Influence of packaging material and storage condition on the sensory quality of broccoli

Annelie Jacobsson a,*, Tim Nielsen a, Ingegerd Sjöholm b, Karin Wendin c

a SIK, The Swedish Institute for Food and Biotechnology, Ideon, SE-223 70 Lund, Sweden
b The Department of Food Engineering, Lund University, PO Box 124, SE-221 00 Lund, Sweden
c SIK, The Swedish Institute for Food and Biotechnology, Box 5401, SE-402 29 Gothenburg, Sweden

Received 2 December 2002; received in revised form 21 April 2003; accepted 4 May 2003

Abstract

The sensory quality of broccoli stored in modified atmosphere packages was studied. Oriented polypropylene (OPP), polyvinyl chloride (PVC) and low-density polyethylene (LDPE) were used as packaging materials. The LDPE contained an ethylene-absorbing sachet. The samples were stored for 1 week, either at a constant temperature of 10 °C or for 3 days at 4 °C, followed by 4 days at 10 °C. The atmospheres that were developed inside the different packaging materials during storage differed significantly. After storage, the broccoli was evaluated both raw and cooked using a triangle test and a quantitative descriptive analysis. The triangle test showed significant differences in the smell of broccoli stored in different packaging materials after cooking. No differences were detected in the raw broccoli. The quantitative descriptive analysis showed significant differences in the fresh smell and flavour, the chewing resistance, and the crispness, between samples after cooking. Overall, including all the sensory properties studied, broccoli packaged in LDPE (5% O2, 7% CO2) that contained an ethylene absorber was perceived to be the sample most similar to fresh broccoli. There were no differences in weight loss between broccoli stored in the different packaging materials.

* Corresponding author. Tel.: +46-46-2868850; fax: +46-46-188765.
E-mail address: aj@sik.se (A. Jacobsson).

Keywords: Broccoli (Brassica oleracea L. var. Italica cv. ‘Marathon’); Packaging; Modified atmosphere; Quality; Sensory properties

1. Introduction

Modified atmosphere packaging (MAP) is commonly used to maintain the quality and improve the shelf life of foodstuffs. MAP utilizes polymeric films of different permeabilities to oxygen, carbon dioxide, ethylene and water vapour to extend the shelf life of fruit and vegetables. Atmospheric modification evolves within the package as a result of the respiration rate of the plant tissue and the gas diffusion characteristics of the film (Kader, Zagory, & Kerbel, 1989). Film selection is important, since a proper matching of the commodity characteristics with the permeability of the film results in the passive evolution of an appropriate atmosphere within the sealed package (Smith, Geeson, & Stow, 1987).

The MAP of broccoli at elevated CO2 and reduced O2 levels has been shown to retard deterioration, i.e. yellowing and softening, and preserve the market quality of broccoli during storage (Barth, Kerbel, Perry, & Schmidt, 1993; Barth, Perry, Schmidt, & Klein, 1992; Elkashif, Huber, & Sherman, 1983; Lipton & Harris, 1974). Broccoli can benefit from 1 to 2% O2 and 5 to 10% CO2 atmospheres at low temperatures. However, a low oxygen level (0.5–2%) or carbon dioxide concentrations in excess of 10%, combined with temperature fluctuations, may result in the production of off-odours, thus reducing the shelf-life of the broccoli (Ballantyne, Stark, & Selman, 1988; Forney & Rij, 1991; Makhlouf, Castaigne, Willemont, & Gosselin, 1989). These strong off-odours have mainly been associated with sulphur volatile compounds, for example, methanethiol, hydrogen sulphide, dimethyl disulphide and dimethyl trisulphide (Forney, Mattheis, & Austin, 1991; Hanssen, Buttery, Stern, Cantwell, & Ling, 1992; Maruyama, 1970). As a consequence, the MAP of broccoli is often designed to maintain both the O2 and CO2 at about 10%. Although broccoli is often sold to consumers packaged in polymeric films or in vented plastic bags, a
beneficial atmosphere is not always created, resulting in poor quality, for example, weight loss, yellowing and texture changes (Jacobsson, Nielsen, & Sjöholm, submitted for publication-b).

