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In-package moisture supports quality maintenance of white asparagus

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Abstract: White asparagus is a highly appreciated, high-value crop with a distinguished economic relevance among vegetables. Freshly harvested asparagus is available only during a short part of the year and the demand varies. The produce is perishable and only proper handling can ensure its quality after a reasonable shelf life. In this study, we investigated a new method to reduce one of the most important reasons for quality decline: fresh matter losses. The potential benefits or disadvantages of moist asparagus packaging for unpeeled white asparagus (cv. 'Gijnlim') was tested. We used polythene sleeves or bags, lined with cellulose fleece to hold added water for moisturizing. 500 g bunches of spears were filled in the bags. Spears were partly covered by the sleeves or totally covered by the bags. All spears were stored for 3 to 11 days at the temperature of 2°C, 8°C and a combination of 2°C/22°C.The last temperatures were to simulate retail conditions. In wet bags spear fresh weight increased, losses in bags with dry fleece were low. Maintaining of fresh weight in wet bags coincided significantly with higher bending firmness, and lower shear force, which points to less fibrousness. Wet storage also reduced the incidence of dried cut surfaces but promoted the incidence of lengthwise fractures and, in combination with higher temperature, grey-brown discolouration and colour saturation. Wet packaging may be beneficial primarily under low temperature and low air humidity storage conditions.

Keywords: packaging; post-harvest; transpiration; storage; humidity; water loss; fresh weight

Fresh white asparagus is a high-value commodity with the largest economical importance among fresh vegetables in Germany (Behr 2014). This is despite the fact that the harvest season of white asparagus in Germany lasts, starting from April, for 8 to 12 weeks, only. During this period the amount of daily harvested spears is variable and is largely dependent on the temperature course (Graefe et al. 2010), which can range from freezing temperature up to 30°C. For this reason and variable market demand storage periods for up to one week can become inevitable.

Shelf life and quality development during this period are determined by water loss (Bovi et al. 2016) and metabolic activity (especially respiration) of the product. Water loss is by far the largest reason for fresh matter losses and can amount (dependent on temperature and relative humidity) to several weight percent daily (Böttcher 1996). Respiration losses mostly of sugar are (again dependent on temperature) in the range of 0.03 to 0.1% daily (Böttcher 1996; Laurin 2002), thus only a very small fraction of total losses, but important for the total amount of sugars, which is only 1 to 2% of the fresh matter.

For retention of quality, various types of packaging have been investigated successfully, including Controlled Atmosphere (CA) and Modified Atmosphere (MA) (Sothornvit, Kiatchanpaibul

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2009; Tiehua, Zhang 2015; Huyskens-Keil, Herppich 2016; Techavuthiporn, Boonyaritthongchai 2016). The most effective measure to keep the water loss and respiration rate low is reducing the temperature of the spears as soon as possible. Fast and cost-effective cooling methods are forced-air cooling (Laurin et al. 2003) and hydro- and ice-water-cooling. The last two have been recommended and widely used in asparagus production (Kader, Rolle 2004; Nikaido et al. 2014).

Water loss can compromise appearance and texture. There have been attempts to replenish transpired water by "feeding" spears with water or even solutions with nutrients (sucrose). Sucrose addition had no effect on appearance or sensory quality, but fresh weight increase has been observed in the first two days after harvest of the green spears in the air control, only, not in the CA-treatments (Renquist et al. 2005).

To reduce the loss of water and avoid firmness loss, wilting, shriveling and discolouration, hydro- and spray cooling had been recommended to be used not only during processing, but also during the storage period (Belker, Hofmann 1992; Böttcher 1996) or even retail display (Kader 2002; Tirawat 2017). But information has been obtained by Garcia et al. (1998), Feng et al. (2003), Srinivasa et al. (2004) and even Kader and Rolle (2004), that under certain circumstances liquid water on the produce surface may lead to defects in the external appearance (colour, texture) or that micro-organisms may overcome plant protection mechanisms (Tapia et al. 2007).

