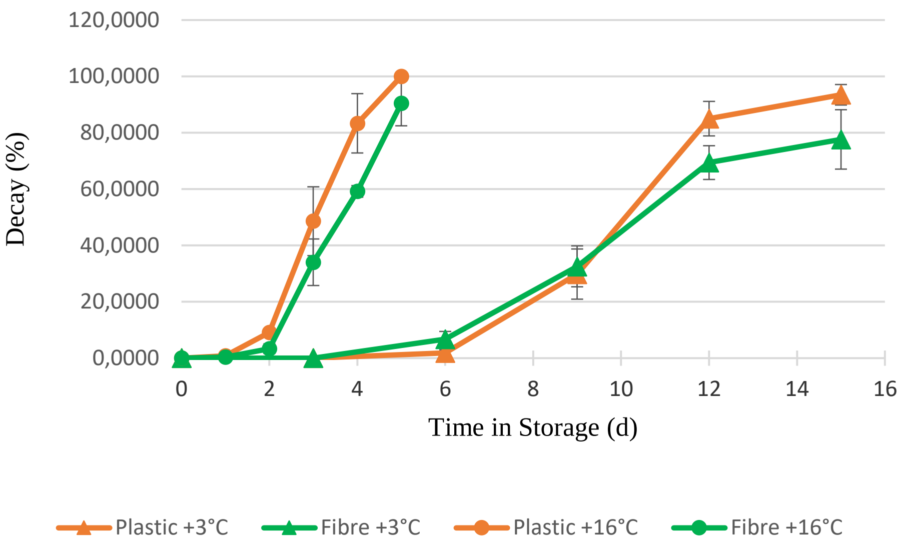

Figure 17. Mean values of the decay percentage of strawberry stored at +16 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5 until except for the last sampling days n=4).

Skin strength of strawberry increased over the time (Figure 18). At +3 °C Skin strength was affected by time in storage (P=0.040) and type of package (P=0.009) at +16 °C it was not affected by time in storage or by the type of package.

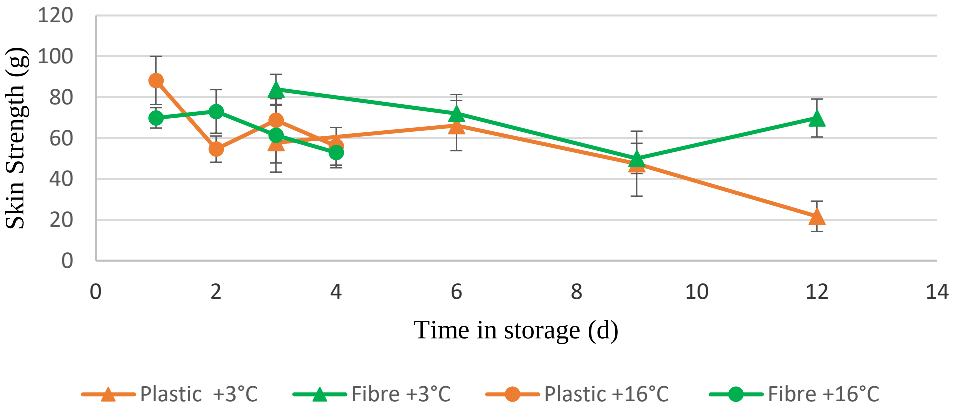

Figure 18. Mean values of the skin strength of strawberry stored at +16 °C and at +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5 except for the last sampling days n=4).

5.2.3 Color

L*, a*, and b* values of strawberry showed decreasing trends at both temperatures (Figure 19). There was a significant difference of time in storage for L* at both +16 °C ($P=0.004$) and +3°C ($P=0.009$). Mean values of strawberry a*(indicates red to green color) and mean values of strawberry b*(indicates yellow to blue color) also had a significant difference over the storage time ($P<0.001$) at both temperatures. There was not any significant difference of package type for L*or a* at both the temperatures. But there was an interaction effect of time in storage and the type of package at +3 °C for a*value ($P=0.007$). There was not any significant difference of the type of package for b*value at +16 °C but the effect was significant at +3 °C ($P=0.003$) (Appendix 3).