To characterize how MAP affects product quality, changes have traditionally been assessed in terms of single attributes such as colour and texture changes or the development of off-odours (Barth et al., 1992; Lipton & Harris, 1974; Makhlouf et al., 1989). In rarer cases, sensory descriptive analyses have been used (Gilles, Cliff, Toivonen, & King, 1997; Hansen, Olsen, Poll, & Cantwell, 1993). In order to maintain eating and market quality, it is important to include all sensory characteristics, i.e. smell, flavour, taste and texture as well as appearance.

Since aroma compounds, especially sulphur compounds, are produced during heat treatment (Forney & Jordan, 1998; Jacobsson, Nielsen & Sjöholm, submitted for publication-a) and consumers eat broccoli today both cooked and raw, it is important to consider the effect of MAP on the quality of raw as well as cooked broccoli. However, few studies have dealt with the effect of the storage of raw broccoli on the quality of cooked broccoli (Batal, Heaton, Granberry, & Beuchat, 1982; Hansen et al., 1993; Kidmose & Hansen, 1999).

The objective of the reported work was to investigate the sensory quality of broccoli stored raw in different commercially available packaging solutions. Another aim was to study the effect of cooking, after storing the fresh broccoli in MAP.

2. Material and methods

2.1. Plant material

Freshly harvested broccoli (Brassica oleracea L. var. Italica cv. ‘Marathon’) was obtained from a grower in Sweden. The broccoli was cooled unpacked overnight, before being subjected to the experiments the next morning, i.e. one day after harvesting. Only broccoli heads, 200–300 g, free from decay, were used.

2.2. Packaging material

Three commercially available polymeric films/bags, in one case specifically designed for broccoli, were used as packaging materials. The investigated polymer materials were oriented polypropylene (OPP), low-density polyethylene (LDPE) containing an ethylene absorbent sachet, and polyvinyl chloride (PVC). The different materials were referred to as A through C (Table 1). The PVC film, referred to as C, is currently the most commonly used broccoli packaging material in Sweden. Some of the significant properties of the packaging materials are summarized in Table 2. The packages were all heat-sealed, except for the PVC film, since this is a cling film.

2.3. Storage conditions

The packaged broccoli, one head per package, was stored in humidified cold-storage rooms for one week. Unpacked broccoli, referred to as D, was also examined. Two different temperature conditions were used; (I) 7 days at a constant temperature of 10 °C, and (II) 3 days at 4 °C, followed by 4 days at 10 °C. The storage conditions that were used in this study were selected after investigating the temperature profile that broccoli was exposed to from harvest to purchase. The temperature was monitored during transport, storage and in stores. These data are unpublished, but it was observed that the temperature fluctuated between 2 and 12 °C.

Storage condition (I) was chosen, as it was not uncommon to find broccoli kept at this relatively high temperature in the retail. Storage condition (II) was selected in order to find out what effect a change in temperature might have on the sensory properties of broccoli, as it was observed that the temperature fluctuated considerably during handling.

2.4. Sensory evaluation

A difference test and quantitative descriptive analyses were used to evaluate the sensory properties of broccoli. The difference test was performed to find out if there were difference between the samples depending on packaging material and temperature used for storage, and the quantitative descriptive analysis was used to describe these differences. Sensory evaluation was
performed by an external, analytical panel (SIK, Sweden). Carbonated water and neutral wafers were used for cleansing the palate between samples.

2.4.1. Difference test

Packaged and unpackaged broccoli was stored for one week at 10\(^\circ\)C. Two triangle tests were performed, one on raw and one on cooked broccoli samples after one week of storage of the raw product. Twenty-seven broccoli heads from each packaging and storage temperature were divided, either raw or after cooking for 5 min, into bite sizes and mixed. From this collection, 35–40 g was selected and put into analytical glasses with a glass lid, for sensory evaluation. All samples were served to the assessors at ambient temperature. Each triangle was evaluated 36 times by an analytical sensory panel. During the triangle test, the analytical panel was presented with three samples at a time, one of which was stored in a different packaging material from the other two. The panellists were then supposed to identify the sample that differed by smelling the samples. If they were unable to detect any differences, they were instructed to guess which sample was different.