To avoid direct contact of liquid water with the produce surface, but still providing a barrier to transpiration, plastic packaging has been widely recommended (Scheer et al. 2003). Besides retarding moisture loss plastic packaging can reduce hardening in the spear basal part and slow down discolouration (Tzoumaki et. al. 2009). An unsolved problem of plastic packages is condensation of liquid water on the inside surface of the package material and on the produce under fluctuating changing temperatures during the distribution chain. There have been made attempts to add water-absorbing material (e.g. NaCl) into the package by Rux et al. (2016), but insufficient water uptake-capacity in case of highly transpiring commodities and low ability to maintain a specific in-package humidity as well as high package costs limited success so far (Holcroft 2015).

An alternative concept is to provide water to an absorbing cloth, paper or cellulose fleece and bring it into direct contact with the produce. This will prevent water loss of the produce, maintain high relative air humidity and avoid free liquid water. Traditionally, in private households, asparagus is wrapped into moist cloth (Mahr 2016). The application of moist paper in a professional setting has been proposed successfully e.g. for roses (Wills et al. 2007), and moist cloth was mentioned for asparagus storage, but not tested (Böttcher 1996).

As to our knowledge, there is no scientific study, investigating the role of moisture in packages of unpeeled, white asparagus, and its effects on important quality parameters like water retention, firmness, colour and appearance.

In this context, the aim of this study was to compare the quality of 500 g bunches of white asparagus spears after storage under the influence of different moisture regimes within the packaging treatment. Polyethylene (PE) plastic film in combination with dry cellulose fleece or in combination with moistened cellulose fleece was tested. Three temperature regimes with practical relevance were chosen and two methods to cover the spears partly (sleeve) or totally (bag) were applied to gain insights in different, but common storage scenarios.

MATERIAL AND METHODS

Plant Material. White asparagus spears of the cultivar Gijnlim were harvested in Southern Brandenberg by the commercial farm Spargelanbau Sallgast, Sallgast, Germany in Brandenburg on June 2 and June 4, 2003. The spears were harvested in the morning hours, washed with tap water, tested to be germ-free, cut to 22 cm length and sorted. Uniform spears with a diameter of 12–16 mm, straight appearance and no quality defects were selected and stored in loosely closed boxes in a storage chamber at 2°C. On the next morning, the packaging treatments were applied.

Packaging. All asparagus spears were packaged using a low-density PE-film of 50 μm thickness. From this material open pockets were provided (rotaris GmbH, Germany). The pockets had closed lateral edges and bottom and were open at the top side. 500 g, ca. 14–20 asparagus spears were filled into each of four pockets per treatment (each replicate = 1 pocket) with the tips towards the open side.

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Two types of pockets were used, depending on their size. The smaller pockets (ca. width 15 cm × length 20 cm, 15 g), called sleeves remained ca. 4–5 cm of the asparagus tips uncovered, the larger pockets (ca. width 20 cm × length 30 cm, 26 g), called bags covered the asparagus spears completely, and the protruding top of the pockets (5 cm length) was reverted downwards. No further sealing was applied.

Both types of pockets (sleeves and bags) were lined at the inside with cellulose fleece. This was used dry (dry sleeve and dry bag treatments) with no water added, or wet (wet sleeve and wet bag treatments) where 50 ml germ-free water was added to each of the sleeve packages, and 75 ml added to the bag packages.

Storage. The packaging treatments were distributed in boxes of the dimensions of 60 cm × 40 cm × 30 cm with the spear tips directed upwards. The boxes were placed on a table in the centre of the cooling chamber. Three different temperatures were adjusted:

– 2°C ± 1 K and a relative air humidity (RH) (Rotronic Hygroclip S, Ettlingen, Germany) of 90% ± 5% for a period of 3, 5, 7, 9 and 11 days or at the temperature of 8°C ± 0.5 K for 3 and 7 days at the relative air humidity (RH) of 80% ± 5%. A third storage regime combined storage at:
– 2°C ± 1 K with a relative air humidity of 90% ±5 %, for four days and at 22°C ± 1.5 K 60% ± 10 % relative air humidity to simulate a stress period (e.g. transport or retail display).

Elasticity measurement. The instrumental measurement of elasticity was performed using the standard method for food products (Bourne 2002). With the Young-Modulus we obtained objective information on the bendability of asparagus spears, as described in Scheer (2002). Three asparagus spears of each of the 4 replicates were used supporting points were 10 cm apart, crosshead speed was 50 mm/min. The measured force was related to the cross-section area (unit: N/(mm × 10^2 mm^2)). Low force readings correspond to increased elasticity (bendability).

