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Effect of Passive Modified Atmosphere in Different Packaging Materials on Fresh-Cut Mixed Fruit Salad Quality during Storage

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***Abstract*—**Experiments were carried out at the Latvia State Institute of Fruit-Growing in 2011. Fresh-cut minimally processed apple and pear mixed salad were packed by passive modified atmosphere (MAP) in PP containers, which were hermetically sealed by breathable conventional BOPP Propafresh™ P2GAF, and Amcor Agrifresh films. Biodegradable NatureFlex™ NVS INNOVIA Films and VC999 BioPack PLA films coated with a barrier of pure silicon oxide (SiOx) were used to compare the fresh-cut produce quality with this packed in conventional packaging films. Samples were cold stored at temperature +4.0±0.5 °C up to 10 days. The quality of salad was evaluated by physicochemical properties – weight losses, moisture, firmness, the effect of packaging modes on the colour, dynamics in headspace atmosphere concentration (CO_2 and O_2), titratable acidity values, as well as by microbiological contamination (yeasts, moulds and total bacteria count) of salads, analyzing before packaging and after 2, 4, 6, 8, and 10 storage days.

***Keywords*—**Biodegradable packaging, conventional, fresh-cut fruit salad

I. Introduction

FRESH-CUT fruits and vegetables are products that are minimally processed and altered by peeling, slicing or chopping with or without washing [1]. Production of fresh-cut fruits and vegetables is increasing as consumers are becoming aware of the nutritional benefits and convenience of ready-to-eat products. As a result, the fresh-cut industry has undergone rapid growth [2], [3]. The demand for fresh-cut produce on the market has been greatly increased relevant to consumer choice for ready-to-eat products [4], [5]. These products are processed from fresh fruits and vegetables which remain metabolically active even after harvesting and undergo ripening and senescence processes. The shelf life of these commodities is very short, usually a few days (1-3 days).

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Processing of fruit promotes a faster physiological deterioration, biochemical changes and microbial degradation of the products which may result in degradation of its colour, texture and flavour, even when only slight processing operations are used [6], [7]. The incidence of food borne outbreaks caused by contaminated fresh fruit has recently increased. Cutting process of fruits and vegetables degrades appearance, textural quality, and freshness. Modified atmosphere packaging with gas flash of 2-5% O_2 and 2-5% CO_2 was traditionally used to keep fresh fruits and vegetables, but higher gas concentration should be required for fresh cut produce [8]. Quality factors that can shorten the shelf life are numerous: dehydration, discoloration, microbial growth and decay, and off-odor development.

Developed modified atmosphere packaging (MAP) can assist in increasing shelf life by reducing enzymatic browning, respiration rate, moisture loss, and some microbial growth, it must be accompanied by appropriate storage temperature, minimal physiological damage and other microbial reduction methods [9]. MAP is one of the most important techniques used to achieve safety in fresh-cut fruits and/or to prolong their shelf life. Fresh fruit continues to respire, consuming oxygen and producing carbon dioxide and water vapour. Very successful applications of MAP are reported for fresh-cut pineapple, apples, kiwifruit, honeydew, bananas, and mangoes [10]–[15]. Low levels of O_2 and high levels of CO_2 were used to reduce the fresh produce respiration rate, with the aim of prolonging shelf life. Very low O_2 atmospheres may result in an increase in fermentation [16], [17].

Packaging is an integral and determinant part of the industrial and commercial food supply chain [18]. For shelf life extension of processing products different packaging materials and technologies can be used. It is known that beneficial modified atmospheres within fresh-cut fruit packages are attained by correctly choosing packaging materials that will provide the appropriate levels of oxygen and carbon dioxide into packets [19]. Each packaging film has specific O_2 and CO_2 permeability. Generally, conventional polymer films are chosen for whole fruit MAP. [20]. However, for fresh-cut or minimally processed fruits and vegetables, which have a higher respiration rate values and require a higher O_2 concentration and lower CO_2 concentration, perforated MAP is indeed as potential alternative, where the gas permeation of films can be adjusted by changing the dimensions of perforation [21].