2.4.2. Quantitative descriptive analysis

During four training sessions with 10 assessors, a number of sensory attributes were developed and described in words by comparing broccoli that had large differences in sensory qualities. The 10 assessors were selected from the analytical panel used in the difference tests: they were trained to evaluate the smell, flavour, taste and texture attributes of cooked broccoli as well as the appearance of raw broccoli. In their training, a reference sample of fresh broccoli was used. They were also trained in how to use a 100 mm continuous line scale anchored with ‘low’ intensity at 10 mm and ‘high’ intensity at 90 mm. The sensory attributes and their definitions are given in Table 3.

Table 2
Properties of the packaging types used in the study

<table>
<thead>
<tr>
<th>Packaging type</th>
<th>Thickness (µm)</th>
<th>Area (m²)</th>
<th>Void volume (dm³)</th>
<th>Transmission rate (TR) (\text{O}_2)(^{a}), (\text{CO}_2)(^{b}) (ml/(m²<em>day</em>atm))</th>
<th>Water vapour TR(^c) (g/m²*day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>35</td>
<td>0.15</td>
<td>3.3</td>
<td>1300</td>
<td>4900</td>
</tr>
<tr>
<td>B</td>
<td>23</td>
<td>0.16</td>
<td>2.8</td>
<td>10960</td>
<td>&gt;46 000</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>0.16</td>
<td>–</td>
<td>56 100</td>
<td>&gt;173 000</td>
</tr>
</tbody>
</table>

\(^a\) Measured at 23°C and 50%RH (Oxtran 1000, Mocon).
\(^b\) Measured at 25°C and 0%RH (Permatran C, Mocon).
\(^c\) Measured at 25°C and 75%RH (Permatran W 3/31, Mocon).

Packaged broccoli samples, as well as unpackaged broccoli, were stored in accordance with conditions I and II. Twelve broccoli heads from each sample were placed in boiling water and cooked for 5 min, then cut into pieces and mixed. Samples (35–40 g) were served in analytical glasses with a glass lid, at ambient temperature. The assessors were told firstly to evaluate the smell, and were then instructed to keep the lid on the samples as much as possible so as not to disturb the evaluation. They were then instructed to let their smell sensitivity recover by resting for 2 min before evaluating flavour, taste and texture. Cooked fresh broccoli was served as a reference sample. The broccoli samples were served in triplicate in randomized order, and each sample was assessed three times. All samples were evaluated during 4 h-sessions over 2 days. The visual appearance was evaluated by studying only uncooked broccoli samples.

2.5. Atmosphere analyses

The concentration of oxygen and carbon dioxide inside the different types of packaging was monitored by using a Gaspace 2-V3.3 (Systech Instruments Ltd, Thame, Oxfordshire, UK) after 2, 4 and 7 days of storage. A syringe was inserted into the package through a rubber seal placed on the film. The instrument was calibrated towards air.

2.6. Weight loss evaluation

The broccoli heads were weighed prior to packaging and again after 7 days of storage. Weight losses were expressed as the percentage of the weight on the day of packaging, i.e. one day after harvesting.

2.7. Statistical analyses

Statistical evaluation was performed using analysis of variance (ANOVA), the sources of variance being packaging material, storage temperature and storage time, followed by Tukey HSD (honestly significant difference) multiple comparison of means, using Systat 10 (SPSS Inc., Chicago, IL, USA). Mean values were considered significantly different at \(P \leq 0.05\). Two-way ANOVAs with samples and assessors as fixed effects were made on the descriptive profiling. Tukeys multiple comparison test was performed on attributes showing significant effects. Fizz (\(P = 1/3\)) for Windows 2.00E (Biosystems, France) was used to statistically evaluate the difference test.
Standard error of the sensory measurements ($S_{ref}$) was calculated (Ellekjaer et al., 1994) in order to obtain an indication of the uncertainty of the analysis attributable to the assessors. $S_{ref}$ is defined for the sensory attribute $y_i$ by:

$$S_{ref} = \sqrt{\frac{MSE}{A \times R}}$$

where $MSE$ is the mean square error derived from two-way ANOVA with samples and assessors, $A$, as class-variables and with the interaction included. $R$ represents the number of sensory replicates.

