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Cold Water Mist Humidification to Preserve the Quality of Fresh Vegetables During Retail Sale

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The effects of water misting on the maintenance of quality of field-lettuce, head-lettuce, broccoli, chicory and carrots, under retail trade storage conditions were analysed. The results were compared with samples which were stored without misting. Water misted crops (e.g. spraying time of 6 s, interval of 20 min) have far lower weight losses and a lower increase of dry matter. The texture (firmness and crispness) of the raw material was preserved for much longer. Thereby an evidently slower decrease in the ascorbic acid content was found. An impact on colour was not observed. Misted as well as non-misted vegetables showed an increase in the number of microorganisms/g within the same log cycle only.

Introduction

Fresh vegetables are an essential component of the human diet, they contain important ingredients such as minerals, vitamins and fibre. Vegetables are perishable due to metabolic activity during the post-harvest period.

The osmotic behaviour of plant organs depends on the equilibrium between the tendency to lose water during transpiration and the ability to draw water into cells. Since the source of water, which flows into the cells during growth, is interrupted at harvest, there is no possibility of compensating for this deficiency post-harvest. The result is a loss of turgor pressure which is the most drastic change in quality. The main factor contributing to water loss besides temperature and humidity is the surface area:volume ratio; a leaf loses moisture much faster than a root. Respiration is another important factor. This involves the reduction of complex compounds in the plant cells, which liberates carbon dioxide and water and leads to a loss of quality. These factors do not only represent a loss of quality, but also—because of the reduction in weight and saleability—high economic losses. Post-harvest treatment therefore plays an essential role in maintaining the quality of fresh vegetables. Automatic misting with water is one possible solution to this problem.

Materials and Methods

Raw material

Common leaf, root and sprouting vegetables were selected for this investigation. The commodities investigated were field-lettuce, head-lettuce, broccoli, chicory and carrots.

The samples were obtained from a local retail chain. All field vegetables were harvested at 0400–0500 hrs; glasshouse commodities were harvested later in the morning. Most of the vegetables originated from Germany, head-lettuce from Holland and broccoli from Belgium. Chicory is imported from Belgium and Holland. They were transported in trucks without refrigeration or a controlled atmosphere. The vegetables were distributed to the retail stores 24 h after harvest; those bought by auction took an extra day (48 h).

Water misting system

The water misting system used (KES 2000) is manufactured by KES, Atlanta, Georgia, U.S.A. The misting system is composed of a filter and regulation unit, an electronic timer and a water spray unit. The spray unit consists of a square tube with double nozzles, which are 45 cm apart and can be turned off individually. The tubes and nozzles are made from plastic, and the interior is black to avoid algae formation. Fresh, not chlorinated water at a temperature of about 15 °C flows through the filter into the water misting system and is emitted as a fine spray through the nozzles. After each spraying the pressure of the system drops to avoid after-dropping and the filter is cleaned automatically.

The spraying time (*S*) and the interval (*I*) of misting can be adjusted with the electronic timer. For our analysis a square arrangement with six pairs of nozzles was chosen and installed over the non-refrigerated display with an area of 1.2 × 1.2 m.

Selection of the spraying times and intervals

Initial spraying times of 2–7 s at intervals of 15–30 min were tested, to evaluate the best compromise between amount of misted water and individual losses of weight

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from the vegetables. The combination of $S = 6$ s, $I = 20$ min was found to be the most suitable. The amount of water which was delivered by the 12 nozzles within 6 s was 79 mL. The accumulated daily amount was 5.7 L over an area of 1.2 × 1.2 m.

Measurement of weight loss
The fresh vegetables (about 1–3 kg of leaf vegetables and up to 3–5 kg of root vegetables) were packed in 60 × 40 cm plastic trays and weighed immediately. Control vegetables were placed on an opposite shelf to the misted vegetables. The storage temperature was 20 ± 3 °C and the relative humidity (R.H.) was 50 ± 5%. For the accurate measurement of weight loss the vegetables were weighed after 24, 48, 72 and 96 h. The misted samples were shaken prior to weighing.

Determination of dry matter
About 100 g of the samples were ground with the 'Retsch crushing mill' and subsequently 4 g were placed in a quartz cup and dried at a temperature of 105 °C until the weight remained constant.

Determination of texture
The Instron Universal Testing Machine with a 500 kg measuring head and the Kramer shear press were used for texture measurements. Carrot slices (15 g), head-lettuce (10 g) or field-lettuce (10 g) were weighed and placed in the shear press. The maximum expended force (N) taken to shear the samples was measured.

