

# Determination of spoilage levels of fresh fruit and vegetables according to the type of packaging

**Evaluation report**

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## 1 Introduction and objectives of the study

In 2011, the debate on the handling of fresh foodstuffs in Germany gained new momentum, not least through the film *Taste the Waste*. Although statistics on how much food is thrown away unused in Germany vary greatly, there is, however, a consensus that the amount needs to be reduced. Estimates of food wastage range from around 20 million tonnes per year – for total domestic wastage in Germany (source: *Taste the Waste*) – to as much as 300,000 tonnes for the German food trade as a whole (source: EHI).

This significant variation between different sources clearly shows that there is still not enough transparency with regard to wastage. This also applies to fresh fruit and vegetables. In this connection, it is of particular interest whether and to what extent the packaging method used (disposable vs reusable packaging) influences the spoilage of products.

The Fraunhofer Institute for Material Flow and Logistics and the Cold-Chain Management Working Group at the University of Bonn have addressed this problem. Their study investigated the potential link between packaging damage and packaging type on the one hand, and the potential link between loss of freshness of fruit and vegetables and packaging type on the other.

The following issues are the focus of the present study:

- **Losses due to damage to packaging throughout the supply chain (Part 1):**

Throughout the logistics chain to the point of sale, transport packaging is subject to static and dynamic loads. Project experiences show that these cause damage to packaging and damage to produce. It is the aim of this investigation to determine, along defined points of the supply chain (central warehouse and outlet), the extent of the damage and loss ratios according to the type of packaging.

- **Loss of freshness of fruit and vegetables due to the type of packaging (Part 2):**

The shelf life of fruit and vegetables throughout the supply chain is, as expected, influenced by factors such as surface bacterial count and the environment within the packaging. It is the aim of this investigation to identify and quantify the impacts of the type of packaging on the sensory and microbiological quality of these foodstuffs.

## 2 Definition of terms and differentiation of terms

### 2.1 Reusable and Disposable Packaging

Reusable packaging is sales, outer or transport packaging that is intended to be reused repeatedly for containing, protecting, handling, supplying or presenting goods (VDI (Association of German Engineers) 4407). Disposable packaging fulfils this purpose only once and is then recovered or disposed of.

### 2.2 Crates

The term "crate" designates packaging made of wood, plastic or cardboard that does not fully cover the packaged goods or products. Crates are primarily used for transporting fruit and vegetables. Crates are available in both types of packaging (disposable and reusable).

Within the context of this study, the terms "crate" and "packaging" are used interchangeably.

### 3 Part 1:

## Empirical determination of damage to disposable and reusable packaging

### 3.1 Procedure and data collection

Packaging damage was assessed for incoming goods both in central warehouses and in retail outlets.

#### 3.1.1 Data collection in central warehouses

Following the harvest, fresh fruit and vegetables are packed in crates. Multiple layers of transport packaging of one type of fruit or vegetable are grouped on a pallet to form what is known as a homogeneous loading unit. This means that only one product type and one packaging type are contained in a loading unit. As a rule, the loading unit is then transported to a central warehouse. After the delivered loading units are unloaded, they are placed in a buffer zone for goods inward within the central warehouse, where the loading units will remain for a short time before being made available in the picking area. The collection of data took place immediately after the unloading process in the buffer zone of the goods inward area. An employee of the Fraunhofer Institute inspected the loading units located there on each side and documented any damage to individual transport packaging units.

In the process, the following data was recorded:

- Data concerning products and loading units
  - Product group (fruit/vegetables)
  - Product type
  - Country and region of origin
  - Type of packaging
    - Reusable
    - Disposable corrugated cardboard
    - Disposable solid cardboard
    - Disposable wood
  - Dimensions of packaging
  - Number of loading units
  - Number of transport packaging units
  - Photo documentation
  
- Data concerning the documentation of damage
  - Number of damaged transport packaging units
  - Causes of damage
    - Breakage in stack
    - Inadequate securing of cargo
    - Outside influences
  - Product condition
    - Undamaged

- Partially damaged
- Completely damaged
- Photo documentation

The data was collected during the period from July to August 2012. Data was collected in three central warehouses belonging to Top 5 retail groups and one central warehouse belonging to one of the Top 5 discount retail groups.

### 3.1.2 Data collection in retail outlets

The central warehouse pools all deliveries from producers and distributes them to retail outlets. This involves composing loading units according to demand in the course of the picking process for each individual outlet. Consequently, a loading unit typically comprises different product types and also different types of packaging. These mixed loading units are then transported to the outlet. Data collection at the outlet took place after the loading units were unloaded and handed over to an employee of the store. Following the same principles applied in the central warehouse, an employee of the Fraunhofer Institute inspected the loading unit on each side, and determined and documented any damage to individual transport packaging units.

The following data was recorded in the goods inward areas of the outlets in question:

- Data concerning the loading unit
  - Number of transport packaging units per pallet for each type of packaging
    - Reusable
    - Disposable corrugated cardboard
    - Disposable solid cardboard
    - Disposable wood
  - Photo documentation
  
- Data concerning the documentation of damage
  - Number of damaged transport packaging units for each type of packaging
  - Causes of damage
    - Breakage in stack
    - Inadequate securing of cargo
    - Outside influences
    - Inconsistent module dimensions
    - Incompatible transport packaging
  - Product condition
    - Undamaged
    - Partially damaged
    - Completely damaged
  - Photo documentation

The data was collected during the period from July to August 2012. Data was collected in the outlets of two of the Top 5 retail groups and in the outlets of one of the Top 5 discount retail groups. A total of 25 stores were visited.

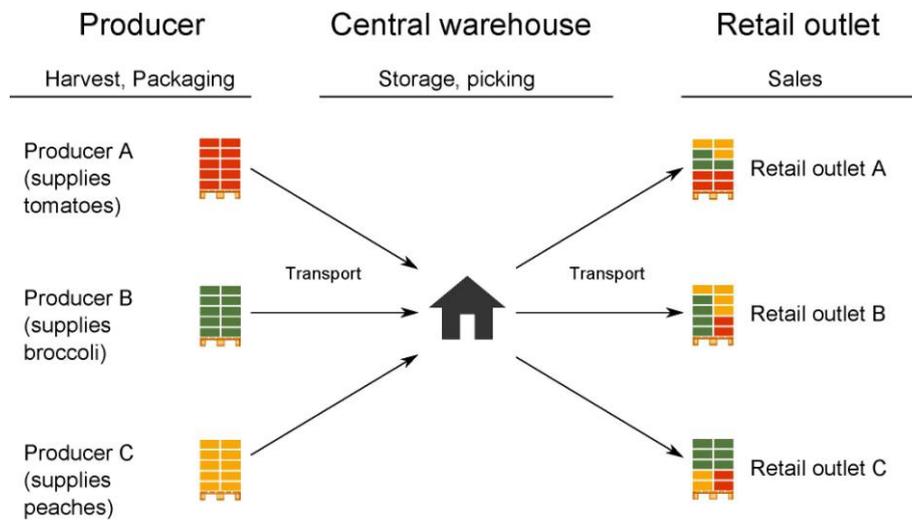


Figure 1: Exemplary supply chain for a retail group

### 3.2 Central warehouse results

A total of 78,153 transport packaging units were examined. 52% were reusable and 48% were disposable.

#### 3.2.1 Recorded products

The two following tables show the products recorded in descending order according to the number of transport packaging units recorded. Moreover, for each product, the proportions of each type of transport packaging are indicated as percentages.

Fruit

Type of fruit	Proportion of all packaging used for this fruit	Of which disposable corrugated cardboard	Of which disposable solid cardboard	Of which disposable wood	Of which reusable
Peaches	23%	20%	-	-	80%
Apples	14%	73%	-	-	27%
Nectarines	12%	35%	-	-	65%
Melons	9%	46%	-	-	54%
Grapes	8%	57%	1%	7%	34%
Bananas	6%	100%	-	-	-
Cherries	6%	82%	-	-	18%
Lemons	3%	8%	30%	30%	32%
Raspberries	3%	100%	-	-	-
Apricots	3%	100%	-	-	-
Blueberries	3%	41%	-	-	59%
Pears	2%	94%	-	-	6%
Strawberries	1%	-	74%	-	26%
Oranges	1%	100%	-	-	-
Limes	1%	100%	-	-	-
Physalis	< 1%	100%	-	-	-
Pineapples	< 1%	100%	-	-	-
Plums	< 1%	45%	-	55%	-
Mangoes	< 1%	100%	-	-	-
Gooseberries	< 1%	-	51%	-	49%
Redcurrants	< 1%	-	-	-	100%
Grapefruit	< 1%	100%	-	-	-
Kiwi fruit	< 1%	100%	-	-	-
Papaya	< 1%	100%	-	-	-

Table 1: Types of fruit recorded, listed according to the proportion of packaging recorded for each type of fruit, and broken down by packaging type

## Vegetables

Type of vegetable	Proportion of all packaging used for this vegetable	Of which disposable corrugated cardboard	Of which disposable solid cardboard	Of which disposable wood	Of which reusable
Tomatoes	50%	34%	-	-	66%
Cucumbers	11%	16%	48%	-	36%
Peppers	6%	49%	7%	-	44%
Potatoes	6%	28%	-	-	72%
Red radishes	4%	0%	-	100%	-
Iceberg lettuce	3%	15%	-	-	85%
Zucchini (Courgette)	3%	20%	10%	-	70%
Mushrooms	3%	23%	-	-	77%
Onions	2%	11%	-	-	89%
Carrots	2%	-	-	-	100%
Cauliflowers	2%	-	-	-	100%
Spring onions	2%	-	-	30%	70%
Romaine lettuce hearts	1%	-	-	-	100%
Lettuce	< 1%	-	-	-	100%
Avocados	< 1%	100%	-	-	-
Rocket	< 1%	-	-	-	100%
Aubergines (Egg-plants)	< 1%	63%	37%	-	-
Radicchio	< 1%	45%	-	9%	45%
Mirepoix	< 1%	-	-	-	100%
Chicory	< 1%	-	100%	-	-
White radishes	< 1%	-	-	-	100%
Fennel	< 1%	-	-	100%	-
Lamb's lettuce	< 1%	33%	-	67%	-
Artichokes	< 1%	-	-	100%	-
Peas	< 1%	100%	-	-	-
Garlic	< 1%	-	100%	-	-
Turnips	< 1%	-	-	-	100%
Sweet corn	< 1%	100%	-	-	-
Others	< 1%	100%	-	-	-
Spinach	< 1%	100%	-	-	-
Loose leaf lettuce	< 1%	100%	-	-	-

Table 2: Types of vegetable recorded, listed according to the proportion of packaging recorded for each type of vegetable, and broken down by packaging type

### 3.2.2 Damage rates

Table 3 shows the number of packaging units recorded and all damage observed, as well as the corresponding damage rates for disposable and reusable packaging.