Innovia films Limited in 2010 has launched a new range of non perforated and breathable biaxially oriented BOPP films PropaFresh P2G & P2GAF for fresh produce packaging [22]. They are tailor made to fulfil the specific needs of packaging industry and have the flexibility to monitor and control the rate at which oxygen and carbon dioxide goes in or out of a particular packaging through the BOPP film ensuring a longer storage life, with the assurance for freshness being intact and preserved. Currently, most active packaging technologies for fruits and vegetables depend on sachet technology, which contain the active ingredients inside the small bags that are placed inside of the food package. Sachets have low consumer acceptance due to possible accidental ingestion of their contents [23]. Active film/container application is more appropriate for fresh-cut produce [24]. Various moisture absorbers can modify package humidity. Commonwealth Scientific and Industrial Research Organization (CSIRO) developed a moisture control system used in a form a liner inside any box to control humidity [25]. Antifogging films are usually used for respiring products – fresh-cut fruits and vegetables to reduce the internal vapour presser and prevent water vapour condensation [25]. Active and intelligent packaging technologies are efficient in controlling the deterioration reactions of fresh-cut fruit and vegetables, applications of active and intelligent packaging in fruits and vegetables are still in their infancy [21].Edible coatings were found to be able to extend the shelf life of fresh-cut products by decreasing respiration and senescence and protecting aroma, texture and colour [26], [28]. They also inhibit the surface spoilage by blocking aerobic micro-organisms from the access of oxygen [28]. Biodegradable polymer market introduction has started successfully all over Europe [38], [30], [18]. Most important application sector of biodegradable polymers at the present time mainly is packaging of organically produced food, conventional fruit and vegetables. PLA (polylactic acid) is the most widely used biodegradable polymer for fresh-food applications. Nowadays new biodegradable materials have been produced with improved barrier properties, for instance VC999 BioPack lidding film PLA, coated with a barrier of pure silicon oxide (SiOx) [31].

The objective of this work was to evaluate the effect of passive modified atmosphere in different packaging materials on the quality of fresh-cut mixed apple and pear salads during cold storage and to determine the microbiological stability.

II. Materials and Methods

A. Experimental Design

Experiments were carried out in laboratories of Latvia State Institute of Fruit Growing in 2011. The object of the research was salad made of apples *(Malus domestica* L.) 'Sinap Orlovskij' and pears *(Pyrus communis* L.) 'Conference' grown in Dobele, Latvia. After harvesting fruits were stored for 3 months in a warehouse of the Institute at temperature +4 ºC and relative humidity (RH) 90%. Before processing the fruits were washed in running water and their surface treated for 30 min by Natureseal® FS antimicrobial solution (pH 2.4) to eliminate initial microbiological contamination. Natureseal® AS5 (AgriCoat Ltd., Great Shefford, United Kingdom) was used as antibrowning agent. Fruits were peeled and cut by sharp knife in small pieces (10.0 x 15.0 mm) and soaked for 3 min in 5% solution of Natureseal® AS5, prepared one hour before experiments. The samples after treatment with antibrowning solution were strained on the sieve for 10 min. Part of samples was treated 2 min by ozone as antimicrobial agent to eliminate the secondary contamination using A2ZOzone systems INC (oxygen feeding from balloon was 5 l min^{-1}, concentration of ozone 40 pp). Fruit pieces were sweetened by 30% sugar syrup (DanSukker, Denmark). The laboratory premises and instruments were treated by disinfection solution ASEPTOL XL (Spodriba, Latvia).

B. Packaging and Storage of Samples

1. Packaging of Samples

Seven different packaging variants (films and boxes) were accomplished for packaging and testing of fruit salad prepared from apples and pears in proportion 4:1 (80% and 20%). The characteristic of packaging forms and films used in experiments is shown in the Table I.