Principal component analysis (PCA) was performed (Unscrambler v7.6, CAMO ASA, Oslo, Norway) on the averages of subjects and replicates in order to describe the main variation in the sensory data. The model was validated using full cross validation, where each sample was used to test the model estimation by all the other samples.

### 3. Results and discussion

#### 3.1. Atmosphere analyses

The atmosphere analysis showed that, in all three packages, the atmosphere had been modified (Figs. 1 and 2). The oxygen and carbon dioxide concentrations created inside the packaging differed significantly ($P < 0.05$) between packaging materials (Table 4). Low oxygen concentrations, in combination with temperature fluctuations, have been reported to result in the production of off-odour volatiles containing sulphur (Forney & Jordan, 1999). The $O_2$ concentration was above the critical concentration (0.5–2.5%) for developing off-odours (Ballantyne et al., 1988; Makhlof et al., 1989) in all three packaging materials used, however, the development of aroma compounds differed between samples stored in the various packaging materials (Jacobsson et al., submitted for publication-a), due to different atmospheres affecting the respiration rate.

### Table 3

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Standard error of measurements ($S_{ref}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total smell</td>
<td>The total intensity of smell</td>
<td>0.19</td>
</tr>
<tr>
<td>Fresh</td>
<td>Smell of fresh newly cut green grass</td>
<td>0.73</td>
</tr>
<tr>
<td>Cooked cabbage</td>
<td>Smell of cooked cabbage</td>
<td>0.26</td>
</tr>
<tr>
<td>Flavour/taste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total flavour</td>
<td>The total intensity of flavour during the first five chewings</td>
<td>0.18</td>
</tr>
<tr>
<td>Fresh</td>
<td>Flavour of grass, souness and summer</td>
<td>0.65</td>
</tr>
<tr>
<td>Cooked cabbage</td>
<td>Flavour of cooked cabbage</td>
<td>0.25</td>
</tr>
<tr>
<td>Sweetness</td>
<td>Sweet taste</td>
<td>0.21</td>
</tr>
<tr>
<td>Bitterness</td>
<td>Bitter taste</td>
<td>0.10</td>
</tr>
<tr>
<td>Texture (mouth feel)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chewing resistance</td>
<td>The perceived resistance while chewing (five chews)</td>
<td>0.14</td>
</tr>
<tr>
<td>Crispness</td>
<td>Opposite to rubbery</td>
<td>0.22</td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshness</td>
<td>Overall impression of the freshness</td>
<td>0.003</td>
</tr>
<tr>
<td>Greenness</td>
<td>Low = yellow green; High = blue green</td>
<td>0.003</td>
</tr>
<tr>
<td>Compactness</td>
<td>Denseness of the broccoli florets</td>
<td>0.002</td>
</tr>
<tr>
<td>Brownness</td>
<td>Brightness of the broccoli head</td>
<td>0.001</td>
</tr>
<tr>
<td>Evenness</td>
<td>Evenness of the distribution of the broccoli flowers</td>
<td>0.003</td>
</tr>
<tr>
<td>Size</td>
<td>Size of the broccoli flowers</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Fig. 1. $O_2$ and $CO_2$ concentrations inside the packages under storage condition (I), i.e. 7 days at 10°C.
3.2. Weight loss

Weight losses were between 0.6 and 1.6% of original fresh weight after 7 days of storage, in material A–C. No significant differences were found between the two storage conditions (Table 4). The broccoli stored unpackaged, D, lost significantly more weight during the same period of time (Table 4). The importance of storage temperature could be seen here. The unpackaged broccoli stored at 10°C lost significantly more weight (13.2%) than the broccoli stored in 4°C followed by storage in 10°C (7.4%). The weight losses found here are relatively minor for the packaged broccoli, and are not expected to have significant effects on quality of the broccoli, however, the weight loss for the unpackaged broccoli might have an influence.