Tissue firmness. Instrumental quantification of the shear force gives information on the fibrousness of the spear (Rodríguez et al. 2004). According to Scheer (2002) the lower part of 3 asparagus spears out of each of the 4 replicates was peeled and shear force measured with a Warner-Bratzler tool. The maximum force during shearing was related to the spear diameter (N/mm). Low values indicate tender, higher values reveal firm tissue and increased formation of fibres.

Colour measurement. For instrumental colour measurement Minolta CR 321 colourimeter (Minolta GmbH, Ahrensburg, Germany) with light type D65 was chosen. Six measurement points were randomly selected along each of 3 asparagus spears out of each of the 4 replicates. Brightness (L) and the colour notes green (–a), red (+a), blue (–b) and yellow (+b) could be distinguished; the colour saturation Chroma (C) was calculated using the formula: $C = ((a^*)2 + (b^*)2)^{½}$.

Dried cut surface. Drying cut surface at the spear base leads to brighter appearance, fibre bundles become visible. Visual assessment of all of the spears in each of the 4 replicates distinguished between 0 (no incidence of dry cut surface), 1 (minor incidence) to 2 (serious incidence at 3 or more spears per replicate).

Lengthwise fractures. Lengthwise fractures mostly occurred at the basal end of the asparagus spears. Visual assessment was performed at all of the spears in each of the 4 replicates. The occurrence of fractures regardless of their size was assessed according to the scale: 0 – no incidence of lengthwise fractures, 1 – minor incidence to 2 – serious incidence at 3 or more spears per replicate.

Weight loss. All packages were weighed when put into storage and at removal on the respective date after the storage period using an electronic scale (Sartorius PT1200, Göttingen, Germany) with an accuracy of 0.1 g. To determine the weight loss of the whole package the following calculation was performed: *Weight loss* = (*weight in* – *weight out*)/*weight in*.

Also, the spear weight loss (without packaging) was determined by weighing when put into storage and at removal on the respective date after the storage period using the above calculation.

Dry matter content. Three asparagus spears out of each of the four replicates were cut into 1 cm long pieces and weighed before and after placing them in a drying oven at 80°C until weight did not change any more (ca. one week). An electronic scale with an accuracy of 0.1 g was used.

Dry matter content was determined according to the following calculation:

Dry matter = (*weight in* – *weight out*)/*weight in.*

Statistics. Four different treatments of packaging were implemented and subject to different storage periods and temperatures. For each of the

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packaging treatments 4 packages (replicates) were provided and filled with 500 g of white asparagus spears. Tables and figures present mean values and ± standard deviation of results. Statistical analysis ANOVA was performed using the Statistica Package™. Reported significant differences of means were tested with Duncan's multiple range test at $P > 0.05$.

RESULTS

Weight loss of asparagus spears

Asparagus in dry packages lost during the first 7 days of storage a high percentage of fresh matter compared to the wet packages (Fig. 1).

Depending on the temperature the losses were between 1.77 and 2.06% at 2°C and 1.83 and 3.70% at 8°C. Even higher losses occurred in the combined regimes of 2°C and 22°C with up to 6.42% in the sleeve and 3.28% in the bag treatment. The lower values of losses occurred in the closed bags, the higher values when stored in the open sleeves.

With storage duration the losses increased, up to the eleventh day, fresh matter diminished, but the rate became slower with time (Table 1).

The loss of fresh weight in wet sleeves and bags was different to the dry treatments. Losses could not only be stopped, but spears gained weight, at a rate slower in the open sleeves, compared to the closed bags. The difference to dry treatments was significant, and the weight gain was significantly higher in the closed bags than in the open sleeves up to the 9th day of storage. Weight gains also occurred at the higher storage temperature of 8°C in bags, whereas asparagus in the sleeve packages lost a small amount of fresh matter under this condition after 7 days of storage. In the 2/22°C storage regime low losses (2.12%) were measured in the wet sleeve package, in the bags, asparagus gained 2.24% of its fresh matter.