TABLE I
CHARACTERISTICS OF USED MATERIALS IN EXPERIMENTS

Sample Nr.	Geometry of packaging	Sealing type and material	Dimensions, mm
1.	PP containers	Hanging lid, PP	140x102x42
2.	PP containers + enclosed humidity absorbent pad	Hanging lid, PP	140x102x42 δc=53±1µm
3.	PP box, fruits treated by O_3	Hanging lid, PP	140x102x42
4.	Duni PP container	Sealed by Amcor Agrifresh breathable film	80x120x42
5.	Duni PP container	Sealed by BOPP film Propafilm™ P2GAF	80x120x42 δf=38 ±1µm
6.	Duni PP container	Enclosed in pouch of NatureFlex™ NVS INNOVIA Films	80x120x42 δf=35 ±1µm
7.	Duni PP container	Enclosed in pouch of VC999 BioPack PLA film	80x120x42 δf=50±2µm

PP = polypropylene, PLA = polylactic acid, δc = thickness of film, µm = micrometer.

Duni PP containers were used as experimental packaging. They were hermetically sealed by equipment SEAL-300 using two kinds of breathable films – BOPP film Propafresh™ P2GAF with antifog coating and Amcor AgriFresh – US style integral OTR film for fresher prepared salad. Two types of biodegradable breathable films (cellulose based NatureFlex™ NVS INNOVIA Films and VC999 BioPack PLA coated with a barrier of pure silicon oxide (SiOx)) were used. Those films could not be sealed to PP containers; therefore pouches by appropriate dimensions were made from films and PP containers enclosed. Polypropylene (PP) containers with hanging lids were used as control packaging. The prepared apple and pear mixed salad were packed in beforehand described PP containers by 180±5 g in each and sealed in air ambiance for passive modified atmosphere formation during storage.

2. Storage and Analyses of Samples

Samples were stored in a commercial freezer/cooler camera for 10 days at the temperature of +4.0±0.5 °C, controlled by MINILog Gresinger electronic. Physical and chemical properties: headspace gas composition, moisture content, mass loss, titratable acidity, pH, colour of salad samples and firmness were evaluated. The content of micro organisms – mesophylic aerobic and facultative anaerobic (total bacteria), yeasts and moulds, lactic acid bacteria was pointed. At each time of measurement, three identical packages for each packaging mode were randomly selected on sampling day and at 2nd, 4th, 6th, 8th, and 10th day of storage. Six measurement repetitions of each sample were performed.

C. Physical and Chemical Analyses

Headspace gas composition (%) – oxygen (O_2) and carbon dioxide (CO_2) was measured using a gas analyzer OXYBABY® V O_2/CO_2. *Moisture content (%)* was determined by ISO 6496:1999**.** *Total soluble solids (ºBrix)* were measured using standard LVS EN 12143:2001. *Mass loss (%)* was detected by standard LVS ISO 1442:1997. *Colour* of fruit salad samples was measured in CIE L*a*b* colour system using Tristimulus Colorimeter, measuring Hunter colour parameters by Colour Tec PCM/PSM. Colour values were recorded as L* (brightness) – the vertical co-ordinate runs from L* = 0 (black) through grey to L* = 100 (white); a* (-a, greenness, +a, redness) – the horizontal co-ordinate, that runs from -a* (green) through grey to +a* (red) and b* (-b, blueness, +b, yellowness) – another horizontal co-ordinate, that runs from -b* (blue) through grey to +b* (yellow). The colour measurements were performed of 20 fruit peaces in three repetitions for each. The colour of fruit flesh was expressed as whiteness index (WI), which was calculated according to equation (1) using colour indices L*, a* and b* as reported by Albanese [32]:

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \qquad (1)$$

Where: L*, a*, b*– Colour measurements of the fruit piece sample. *Flesh firmness (N)* was determined by digital penetrometer TSM-Pro according to LVS EN 1131:2001. Nozzle diameter used – 6 mm, penetration depth – 5 mm, speed of measurement – 60 mm min^{-1}. The firmness was reported as the maximum force. *Titratable acidity (%)* was detected by the potentiometer titration with 0.1 N NaOH till pH 8.1 using pH meter (Jenway 3510) with combined electrode was used for the potentiometer titration. *Microbial analyses (colony forming units (CFU)/g fruit tissue)* were tested according to LVS EN ISO 6887-5:2011. Determination of the total amount of microorganisms – mesophylic aerobic and facultative anaerobic (total bacteria) – was conducted according to the standard LVS EN 4833:2003. Determination of yeasts and moulds was performed according to the standard LVS ISO 21527:2003.