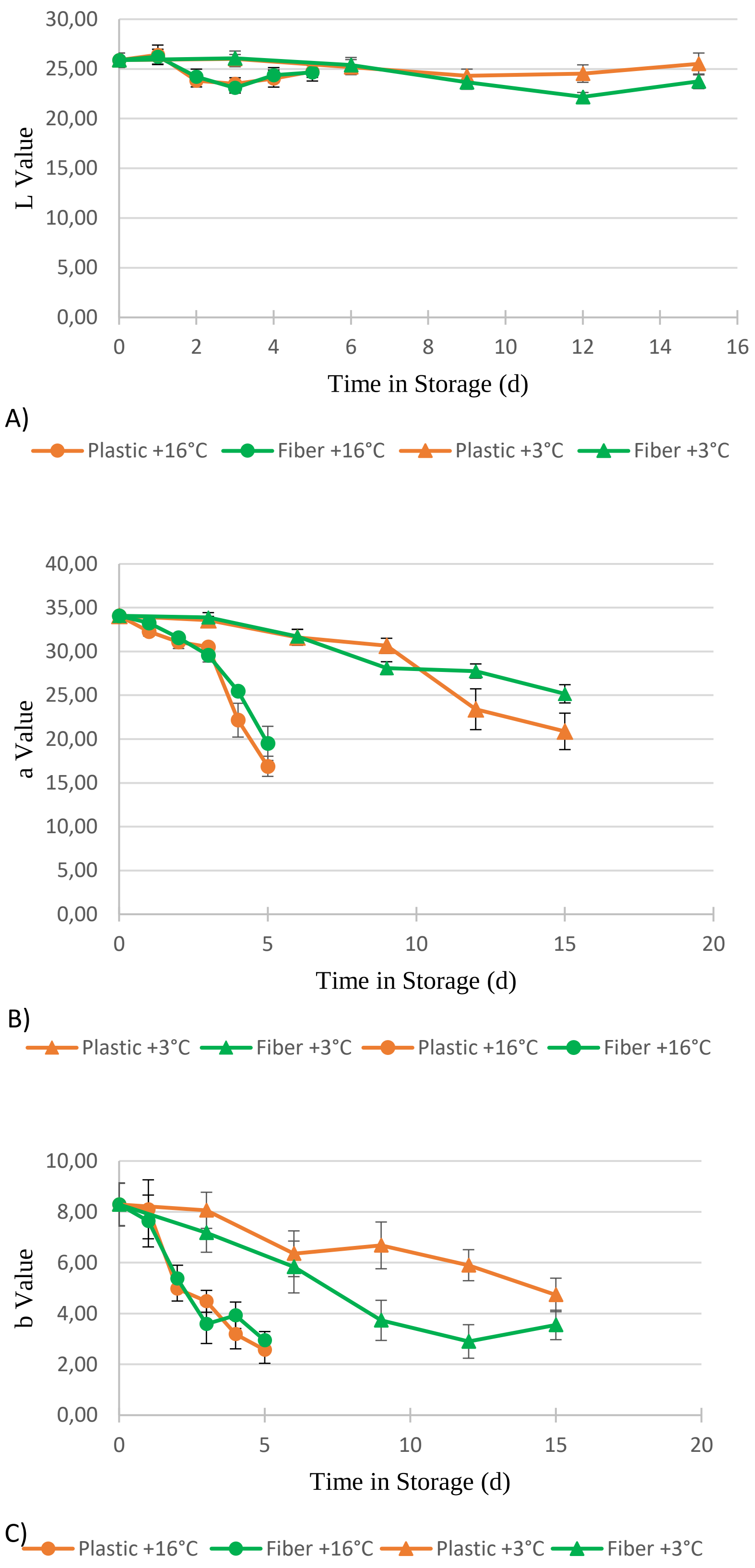

Figure 19. Mean values of the L*, a*, b* color values in strawberry stored at +16 °C (A) and +3 °C (B) in either plastic or fiber package. L indicates lightness, a and b are color directions: +a was the red direction, -a was the green direction, +b was the yellow direction and -b was the blue direction.

The Delta E values (Figure 20) highlighted the fact that the overall color difference (compared to the fresh berries) became more and more obvious as a function of time and was detectable by human eye starting from day 2 (delta values higher than 3 can be detected by human eyes in side-by-side comparison).

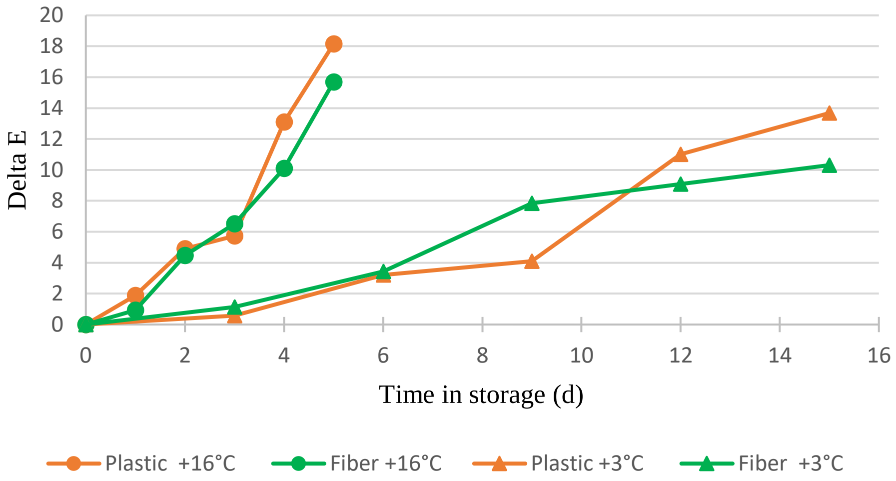

Figure 20. Delta E values of plastic and fiber packages at +17 °C and +3 °C derived from L,a and b values of color.

The images of strawberry sepals showed more shrinked over the time in fiber packages than in plastic packages at both temperatures (Figure 21 and Figure 22).

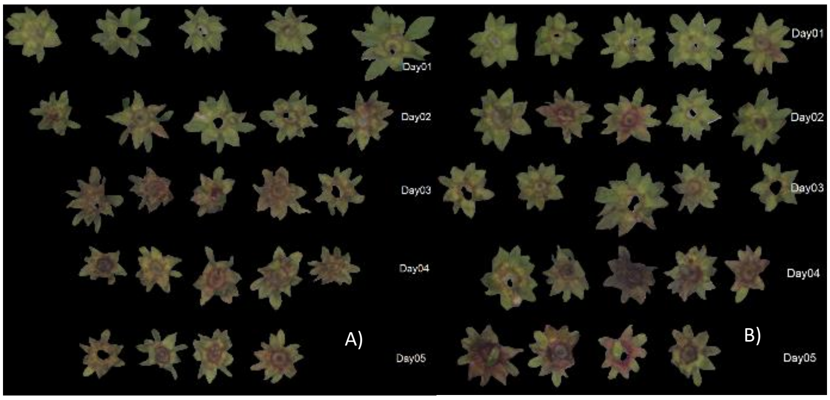

Figure 21. A - Strawberry sepals in fiber packages at +16 °C, B- Strawberry sepals in plastic packages at +16 °C.

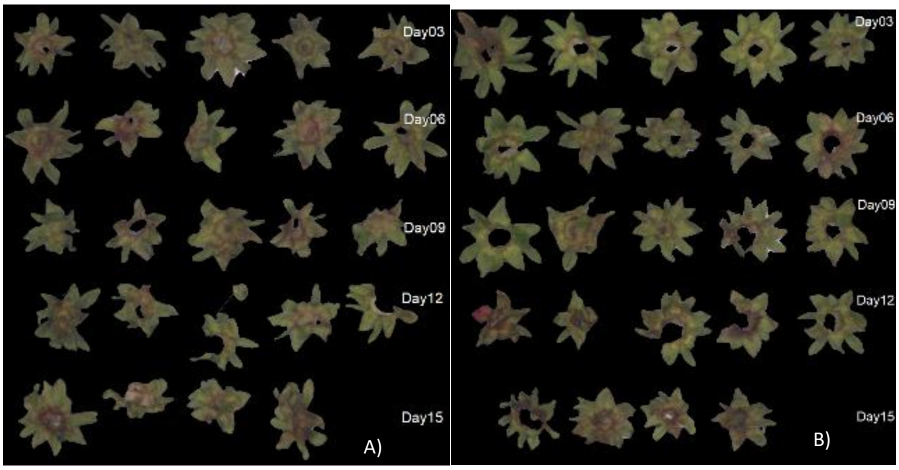

Figure 22. A - Strawberry sepals in fiber packages at +3 °C, B- Strawberry sepals in plastic packages at +3 °C.

5.2.4 Concentrations of total soluble solids (TSS) and titratable acidity (TA)

There was a decreasing trend of TSS at +16 °C over the storage time. There was not any significant difference in the type of package for TSS of strawberry at +16 °C storage (Figure 23). But at +3 °C, soluble solid content was affected by both day (P=0.004) and the type of package (P<0.001). At +3 °C, fiber package showed a value of 6.9 °Brix on the 3rd day and it has reached 10 °Brix on the 15th day. There was an interaction effect between time in storage and type of package at +16 °C.