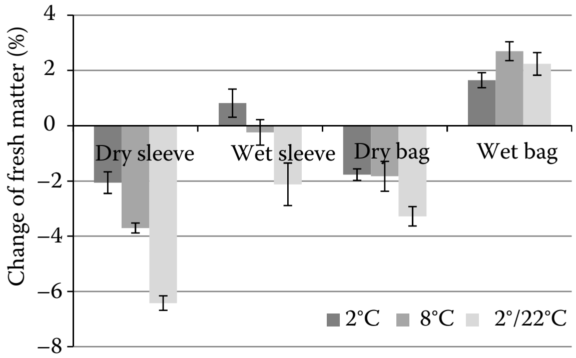

Fig.1. Fresh matter change of asparagus spears during 7 days of storage (change during storage, %)

error bars indicate the standard deviation within replicates

Dry matter content

The dry matter content ranged between 5.0% and 6.6%. No influence of the storage conditions could be determined given the natural variability of dry matter values in the product.

Elasticity

Water loss of asparagus spears can lead to reduced stiffness, which can be measured as lower -bending forces necessary to bend the spears. In dry packages lower bending forces could be measured compared to the wet packages (Fig. 2, Table 2). This effect was measured mostly at 8°C and 2/22°C.

The closed bags did not prevent the spears from losing bending force compared to the open sleeves. There was a large variation of the bending forces, no systematic developments of the values could be detected during the storage period.

Table 1. Fresh weight development of asparagus spears (change during storage in %)

Type of packaging	2°C, 90% RH					8°C, 80% RH		2°C, 90% & 22°C, 60% RH
	3 days	5 days	7 days	9 days	11 days	3 days	7 days	4/3 days
Sleeve + dry fleece	–1.25 ± 0.38	–1.69 ± 0.19	–2.06 ± 0.39	–2.33 ± 0.36	–2.95 ± 0.29	–2.02 ± 0.21	–3.70 ± 0.18	–6.42 ± 0.26
Sleeve + wet fleece	0.74 ± 0.27	0.83 ± 0.55	0.82 ± 0.51	1.10 ± 0.48	1.69 ± 0.44	1.00 ± 0.52	–0.24 ± 0.46	–2.12 ± 0.77
Bag+ dry fleece	–1.36 ± 0.10	–1.55 ± 0.19	–1.77 ± 0.21	–1.69 ± 0.05	–2.09 ± 0.35	–1.27 ± 0.06	–1.83 ± 0.54	–3.28 ± 0.35
Bag+wet fleece	1.45 ± 0.31	1.90 ± 0.18	1.65 ± 0.27	1.99 ± 0.10	1.56 ± 0.13	2.26 ± 0.39	2.70 ± 0.34	2.24 ± 0.41

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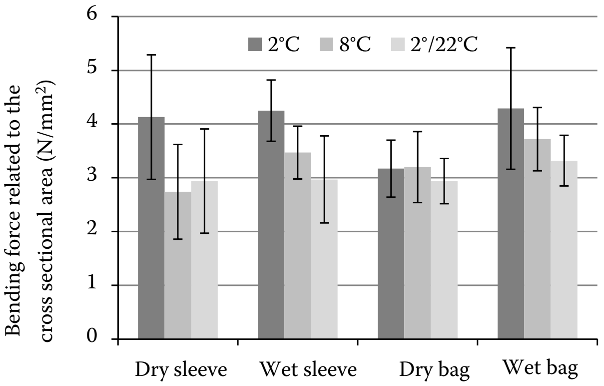

Fig. 2. Bending force related to the spear cross sectional area (N/mm^2) after 7 days of storage

error bars indicate the standard deviation within replicates

Tissue firmness

With the measurement of shear force values an indication of fibrousness at the spear basis could be obtained. In this experiment the shear force values were generally low (Table 2). In the average of temperatures and storage durations, the shear forces after dry treatments were 0.30 N/mm higher than wet treatments. A significant difference with higher values in the warmer treatments (8°C) compared to the colder samples (2°C) could be found first at day 7, not yet at day 3 (Table 2). The types of packaging and also the storage duration had no effect on the shear force of the spears.