D. Statistical Analyses

The results were processed by mathematical and statistical methods. Statistics on completely randomized design were determined using the General Linear Model (GLM) procedure using SPSS 15 software package. Two-way analyses of variance ($p \leq 0.05$) were used to determine significance of differences between mass losses, firmness, changes of atmosphere content (CO_2 and O_2) in headspace of packs, and microbial conditions by different packed samples.

III. Results and Discussion

Physicochemical properties of fresh-cut slices of apples ('Sinap Orlovskij') and pears ('Conference') before processing are presented in Table II.

TABLE II
PHYSICOCHEMICAL PROPERTIES OF FRESH-CUT FRUIT SLICES

Property	Unit of measurement	Apples	Pears
Titratable acidity – Malic acid	%	0.66±0.04	0.09±0.2
Total soluble solids	ºBrix	11.17±0.24	11.55±0.15
L *		74.26±1.12	67.83±2.14
a *		-5.52±1.61	-3.13±2.01
b*		18.4±3.47	12.32±3.43
Whiteness index (WI)		67.76±2.85	65.17±2.0
Firmness	N	18.39±0.97	9.08±1.12

N = newton, g = gram.

Breathable and biodegradable lidding films with appropriate oxygen transmission rate (OTR) play an important role in developing of equilibrium modified atmosphere (EMA) and quality maintenance in packages of fresh-cut produce during storage. Water vapor permeability of packaging materials is essential for generation of mass losses as water evaporates from product during storage. Observed mass losses of fruit salad were insignificant during 10 storage days. In our experiments established that mass losses as evaporated water permeated through VC999 BioPack PLA lidding film was the highest (0.46%) compared to other modes of salad packaging.

The mass losses mainly arise due to higher water vapour permeability of PLA films. Treatment of fruit samples by ozone (O_3) promoted water evaporation from fruits during storage. Therefore the mass losses of fruits treated by ozone and packed in traditional closed containers were higher (0.23%) than in other samples packed in closed PP containers (0.15-0.18%). Similar mass losses were reported by Rocha and Morais (2003), determined in air ambiance packaging during 10 days of storage at 4 °C, that was admitted as quite low – 0.22% [33]. The passive equilibrium modified atmosphere (EMA) composition in the headspace of packs during storage changed and the increase of carbon dioxide (CO_2) and decrease of oxygen (O_2) was miscellaneous dependent from barrier properties of used lidding films. The higher increase of CO_2 content during first two storage days was observed in packs sealed by Amcor Agrifresh and NatureFlex™ NVS INNOVIA Films – up to 7-8%. The increase of CO_2 in sealed PP containers was not notable – not more than 1-3%, and that concentration remained constant during all 10 storage days (Fig. 1). CO_2 content in containers sealed by BOPP Propafresh™ P2GAF film increased most of all and reached 18%, while in containers sealed by Amcor Agrifresh – by 13%, enclosed in NatureFlex™ NVS INNOVIA Films pouch –

15%, and in VC999 BioPack PLA film pouch – by 9%.

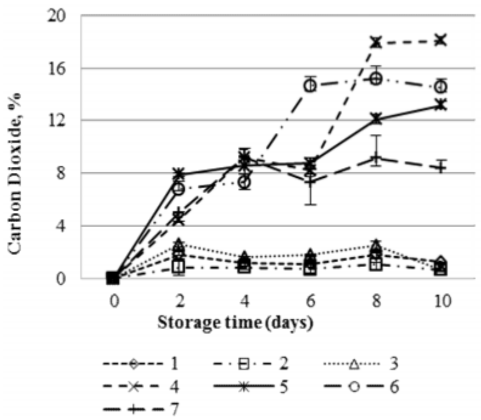

Fig. 1 Dynamics of Carbon Dioxide (CO_2) Content in the Headspace of Packages in Passive Modified Atmosphere of the Fresh-Cut Mixed Apple and Pear Salad

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP PropafreshTM P2GAF film; **6** – Duni PP container enclosed in NatureFlexTM NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch.