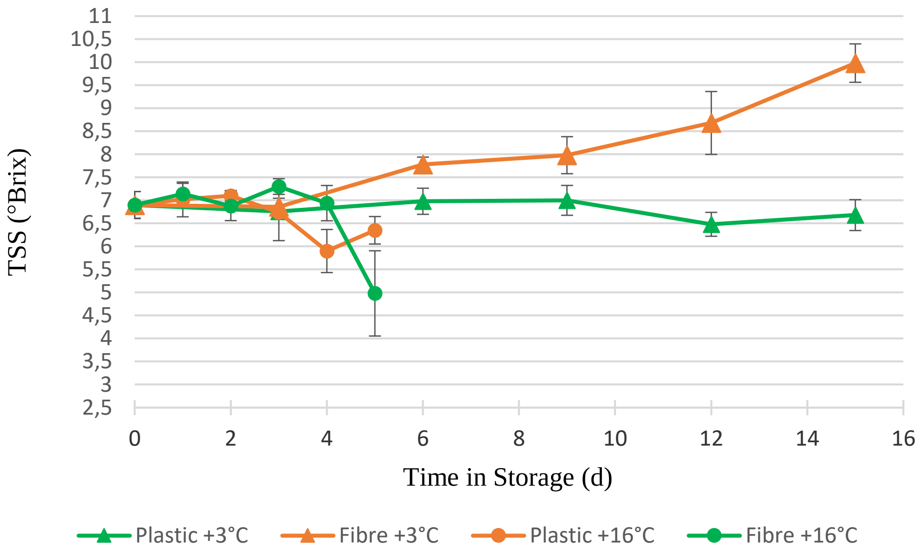

Figure 23. Mean values of the soluble solid content of strawberry stored at +16 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5, except for the last sampling days n=4).

Strawberries showed an acidity range from 0.5 % to 0.8 % at both the temperatures in both fiber and plastic packages (Figure 24). There was not any significant difference of the time in storage or the type of package for the acidity of strawberry at +16 °C temperature. At +3 °C there was an effect of time in storage (P=0.001) but there was not any effect of type of package.

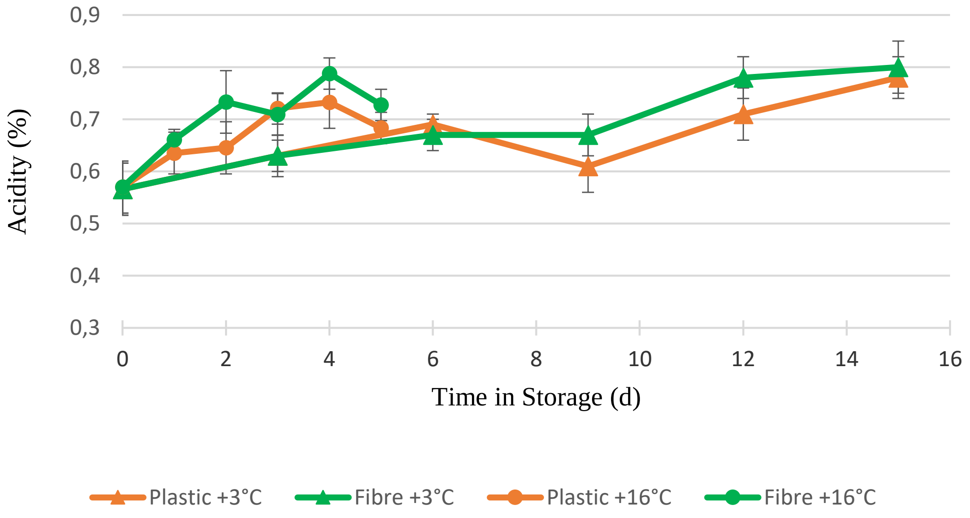

Figure 24. Mean values of the acidity of strawberry at stored at +16 °C and +3 °C in either plastic or fiber package. Vertical bars show ± standard error of mean (n=5, except for the last sampling days n=4).

TSS/TA of strawberry at +3 °C was between 8 and 13 and did not have any effect due to the storage time (Figure 25). The type of package had a significant effect on TSS/TA at +3 °C (P=0.001), but there was not any interaction effect between the type of package and time in storage.

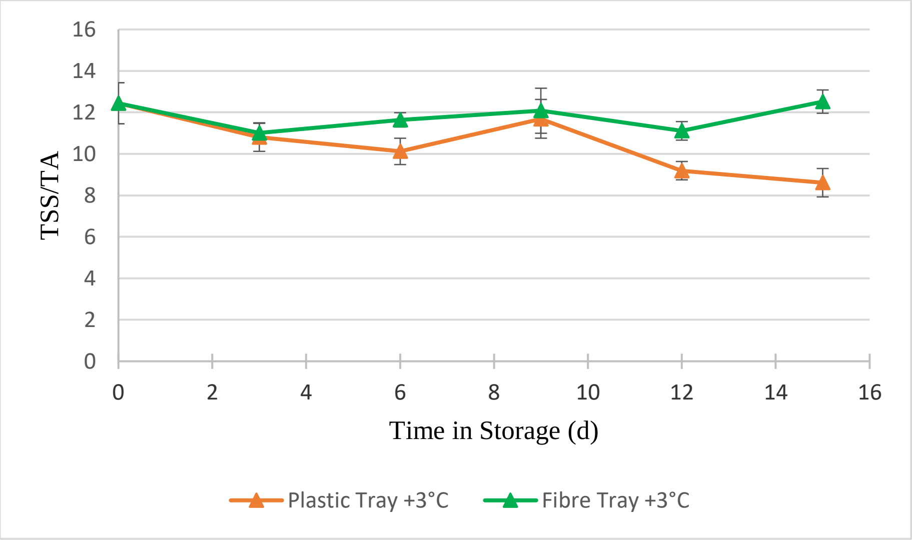

Figure 25.TSS/TA ratio (sugar/acid ratio) of strawberries at +3 °C when stored in plastic and fiber packages (n=5 and on the last day n=4).

5.2.5 Absorption of juice

Fiber package weight increased up to 7 % due to absorption of leaked strawberry juice by the package on the 4th day at +16 °C and it was 3 % on the 15th day at +3 °C temperature (Figure 26). (Appendix 2).

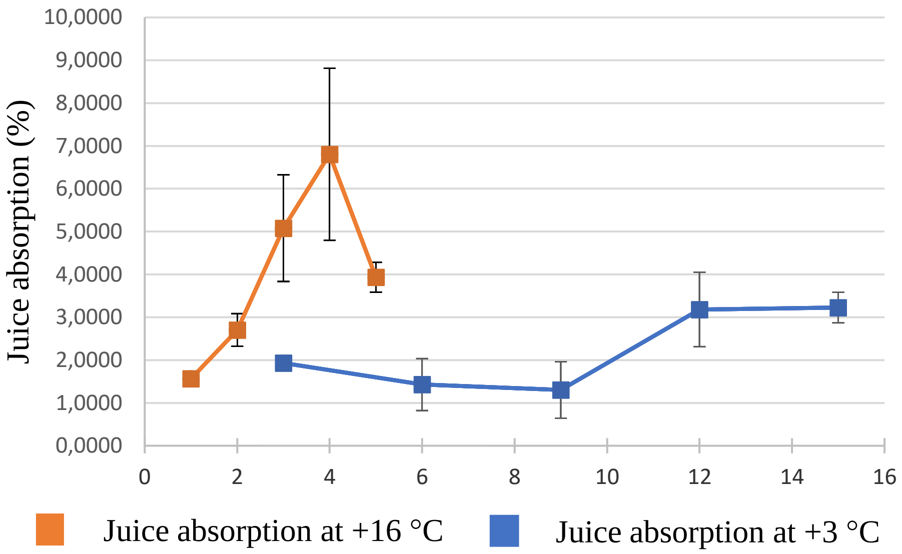

Figure 26. Mean values of the juice absorption percentage of fiber packages at +16 °C and +3 °C. Vertical bars show ± standard error of mean (n=5, except for the last sampling days n=4).