Determination of ascorbic acid
After adding metaphosphoric acid the samples were ground in a kitchen-grinder. Aliquot analysis was carried out enzymatically according to the method of Boehringer GmbH, Mannheim, Germany.

Colour measurement
A Chroma-Meter Type CR 200, Minolta, Osaka, Japan was used to determine colour differences. The colour of previously marked spots on the vegetables was measured every morning. The resulting L^*, a^* and b^*-coefficients were noted.

Microbiological investigation
Samples of the vegetables were taken every morning. After homogenizing, they were diluted on a log scale. Acidified malt extract-agar (Merck 5389) was used for the total count determination of yeasts and moulds. Standard-I-agar (Merck 7881) was used for the determination of bacteria, which were not classified further. The analyses described above were made on duplicate samples taken at each sampling interval.

Results and Discussion

Weight losses
The important question was how far the weight loss due to transpiration and respiration would be compensated for by the water misting system. In addition to the tests under normal storage conditions (mist and non-mist at 20 ± 3 °C, 50 ± 5% R.H.) the effect of cold storage conditions (5 °C, 35% R.H.) overnight was investigated on head-lettuce and carrots. The experiments were performed concurrently, using the same batch of commodities.

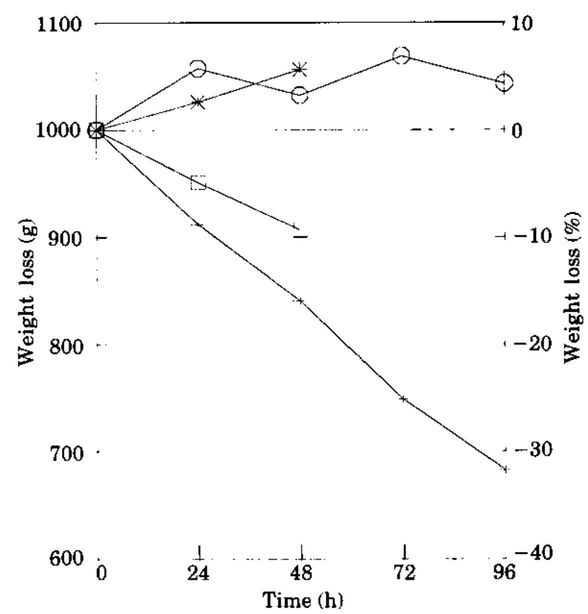

Fig. 1 Weight loss of field-lettuce and broccoli. (○) misted field-lettuce; (+) non-misted field-lettuce; (✻) misted broccoli; (□) non-misted broccoli. Interval = 20 min, at a spray duration of 6 s

Field-lettuce (**Fig. 1**). The greatest loss of weight was found in non-misted field-lettuce. The daily loss averaged 10.5%. Conversely, the greatest increase in weight was measured during misting field-lettuce. The weight increased by up to 8% over a period of several days. One reason for this is that this kind of lettuce has alot of small leaves and therefore a large surface area on which the water can be distributed. Since field-lettuce are sold by weight, large amounts of water on the leaf surfaces should be avoided. This can be done by adjustment of spray duration and intermediate interval. With a lesser amount of misting water (e.g. $I = 30$ min, $S = 2$ s) the initial weight was found to decrease slowly. In all, the misting process had an advantageous effect on the appearance of the lettuce. Even after 72 h of storage, the field-lettuce was still in a good and marketable state when misted at an I of 20 min and S of 6 s. The non-misted product was non-saleable after 24–48 h.

Head-lettuce (**Figs 2–4**). Head-lettuce is not dense or closely packed and so wilting is a serious problem. The outer leaves of non-misted lettuce do not protect the inner leaves from drying out, and evaporation losses are a linear function of time. The loss was in the region of 4.1 to 9.1%/d. Head-lettuce that were stored overnight in the refrigerator, had smaller weight losses. The range was between 2.3 and 4.1%/d. The misted head-