The O_2 content in all fruit salad packs decreased as a result of fresh-cut fruit breathing and forming of equilibrium modified atmosphere. The dynamics of O_2 concentration is presented in Fig. 2. The decrease of O_2 content and corresponding gas composition in different hermetically closed packaging made of various materials is disparate. In sealed PP containers the decrease of O_2 was not more than 1-3%, and that concentration remained constant during all 10 storage days.

Oxygen content in containers sealed by BOPP PropafreshTM P2GAF film decreased most of all and reached 8%, in containers sealed by Amcor Agrifresh – 15%, enclosed in NatureFlexTM NVS INNOVIA Films pouch – 13%, and in VC999 BioPack PLA film pouch – 16%, accordingly to CO_2 increase. Equilibrium among O_2 and CO_2 concentration developed within 10 storage days. These conditions resulted in retention of quite good textural, aroma, flavour and microbial characteristics of tested fruit salad. Passive modified atmosphere conditions established in conventional film BOPP PropafreshTM P2GAF film and biodegradable NatureFlexTM NVS INNOVIA Films therefore they could be recognized as the best materials for minimal fresh-cut produce respiration and quality maintenance.

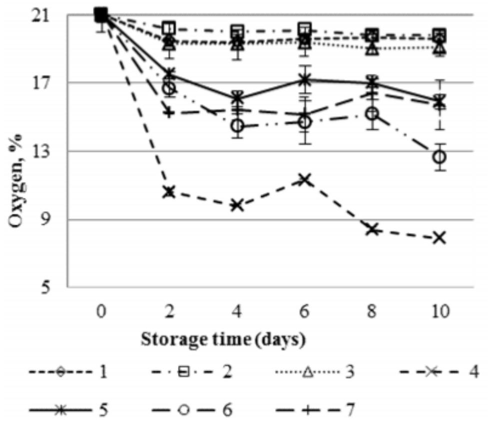

Fig. 2 Dynamics of Oxygen (O_2) Content in the Headspace of Packages in Passive Modified Atmosphere of the Fresh-Cut Mixed Apple and Pear Salad

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP PropafreshTM P2GAF film; **6** – Duni PP container enclosed in NatureFlexTM NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch.

The changes of flesh firmness of fresh-cut fruit salad dices packed in various packaging types in passive modified atmosphere are presented in Fig. 3. The firmness of fresh-cut apple slices before various treatment processes was 18.3 ±1 N, which after treatment differed and during storage reduced gradually.

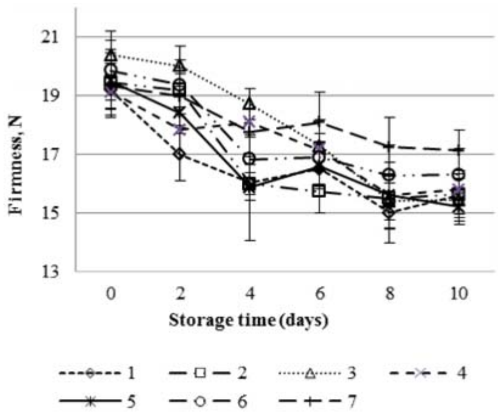

Fig. 3 Dynamics of the Fresh-Cut Mixed Apple and Pear Salad Firmness during the Storage

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP PropafreshTM P2GAF film; **6** – Duni PP container enclosed in NatureFlexTM NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch.

The firmness of fruits least have changed in Duni PP container enclosed in VC999 BioPack PLA film pouch (from 19.4±0.8 to 17.1±0.5 N) and NatureFlexTM NVS INNOVIA Films packaging (from 19.9±1 to 16.3±0.9 N), which could be explained by the influence of appropriate equilibrium atmosphere. However, the difference among sample firmness after 10 days storage was not substantial ($p>0.05$), and salad firmness could be evaluated as good.