6 Discussion

Internal and external factors affect the quality criteria of the postharvest physiology of berries (Wills et al. 2007). Appearance, color, size and shape, surface and internal defects, texture, flavour and nutritional value are important quality attributes for the consumers. Raspberry fruits should be fresh, juicy, clean, free from pests and damage, attractive, uniform color without spots or discoloration, regular, well-formed size, firm yet delicate to the touch (Sawicka et al. 2023). Red color, visually appealing, moderately firm, fresh strawberries are preferred by the consumers (Bhat et al. 2015).In this research, there were significant and non-significant differences in the impact of plastic and fiber packages for the postharvest quality and the shelf life of raspberry and strawberry over the time.

However, the storage periods in our experiment could be too long for the recommended storage periods commercially. According to Huynh et al. (2023), the recommended shelf life of raspberry is 7–10 days after harvest when kept at 0 °C – 2 °C and according to Wills et al. (2007) the recommended storage life for strawberries is 1-5 days at -1°C to 4 °C.

The postharvest quality during storage is affected by the variety or the cultivar (Forney 2009, Robins et al.1989). With the availability of the berries from farmers during the time of experiment, cv. Vajolet was used for the raspberry experiment and cv. Malling Centennary was used for the strawberry variety.

The same fiber package was used for both raspberries and strawberries. But two different plastic packages were used since the strawberries needed a bit deeper/higher package size than raspberries due to their larger size. Both plastic packages were close enough in size with the fiber packages.

Adequate perforation is important in packaging (Oliveira et al. 2019). There should be sufficient aeration within the package to maintain the internal temperature and moisture content and finding the optimal perforation is complex. Before our experiment was conducted, several commercially available berry packages were bought, and the perforation ratio was calculated as a ratio of surface area to holes. The values were close to or equal to 0.01. The ratio of 0.01 was selected and used in both fiber and plastic packages.

In Giovanelli et al. (2014), most sensitive parameters of raspberry quality decay, i.e., percentage of damaged berries, weight loss, softening and odour changes, are significantly influenced using different packaging materials during shelf-life at +4 °C. Comparable to their research, weight loss was significantly influenced using different packaging materials at +3 °C in our study. In Giovanelli et al. (2014), the packaging materials (including lids) allow the production of low O_2 and high CO_2 concentrations inside the package during the storage period making the berries retard over ripening. Regarding our research, there was not a lid produced for the fiber package at the time of our experiment. So, producing a lid for the fiber package with suitable permeability properties for berries is suggested for the better management of the postharvest quality of the berries.

Flavour is a combination of taste and aroma (Wills et al. 2007). The taste of fruits is a blend of sweet and sour and aroma is the olfactory senses for the nose. Furthermore, flavor is an important aspect of deciding the consumer preference and, packaging materials must preserve flavour for sufficient shelf-life and product quality management (Caner 2011, Villamor et al. 2013). High sugars (TSS) contribute to good berry flavor (Haffner and Vestrheim 1997) and the titratable acidity of the berries is used as an indicator of potential storage quality (Caner and Aday 2008).

Interestingly, both raspberries and strawberries showed higher °Brix values (TSS) meaning higher level of sugar content, when stored at +3 °C in fiber packages, than stored in the plastic packages at the same temperature. Raspberries had higher TA values at +3 °C when they were stored in fiber packages. However, TSS and TA of raspberry were in the typical range in accordance with the previous literature. Typical TSS for raspberry is in the range of 7 – 12 °Brix and TA was 0.9 - 2.8 % (Palonen et al. 2017, Palonen and Weber 2019, Hansen et al. 2021). Strawberry also had TSS values in the general range of 5– 13 °Brix as observed in previous articles (Haffener and Vestrheim 1997, Caner and Aday 2008, Aday 2013, Zhang et al. 2022b).

According to Caner and Aday (2008), strawberry acidity depends on the permeability of the packaging. The permeability of the package impacts the available concentration of $CO_{2.}$ CO_2 dissolution on the fruit surface generates carbonic acid and acidifies the fruit. Anyway, in our study, TA of strawberries at +3 °C decreased over the time and there was not any significant effect of the type of package for the acidity of the strawberries. It can be assumed that the permeability properties of the two types of packages used in this study have not affected the acidity of the strawberries differently.

Finding TSS/TA ratio is important since it provides information on the balance of sugars and acids in the berry which decides the quality of the fruit (Koraqi et al. 2019). Berries with a higher TSS/TA index have the best flavour harmony (Akagi´ et al. 2020). In our research, flavour has not changed over the time because of the type of package.

At +3 °C, raspberries in fiber packages lost more weight and decreased in size more than the ones in plastic packages. This can be due to the fiber material absorbing moisture from the berry. Fruit weight loss is mainly associated with respiration and moisture evaporation through the skin (Hernandez-Munoz et al. 2008, Giovanelli et al. 2014). It can be assumed that the moisture absorbance in berries from fibre packaging increased the weight loss and shrinked the berry. Although the weight loss of raspberries at +17 °C was higher in fiber than in plastic, it did not result in a considerable difference in the size of the berries.

It can be concluded that the material of the fiber package absorbs moisture, and the amount of absorbance was higher in +3 °C conditions than in +17 °C or +16 °C conditions. According to Hernandez-Munoz et al. (2008) higher moisture absorptions can result in higher concentration of total soluble solids. Moreover, 1 °Brix equals 1 gram of dissolved sucrose sugar in 100 grams of water (Kafkas 2021), Consequently, when the amount of water becomes less, °Brix value gets higher. So, in our study, higher sugar concentration in fiber packages at +3 °C was due to the moisture absorption by the fiber material.

Variable results for weight losses of raspberries during storage are reported in the literature, and variability may be due to the cultivar and the ripening degree of raspberries, and the storage temperature and relative humidity also play a key role in weight loss (Giovanelli et al 2014).Weight loss of 6–8 % is considered as the limit of marketability (Robinson et al. 1975, Nunes et al. 2002). In this study, at +17 °C, weight loss of raspberries exceeded the limit of 6 % in plastic packages on the 5th day, in fiber packages on the 4th day. At +3 °C, weight loss exceeded the limit of 6 % in fiber packages on the 9th day and in plastic packages on the 12th day.

In our research, strawberries also had higher weight losses in fiber packages than in plastic packages at both temperatures. At +16 °C, weight loss exceeded the limit of 6 % in plastic packages on the 4th day, in fiber packages on the 3rd day. At +3 °C, weight loss exceeded the limit of 6 % in fiber packages on the 6th day and in plastic packages on the 9th day.