Discolouration

Starting from harvest some spears showed a weak pink to red discolouration below the spear tip, affected spots were not subject to instrumental colour measurement. Independent of the post-harvest treatment this discolouration persisted partly until the end of the storage period. Green discolouration did not occur.

Spots of grey-brown discolouration were not present before storage but appeared depending on the storage condition. The visual assessment showed, that asparagus in wet treatments developed discoloured spots starting from day 3 in closed bags and day 5 in the sleeve packages. Dry package prevented discolouration until storage day 7 (data not shown).

After day 3 at the elevated temperatures of 8°C and 2/22°C discoloration was present regardless of packaging treatments.

Instrumental colour saturation (Chroma)

During storage only very little change of the brightness (*L*) of the asparagus spears occurred (data not shown). Colour saturation increased considerably instead, mostly due to intensification of the yellow colour component.

Wet packaging increased the colour saturation compared to dry packaging in many treatments (Table 3). More pronounced was the colour satura-

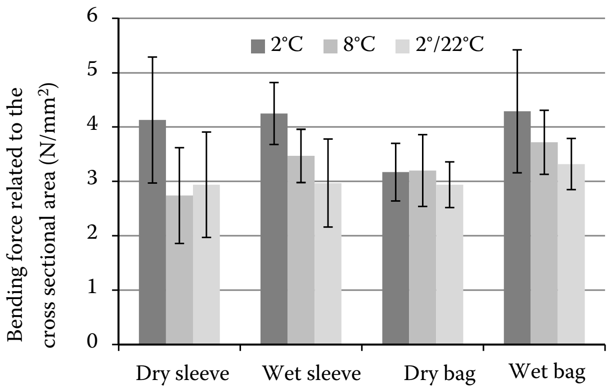

Fig. 3. Colour saturation (Chroma) at storage day 7

higher values indicate increased yellow and red colour intensities; error bars indicate the standard deviation within replicates

Table 2. Sheer force (N/mm) related to the spear diameter

Type of packaging	Fresh	2°C, 90% RH					8°C, 80% RH		2°C, 90% & 22°C, 60% RH
		3 days	5 days	7 days	9 days	11 days	3 days	7 days	4/3 days
Sleeve + dry fleece	2.93 ± 0.47	2.98 ± 0.74	2.53 ± 0.67	2.93 ± 0.46	2.73 ± 0.58	3.34 ± 0.77	2.90 ± 0.49	3.51 ± 0.66	3.45 ± 0.82
Sleeve +wet fleece		2.30 ± 0.28	2.00 ± 0.30	2.71 ± 0.59	2.60 ± 0.65	2.58 ± 0.58	3.15 ± 0.53	3.39 ± 0.58	2.84 ± 0.79
Bag + dry fleece		3.10 ± 0,68	2.69 ± 0.51	3.00 ± 0.76	2.97 ± 0.58	2.83 ± 0.42	2.68 ± 0.49	4.01 ± 0.85	3.21 ± 0.64
Bag + wet fleece		2.87 ± 0.66	2.84 ± 0.65	2.78 ± 0.48	2.64 ± 0.18	2.56 ± 0.22	2.83 ± 0.80	3.38 ± 0.39	2.58 ± 0.54

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Table 3. Bending force related to the spear cross sectional area (N/mm^2)

Type of packaging	Fresh	2°C, 90% RH					8°C, 80% RH		2°C, 90% & 22°C, 60% RH
		3 days	5 days	7 days	9 days	11 days	3 days	7 days	4/3 days
Sleeve + dry fleece	3.29 ± 0.65	3.68 ± 1.34	3.15 ± 0.47	4.13 ± 1.16	4.13 ± 1.37	3.80 ± 0.95	3.40 ± 1.38	2.74 ± 0.88	2.94 ± 0.97
Sleeve + wet fleece		3.78 ± 0.79	3.61 ± 0.67	4.25 ± 0.57	4.04 ± 0.85	4.27 ± 0.66	3.76 ± 0.86	3.47 ± 0.49	2.97 ± 0.81
Bag + dry fleece		3.26 ± 0.52	4.25 ± 1.04	3.17 ± 0.53	3.59 ± 0.50	3.37 ± 0.38	2.93 ± 0.44	3.20 ± 0.66	2.94 ± 0.42
Bag + wet fleece		4.11 ± 0.81	4.67 ± 0.50	4.29 ± 1.13	3.53 ± 0.53	3.76 ± 0.79	3.22 ± 0.22	3.72 ± 0.59	3.32 ± 0.47

tion increase in the treatments at the temperature of 8°C and 2/22° C (Fig. 3, Table 4). There also was a tendency for higher chroma values of asparagus in the bag treatments compared to the sleeves.