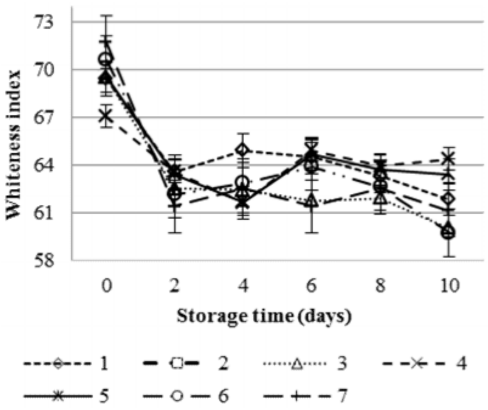

Fig. 4 The Effect of Packaging Methods on the Colour (whiteness index) Changes of the Fresh-Cut Mixed Apple and Pear Salad during the Storage

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP Propafresh™ P2GAF film; **6** – Duni PP container enclosed in NatureFlex™ NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch.

Many researchers have reported their observations of fast fresh-cut apple browning in the first storage days [34]. Consequently, our results could be evaluated similarly.

The titratable acidity content of apple slices differed from pear slices (Table II). The salad sample was analyzed as an average of the fruit mixture. The changes in titratable acidity in different packaging modes differed ($p=0.01$) and during all storage time the acidity decreases substantially ($p<0.05$) (Fig.5). Comparatively less acidity decrease was observed in salad packed in PP container with enclosed humidity absorbent pads and Duni PP container hermetically sealed by breathable BOPP Propafresh™ P2GAF film. The acidity decrease mainly was influenced in salad treated by ozone and packed in PP containers and samples packed in PP containers hermetically sealed by BOPP Propafresh™ P2GAF film. It could be connected with more slowly breathing and less oxygen content decrease in packaging (Fig.2). The major decrease of titratable acidity was similar during the first storage days in all packaging manners. It could be explained by increase of breathing intensity after peeling and slicing of fruits [34]. The organic acids together with another compounds take part in the breathing reactions, as a result the total content of acids decreases and pH value increases [37], [38], [39].

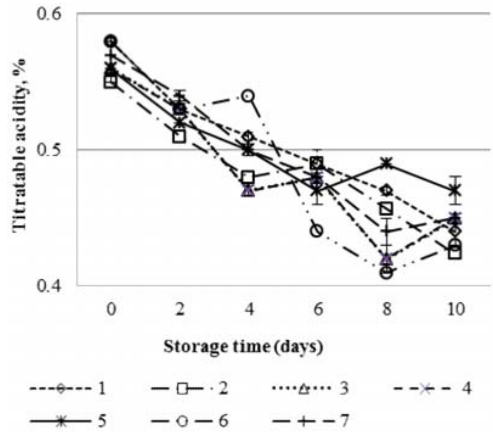

Fig. 5 Dynamics of the Titratable acidity of Fresh-Cut Mixed Apple and Pear Salad during the Storage

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP Propafresh™ P2GAF film; **6** – Duni PP container enclosed in NatureFlex™ NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch

Microbial safety is one of the most important factors to be considered for the preservation of minimally processed foods [38]. The high humidity conditions within a package and the presence of a large area of cut surfaces, which provide a rich source of nutrients, create an environment conducive to growth of microorganisms.