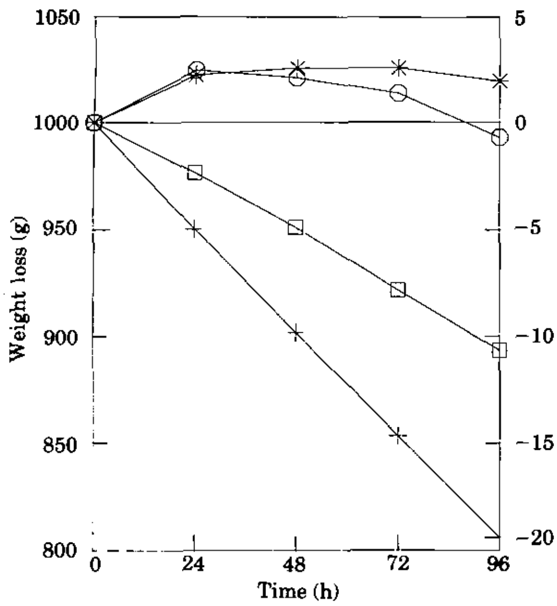

Fig. 2 Weight loss of head-lettuce and carrots. (○) misted head-lettuce; (+) non-misted head-lettuce; (✱) misted carrots; (□) non-misted carrots. Interval and spray duration as in **Fig. 1**

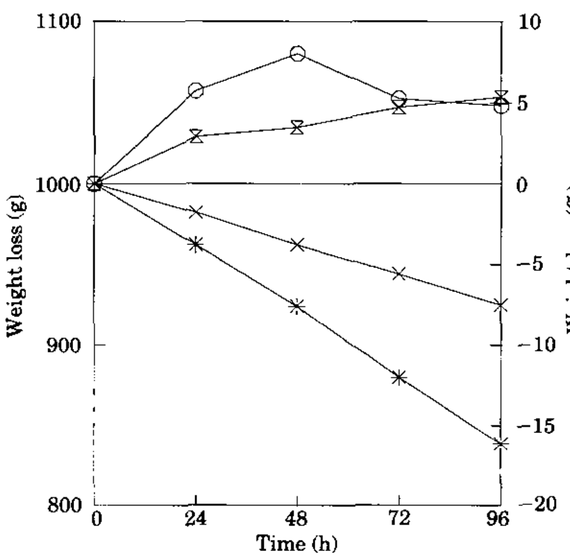

Fig. 3 Weight loss of head-lettuce and carrots, with non-misted samples stored overnight in a refrigerator. (○) misted head-lettuce; (✱) non-misted head-lettuce; (⧖) misted carrots; (×) non-misted carrots.

lettuce showed an increase in weight between 0.2 and 5.7% during the period investigated.

Broccoli (**Fig. 1**). The weight loss of broccoli without water misting of between 3.4–5.7%/d can be explained by the large surface area of the buds. In misted broccoli the values for weight loss were found to be in the range of 0.1–2.2%/d. These values are based on a spraying regime of $I = 20$ min; $S = 6$ s. With a lower amount of water spraying, e.g. $I = 20$ min, $S = 4$ s, losses at an average of 4.1%/d were found.

Chicory. Dwindling of non-misted chicory was fairly low, the average being 1.8%/d. A spraying regime of $I = 30$ min, $S = 4$ s gave satisfactory results. Excess water

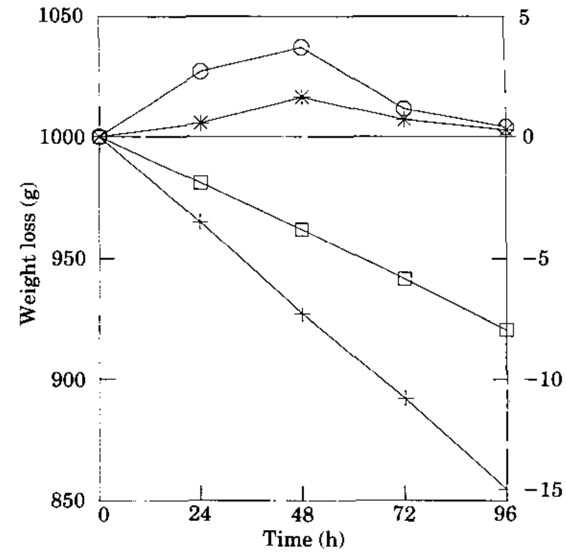

Fig. 4 Weight loss of head-lettuce and carrots, with both misted and non-misted samples stored overnight in a refrigerator. Key as in **Fig. 2**

misting of, for example, $I = 20$ min, $S = 6$ s resulted in a negligible increase in weight (0.7%). This is due to the low surface area:volume ratio, and the smooth surface of this vegetable.