Weight loss of fruits has a direct relationship with respiration and moisture evaporation through the skin and strawberries have thin skin making them susceptible to rapid water loss (Hernandez-Munoz et al. 2008). Water vapour pressure gradient between the fruit tissue and the surrounding atmosphere, and the storage temperature determine the rate of the water loss. Higher water loss results in shrivelling and deterioration. Low vapor pressure differences between the fruit and its surroundings and low temperature are suitable to store strawberries.

Color is an excellent indicator being the first sensation that the consumer perceives and uses as a tool to either accept or reject food (Leon et al. 2006). The L*a*b* (CIELab) color space used in this research is an international standard for color measurements used by the Commission Internationale d'Eclairage (CIE) in 1976. Here in the study, color change of raspberries was comparable to the reported literature getting darker (L* value getting lesser), less red (a value getting lesser), and more bluer during storage (Robbins and Moore 1990, Giovanelli et al. 2014, Palonen and Weber, 2019). Strawberries showed a reduction in a* values meaning reductions of red color over the time . Similar results were observed in Aday and Caner (2013) with strawberries getting brown during the storage.

The retention of the inherent color of fresh fruits indicates the quality and has a considerable impact on consumer acceptance (Caner and Aday 2008). So, in our study, Delta E values of color were calculated to see the visible color difference over the storage period compared to the color before storing. In both packages the color difference was visible to the human eye, beginning from the same day. So, the packages act in the same level for the visibility of the color change of raspberry and strawberry.

Similarly, to the previously written articles (Palonen and Weber, 2019) the decay of berry increased over time. In our study, at +16 °C strawberry showed higher decay percentage when they were in the plastic packages. The bottom of the plastic package was taped, and strawberry juice was collecting inside (Appendix 2, figure 42). It can be a reason for strawberries inside the plastic packages were higher in decay percentage. It is obvious that packaging is important to slow down the biological processes caused by senescence/decay along with the other factors like storage time and temperature management, relative humidity, chemical and/or physical treatments (Palumbo et al. 2022).

Gas composition and the level of humidity inside the package are important to avoid condensation and/or mould and bacterial development (Sousa-Gallagher et al. 2013). Package humidity is influenced by respiration and transpiration of the fresh produce as well as the water vapour permeability of the packaging material. If the package material has lower water vapour permeability relative to transpiration rates of fresh produce, most water molecules evaporated from the produce do not escape through and remain within the package, enhancing the water vapour pressure in the package microenvironment. This creates a favourable environment to microbial growth and decay of produce (Linke and Geyer 2013). Creating an optimal atmosphere and reducing the risk of water condensation in the package while still maintaining produce weight loss as low as possible is needed. Recently some package films have used hygroscopic additives, but they are not suitable for fresh produce, which have high water activity, and causes excessive weight loss of the packed food.

Tissue softening (change in texture) is problematic, being a limiting factor for many ready-to eat products (Cortellino et al. 2018). However, there is not a common standardized method to measure the firmness or the texture of berries. Since, berry firmness depends on the microstructure of the fruit, it can decrease, increase, or remain unchanged during storage based on the cultivar differences and postharvest storage conditions (Giacalone and Chiabrando 2012).

In our research firmness of raspberries decreased during the storage time like in Giovanelli et al. (2014). Skin strength of strawberries at +3 °C decreased during storage and comparable to Hernandez-Munoz et al. (2008). The package effect for the berry firmness was only shown in raspberries when stored at +17 °C. It showed fiber packages had less firmness than plastic packages, but the difference was only on the 3rd day. It can be that the individual berries have some other effect, maybe the initial quality because the values of firmness are greatly influenced by the variability in individual berries (Giovanelli et al. 2014). Therefore, no difference of firmness of berries was observed between the two types of packages.

The stains of the berry juice were more visible in the fiber packages than in plastic packages in the photographs taken during the experiment. The reason is the whiter surface of the fiber packages, and if the photographs of the plastic packages were taken keeping a white surface under the plastic package, those stains would have been also as visible as in the fiber packages. It seemed the same amount of stains were in both packages but visibility in fiber packages was higher.

The berries are likely to release more juice over the storage time, getting less firm and more decayed. This resulted in more juice stains in the packages over the storage time. During the experiment, the berry packages were carried from place to place for measurements, berry packages were taken out from the carried styrofoam box, then put back, and this was done several times a day which would have affected the juice coming out from the berries. This much of shaking of the berries may or may not happen in the retail shops or with the consumers.

The microscopic images of the stains of the fiber packages showed the juice has stopped in a middle layer of the package which was a good sign for the consumer. Otherwise, leaking the juice outside of the package will be a problem for the appearance and the convenience of using the package for berries. However, to prevent the stains of the fiber packages, an absorbent pad can be suggested which is currently available in some of the commercial berry packages.

Because the measurements were destructive, Not the same berry package was evaluated every day, different package was observed each day, so some data (for example decay and color) did not show constant increase or decrease with time.

7 Conclusion

Fiber packages absorbed more moisture from berries than plastic packages. Raspberries in fiber packages at +3 °C exceeded the weight loss or the water loss of 6 %, which is the margin of marketability, from 9th day onwards and strawberries in fiber packages at +3 °C from 9th day onwards. Therefore, it can be concluded that the fiber packages can keep raspberries upto 8 days and strawberries upto 5 days under the marketable condition at +3 °C, and are possible replacements to plastic clamshells. For longer storage periods fiber packages need to be developed further to reduce moisture losses.

8 Acknowledgements

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9 Bibliography

Aday, M. S. & Caner, C. 2013. The shelf-life extension of fresh strawberries using an oxygen absorber in the biobased package. LWT - Food Science and Technology 52: 102 – 109.

Akagi´, A., Oras, A. V., Žuljevi´c S. O., Spaho N., Drkenda P., Bijedi´c A., Memi´c S. & Hudina M. 2020. Geographic variability of sugars and organic acids in selected wild fruit species. Foods 2020, 9: 462.

Bhat R., Geppert J., Funken E. & Stamminger R. 2015. Consumers Perceptions and Preference for Strawberries—A Case Study from Germany. International Journal of Fruit Science 15: 405-424.

Caner, C., Aday, M. & Demir, M. 2008. Extending the quality of fresh strawberries by equilibrium modified atmosphere packaging. European Food Research and Technology 227: 1575-1583.

Caner, C. 2011. Sorption phenomena in packaged foods: Factors affecting sorption processes in package – product systems. Packaging Technology and Science 24: 259–270.

Cordenunsi, B. R., Genovese, M. I., Nascimento, J. R. O., Hassimotto, N. M. A., Santos, R. J. & Lajolo, F. M. 2005. Effects of temperature on the chemical composition and antioxidant activity of three strawberry cultivars. Food Chemistry 91: 113–121.