3.3. Difference test

For the raw broccoli, no significant differences in smell were found between the samples using the difference test, which was in accordance with previous reports (Gilles et al., 1997). However, there were significant differences ($P \leq 0.005$ and $P \leq 0.0001$) in smell in all the cooked broccoli samples, depending on the packaging material used for storing the raw broccoli, except in broccoli packaged in materials B and C (Table 5). The panellists were able to select the broccoli sample that had been stored in a different package, i.e. atmosphere, when the broccoli was cooked after storage. Forney and Jordan (1998) reported that heat treatment caused the enhanced development of dimethyl disulphide (DMDS) and dimethyl trisulphide (DMTS), which are responsible for off-odours in broccoli. This may explain why differences were found in the cooked broccoli but not in the raw broccoli. Another explanation could be that, the O₂ concentration might not have reached the low concentrations needed for the difference in aroma production to be noticeable in raw broccoli.

3.4. Quantitative descriptive analysis

The quantitative descriptive analysis was performed using a range of sensory attributes (Table 3). The standard errors of sensory measurements, $S_{ref}$, were similar to those reported in previous studies on food (Ellekjaer et al., 1994). $S_{ref}$ is an indication of the uncertainty of the sensory measurements. Since no differences in smell in raw broccoli stored in the different packages could be detected in the difference test, the quantitative descriptive analysis of smell, flavour, taste and texture was undertaken on cooked broccoli only. However, the appearance of the samples was evaluated on raw broccoli.

The quantitative descriptive analysis showed that the sensory properties, i.e. the smell, flavour, taste, texture and appearance of the stored broccoli were affected by the packaging material and the storage temperature used in this study. This was in accordance with previous studies (Gilles et al., 1997; Hansen et al., 1993; Jacobsson et al., submitted for publication-b). Gilles et al. (1997) found that the packaging type and storage time influenced the aroma, flavour and texture of the broccoli.

3.4.1. Influence of storage temperature on smell, flavour, taste and texture

The storage temperature affected the smell, flavour, taste and texture attributes in different ways. A temperature

![Fig. 2. O₂ and CO₂ concentrations inside the packages under storage condition (II), i.e. 3 days at 4°C followed by 4 days at 10°C.](image-url)
change during storage, as in condition (II), resulted in significant differences in broccoli stored in the different packaging materials, while broccoli kept at a constant temperature had similar intensities of the sensory properties, regardless of the type of packaging material used. Changes in atmosphere and temperature during the storage of vegetables have been found to affect the physiology and biochemistry of the vegetables (Nilsson, 2000; Watada, Ko, & Minott, 1996). Watada et al. (1996) found that stress induced a faster deterioration of the vegetable. The temperature change during storage condition (II), from 4 to 10 °C, together with the induced atmosphere change inside the packages, probably affected the development of the aroma compounds, as well as the water loss, in the broccoli differently than did storage at a high constant temperature, i.e. storage condition (I). Low temperatures decrease the respiration rate. However, the decline in respiration at 4 °C could be a consequence of cellular deterioration (Romani, 1987; Toivonen, 1997), resulting in the enhanced development of aroma compounds (Dan, Todoriki, Nagata, & Yamashita, 1997; Forney & Jordan, 1998). This cellular senescence, as well as the stress provided by the change in temperature under condition (II), could explain the differences in the smell, flavour and texture in broccoli subjected to the two storage conditions.

### 3.4.2. Influence of packaging material on smell, flavour, taste and texture

No significant differences in broccoli stored in the packaging materials were found under storage condition (I), i.e. 10 °C (Table 6). However, the results indicated that the smell and flavour of the unwrapped broccoli, stored at 10 °C for 7 days, were less fresh than those of the other samples. The unpackaged broccoli, D, also had a somewhat higher total smell and flavour, compared with the other samples. The results indicated that the fresh sample had the highest intensities of the texture attributes, i.e. crispness and chewing resistance, followed by broccoli packaged in materials C, A, unpackaged broccoli and then broccoli packaged in material B.

Broccoli kept under storage condition (II), i.e. 3 days at 4 °C followed by 4 days at 10 °C, and then cooked, differed significantly in five of the evaluated attributes; i.e. fresh smell, fresh flavour, flavour of cooked cabbage, chewing resistance, and crispness (Table 6). Broccoli stored in packaging material A differed most from the other broccoli samples (Fig. 3). Storage in packaging material A resulted in broccoli with a less fresh smell and flavour than the other samples. Broccoli packaged in material A was also found to have a more intense taste of cooked cabbage (P ≤ 0.05, Table 6), compared with the fresh reference sample. Broccoli stored in materials B and C, and the unpackaged samples, had similar properties to the fresh reference sample with respect to smell and flavour. However, the results indicated that the intensity of total smell, the smell of cooked cabbage, and the total flavour were more pronounced in the broccoli stored for one week, regardless of packaging material, when compared to the reference sample.