	All disposable types	Disposable cardboard	Disposable wood	Reusable
Total number of packaging units	37,577	34,935	2,642	40,576
Total number of damaged packaging units	309	307	2	9
Damage rate	0.82%	0.88%	0.08%	0.02%

Table 3: Damage rates in the central warehouses

Table 4 shows the damage rates for disposable packaging, broken down according to the types of packaging (corrugated cardboard, solid cardboard and wood).

	Corrugated cardboard	Solid cardboard	Wood
Proportion of disposable packaging units	84%	9%	7%
Total number of packaging units	31,557	3,378	2,642
Total number of damaged packaging units	224	83	2
Damage rate	0.71%	2.46%	0.08%

Table 4: Damage rates for different types of disposable packaging

### 3.2.3 Causes of damage

In the central warehouse, the following causes of damage were identified:

- insufficiently robust packaging;
- inadequate securing of loading units;
- outside influences.

"Insufficiently robust packaging" covers packaging that is unable to support loads stacked on top of it.

"Inadequate securing of loading units" covers damage caused by loading units that are insufficiently or incorrectly secured (by means of stretch film or straps, for instance).

"Outside influences" typically occur when damage to the packaging stems from incorrect or improper handling or from negligence. Examples include:

- damage during unloading from the lorry or damage caused by forklift prongs;
- mistakes made during the formation of the loading unit (excessive length);
- incorrect securing of load within the lorry.

The following photos illustrate the three main causes of damage identified above:



Table 5: Examples of causes of damage (in central warehouses)

The following table shows the absolute and relative frequency of causes of damage among disposable packaging. Damage because of insufficiently robust packaging concerns only cardboard boxes.

	Insufficiently robust packaging	Inadequate securing of loading units	Outside influences
Absolute frequency	199	61	49
Relative frequency	64%	20%	16%

Table 6: Absolute and relative frequencies of causes of damage among disposable packaging

The following table shows the absolute and relative frequency of causes of damage among reusable packaging.

	Insufficiently robust packaging	Inadequate securing of loading units	Outside influences
Absolute frequency	0	6	3
Relative frequency	0%	67%	33%

Table 7: Absolute and relative frequencies of causes of damage among reusable packaging

The following diagram compares the causes of damage for both types of packaging.

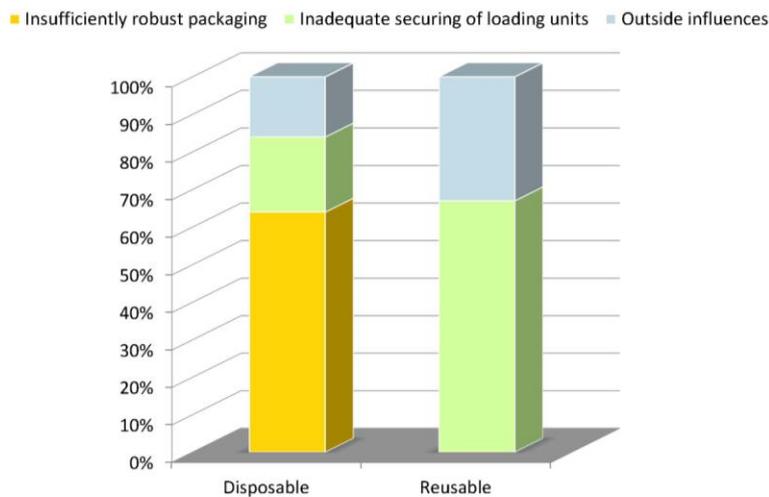


Figure 2: Comparison of causes of damage in central warehouses

Figure 2 illustrates that the most frequent cause of damage to cardboard boxes results from insufficient robustness. The main cause of damage to reusable packaging, on the other hand, is incorrect and improper handling: the producer secured the loading unit incorrectly, or the haulage contractor did not secure the load well enough on the lorry, or the damage was caused by negligence on the part of staff during the loading or unloading processes.

### 3.2.4 Damage to products

For each damaged packaging unit, the quantity of products damaged was recorded. This process involved classifying the damage to products according to three categories:

- Products completely damaged
- Products partially damaged
- Products undamaged

Table shows the absolute and relative frequencies for the three categories of damage, broken down according to the types of packaging (disposable and reusable). Figure 3 presents these values in graph form.

	Cardboard boxes	Reusable
Completely damaged	0 / 0%	0 / 0%
Partially damaged	123 / 40%	2 / 22%
Undamaged	184 / 60%	7 / 78%

Table 8: Absolute and relative frequencies for the product condition (Central warehouse)

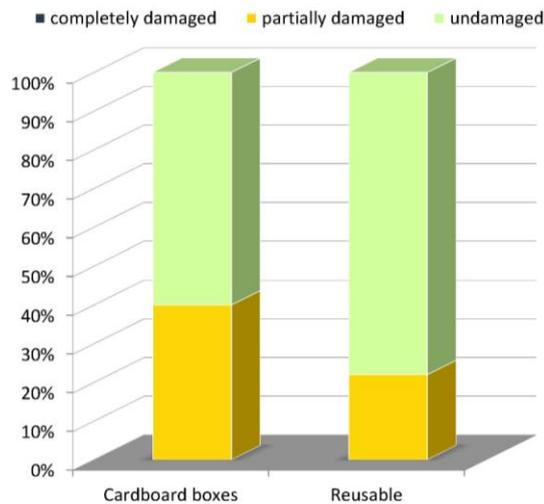


Figure 3: Condition of products contained in damaged packaging (in central warehouses)

Figure 3 shows that damage to packaging does not necessarily mean damage to the products it contains. In most cases, products remain undamaged despite packaging damage. The probability of a product being damaged in the event of packaging being damaged is significantly lower for reusable packaging.

### 3.2.5 Process costs in the event of damage

In addition to the product loss caused by packaging damage, additional expenses— incurring further economic losses – which may arise must be considered. To demonstrate this, we shall consider the example of a settlement for damage caused in a central warehouse: As a rule, a damaged packaging unit within the stack of a loading unit destabilises the whole loading unit and may cause the stack to become unbalanced. In extreme

cases, this may lead to a tipping over of the whole loading unit or individual stacking columns. In order to prevent a significantly higher product loss in terms of material flow costs, severely damaged packaging must be removed from the stack of the loading unit. As damaged packaging is typically situated in the lower third of a loading unit, a loading unit must often be depalletised completely, or the individual transport packaging unit must be repacked to another pallet, in order to reach the damaged packaging. As a result, process costs of around €6.70\* are incurred per pallet. In this study, it was not ascertained in how many cases of damage a repacking of the loading units was necessary.

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\*One pallet contains 80 transport packaging units on average, of which 60, on average, must be depalletised or repacked in the case of damage. The average process duration of each repacking procedure for a transport packaging unit amounts to around 20 seconds. The average personnel costs of a warehouse employee amounts to around €20 per hour.

### 3.3 Retail outlet results

A total of 1,879 transport packaging units were examined. Of these, 52% were reusable and 48% were disposable.

#### 3.3.1 Damage rates

Table shows the total number of packaging units recorded, the number of damaged packaging units observed and the resulting damage rates for disposable and reusable packaging.

	Disposable	Reusable
Total number of packaging units	903	976
Total number of damaged packaging units	30	1
Damage rate	3.32%	0.10%

Table 9: Damage rates in retail outlets

#### 3.3.2 Causes of damage

In retail outlets, the following causes of damage were identified:

- insufficiently robust packaging;
- inadequate securing of loading units;
- outside influences;
- inconsistent module dimensions;
- lack of compatibility.

The first three causes of damage correspond to the descriptions given in section 3.2.3 above.

Since mixed commissioning units are combined at the second distribution level (central warehouse to retail outlet), two further causes of damage (inconsistent module dimensions and lack of compatibility) can be added to the list. These causes refer to the suitability of packaging for the formation of heterogeneous commissioning loading units.

"Inconsistent module dimensions" typically refers to packaging whose dimensions do not comply with the basic 600 x 400 mm module, and which are consequently the cause of damage. This often arises when the packaging has unusual base dimensions and is thus only partly stackable, meaning that parts of the packaging therefore rest directly on the products.

A "lack of compatibility" refers to situations where the packaging unit causing damage has standard modular dimensions, but cannot be properly stacked (by means of interlocking stacking lugs on the ends of packaging units, for example). Incompatible packaging units often slip into the unit below and rest directly on top of produce.

The following photos illustrate the causes of damage identified above:

Insufficiently robust packaging



Inadequate securing of loading units



Outside influences



Inconsistent module dimensions



Lack of compatibility



Table 10: Examples of causes of damage (in retail outlets)

The following table shows the absolute and relative frequency of the causes of damage among disposable packaging.