Cortellino, G., Vecchi, P. D., Lo, S. R., Ughini, V., Granelli, G. & Buccheri, M. 2018. Ready-to-eat raspberries: qualitative and nutraceutical characteristics during shelf-life. Adv. Hort. Science 32: 399-406.

Environment Committee, European Parliament. 2023. Packaging: new EU rules to reduce, reuse and recycle | News | European Parliament (europa.eu). Last updated on 24th of October 2023. Accessed on 3rd November 2023.

Fan, Y., Xu, Y., Wang, D., Zhang, L., Sun, J., Sun, L. & Zhang, B. 2009. Effect of alginate coating combined with yeast antagonist on strawberry (*Fragaria × ananassa*) preservation quality Postharvest Biology and Technology 53: 84–90.

Fischer, N. & Hammerschmidt, F. J. A 1992. Contribution to the analysis of fresh strawberry flavour. Chem. Mikrobiol. Technol. Lebensm. 14: 141-148.

Forney, C.F. 2009. Postharvest issues in blueberry and cranberry and methods to improve market-. Acta Hort. 810: 785-792.

Funt R. C. & Hall, H.K. 2013. Raspberries. Crop production science in horticulture series 23. CABI, UK: CABI head office. pp. 177 – 178.

Giacalone, G. & Chiabrando, V. 2012. Problems and methods to improve the market-life of berry fruit in: berries: properties, consumption and nutrition. Tuberoso C. (eds.). pp. 185-192.

Giovanelli, G., Limbo, S. & Buratti S. 2014. Effects of new packaging solutions on physico-chemical, nutritional and aromatic characteristics of red raspberries (*Rubus idaeus* L.) in postharvest storage. Postharvest Biology and Technology 98: 72-81.

Girgenti, V., Massaglia, S., Mosso, Angela., Peano, C. & Brun, F. 2016. Exploring perceptions of raspberries and blueberries by Italian consumers. Sustainability 8: 1027.

Giuggioli, N.R., Briano, R., Baudino, C. & Peano, C. 2015. Effects of packaging and storage conditions on quality and volatile compounds of raspberry fruits. CyTA Journal of Food 13: 512-521.

Goulas, V. & Manganaris, G. A. 2011. The effect of postharvest ripening on strawberry bioactive composition and antioxidant potential. J. Sci. Food Agriculture 91: 1907–1914.

Hadadinejad, M., Ghasemi, K. & Mohammadi, A. A. 2018. Effect of storage temperature and packaging material on shelf Life of thornless blackberry. International Journal of Horticultural Science and Technology 5: 265-275.

Haffner, K., Vestrheim, S., 1997. Fruit quality of strawberry cultivars. Acta Hort. 439: 325–332.

Haffner, K., Rosenfeld, H.J., Skrede, G. & Wang, L. 2002. Quality of raspberry *Rubus idaeus* L. cultivars after storage in controlled and normal atmospheres. Postharvest Biol. Technol. 24: 279–289.

Hansen, S., Black, B., Alston, Diane., Lindstrom T. & Olsen S. 2021. A comparison of nine primocane fruiting raspberry cultivars for suitability to a high-elevation, arid climate. International Journal of Fruit Science 21: 500-508.

Hernandez-Munoz, P., Almenar, E., Del Valle, V., Velez, D. & Gavara, R. 2008. Effect of chitosan coating combined with postharvest calcium treatment on strawberry (*Fragaria x ananassa*) quality during refrigerated storage. Food Chemistry 110: 428-435.

Horvitz, S. 2017. Post harvest handling of berries. In: Kahramanoglu, I. (ed.). 2017. Postharvest Handling. InTech. pp. 108-118.

Huynh, N.K., Wilson, M.D. & Stanley R.A. 2023. Extending the shelf life of raspberries in commercial settings by modified atmosphere/modified humidity packaging. Food Packaging and Shelf Life 37: 101069.

Kader, A. A. 1997. Fruit maturity, ripening, and quality relationships. Acta Hort. 485: 203-208.

Kafkas, E.Y. 2021. Comparison of fruit quality characteristics of berries. Journal of Materials Science and Chemical Engineering 12: 907-915.

Kalt, W., Forney, C.F., Martin, A. & Prior, R.L. 1999. Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. Journal of Agriculture and Food Chemistry 47: 4638-4644.

Khanizadeh, S., Rekika, D., Ehsani-Moghaddam, B., Tsao, R., Yang, R., Charles, M. T., Sullivan, J. A., Gauthier, L., Gosselin, A., Potel, A. M., Reynaud, G. & Thomas, E. 2009. Horticultural characteristics and chemical composition of advanced raspberry lines from Quebec and Ontario. LWT - Food Science and Technology 42: 893 – 898.

Ktenioudaki A., Esquerre C. A. , Nunes C. M. D. N. & O'Donnell C. P. 2022. A decision support tool for shelf-life determination of strawberries using hyperspectral imaging technology. Biosystems engineering 221:105 -117

Koraqi, H., Durmishi, N., Rizani K. L. & Rizani S. 2019. Chemical composition and nutritional value of Raspberry fruit (*Rubus idaeus* L.).UBT International Conference. 397.

Koutsimanis, G., Getter, K., Behe, B., Harte J. & Almenar E. 2012. Influences of packaging attributes on consumer purchase decisions for fresh produce. Appetite 59: 270–280.

Krüger, E., Dietrich, H., Schöpplein, E., Rasim, S. & Kürbel, P. 2011. Cultivar, storage conditions and ripening effects on physical and chemical qualities of red raspberry fruit. Postharvest Biology and Technology 60: 31-37.

Leo´n, K., Mery, D., Pedreschi, F. & Leo´n, J. 2006. Color measurement in L* a * b* units from RGB digital images. Food Research International 39: 1084–1091.

Leet, L., Arult, J., Lencki, R. & Castaignet, F. 1996. A review on modified atmosphere packaging and preservation of fresh fruits and vegetables: Physiological basis and practical aspects-Part II. Packaging Technology and Science 9: 1-17.

Linke M. & Geyer M. 2013. Condensation dynamics in plastic film packaging of fruit and vegetables. Journal of Food Engineering 116: 144–154.

MacLeod, M., Arp, H. P. H., Tekman, M. B. & Jahnke, A. 2021. The global threat from plastic pollution. Science 373: 61-65.

Mezzetti, B. 2013. EUBerry: The sustainable improvement of European berry production, quality, and nutritional value in a changing environment. International Journal of Fruit Science 13: 60-66.

Nunes, M.C.N., Brecht, J.K., Morais, A.M.M.B. & Sargent, S.A. 1995. Physical and chemical quality characteristics of strawberries after storage are reduced by a short delay to cooling, Postharvest Biology and Technology 6: 17-28.

Nunes, M.C.N., Morais, A.M.M.B., Brecht, J.K. & Sargent, S.A. 2002. Fruit maturity and storage temperature influence response of strawberries to controlled atmospheres J. Amer. Soc. Hort. Sci. 127:836–842.