The growth of yeasts in fresh-cut mixed apple and pear salad during 10 days of storage was observed in all packaging manners and substantially depends from the influence of different packaging modifications ($p<0.05$) (Fig. 6). The highest mould contamination count (log CFU g^{-1} 3.7) was observed in salad samples packed in PP container with enclosed humidity absorbent pad, and control sample packed in non-hermetically closed PP containers (log CFU g^{-1} 3.3). The lowest yeast contamination count (< log CFU g^{-1} 3.0) was appointed in fruit salad samples treated by ozone (O_3), Duni PP container enclosed in NatureFlex™ NVS INNOVIA Films, VC999 BioPack PLA film pouch, and Duni PP container sealed Amcor Agrifresh. The growth rate of yeasts has been influenced by initial pollution. At the beginning of experiments the yeast contamination was log CFU g^{-1} 0.6-1.53, but at the end it increased till log CFU g^{-1} 2.4-3.7. However, in literature a higher initial microbial pollution was mentioned, for example, in Spain scientists have performed experiments with fruit initial yeasts and mould contamination count approximately log CFU g^{-1} 2 [37]. A disparity of yeast's contamination content was observed at the end of storage among samples packed in Duni PP container and sealed by BOPP Propafresh™ P2GAF film and Amcor Agrifresh ($p=0.011$).

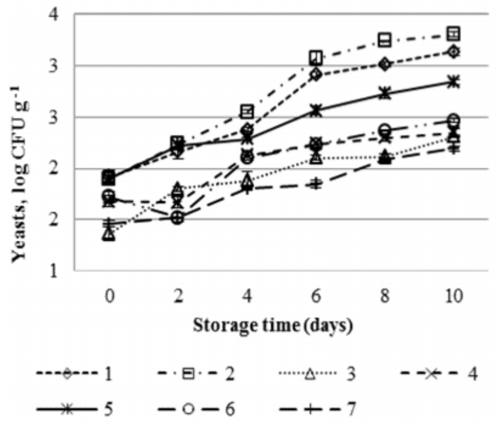

Fig. 6 The Dynamics of Yeast Growth of the Fresh-Cut Mixed Apple and Pear Salad during the Storage

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP Propafresh™ P2GAF film; **6** – Duni PP container enclosed in NatureFlex™ NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch

The treatment by ozonated water delays the microbial growth rate. Scientists in China have ascertained that treatment of ozonated water can reduce bacteria growth rate on fresh-cut celery during storage [40].

The dynamics of mould growth in fresh-cut mixed apple and pear salad during the first two storage days was diverse (Fig. 7). In fruits packed in both biodegradable packaging films the growth of moulds was suppressed and the mould count decreased a little.

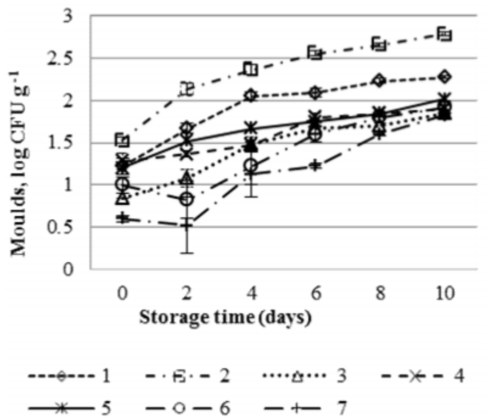

Fig. 7 The Dynamics of Moulds Growth of the Fresh-Cut Mixed Apple and Pear Salad during the Storage

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP Propafresh™ P2GAF film; **6** – Duni PP container enclosed in NatureFlex™ NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch

The mould growth in other packaging materials started immediately and in PP container with enclosed humidity absorbent pad reached the highest amount – log CFU g^{-1} 2.79.

The lowest mould count (log CFU g^{-1} 1.12) was detected in both biodegradable film packaging. It is connected with equilibrium modified atmosphere development formed as a result of fruit breathing. At the end of storage in VC999 BioPack PLA film packaging the passive modified atmosphere composition (15.7%O_2; 8.4 % CO_2) was developed, drawing attention to right gas permeability relation properties of this material.

In the fruits treated by O_3 and packed in non-hermetically closed PP containers the colony forming units of moulds was similar to biodegradable films (log CFU g^{-1} 1.85). That is substantially less than in non-hermetically closed PP control containers (log CFU g^{-1} 2.3) and PP container + enclosed humidity absorbent pad (log CFU g^{-1} 2.79).