	Insufficiently robust packaging	Inadequate securing of loading units	Outside influences	Inconsistent module dimensions	Lack of compatibility
Absolute frequency	5	1	1	11	12
Relative frequency	17%	3%	3%	37%	40%

Table 11: Absolute and relative frequencies of causes of damage among disposable packaging

The following table shows the absolute and relative frequency of causes of damage among reusable packaging.

	Insufficiently robust packaging	Inadequate securing of loading units	Outside influences	Inconsistent module dimensions	Lack of compatibility
Absolute frequency	0	0	1	0	0
Relative frequency	0%	0%	100%	0%	0%

Table 12: Absolute and relative frequencies of causes of damage among reusable packaging

The following graph compares the causes of damage for both types of packaging:

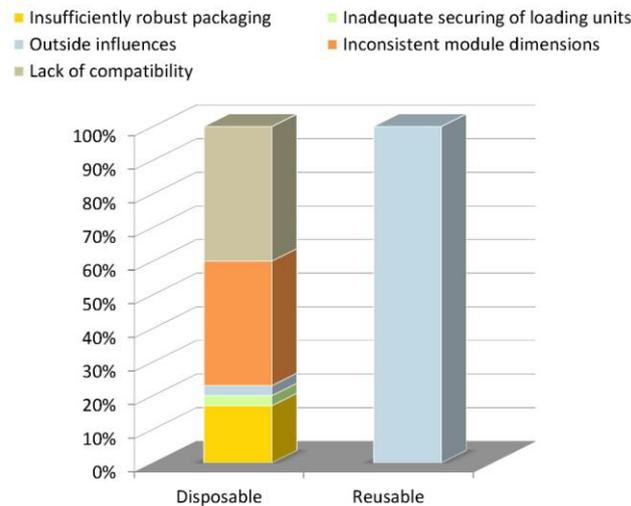


Figure 4: Comparison of causes of damage (in retail outlets)

Unlike in the central warehouses, the main causes of damage to disposable packaging in the retail outlets are a lack of standardisation and compatibility. Lack of compatibility here refers not just to the compatibility of disposable vs reusable packaging, but also the compatibility of different types of disposable packaging. In the case of reusable packaging, only one case of damage was recorded, which was due to outside influences.

### 3.3.3 Damage to products

Using a procedure similar to that employed in the central warehouse, the extent of damage to the product for each damaged packaging unit was also recorded in the retail outlet.

Table shows the absolute and relative frequencies for the three damage categories, broken down according to the types of packaging (disposable and reusable). Figure 5 shows these values in graph form.

	Disposable	Reusable
Completely damaged	0 / 0%	0 / 0%
Partially damaged	6 / 20%	0 / 0%
Undamaged	24 / 80%	1 / 100%

Table 13: Absolute and relative frequencies of product condition (in retail outlets)

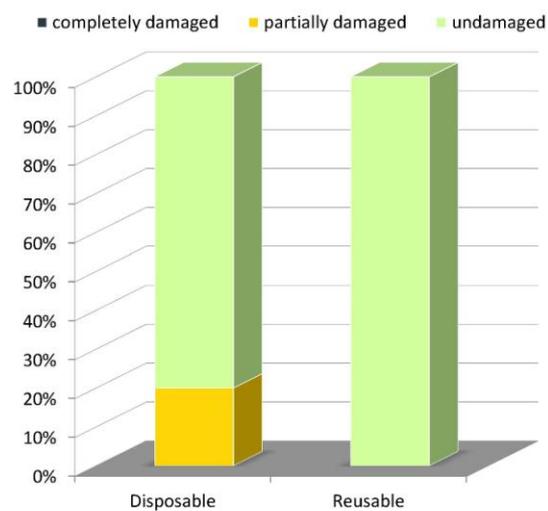


Figure 5: Condition of products in damaged packaging (in retail outlets)

As was already observed at the first distribution level (from the producer to the central warehouse), the majority of the products in damaged packaging units in fact remain undamaged on their way to the outlet. For disposable packaging, around 20% of the products in damaged packaging units were partially damaged. In the one case of damage observed for reusable packaging, the product was not damaged.

### 3.4 Damage to packaging throughout the whole supply chain

Figure 6 shows the damage rates for disposable and reusable packaging throughout the whole supply chain, from the producer to the central warehouse to the retail outlet.

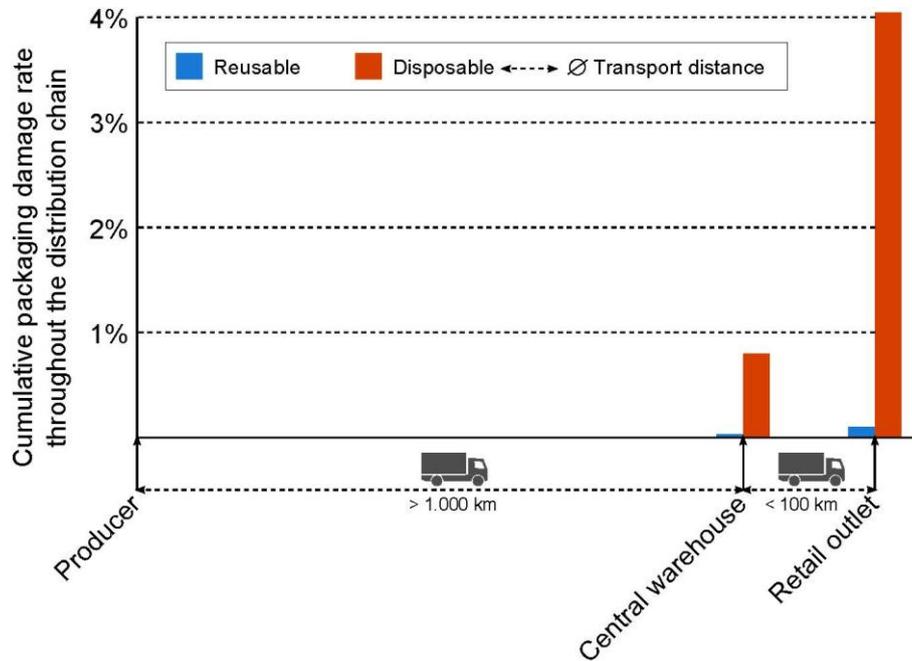


Figure 6: Cumulative damage rates throughout the whole supply chain

In the case of disposable packaging, around 4% of all packaging is damaged on its way to the consumer. For reusable packaging, the corresponding figure is around 0.1%.

### 3.5 Applying the results to the current market situation

In this section, the damage rates determined above are used to model the effects on the entire German market for fresh fruit and vegetables. Here, a distinction is made between two scenarios. The first scenario assumes that disposable packaging is used exclusively across the entire supply chain, while the second scenario involves the exclusive use of reusable packaging. The calculation is based on the annual per-capita consumption levels of fresh fruit and vegetables in the Federal Republic of Germany. As there exist some significant variations in consumption data, an average was taken of the various data sources (Zentrale Markt- und Preisberichtsstelle = Central Market and Price Reporting Agency (ZMP); Marktbilanz (Market Balance); Deutscher Fruchthandelsverband = The German Fruit Trade Association (DFHV)). Thus, the annual per-capita consumption in the Federal Republic of Germany amounts to around 50.2 kg for fruit and about 57.2 kg for vegetables. This gives a total nationwide consumption of around 8.7 billion kg of fruit and vegetables per year, which in turn represents around 1.1 billion crates per year<sup>1</sup> that are consumed overall by German consumers.

*Scenario 1 (disposable packaging only):* By the end of the supply chain, around 45 million packaging units per year will be damaged. From this, we may conclude that around 36,000 tonnes of fruit and vegetables are damaged each year.<sup>2</sup> This corresponds to a loss of some €68 million.<sup>3</sup>

*Scenario 2 (reusable packaging only):* By the end of the supply chain, around 1.4 million packaging units per year will be damaged. From this, we may conclude that 1.1 thousand tonnes of fruit and vegetables are damaged per year<sup>2</sup>. This corresponds to a loss of some €2 million.<sup>3</sup>

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<sup>1</sup>An average crate contains around 8 kg of fruit or vegetables.

<sup>2</sup>Assumption: an average of 10% of products are damaged in the event of damage to packaging. This value is an estimate based on the observations in the central warehouses and in the retail outlets. A more precise quantification requires a separate survey.

<sup>3</sup>The average value of a fruit/vegetable crate is around €15 (including VAT).

### 3.6 Summary (Part 1)

The first part of the study sought to determine the level of packaging and product damage, depending on the type of packaging, throughout the distribution chain of fresh fruit and vegetables. To this end, packaging damage was recorded both after the first distribution level (producer to central warehouse) and after the second distribution level (central warehouse to retail outlet).

The data collected shows that the type of packaging (disposable or reusable) has a significant influence on the damage rate for packaging. As opposed to disposable cardboard-packaging, reusable packaging experiences a significantly lower rate of packaging damage. It should be noted that, among the reusable packaging, not a single case of damage was observed due to insufficiently robust packaging. The main causes of packaging damage with regard to reusable packaging were instead inadequate securing of loading units and improper handling. As regards disposable packaging, the most frequent causes of damage to cardboard boxes were insufficiently robust packaging, inconsistent dimensions and a lack of compatibility with other packaging.

The distribution level has an additional influence on the packaging damage rate. Damage rates increase at the second distribution level (supply to retail outlets) for both types of packaging by around fourfold. This is caused by a lack of compatibility among the different types of packaging, as compatibility is essential during the formation of picking units or heterogeneous loading units. This problem is observed with both disposable and reusable packaging and also among all the different types of disposable packaging.