Nunes, M. C. N., Brecht, J. F., Morais, A. M. M. B. & Sargent, S. A. 2005. Possible influences of water loss and polyphenol oxidase activity on anthocyanin content and discoloration in fresh ripe strawberry (cv. Oso Grande) during storage at 1 °C. Journal of Food Science 70: S79–S84.

Oliveira J.C., Ramos, A. V. & Sousa-Gallagher, M. J. A. 2022. Meta-study of the permeance of perforated packaging films to oxygen and carbon dioxide. Food Engineering Reviews 14: 328–352.

Palumbo, M., Attolico, G., Capozzi, V. , Cozzolino, R. , Corvino, A., Chiara, M. L. V. , Pace, B., Pelosi, S., Ricci, I. , Romaniello, R. & Cefola, M. 2022. Emerging postharvest technologies to enhance the shelf-life of fruit and vegetables: An overview. Foods 2022, 11: 3925.

Palonen, P., Pinomaa, A. & Tommila, T. 2017. The influence of high tunnel on yield and berry quality in three floricane raspberry cultivars. Scientia Hort. 214: 180–186.

Palonen, P. & Weber, C. 2019. Fruit color stability, anthocyanin content, and shelf life were not correlated with ethylene production rate in five primocane raspberry genotypes. Scientia Hort. 247: 9–16.

Palonen P., Laine T. & Mouhu K. 2021. Floricane yield and berry quality of seven primocane red raspberry (*Rubus idaeus* L.) cultivars. Scientia Hort. 285:110201.

Petersen, K., Nielsen, P. V., Bertelsen, G., Lawther, M., Olsen, M. B., Nilssonk, N. H. & Mortenseny, G. 1999. Potential of biobased materials for food packaging. Trends in Food Science & Technology 10: 52 – 68.

Piljac-Žegarac, J. & Šamec, D. 2011. Antioxidant stability of small fruits in postharvest storage at room and refrigerator temperatures. Food Research International 44: 345–350.

Robinson, J. E., Browne K. M. & Burton W. G.1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biology 81: 399-408.

Robbins, J. & Sjulin, T. M. & Patterson M. 1989. Postharvest storage characteristics and respiration rates in five cultivars of red raspberry. HortScience 24: 980-982.

Robbins, J. A. & Moore, P. P. 1990. Color Change in Fresh Red Raspberry Fruit Stored at 0, 4.5, or 20C Hort.Science 25:1623-1624.

Robertson, G.L. 2013. Food Packaging. Principles and practice. 3rd edition. CRC,NW:Taylor & Francis Group. pp. 494 – 496.

Sawicka, B., Barbas, P., Skiba, D., Krochmal-Marczak, B. & Pszczółkowski, P. 2023. Evaluation of the quality of raspberries (*Rubus idaeus* L.) grown in balanced fertilization conditions. Commodities 2023 2: 220–245.

Seglina, D., Krasnova, I., Heidemane, G., Kampuse, S., Dukalska, L. & Kampuss, K. 2010. Packaging technology influence on the shelf life extension of fresh raspberries. Acta Hort. 877:433-440.

Sousa-Gallagher M.J., Mahajan P.V. & Mezdad, T. 2013. Engineering packaging design accounting for transpiration rate: Model development and validation with strawberries. Journal of Food Engineering 119: 370–376.

Thøgersen, J. 1999. The Ethical Consumer. Moral Norms and Packaging Choice. Journal of Consumer Policy 22: 439–460.

Villamor, R.R., Daniels, C.H., Moore, P.P. & Ross, C.F. 2013. Preference mapping of frozen and fresh raspberries. Journal of Food Science 78: S911-S919.

Wang, S.Y. & Gao H. 2013. Effect of chitosan-based edible coating on antioxidants, antioxidant enzyme system, and postharvest fruit quality of strawberries (*Fragaria x ananassa* Duch.) LWT - Food Science and Technology 52: 71-79.

Wills, R.B.H., McGlasson, W.B., Graham, D. & Joyce, D.C. 2007. An introduction to the physiology and handling of fruit, vegetables and ornamentals. Postharvest 5th edition. CABI, UK: CABI head office. 227 p.

Zhang, Y., Duan, C., Bokka, S. K., He, Z. & Ni, Y. 2022a. Molded fiber and pulp products as green and sustainable alternatives to plastics: A mini review. Journal of Bioresources and Bioproducts 7: 14–25.

Zhang, Y., Li S., Deng M., Gui R., Liu Y., Chen X., Lin Y., Li M., Wang Y., He W., Chen Qing., Zhang Y., Luo Y., Wang X. & Tang H. 2022b. Blue light combined with salicylic acid treatment maintained the postharvest quality of strawberry fruit during refrigerated storage. Food Chemistry 15: 100384.

Appendix 1. Fiber packages which contained raspberries

Figure 27. Fiber packages after emptying raspberries on day 1 at 17 °C.

Figure 28. Fiber packages after emptying raspberries on day 2 at 17 °C.

Figure 29. Fiber packages after emptying raspberries on day 3 at 17 °C.

Figure 30. Fiber packages after emptying raspberries on day 4 at 17 °C.

Figure 31. Fiber packages after emptying raspberries on day 5 at 17 °C.

Figure 32. Fiber packages after emptying raspberries on day 7 at 17 °C.

Figure 33. Fiber packages after emptying raspberries on day 3 at +3 °C.

Figure 34. Fiber packages after emptying raspberries on day 6 at +3 °C.

Figure 35. Fiber packages after emptying raspberries on day 9 at +3 °C.

Figure 36. Fiber packages after emptying raspberries on day 12 at +3 °C.

Figure 37. Fiber packages after emptying raspberries on day 21 at +3 °C.

Appendix 2. Fiber packages which contained strawberries

Figure 38. Fiber packages after emptying strawberries on day 1 at +16 °C.

Figure 39. Fiber packages after emptying strawberries on day 2 at +16 °C.

Figure 40. Fiber packages after emptying strawberries on day 3 at +16 °C.

Figure 41. Fiber packages after emptying strawberries on day 4 at +16 °C.

Figure 42. Fiber packages after emptying strawberries on day 5 at +16 °C.

Figure 43. Fiber packages after emptying strawberries on day 3 at +3 °C.

Figure 44. Fiber packages after emptying strawberries on day 6 at +3 °C.

Figure 45. Fiber packages after emptying strawberries on day 9 at +3 °C.

Figure 46. Fiber packages after emptying strawberries on day 12 at +3 °C.

Figure 47. Fiber packages after emptying strawberries on day 15 at +3 °C.

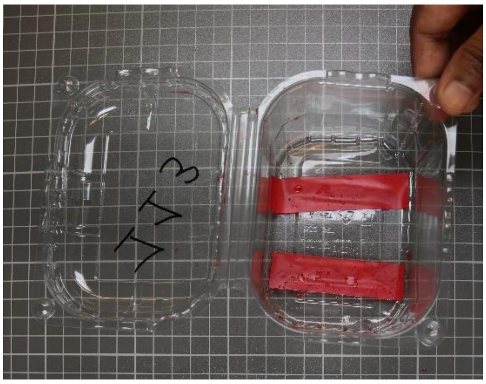

Figure 48. Representative empty plastic package after removing the strawberries.