Dried cut surface

Starting from day 3 of storage at 2°C in the sleeve package minor incidence of dry cut surfaces was detectable through visual assessment. From day 9 the incidence became serious in the dry treatments only. At the higher temperature of 8°C serious incidence was detectable from day 7 except in the wet bags.

The added water clearly reduced the incidence of dry cut surfaces with visible bundles through visual assessment. After 7 days of storage at 2°C in the wet sleeve packages only a very low incidence, in wet bags none was detectable. In dry treatments, a minor incidence was recorded.

At the higher temperature (8°C) serious incidence was detectable in the dry sleeves or bags and even in the wet sleeves. Wet bags reduced the incidence to a minor frequency.

In the treatment with the highest temperature, 2/22° C both, wet and dry packaging could not prevent dried cut surfaces.

Lengthwise fractures

Lengthwise fractures occurred on some of the asparagus spears mostly on the basal part. There was a tendency towards more fractures with longer storage periods, which was more pronounced in bags and wet treatments, but variation was high.

Combining the influencing factors

By comparing the different postharvest treatments of asparagus spears, it is demonstrated that the coldest storage temperature of 2°C in this study was most appropriate for the maintenance of all of the quality attributes investigated. In addition, also the wet treatment further improved storage results regarding the reduced fresh matter losses, maintenance of higher stiffness, lower development of firmness and reduced dried cut surfaces even at the best temperature of 2°C. On the other hand, wet treatment increased the incidence of brown spots and higher chroma was encouraged at elevated temperatures, but also to some extent at 2°C (Table 5).

The use of closed bags could successfully reduce fresh matter losses and frequency of dried cut surfaces compared to the open sleeves, but especially

Table 4. Synopsis of the effect of the treatments on the quality attributes in this study

Storage treatment	Reduced losses	More stiffness (less bending)	Less firmness (tough)	Fewer brown spots	Lower chroma saturation	Reduced dried cut surface
Wet	+	+	+	–	–	+
Closed	+			–	–	+
Cold	+	+	+	+	+	+
Short	+			+	+	+

wet – water added, closed – bags instead of sleeves, cold – 2°C instead of 8° C or 2/22°C, short – shorter storage duration

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Table 5. Colour saturation chroma (%)

Type of packaging	Fresh	2°C, 90% RH					8°C, 80% RH		2°C,90% &22°C,60% RH
		3 days	5 days	7 days	9 days	11 days	3 days	7 days	4/3 days
Sleeve + dry fleece	11.1 ± 1.04	12.1 ± 0.45	11.2 ± 0.98	12.6 ± 0.71	13.2 ± 0.54	11.2 ± 0.86	12.3 ± 0.74	12.7 ± 0.55	14.5 ± 0.07
Sleeve + wet fleece		12.4 ± 0.79	11.6 ± 0.65	12.4 ± 0.92	13.6 ± 1.09	14.3 ± 0.73	12.7 ± 0.48	14.4 ± 0.63	15.0 ± 0.91
Bag + dry fleece		12.3 ± 0.34	10.7 ± 0.73	12.6 ± 1.10	11.4 ± 0.65	13.0 ± 1.40	13.2 ± 1.12	14.3 ± 0.66	14.9 ± 0.42
Bag + wet fleece		12.5 ± 0.42	10.6 ± 0.89	14.62 ± 0.55	12.8 ± 0.19	13.5 ± 1.01	13.4 ± 0.57	14.8 ± 0.94	13.6 ± 0.48

at the higher temperatures (8°C and 2/22°C) brown discolouration was more prevalent.

Within the investigated storage period texture changes within each treatment during the storage period were not pronounced and variation was high. Low temperature and wet treatment maintained the texture (high stiffness and low firmness) better than higher temperatures, closed bags/open sleeves and the storage duration had only weak influence.