Damage to transport packaging can also lead to the quality of the goods transported being compromised. This is, for example, the case in the central warehouse for 40% of the fruit and vegetables transported in damaged disposable cardboard boxes; for reusable packaging, however, the proportion is only 22%. It should be noted that the study does not take into consideration the final destination of damaged produce.

In addition to the value of the goods damaged – around €68 million per year for an all-disposable packaging scenario and around €2 million per year for an all-reusable packaging scenario – further economic losses may arise due to additional costs of handling damaged transport packaging. For the central warehouses, it was shown that the repacking of a loading unit containing damaged packaging results in process costs of around €6.70 per loading unit. A low damage rate thus leads to low product losses and consequently low damage costs throughout the supply chain, from the producer to the retail outlet.

## 4 Part 2:

### Determining the influence of the type of packaging on the loss of freshness of fruit and vegetables

#### 4.1 Background and objective

The loss of freshness and the shelf life of perishable foodstuffs are significantly influenced by the microbiological contamination, the growth rate of microorganisms present and the speed of enzymatic, chemical and physical reactions within the product. The specific reaction and growth rates here are functions of intrinsic parameters of foodstuffs and of environmental factors such as temperature, gas atmosphere, humidity or packaging structure and materials (Mossel 1971; Heard 1999; Kreyenschmidt & Ibal 2012). In order to obtain a high-quality and safe product at the end of the value-added chain, these parameters need to be optimised in a product-specific way and monitored.

The influence of disposable and reusable packaging on the loss of freshness of fruit and vegetables is currently a topic of debate, the main focus of which concerns the potential impacts of packaging on product hygiene, the cross-contaminations involved and the temperature and humidity conditions. The objective of this part of the study was to evaluate the effect of disposable and reusable packaging on the loss of freshness of fruit and vegetables using selected parameters.

The study was divided into three parts: in the first part, the comparison of the surface bacterial counts on disposable and reusable packaging was the primary concern. In the second part, the loss of freshness of selected products, stored in disposable packaging and reusable packaging under laboratory conditions, was compared using sensory and microbiological parameters. Examinations were carried out on red radishes, tomatoes and nectarines. In the last part of the study, the losses of freshness in strawberries and lettuce were measured and compared in disposable packaging and reusable packaging respectively in realistic conditions.

#### 4.2 Comparison of the surface bacterial counts on disposable and reusable crates

##### 4.2.1 Procedure

The surface bacterial count of the empty packaging was measured before the filling process in terms of bioburden for a total of 100 reusable packaging units and 100 disposable crates, by means of a swab technique. Increased bacterial counts on surfaces (measured as bioburden) indicate a lack of hygiene and subsequently an increased risk of cross-contamination (surface – product). Depending on the type of bacterial flora, it is possible that cross-contaminations may accelerate the loss of freshness and influence the safety of a product. The examination method was conducted according to the official test procedures of §64 LFGB B 80.00.2 or according to standard DIN 101 13-2, whereby 20 cm<sup>2</sup> per crate was sampled. Sampling was carried out on 10 different days. The statistical analysis of the microbiological examinations was conducted according to the Mann-Whitney *U* Test. The significance level was set up in such a manner that two test series with  $p > 0.05$  would not be considered statistically significant.

##### 4.2.2 Results

Figure 7 shows the bacterial counts on the disposable and reusable crates before the filling process. In each case, the medians, the 25% and 75% inter-quartile ranges and the respective extreme values of the bioburden are shown.

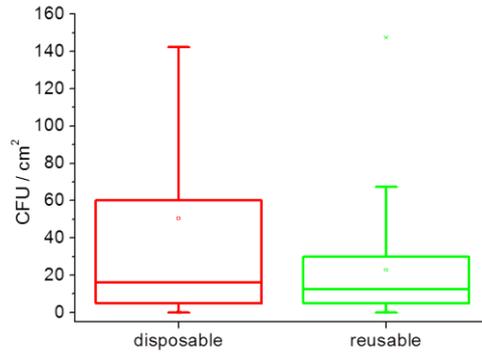


Figure 7: Surface bacterial counts on disposable and reusable crates (n = 100)

The bacterial counts on the different crates do not show any significant differences ( $p > 0.05$ ). The median of the bacterial counts lies at 15.0 CFU/cm<sup>2</sup> for the disposable crates and at 12.5 CFU/cm<sup>2</sup> for reusable crates, with a higher scatter for disposable crates.

6/7 9/7 11/7 12/7 13/7 16/7 17/7 20/7 23/7 24/7

Figure 8 shows the bacterial counts on reusable crates on the different test days.

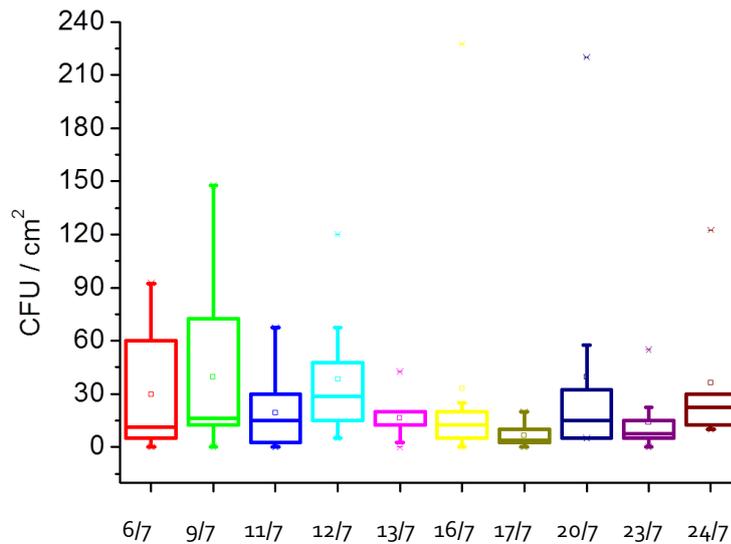


Figure 8: Surface bacterial counts on reusable crates on different test days (n = 10 per examination day)

The median bioburdens fluctuate between 2.5 and 22.5 CFU/cm<sup>2</sup>. On the first two days on which the crates were washed, the high variability of the surface bacterial count on the reusable crates is remarkable.

### 4.3 Influence of the type of packaging on the loss of freshness of fruit and vegetables under standardised laboratory conditions

#### 4.3.1 Procedure

The influence of the type of packaging (disposable vs reusable) on the loss of freshness of fruit and vegetables contained was examined using the following products: nectarines, vine tomatoes and red radishes. In each test series, three product-specific disposable crates and three reusable crates were filled with the respective products and the loss of freshness was compared over time using selected parameters. To ensure the standardisation of the tests, the surface bacterial counts were taken before the filling process.

The fruit and vegetables were delivered by a forwarding agent to the institute, in each case with one crate more than necessary for the filling of the three disposable and three reusable crates. The suppliers were required to supply, for each test series, products from only one batch which were all stored in the same conditions during transport. After delivery of the products, the crates were filled and stored under retail- or household-specific temperature conditions for the product. The temperature and time scenarios were agreed beforehand with IFCO. During storage, the temperature conditions and humidity levels inside the crates were measured continuously, in order to record any possible effects of the packaging on the temperature conditions within the crates. For this purpose, a data logger was placed in the centre of the base of each crate.

In order to record potential differences in heat transfers and associated temperature adjustments in the disposable and reusable crates, the crates were stacked one at a time (see Figure 9). In the bottom crates, heat transfers mainly occur via thermal conduction; in the top and middle crates, there is an additional transfer via convection). Figure 9 shows the experimental set-up.

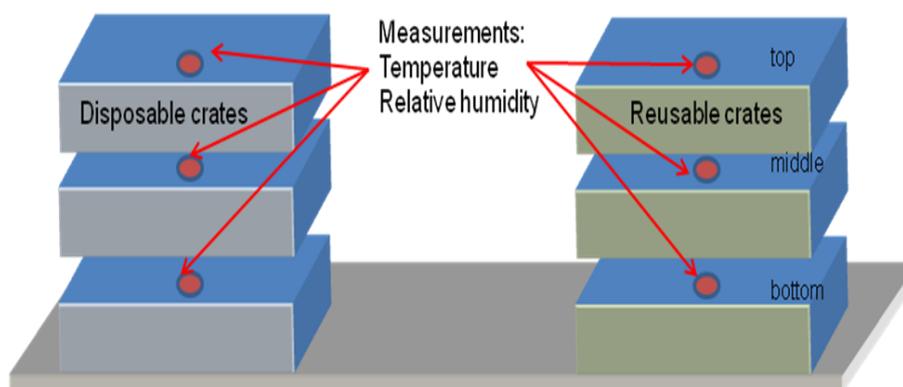


Figure 9: Storage of the crates during the experiment

Depending on the product, a sensory evaluation was carried out at the beginning and in the middle of the chain-typical storage times (including storage in household-like areas) by a trained panel of 6 people, together with photographic documentation. The sensory examination seeks to evaluate the product's current degree of freshness. The evaluation of the samples was made using a hedonic scale (0 = very good, 5 = unacceptable). As a basic guide, an evaluation scheme was developed for each product, where product-specific characteristics of the loss of freshness were included. Criteria such as colour, smell, juiciness/texture and the overall impression were considered in the evaluation as characteristics. Different weighting factors were then assigned to the various characteristics, depending on the product, and illustrated in the form of a sensory index (S). In addition to the grading of freshness level, the sensory index and the level of features of the different criteria provide insight on possible factors of spoilage. The sensory tests were conducted "blind". Furthermore, at the end of the storage period, the quantities of nectarines and tomatoes showing mould growth, dents or other sensory deficiencies were counted per crate.