Appendix 3. Images of strawberries

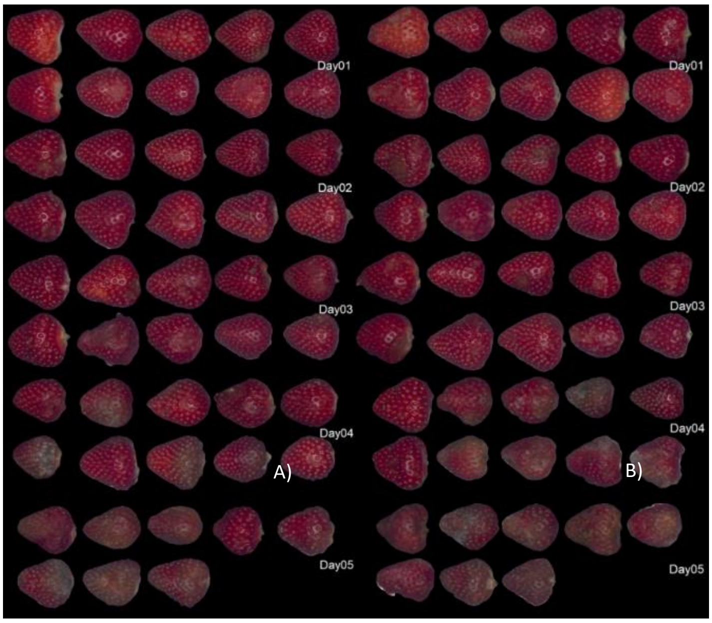

Figure 49. A - Strawberries in fiber packages at +16 °C, B - Strawberries in plastic packages at +16 °C.

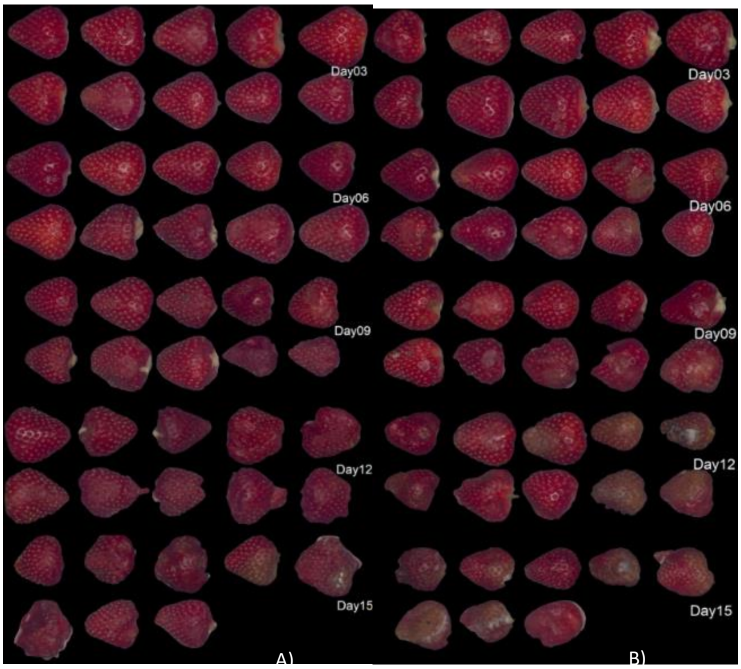

Figure 50. A - Strawberries in fiber packages at +3 °C, B - Strawberries in plastic packages at +3 °C.

Appendix 4. Images of raspberries

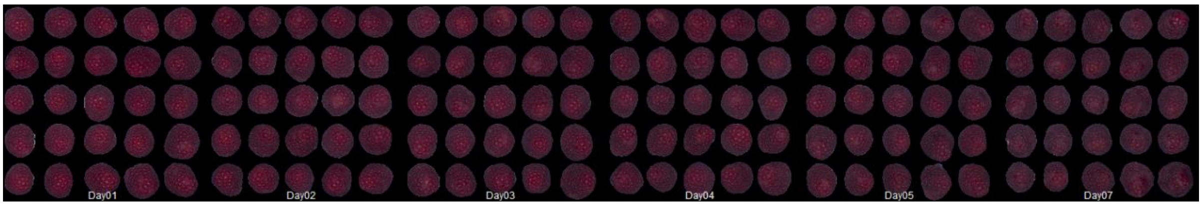

Figure 51. Raspberries in plastic packages at +17 °C.

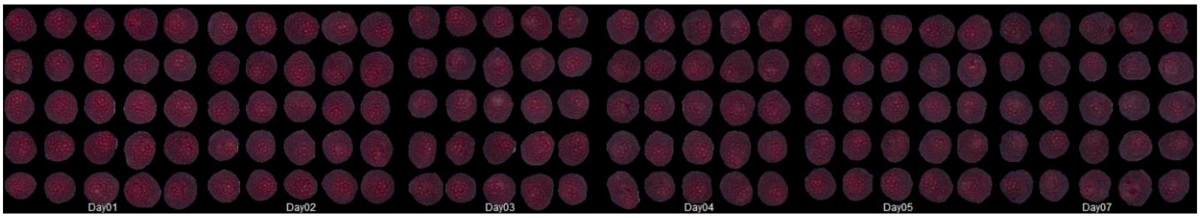

Figure 52. Raspberries in fiber packages at +17 °C.

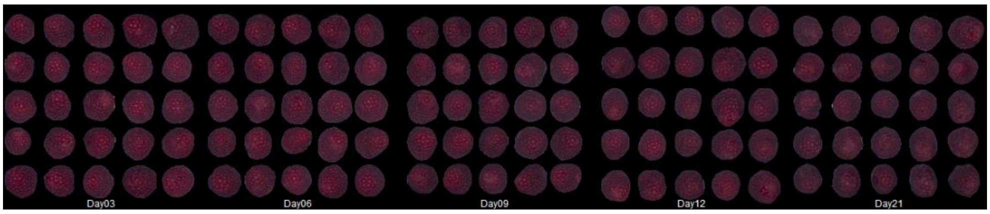

Figure 53. Raspberries in plastic packages at +3 °C.

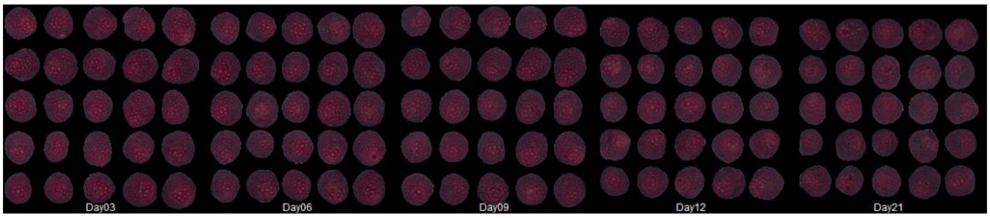

Figure 54. Raspberries in fiber packages at +3 °C .