DISCUSSION

Postharvest quality maintenance is essential for any kind of fruit or vegetable, and even more for perishable, high quality and high value produce. The sensitivity to adverse influences from the storage environment is highly dependent on the type of commodity. High respiration items benefit from low temperature or/and reduced oxygen and increased CO_2 atmospheres to lower the metabolic activity. In fruit or vegetables with high transpiration rate losses can effectively be reduced by high relative humidity in the storage atmosphere, or packaging to minimize moisture depletion (Kader, Rolle 2004).

Asparagus spears show both, very high respiration and metabolic rate compared to other fruit and vegetables (Rao 2015) and a high rate of water loss through transpiration (Bovi et al. 2016). Consequently suboptimal storage conditions lead to rapid quality deterioration, namely water loss, toughening and colour changes. Weight loss is of particular relevance because it is used as an important and apparent quality indicator.

Technically and from managerial circumstances, constant and sufficiently high relative humidities are not always achieved in the post-harvest chain. In our experiments the conditions of 2°C and 8°C and 90/80% rel. humidity combined with sleeve or bag packaging was appropriate to limit water loss to around 3 % even until thestorage period of 7 days. The storage temperature of 2/22°C combined with low air humidity (60% ± 10%), which resembled much closer potential real situations in the marketing chain, caused in our experiment high losses in the non-moisted packages, consequently additional moistening and/or tight packaging was beneficial under these circumstances. Siomos (2003) gives the figure of 8% weight loss as a limit for saleability of asparagus. This limit was not reached throughout the experiment.

The observed water uptake in wet packages led to a higher incidence of lengthwise fractures, especially in the early stages of the storage period. This is a serious quality defect, worse than the higher incidence of dried cut surfaces, which occurred more pronounced in all dry treatments.

The grey-brown discolouration is a serious quality defect. In our experiment it occurred earlier in the wet, compared to the dry treatments and under the higher temperature. An additional layer, separating the liquid water phase in the fleece and the saturated atmosphere around the asparagus spears may have the potential for a solution.

The reason for the discolouration, especially under moist and warmer conditions is not yet fully understood (Nothnagel et al. 2013; Rempe-Vestermann et al. 2014). Suspected reasons have been physiological changes after mechanical damage and infestation with Fusarium and viruses but concluding evidence has not been reached so far. Besides the relevance of the spear water status for the appearance, it strongly affects the stiffness. Herppich et al. (2005) reported that stiffness decreased at high storage temperature even under moisture saturated conditions, whereas it decreased to a lesser extent at a cold temperature of 0°C. Our results confirm the role of cold temperatures for the retention of stiffness. Other than the experiment of Herppich we also included dry, un-moistened treatments, which allowed us to demonstrate,

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that not only cool temperatures but also additional moisture contributes to stiffness retention.

Basal firmness development (toughening) can be distinguished from stiffness. Whereas stiffness is determined by the water potential of the spears (Landahl et al. 2004), the former is mainly generated through the development of fibres and lignification through cell wall alterations (Waldron, Selvendran 1990; Herppich et al. 2005). Perceived as fibrousness, it is regarded as an important negative quality issue. Besides storage duration, its incidence is strongly influenced by temperature (Herppich, Huskens-Keil 2008). This simultaneous but opposed effect of higher stiffness (Fig. 2) and lower firmness (Table 2) by cold treatment, but also by wet treatment could be shown in our study.

Besides modified or controlled atmospheres, coatings and active packaging have been proposed. Depending on the material in use, movement of moisture can be limited (Tsoumaki et al. 2009). Formulations of coatings and films also allow for the use of ingredients (e.g. oxygen, carbon dioxide, ethylene scavenging and others), which may have a positive effect retarding synthesis of anthocyanins and even limit microbial growth (e.g. hygiene packaging), (Rojas-Graü et al. 2009; Krepker et al. 2017). In our study, no formation of anthocyanins occurred. In summary, the use of moist packaging efficiently retarded water loss and associated softening (flexibility), toughening and drying. But water uptake and the formation of spots of grey-brown discolouration under warmer storage conditions must be considered. Under cold storage regimes and at low relative air humidity moist packaging can be beneficial.

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