In parallel to the sensory tests, at the beginning and end of the test series, the surface bacterial count, measured as bioburden of the products of each individual crate was determined. The bioburden on products provides indirect conclusions on the freshness of the product. For the determination of the bioburden, two composite samples of each kind of fruit and vegetable tested were taken at the beginning and the bioburden determined. Then, at the time of the final test, the bioburden of the products was examined in each of the six crates (three disposable, three reusable). The series of tests for each crate were terminated as soon as first products in the crate showed clear signs of a loss of freshness. At the end of the storage period, the surface bacterial counts were additionally determined in all crates. Each test was repeated three times.

Table 1 provides an overview of the products tested:

Product	Quantity of products per test series	Total quantity of products	Total number of crates
Red radishes: 10 bunches, open, crate: 64 × 13 cm	6 × 10 bunches plus 1 bunch = 61 bunches	183 bunches	9 disposable, 9 reusable
Nectarines: 7 kg, loosely arranged, crate: 64 × 10 cm	6 × 7 kg plus 1 kg = 43 kg	129 kg	9 disposable, 9 reusable
Vine tomatoes: 5 kg, loose, crate: 43 × 14 cm	6 × 5 kg plus 1 kg = 31 kg	93 kg	9 disposable, 9 reusable

Table 1: Overview of the sample sizes for the products tested

Figure 10 shows the products and their respective disposable and reusable packaging:



Figure 10: Overview of the products and packaging used for the study

#### 4.3.2 Results

##### Red radishes

Before the beginning of the storage period, no significant differences in the surface bacterial count were measured between reusable and disposable crates (between 1.4 and 1.6 log<sub>10</sub> CFU/cm<sup>2</sup>). At the end of the storage period, the bacterial count on disposable crates was, however, significantly higher, at 3.7 log<sub>10</sub> CFU/cm<sup>2</sup>, than the bacterial count of the reusable crates, which came to 2.7 log<sub>10</sub> CFU/cm<sup>2</sup>. Moreover, as far as the disposable crates were concerned, significant mould growth was identified at numerous points.

When the crates were filled, the bacterial counts of red radishes rose to 6.35 log<sub>10</sub> CFU/g. During the storage period, an increase of around 1 log level was recorded; no difference was measured between those samples stored in disposable packaging and those in reusable packaging. Figure 11 shows the development of the sensory index.

It is notable that products stored at the top tended to receive worse evaluations in both reusable and disposable crates. No significant differences were observed in the sensory index with regard to the type of packaging used.

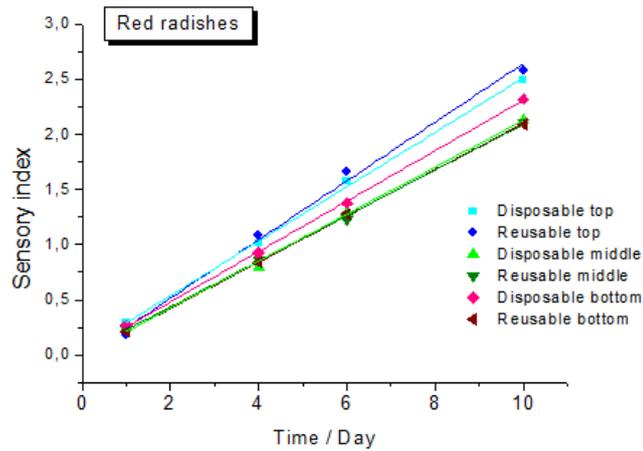


Figure 11: Progression of the sensory index during the storage of red radishes

**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the sensory evaluations of the individual product characteristics at the end of the storage period. In particular, the juiciness and hardness of the products from the top crates was rated worse than the ones in the middle and bottom disposable and reusable crates. See also Figure

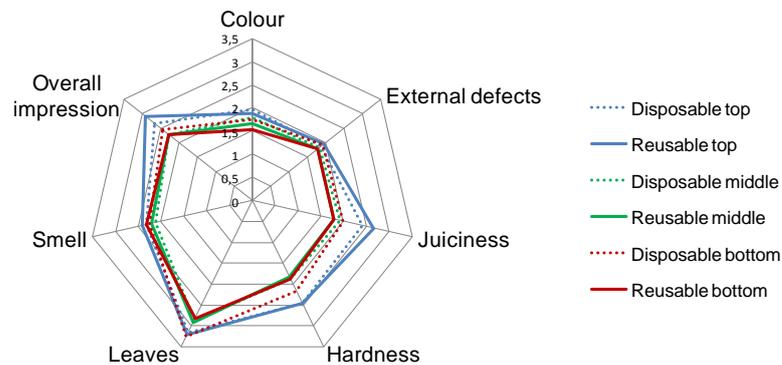


Figure 12: Sensory evaluation of red radishes at the end of the storage (Day 11)



Figure 13: Red radishes in the bottom disposable crate (left) and in the top disposable crate (right)

During storage, no systematic differences could be identified in the temperature profiles and the humidity conditions in disposable and reusable crates. The relative humidity fluctuated between 85% and 100%. Figure

14 shows, by way of example, the temperature profiles in the top and bottom disposable and reusable crates of batch 1.

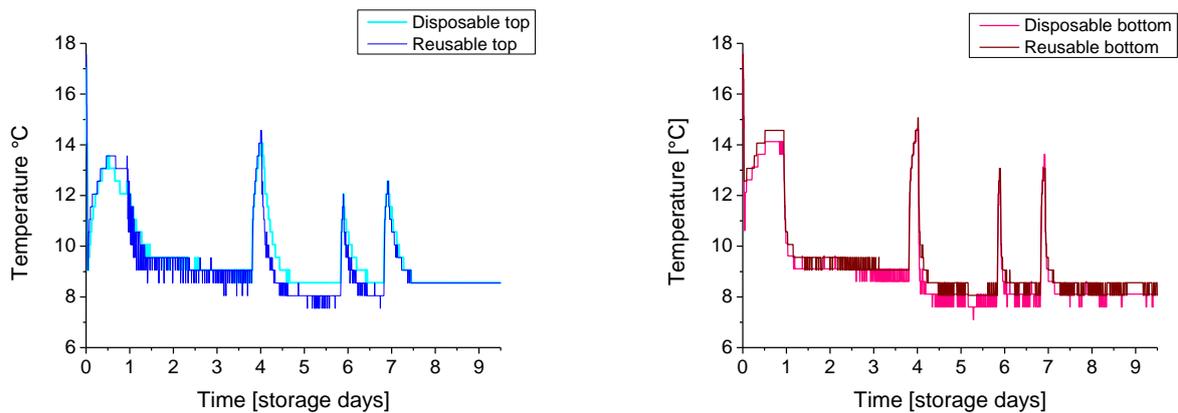


Figure 14: Temperature profiles in the top and bottom disposable and reusable crates using the example of batch 1

### Tomatoes

The surface bacterial counts on disposable and reusable packaging did not show any significant differences either at the beginning or at the end of the storage period. At the end of the storage period, in some places in the disposable crates where tomatoes were affected by mould growth, mould formation was also noted on the disposable crates.

The initial microbial populations of the tomatoes amounted to an average of  $2.8 \log_{10}$  CFU/g at the time of the delivery and  $3.3 \log_{10}$  CFU/g at the end of the storage period. No significant difference in the bioburden with regard to the type of packaging was measured.

The sensory evaluation of the tomatoes did not show any difference with regard to the type of packaging.

In addition to the sensory evaluation of selected criteria, at the end of the storage period all tomatoes that showed mould or defects such as dents were counted, in both the disposable and the reusable crates. The proportion of tomatoes with mould formation was slightly higher in the reusable crates (Figure 15). Mould formation occurred in the reusable crates increasingly in the lower layers (two-layer stacking of products) and in the bottom crates. The cause of the mould formation was presumably a leakage of juice due to burst tomato skins caused by pressure points. It is likely that the pressure points on the tomatoes in the reusable crates were caused by the restricted supporting surface area or the higher pressure involved at particular points on the products.

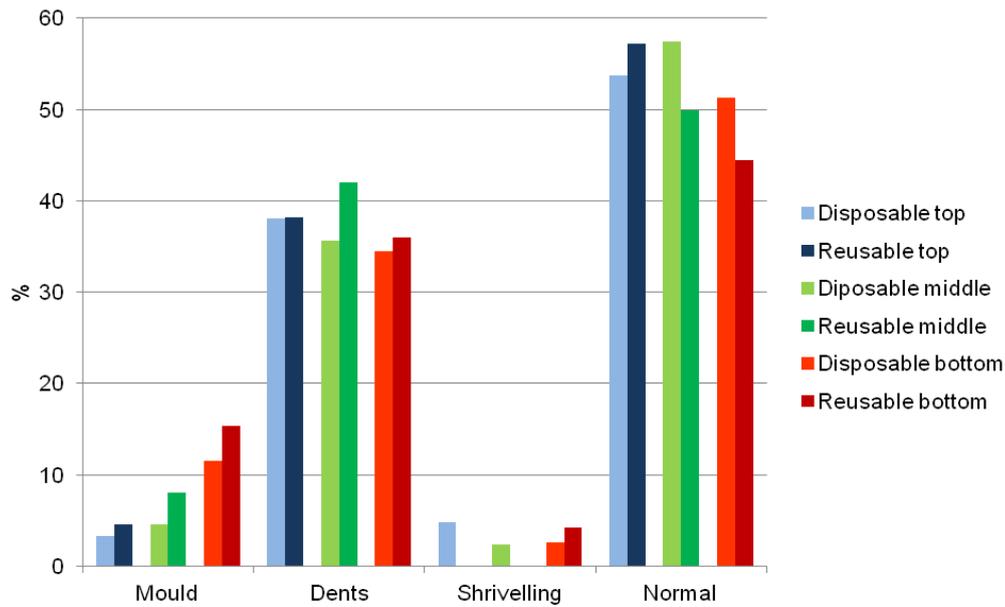


Figure 15: Sensory evaluation of tomatoes in all batches with regard to mould formation, dents and juiciness at the end of storage (20 days)

During the storage of the tomatoes, there were no systematic differences in the temperature profiles and humidity conditions with regard to the type of packaging. The relative humidity fluctuated between 40% and 85%. In the disposable crates stored at the bottom, the relative humidity was continuously above the relative humidity in the middle and top crates.