### 3.4.3. Influence of storage temperature on appearance

The appearance of the broccoli varied with storage temperature. The broccoli stored under condition (II), i.e. 4 and 10 °C, gave a more fresh impression than the broccoli stored exclusively at 10 °C. Storage at 10 °C resulted in greater differences in the appearance attributes evaluated. The differences between the two storage conditions might be due to the fact that a higher temperature increased the respiration rate of the broccoli and thus the chlorophyll degradation (Jacobsson et al., submitted for publication-b). The unpackaged broccoli, D, differed most from the others under storage condition (I), i.e. 10 °C. The broccoli stored unpackaged lacked the protecting modified atmosphere, resulting in faster degradation and higher weight reduction (Table 6) due to the loss of water (Forney et al., 1989).

### 3.4.4. Influence of packaging material on appearance

Significant differences (P ≤ 0.05) in appearance were found between the effects of the packaging materials on the broccoli samples, regardless of storage temperature (Table 6). None of the packaging materials were able to
keep the broccoli as fresh as the reference sample. However, the results showed the importance of using packaging (Figs. 4 and 5). Broccoli stored in material B was perceived to have the highest intensities of freshness, greenness, compactness and evenness, while the unwrapped broccoli, D, was perceived to have relatively low intensities of these attributes (Fig. 4). Material B resulted in a package atmosphere that differed most from air (5% O₂, 7% CO₂), and broccoli stored in material B was rated to have an appearance most similar to fresh broccoli. Broccoli stored in material C was rated as having the poorest appearance, which can be explained by the material providing a less modified atmosphere (17% O₂, 4% CO₂), due to its much higher O₂ and CO₂ transmission rates. Broccoli packaged in materials A and C scored in between broccoli stored in material B and the unpackaged broccoli. Material C was the poorest packaging material for maintaining the appearance, resulting in a broccoli less green, more brown and not as compact and

Table 6
Significant differences in accordance with the storage temperature and packaging material used calculated using Tukey’s test, *P ≤ 0.05*

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Storage condition I</th>
<th>Storage condition II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh</td>
<td>A</td>
</tr>
<tr>
<td><strong>Smell</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total smell</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Fresh</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cooked cabbage</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Flavour/taste</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total flavour</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Fresh</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cooked cabbage</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Sweetness</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Bitterness</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Texture (mouth feel)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chewing resistance</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Crispness</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshness</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Greenness</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>Compactness</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>Brownness</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>Evenness</td>
<td>a</td>
<td>ab</td>
</tr>
<tr>
<td>Size</td>
<td>ab</td>
<td>a</td>
</tr>
</tbody>
</table>

* Significant differences within a row are indicated with different letters, a–d, non significant differences are indicated with ‘ns’.

Fig. 3. The profiles of the mean values for the smell, flavour, taste and texture of the broccoli samples stored under condition (II), i.e. 3 days at 4 °C followed by 4 days at 10 °C (* attributes with significant differences between samples).

Fig. 4. Mean value profiles for the appearance of the broccoli samples stored under condition (I), i.e. 7 days at 10 °C (* attributes with significant differences between samples).
3.4.5. Principal component analysis

To obtain an overview of the results, a principal component analysis (PCA) was performed which included all the sensory attributes investigated. The first two principal components (PCs) explained the main variation, 73% of the total variance (Fig. 6a and b), an additional 12% being explained by PC3 (not shown).

The loading plot for the first two PCs (Fig. 6a) indicated that some attributes described the same variation among the samples. The following attributes were highly correlated; smell and flavour; the texture attributes; greenness and freshness; compactness and evenness as broccoli packaged in materials B and A (Figs. 4 and 5).