Carrots (**Figs 2–4**). The exposed surface area:volume ratio is not excessive, but the surface is susceptible to water loss (1). During the storage period of non-misted carrots, losses in weight were found to be between 1.8–6.8%/d. Over-night storage in the refrigerator had a beneficial effect, with weight losses between 1.5–2.1%/d. In contrast the weight of misted carrots increased between 0.5–2.9% during the same storage period. A regime with lower amounts of water ($I = 30$ min, $S = 2$ s) caused weight losses of up to 4% over a period of 72 h. Since the temperature under retail conditions may vary greatly, the quality of non-misted vegetables depends on the R.H. and temperature. Under a misting regime, the temperature can be lowered by the cooling effect of the water spray and also by evaporation. However, temperature measurements on the surface of misted vegetables were not found to be different to the non-misted vegetables. Therefore the delayed wilting of misted vegetables can be attributed to reduction of water loss by osmosis.

Dry matter

In the context of weight increase of leafy lettuce or weight loss of the other vegetables the analysis of dry matter was of great significance. **Table 1** shows that the non-misted raw material had an increase in dry matter at every stage of analysis. This shows that there is a permanent release of water to the environment. The misted material also increased in dry matter content with time. Hence, it follows that there is no water intake through the plant organs due to misting, but a delayed release of water, compared to the non-misted vegetables. Dry matter analysis is also important as a reference for possible changes in nutritional components.

Table 1 Data of dry matter determination ($n = 2$)

Time	Broccoli		Field-lettuce		Carrots		Head-lettuce	
(h)	Misted	Non-misted	Misted	Non-misted	Misted	Non-misted	Misted	Non-misted
0	9.8	9.8	7.9	7.9	9.8	9.8	3.1	3.1
24	10.4	11.1	7.9	9.6	10.0	11.5	3.2	3.5
48	10.4	11.6	9.6	11.5	10.1	11.3	3.2	3.9
72			9.9	13.1	10.2	11.9	3.7	3.8
96			11.2	15.8	11.0	13.3	3.6	4.9

Texture

The structural and chemical bases for texture of plant food-stuffs and the effect of processing have been reviewed recently by Ilker and Szczesniak (2), but the effects of handling and storage on the mechanical properties of the different tissues have not yet been fully investigated. The vacuoles and their osmotically active solutes have a strong impact on texture via the exerted pressure on cell walls. The textural characteristics of the five vegetables cover different intensities of firmness/softness, tenderness/toughness, flexibility, juiciness. The cell turgor pressure is correlated with the textural characteristics, especially with cell wall stiffness. Migration of water out of the cells leads to cell relaxation.

Measurements of texture were made in field-lettuce, head-lettuce and carrots. In general, it was observed that increasing force was needed to shear the samples in the Kramer shear cell. Lettuce leaves as well as carrot slices showed a decrease in firmness and an increasing flexibility during storage. The following results were obtained:

Table 2 Data of texture determination of field-lettuce (force N)

$n = 5$	Misted		Non-misted	
Time (h)	$\bar{x}$	Sx	$\bar{x}$	Sx
0	351	19	351	19
24	336	93	371	19
48	350	31	385	95
72	359	16	401	33
96	364	32	481	69

Field-lettuce (**Table 2**). Shear press values with a mean of 230 N, in another commodity of 351 N were measured. The misted material hardly lost any crispness. After 2 d of storage the non-misted leaves looked quite unpleasant, because of wilting, and were accompanied with steady increases in shear press values.

Head-lettuce (**Table 3**). The texture values increased steadily with a slope of 50–70 N within 96 h for the misted samples, compared with 140–160 N for the non-misted samples. In another experiment, non-misted head-lettuce were stored in a refrigerator (5 °C, 35% R.H.) overnight. This reduced the slope to about 120–140 N within 96 h, showing the influence of cooling.

Table 3 Data of texture determination of two origins of head-lettuce (force N)

$n = 5$	Misted		Non-misted		Misted		Non-misted (cooled)	
Time (h)	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx
0	554	11	554	11	592	21	592	21
24	617	32	635	28	584	27	623	41
48	676	53	682	25	579	43	659	41
72	642	14	708	12	580	29	632	32
96	625	19	718	42	646	25	732	63

Carrots (**Table 4**). The mean maximum force of 1350 N rose over 96 h by 85–110 N in misted carrots, whereas the non-misted material showed an increase in flexibility, with a 230–260 N greater shear force required. Cooling overnight (5 °C, 35% R.H.) reduced the shear force by 30–50 N after 96 h. Again, these results show that cooling has a beneficial effect on texture, but continuous misting to be much more effective. This is because loosely covered vegetables lose water through evaporation even in the refrigerator.