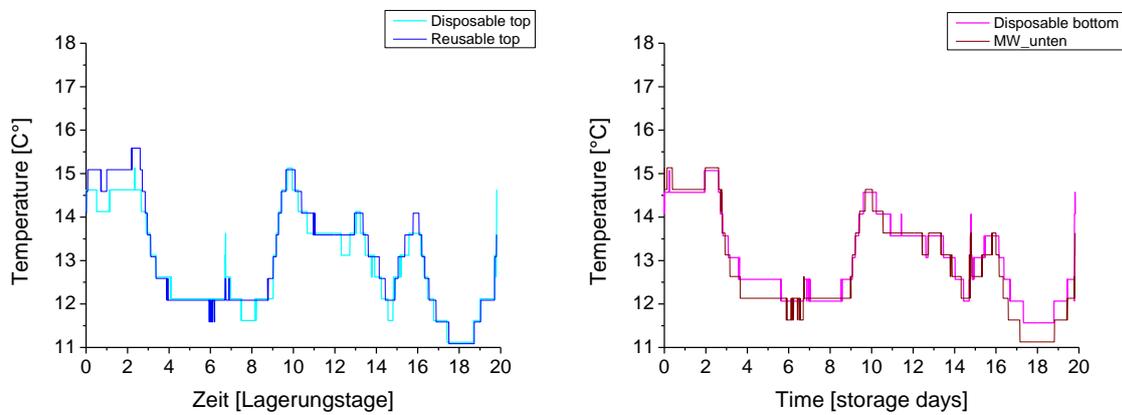


Figure 16: Temperature profiles in the top and bottom disposable and reusable crates using the example of batch 1

**Nectarines**

With nectarines too, no significant differences were measured in the surface bacterial counts between reusable and disposable crates. At the beginning, the average was 1.2 log<sub>10</sub> CFU/cm<sup>2</sup>; after storage, on day 11, it was between 1.8 and 2.1 log<sub>10</sub> CFU/cm<sup>2</sup>.

The bacterial counts on the products in disposable and reusable crates are comparable both at the beginning and at the end of the storage period.

Figure 17 presents the results of the sensory evaluation of the nectarines on the different test days using the sensory index. Analysis shows that the positioning of the crates has a greater influence on the loss of quality than the type of packaging. Thus, the nectarines in the top disposable and reusable crates tended to be assessed more poorly. This difference is presumably due to different temperatures and air-flow rates and, consequently, changed humidity.

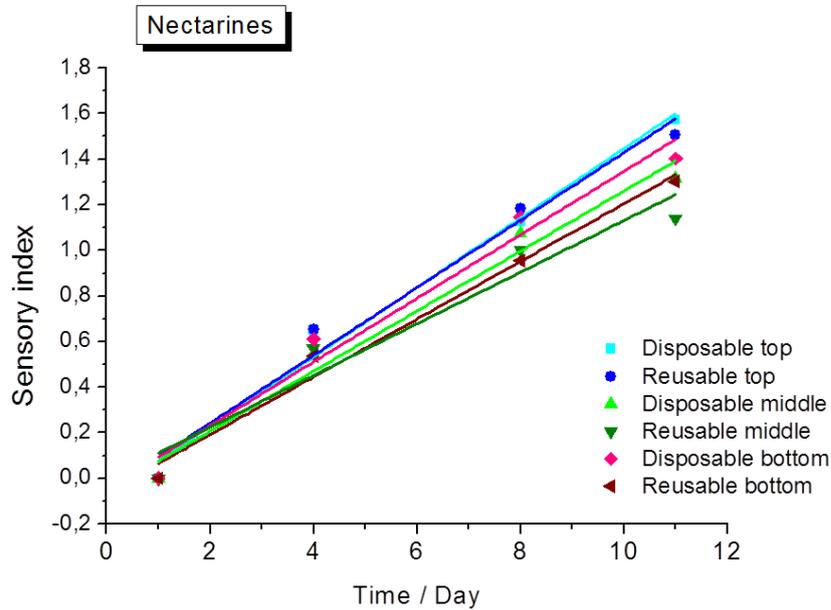


Figure 17: Development of the sensory index during the storage of nectarines

The sensory evaluation of nectarines, which tends to be worse in the upper section of the crate, is also reflected in figure 18. Here, the numbers of nectarines showing mould, visible shrinking of the skin and with no defects was observed in differently positioned disposable and reusable crates. The number of nectarines where a shrinking of the skin was observed was higher in the top reusable and disposable crates than in the middle and bottom crates (disposable crates: 69 to 55 of 126; reusable crates 65 to 51 of 126).

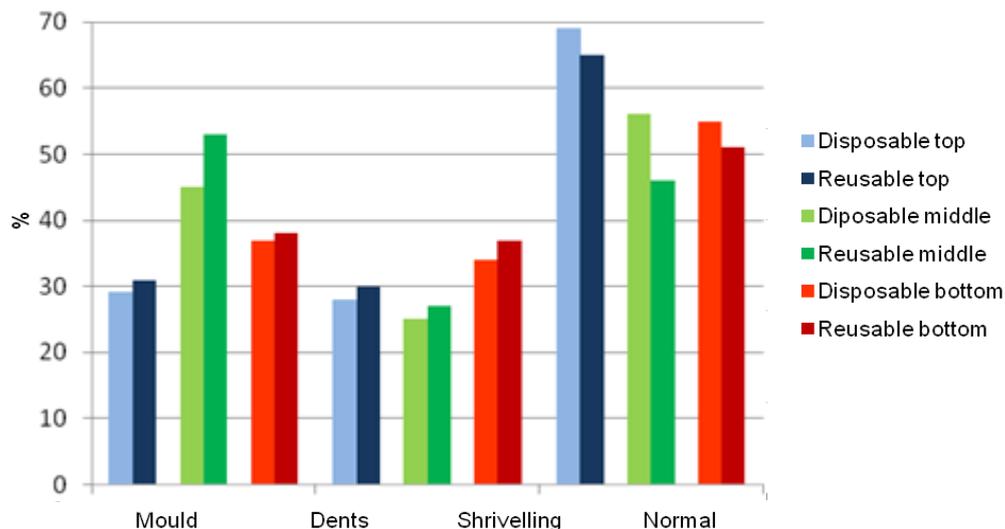


Figure 18: Sensory evaluation of nectarines in all batches with regard to mould growth and juiciness at the end of the storage period (day 11)

The temperature profiles measured in the crates also do not show systematic differences between disposable and reusable packaging. In general, there is a quicker adjustment of temperature and higher storage temperatures for the disposable and reusable crates which are positioned above (Figure 19).

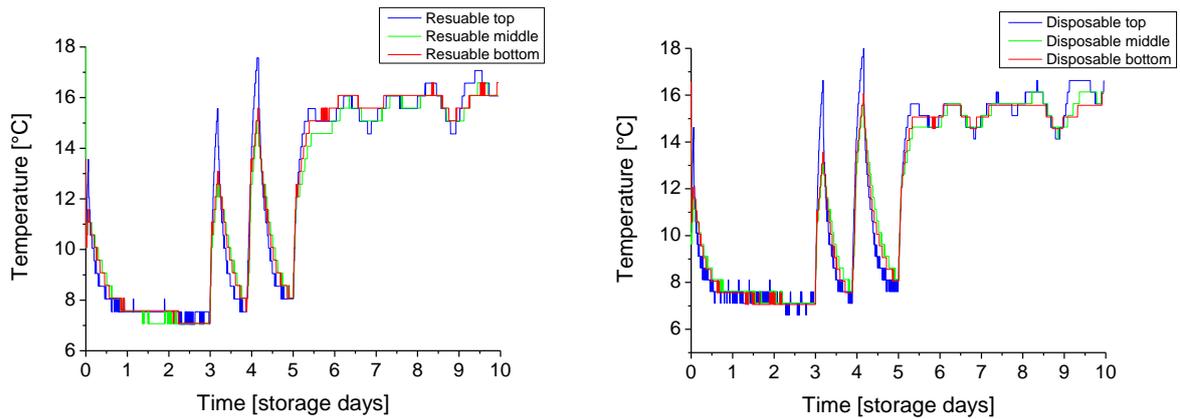


Figure 19: Temperature profiles in the top and bottom disposable and reusable crates for nectarines using the example of batch 1

Relative humidity fluctuated between 55% and 100%. However, no systematic differences between disposable and reusable crates were ascertainable. In general, humidity fluctuated more strongly in the top crates than in the bottom and middle crates (

Figure 20).