![Fig. 5. Mean value profiles for the appearance of the broccoli samples stored under condition (II), i.e. 3 days at 4 °C followed by 4 days at 10 °C (* attributes with significant differences between samples).](image)

![Fig. 6. PCA of sensory data of broccoli. PCA loadings (a) and scores (b) for principal component 1 and 2, including all evaluated sensory attributes (S: smell and F: flavour).](image)
ness. The inverse correlation between greenness and brownness, and between a fresh smell/flavour and a smell/flavour of cooked cabbage was also illustrated. The high correlation between the smell and flavour attributes found in the PCA might have been expected, since flavour is perceived retro nasally by olfactory receptor cells. The less fresh smell and flavour of broccoli stored in material A under condition (II), i.e. 4 and 10 °C, might be due to the high CO₂ concentration inside the package, which has been claimed by other researchers to result in off-odours (Hansen et al., 1993; Lipton & Harris, 1974; Makhlouf et al., 1989). However, in these reports, the off-odours developed when the storage atmosphere contained a high level of CO₂ in combination with a very low O₂ concentration (Hansen et al., 1993).

The score plot (Fig. 6b) gave a visual representation of how effective the different packaging materials were in maintaining the sensory properties of the broccoli. The fresh broccoli was located far to the right and characterized by a green colour, a fresh smell and flavour, a compact head and a crisp texture, while the unpackaged broccoli, D, stored under condition (I), i.e. 10 °C, was rated to have the opposite properties, a brown colour, a high total smell and flavour, and a high smell and flavour of cooked cabbage. The broccoli packaged in packaging materials A–C was rated in between. The sensory properties of broccoli packaged in material C under storage condition (II), i.e. 4 and 10 °C, was similar to the fresh broccoli. However, taking both storage conditions into consideration, broccoli packaged in material B was given the highest rating.

The importance of storage temperature can be seen in Fig. 6a and b by studying the results for the unpackaged broccoli, D. Under storage condition (II), i.e. 4 and 10 °C, the unpackaged broccoli was greener, fresher and somewhat more compact than broccoli stored without a package at a higher temperature. The difference between the sensory properties for broccoli stored in packaging material A and the other materials was clearly shown by the PC analysis (Fig. 6b).

4. Conclusion

The results presented here indicate the importance of the packaging material used for broccoli storage in maintaining its sensory quality. Significant differences in sensory properties were found between the cooked broccoli samples which were dependent on the packaging material used to store the raw product. However, no differences were found in the raw broccoli. The atmospheres that were developed inside the different packaging materials during storage differed significantly. The PCA showed the effectiveness of using a packaging material to maintain sensory quality. The importance of storage temperature and the effect of a change of temperature during storage were also shown. The use of material C under storage condition (II), 4 and 10 °C, resulted in broccoli with similar taste and smell as fresh broccoli. However, at 10 °C, the material was not able to maintain the appearance of the broccoli. Overall, packaging material B, made using LDPE, and containing an ethylene-absorbing sachet, maintained the sensory properties to a greater degree during storage than broccoli stored in the other packaging materials. The sensory properties depend on different physiological and biochemical pathways that are induced by storage temperature and atmosphere, shown here and in earlier studies, which should be considered when choosing a packaging material. The change of temperature during storage induced changes in smell, flavour, taste and texture of broccoli depending on the packaging material used. The appearance of the broccoli was found to be more depending on the atmosphere than the temperature of storage. However, the importance of temperature was also shown.

In order to further explain the difference found in the sensory properties of broccoli stored under different conditions, a chemical analysis of the aroma profiles was undertaken using GCMS analysis. This data is under investigation and will be published shortly (Jacobsson et al., submitted for publication-a).

Acknowledgements

This work was financially supported by The Knowledge Foundation and Sydkrönt, a Swedish farmers’ cooperative. All the contributions made are gratefully acknowledged. Jan Emilsson at Västgötatagörsaker is especially acknowledged for supplying the broccoli samples. Maud Berg and Ingela Gangby, SIK, are also acknowledged for their assistance during the sensory analysis.

References

Dan, K., Todori, S., Nagata, M., & Yamashita, I. (1997). Formation of volatile sulphur compounds in broccoli stored under anaerobic...


Jacobsson, A., Nielsen, T., & Sjöholm, I. Development of aroma compounds in MA-packaged broccoli during storage (submitted for publication-a).