The compressive failure of the three vegetables seems to follow the theory given by Lin and Pitt (3). At higher turgor pressure the dominant mode of failure is cell rupture; at lower turgor pressure it is due to intercellular debonding. Non-misted vegetables have a lowered turgor pressure, are more tensile and less stiff, which leads to an increased applied shear force.

Ascorbic acid retention

The ascorbic acid content was determined in 100 g dry matter samples, not on the samples wet weight in order to compare misted with non-misted material. According to Hudson *et al.* (4), dehydroascorbic acid comprises only a small amount of the total ascorbic acid in broccoli. The vitamin C content is essentially ascorbic acid. Dehydroascorbic acid is destroyed as quickly as ascorbic acid under retail conditions (4). Therefore, the investigation of vitamin C refers to ascorbic acid only.

Field-lettuce (**Table 5**). The ascorbic acid content at the beginning of the storage period was on average 25 mg/100 g fresh weight. The ascorbic acid values of the misted samples calculated on a dry weight basis were greater at every stage of the storage period than those of the non-misted lettuce. The ascorbic acid loss after 4 d was 33.4% for the non-misted material and 11.8% for the misted material.

Table 4 Data of texture determination of two origins of carrots (force N)

n = 5	Misted		Non-misted		Misted		Non-misted (cooled)	
Time (h)	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx	$\bar{x}$	Sx
0	1351	173	1351	173	1350	127	1350	127
24	1387	111	1462	60	1351	51	1494	64
48	1343	83	1408	89	1235	92	1423	86
72	1439	91	1554	80	1475	81	1527	81
96	1435	185	1614	128	1460	96	1576	79

Table 5 Data of ascorbic acid retention for field-lettuce

Time (h)	Ascorbic acid (mg/100 g WW)		Dry matter (g/100 g)		Ascorbic acid (mg/100 g DM)	
	Misted	Non-misted	Misted	Non-misted	Misted	Non-misted
0	25	25	7.9	7.9	319	319
24	24	27	8.1	9.7	307	273
48	26	30	9.8	12.6	268	235
72	28	31	9.9	14.9	283	209
96	35	35	12.5	16.3	281	212

WW, wet weight; DM, dry matter.

Table 6 Data of ascorbic acid retention for broccoli

Time (h)	Ascorbic acid (mg/100 g WW)		Dry matter (g/100 g)		Ascorbic acid (mg/100 g DM)	
	Misted	Non-misted	Misted	Non-misted	Misted	Non-misted
0	113	113	9.8	9.8	1147	1147
24	113	109	10.4	11.1	1086	978
48	112	109	10.4	11.6	1080	935

WW, wet weight; DM, dry matter.

Broccoli (**Table 6**). Broccoli is a good source of ascorbic acid which represents an accurate indicator of handling and storage conditions (4). The average ascorbic acid content of broccoli, based on wet weight was 113 mg/100 g. This value corresponds well to that found by Barth *et al.* (5). The loss of ascorbic acid was 18.4% after 48 h of storage time for the non-misted material. This comes close to the result of Barth *et al.* (5). The decrease of ascorbic acid in misted broccoli did not exceed 5.8%.

Colour

The visual condition of the product is often the decisive factor in buying; the colour is indicative of the quality of fresh vegetables.

Broccoli. The deep green colour of broccoli buds and stems is usually associated with 'freshness' and flavour. Broccoli changed colour after 2 d to a yellowish shade and was therefore unsaleable. In contrast to the results of Barth *et al.* (6) the misted samples were not significantly greener than the non-misted samples. Hue angle ($\tan^{-1} b/a$) indicates relative greeness (7). After 48 h of storage the descending slope of non-misted broccoli differed by 5 units hue angle only, which is too small to distinguish a visual change.

Chicory. Chicory was chosen because it changes colour from yellow to green by forming chlorophyll under the influence of light. Change in colour occurred with the misted as well as the non-misted material within the same period of time, after 24–48 h.

Carrots. When the misted carrots were wiped dry no significant difference in colour between misted and non-misted material could be shown. However, the misted carrots appeared fresher because of their glossy appearance.

Determination of microorganisms

The behaviour of bacteria, yeasts and moulds during the storage period under retail conditions has not yet been investigated. Field-lettuce, head-lettuce and carrots were studied. For each investigation raw material from the same batch was analysed. However, the material might be quite inhomogeneous and variations of the colony forming units (CFU) are to be expected.