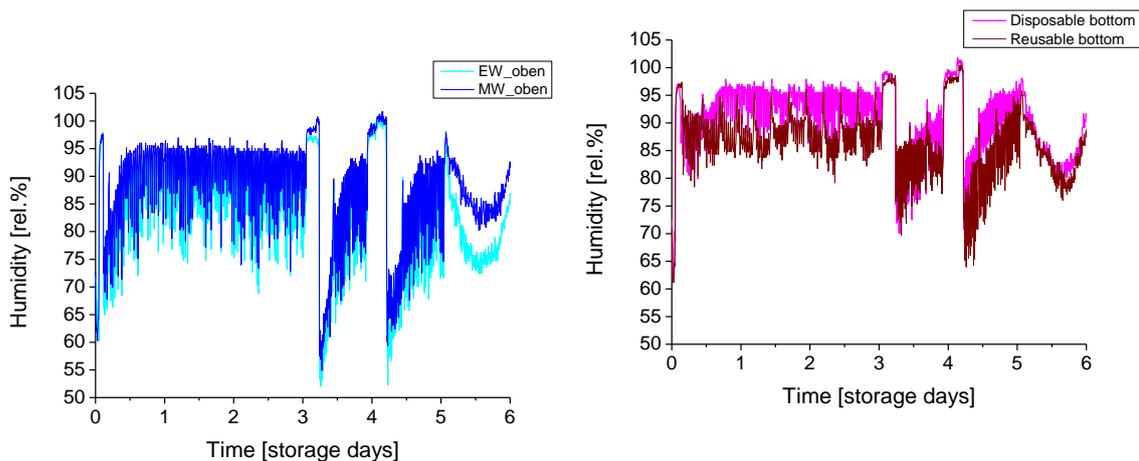


Figure 20: Graphs showing relative humidity in the top and bottom disposable and reusable crates for nectarines, using the example of batch 1

The inferior sensory evaluation of the products in the top crates may be caused by such differences in the temperature and humidity profile.

#### 4.4 Influence of the type of packaging on the loss of freshness of fruit and vegetables with data collection as of the place of harvesting

##### 4.4.1 Procedure

It was the objective of this sub-study to assess the effects of types of packaging on the loss of freshness of the fruit and vegetables contained using selected parameters. In comparison to the laboratory tests previously described, one part of the test was conducted additionally under conditions simulating real-life use, “from the field to the central warehouse”. The survey was conducted using strawberries and lettuce.

First, microbiological swab samples were collected in the field from the intended six disposable and six reusable crates. Before the filling process these crates were additionally equipped with data loggers for measuring

the temperature conditions and humidity. Subsequently, the crates were filled in the field with the products. Furthermore, two composite samples for the microbiological and sensory first examination were taken from the same product batch. The composite samples and the swap samples of the 12 crates were immediately transported to the laboratory and analysed there.

The six disposable and six reusable crates were transported via the usual transport routes to the central warehouse. During transport and in the warehouse the disposable and the reusable packaging units were stacked three high, stored next to each other on a pallet and exposed, wherever possible, to the same environmental conditions. After a typical storage time in the central warehouse the twelve crates were collected and stored in the laboratory under trade-specific or household-specific temperature conditions respectively.

On arrival at the laboratory the freshness conditions of the products were determined using microbiological and sensory parameters. Samples were taken from three disposable and three reusable crates each and examined. The remaining 3 disposable and 3 reusable crates were analysed on a sensory basis at predefined time intervals. At the end of the storage period the bacterial counts of the products were furthermore determined in all other crates. The end of storage was chosen at the time when the first products in the crates showed clear signs of a loss of freshness. All tests were repeated three times. Table 2 provides an overview of the products examined.

Product	Quantity of products per test series	Total quantity of products	Total number of crates
Strawberries (10 × 500 g) crate: 64 × 10 cm	12 × 10 pcs = 120 trays	360 trays	18 disposable, 18 reusable
Lettuce heads (6 pieces) crate: 64 × 10 cm	12 × 6 pcs = 72 pcs	216 pcs	18 disposable, 18 reusable

Table 2: Survey of sample amount

Figure 21 shows the products in the respective disposable and reusable packaging. On the left, the reusable packaging of plastic and on the right the disposable packaging of cardboard is presented each time.



Figure 21: Survey of the products and packaging used for the study

#### 4.4.2 Results

##### Strawberries

The surface bacterial counts on the disposable and reusable crates did not show any significant differences either before the filling process or at the end of the storage period.

The bioburden of the strawberries directly after harvesting amounted to an average of 4.6 log<sub>10</sub> CFU/g. During the transport and the typical storage time in the central warehouse there was no measurable increase in bacterial count on the products after 1.5 days. At the end of the storage period (5 days for local field-grown strawberries [batch 1]; 7 days for greenhouse strawberries [batches 2 and 3]) the bacterial counts increased by a maximum of 1.2 log levels. No significant differences with regard to packaging were measured.

Also the sensory evaluation did not show any differences in quality between the products in disposable and those in reusable packaging. At the end of the storage period, all strawberries in the disposable and reusable crates were counted and evaluated with regard to mould and dent formation. The results are represented in Figure 22.

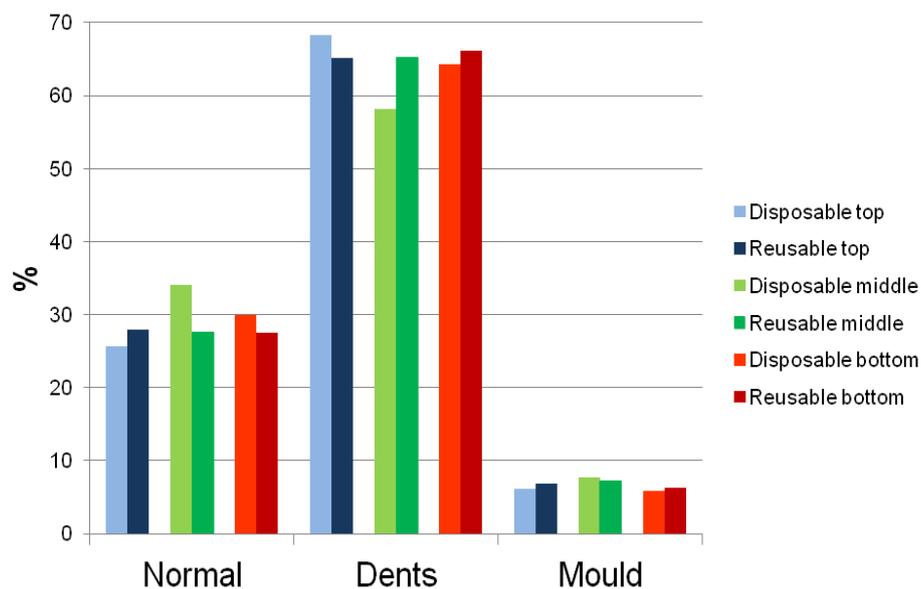


Figure 22: Sensory evaluation of strawberries in all batches with regard to mould formation and dents at the end of storage

Both mould and dent formation was neither influenced by the type of crate (reusable or disposable) nor by the positioning of the crates (top, middle, bottom).

Figure 23 presents the temperature profiles in the top and bottom crates (disposable and reusable), using the example of a batch. No systematic differences were identified in the temperature profiles between disposable and reusable crates.

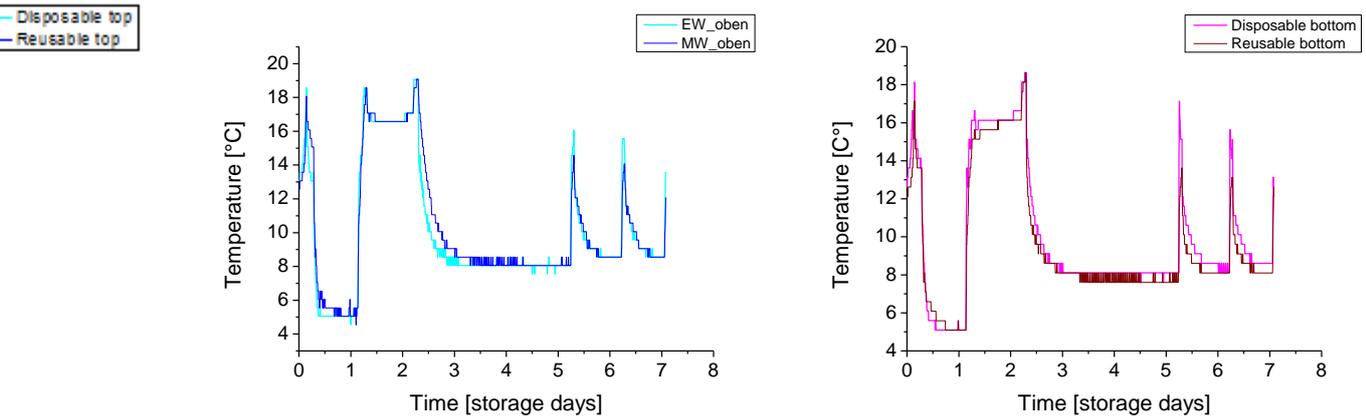


Figure 23: Temperature profiles for the top and bottom disposable and reusable crates, using the example of batch 2

The relative humidity in the crates varied during the execution of the test between 45% and 100%. During the three executions of the tests no systematic differences were identifiable in the relative humidity curves. However, in all tests it showed that the humidity was lowest in the lowest crates.