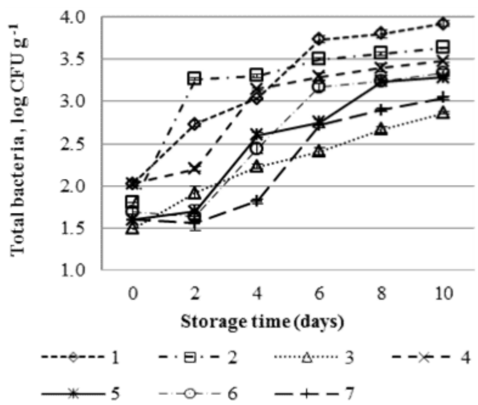

Fig. 8 The Dynamics of Total Bacteria Growth of the Fresh-cut Mixed Apple and Pear Salad during the Storage

1 – PP container (control); **2** – PP container + enclosed humidity absorbent pad; **3** – PP container, fruits treated by O_3; **4** – Duni PP container, sealed by Amcor Agrifresh; **5** – Duni PP container sealed by BOPP Propafresh™ P2GAF film; **6** – Duni PP container enclosed in NatureFlex™ NVS INNOVIA Films pouch; **7** – Duni PP container enclosed in VC999 BioPack PLA film pouch

The colony forming units of total bacteria is pointed in Fig. 8. During storage the CFU growth substantially depends from packaging method, material and storage time ($p<0.05$).

The most intensive bacteria growth was observed in control sample, while in the closed PP container with enclosed humidity absorbent pad bacteria growth rate was a little suppressed (log CFU g^{-1} 3.92 and 3.64, respectively). Moisture regulators can prevent the growth of yeast and bacteria at high water activity in foods like minimally processed fruits and vegetables [41]. At the same time in the ozone treated salad samples packed in the same PP containers with hanging lids the CFU count was the lowest (log CFU g^{-1} 2.8), which differed from all other samples ($p=0.04$). The ozone influence on growth rate decrease of mesophilic and psychotropic bacteria in melon and shredded lettuce previously has been reported [42], [43]. The difference in CFU count of salad samples packed in PP containers and sealed by conventional films and enclosed in biodegradable pouches was essential (log CFU g^{-1} 3.29 and log CFU g^{-1} 3.60, respectively).

IV. Conclusions

Passive equilibrium modified atmosphere (PEMA) formed in biodegradable packaging materials due to their specific barrier properties helps to protect fresh-cut fruit salad quality during storage. PEMA composition in the headspace of packs during 10 days of storage changed and the increase of CO_2 and decrease of O_2 was miscellaneous dependent from barrier properties of used lidding films. Packaging in conventional Amcor Agrifresh film influenced the breathing rate of fresh-cut produce. Comfortable PEMA conditions have established in conventional breathable BOPP Propafresh^{TM} P2GAF, as well as in biodegradable films VC999 BioPack PLA and NatureFlex^{TM} NVS INNOVIA packaging, which could be characterized as the best for minimal fresh-cut produce respiration and quality maintenance. There was only minimal growth of mesophilic aerobic and facultative anaerobic bacteria, yeasts and moulds compared to other samples. Mass losses of fresh-cut mixed apple and pear salad in all packaging manners did not exceeded 5.0%, titratable acidity decreased and a substantial difference of sample acidity packed in various materials was observed ($p=0.01$) during 10 storage days. A disparity among firmness and whitening index of all samples was not detected ($p>0.05$), and the appearance of fresh-cut salad could be evaluated as good.

The treatment of salad with ozonated water negatively influenced the microbial growth. The firmness of samples characterized as higher, while the whitening index was lower compared with not treated samples.

The results of experiment proved that conventional PP containers with hanging lids could be used as cheaper way for specially treated fresh-cut fruit packaging and storage for 5-6 days. The humidity absorbent pads enclosed in non-hermetically sealed PP containers did not considerably suppress the microbial growth.

The results suggest that biodegradable packaging materials can be successful alternative to the conventional polymer for fresh-cut produce packaging, and it could offer essential contribution to reduce environmental pollution.

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