Field-lettuce (**Table 7**). Field-lettuce is by its very nature a highly contaminated crop, with the entrance of microorganisms through organic dung, dust and earth via its small roots. A mean of 8.2×10^7 CFU/g was found at the beginning (Standard-1-agar). This is in accordance to the value found by Geiges *et al.* (8). After 72 h the

Table 7 Mean number of microorganisms on field-lettuce

	Mean number of microorganisms (CFU/g)			
Medium	Standard-I-agar		Malt-extract-agar	
Time (h)	Misted	Non-misted	Misted	Non-misted
0	8.2×10^7	8.2×10^7	9.0×10^5	9.0×10^5
24	1.2×10^8	2.1×10^8	1.6×10^6	1.2×10^6
48	3.6×10^8	2.1×10^8	2.7×10^6	2.1×10^6
72	5.5×10^8	1.0×10^9	7.9×10^6	2.4×10^6

number of microorganisms increased by approximately 1 log cycle, in misted field-lettuce. The non-misted field-lettuce had already started rotting after 48 h, which lead to an increase in microorganisms. Mean counts went up to 1.0×10^9 CFU/g after 72 h. The lower counts of the misted material can be explained through the effect of rinsing off the soil and consequently the microorganisms from the roots. The increase of yeasts and moulds (Malt extract agar) within 1 log cycle for misted as well as for non-misted lettuce was not of great concern.

Table 8 Mean number of microorganisms on head-lettuce

	Mean number of microorganisms (CFU/g)			
Medium	Standard-I-agar		Malt-extract-agar	
Time (h)	Misted	Non-misted	Misted	Non-misted
0	2.6×10^7	2.6×10^7	4.1×10^5	4.1×10^5
24	1.2×10^8	3.7×10^7	9.5×10^5	2.5×10^5
48	1.6×10^8	5.1×10^7	6.0×10^6	1.3×10^6
72	4.1×10^8	2.8×10^8	6.9×10^6	3.5×10^6

Head-lettuce (**Table 8**). The total count average of 2.6×10^7 CFU/g is a little lower than the value reported by Ercolani (9), who found an average count of 6.6×10^7 CFU/g. During the 4 d storage, the number of bacteria as well as yeast and moulds increased by approximately 1 log cycle. The number of CFU on the misted lettuce was slightly higher at every stage than the non-misted material. This could be due to the fact that the microorganisms between the misted leaves enjoyed better conditions for propagation than in non-misted material.

Table 9 Mean number of microorganisms on carrots

	Mean number of microorganisms (CFU/g)			
Medium	Standard-I-agar		Malt-extract-agar	
Time (h)	Misted	Non-misted	Misted	Non-misted
0	1.1×10^6	1.1×10^6	6.3×10^5	6.3×10^5
24	3.9×10^7	1.9×10^6	2.0×10^6	5.1×10^5
48	3.4×10^7	6.0×10^6	3.6×10^6	8.1×10^5
72	6.9×10^7	1.5×10^7	8.8×10^6	5.3×10^6

Carrots (**Table 9**). During the storage period the bacteria increased by more than 1 log cycle after 24 h and reached a value of 6.9×10^7 CFU/g for misted and 1.5×10^7 CFU/g for non-misted carrots after 72 h. A nearly continuous growth of the yeasts and moulds was observed. It can be concluded that misting leads to slightly higher numbers of microorganisms. Some gross identification of the microbes that have been isolated would show whether they truly present a health problem to the commodities or the consumer. This has not yet been done.

Conclusion

The effects of water misting on the quality maintenance of fresh vegetables under the storage conditions of the retail trade were analysed. The results were compared with samples which were stored without misting. Dry matter weight loss, texture and colour, ascorbic acid content and growth of microorganisms on field-lettuce, head-lettuce, broccoli, chicory and carrots were investigated. The results show that the misted crops (e.g. with $S = 6$ s, $I = 20$ min) have far lower weight losses and a lesser increase in dry matter at the same time. The weight increase of the leafy vegetables is caused by loosely adhering surface water. The texture measurements showed that the firmness and crispness of the raw materials were preserved for much longer. Thereby a slower decrease in the ascorbic acid content was found. An impact of misting on colour was not observed. Neither the formation nor the degradation of chlorophyll were found to be affected by the treatment.
Finally, the effect of misting on the growth of microorganisms was investigated. In comparison to the non-misted vegetables, the misted vegetables did not exceed 0.5 log cycles of CFU/g. Therefore no health hazards are to be expected. Finally, it can be concluded that water misting does extend the shelf life of plant raw material for up to 72 h without severe loss of quality.

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