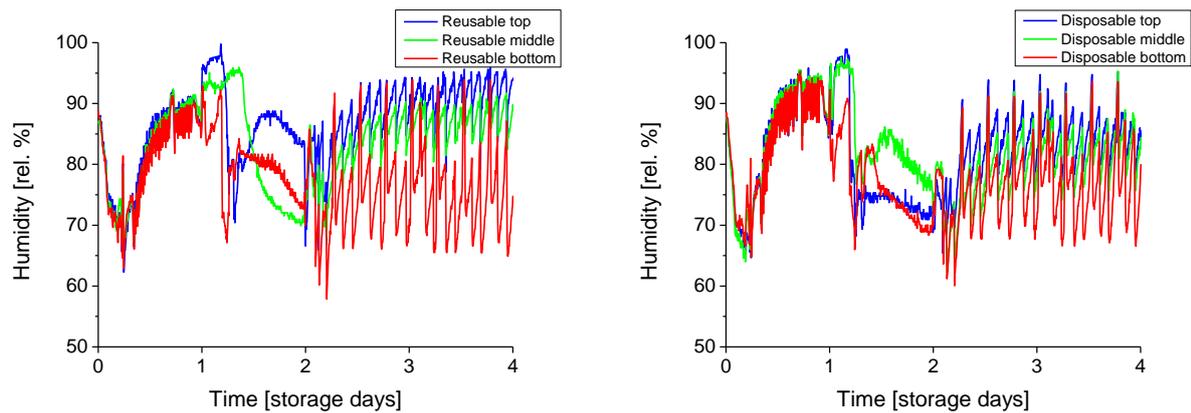


Figure 24: Graphs showing relative humidity in the top, middle and bottom crates (disposable and reusable)

### Lettuce heads

Before the crates were filled the bacterial counts on the reusable crates came up to  $1.2 \log_{10}$  CFU/cm<sup>2</sup>, on the disposable crates to  $1.7 \log_{10}$  CFU/cm<sup>2</sup>. During storage the bacterial counts on the crates increased on average by 2 log levels. At the end of the storage period the surface bacterial count on the reusable crates came up to  $3.5 \log_{10}$  CFU/cm<sup>2</sup> and the one on disposable crates to  $3.7 \log_{10}$  CFU/cm<sup>2</sup>. Thus, the surface bacterial counts were comparable both at the beginning and at the end of the measurement. It is a notable fact, however, that at the end of the storage period the disposable crates or cardboard boxes respectively were heavily soaked and unstable.

The bacterial counts of the lettuce heads directly after harvesting and on arrival at the laboratory fluctuated between 5.5 and  $5.7 \log_{10}$  CFU/g in the disposable and the reusable crates.

During the storage period, bacterial counts of the lettuce heads in the disposable crates rose to an average of  $6.2 \pm 0.37 \log_{10}$  CFU/g and that in the reusable crates to  $5.9 \pm 0.29 \log_{10}$  CFU/g. This difference is not significant.

Figure 25 shows the progression of the sensory index during storage. The sensory evaluation during the storage period was conducted on the stem side of the lettuce. During storage, no influence of the packaging on the specific sensory characteristics was observed. On the last day of storage, the lettuce heads in the top crates were evaluated generally worse with regard to the juiciness of the leaves than the ones in the middle and bottom crates (Figure 26).

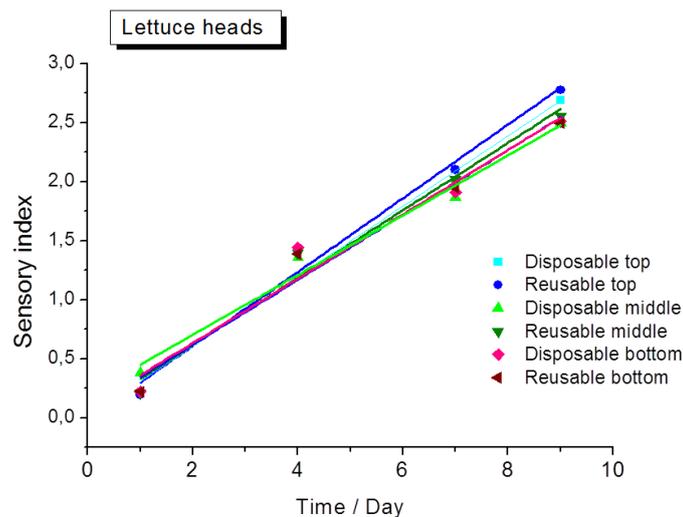


Figure 25: Development of the sensory index during storage of lettuce heads

In addition, on the last day of the storage period the lettuce heads were turned around and another sensory evaluation was conducted on the top of the lettuce heads. Here, the heads in the disposable crates were evaluated as being worse in many cases, notably because the leaves of the lettuces in the disposable crates were more soiled.

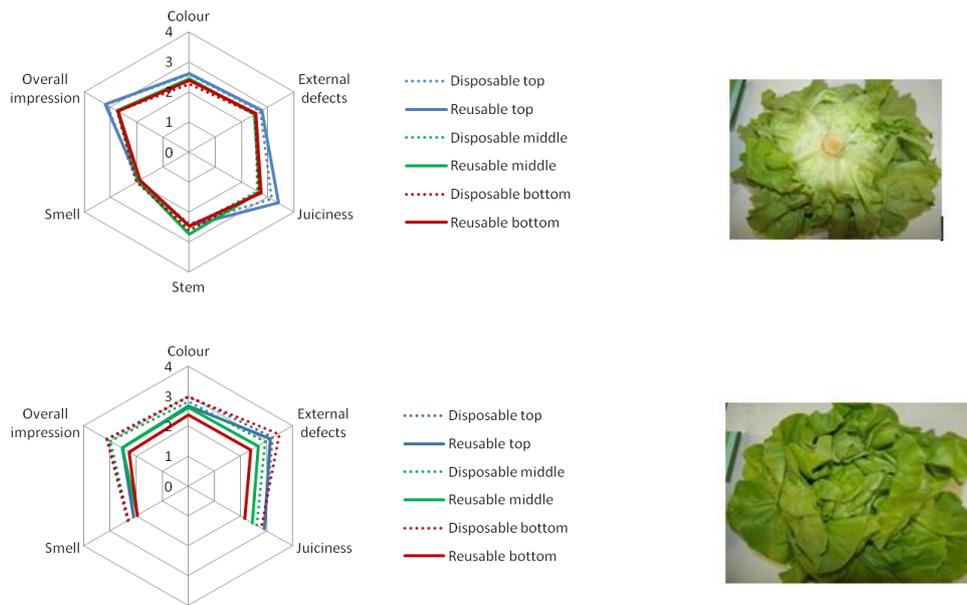


Figure 26: Sensory evaluation of the lettuce heads at the end of the storage period (day 9) from above and below

As regards the temperature profiles, no systematic differences were identified between disposable and reusable crates (Figure 27).

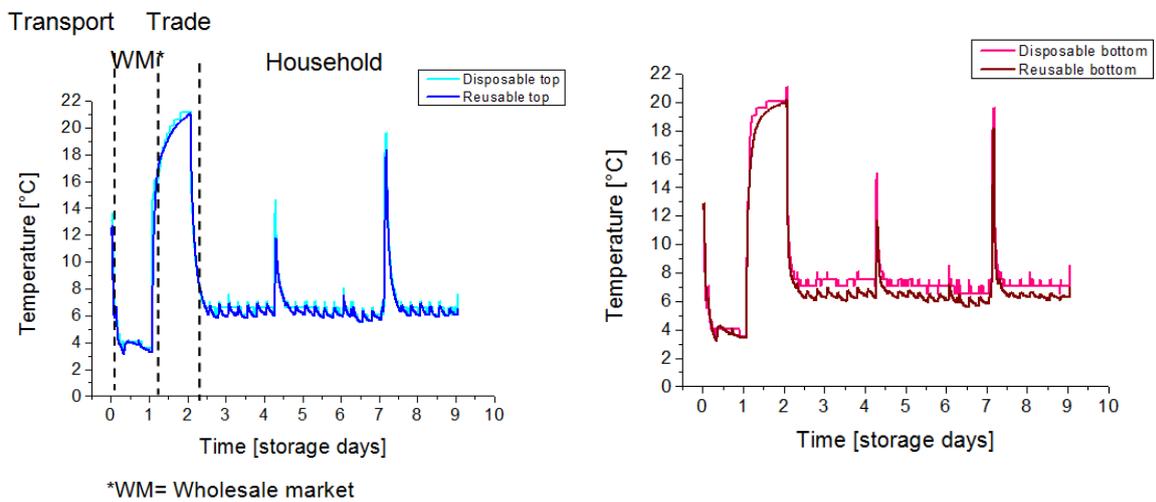


Figure 27: Temperature profiles in the top and bottom disposable and reusable crates for lettuce heads, using the example of batch 2

The relative humidity in the disposable crates was almost at 100%. Stronger fluctuations were identifiable for reusable crates during storage.

## 4.5 Summary (Part 2)

This study also sought to evaluate the impact of disposable and reusable packaging on the loss of freshness of fruit and vegetables using selected parameters. The study was divided into three parts: in the first part, the comparison of the surface bacterial counts on disposable and reusable packaging was the primary concern. Increased bacterial counts on surfaces (measured as bioburden) indicate a lack of hygiene and subsequently an increased risk of cross-contamination (surface – product). Depending on the type of bacterial flora, it is possible that cross-contaminations may accelerate the loss of freshness and influence the safety of a product.

In the second part, the loss of freshness of selected products, stored in disposable and reusable packaging under laboratory conditions, was compared using sensory and microbiological parameters. Examinations were carried out on radishes, tomatoes and nectarines. In the last part of the study, the loss of freshness in strawberries and lettuce was measured and compared in disposable and reusable packaging under realistic conditions, i.e. beginning with the regional producer.

In this study, with one exception, no significant differences between the surface bacterial counts (measured in terms of bioburden) for disposable and reusable packaging could be found, both before the filling process and at the end of the storage period.

During the microbiological examinations, the total bacterial count for the products was measured throughout the process chain. No significant differences were measured between products in disposable packaging and those in reusable packaging.

Furthermore, the results of the sensory evaluations for disposable and reusable packaging were either comparable or did not show any significant differences.

For certain products, such as nectarines and radishes, the position of the packaging (top, middle or bottom) had an influence on the loss of freshness. These differences are mainly caused by temperature-related effects, air-flow velocity and associated changes in humidity. Since the temperature loggers were positioned in the middle of the base of the packaging in this test, these effects were not clearly visible in the measured temperature profile.

No systematic differences were identified inside the disposable and reusable packaging with regard to temperature sequences and humidity conditions.

The results of these regional practice-oriented studies cannot be extrapolated for long-distance transport without a separate investigation. At present, no conclusions can be drawn on this matter.

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