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Test design for condensate analysis in refrigerator vegetable drawers

Astrid Klingshirn, Lilla Brugger, Antje Engstler, Thomas Ertel, Thomas Gindele, Jochen Härlen, Beate Kölzer, Rainer Stamminger und Harald Weber

Abstract

Vegetable drawers in refrigerators are frequently providing humidity control options, reducing transpiration and thus weight loss in fresh produce. Condensation has to be considered as a freshness parameter in such storage zones, as it may constitute a hygienic problem and promote microbial growth and product deterioration. A qualitative condensate test method based on food simulants is set-up, to visualize occurring condensate and to classify condensate intensity. Test runs considering different cooling technologies and test zone designs show, that basic test requirements are met.

Keywords: Condensation, condensate evaluation, humidity control, vegetable storage, vegetable drawer

Entwicklung eines Prüfverfahrens zur Analyse von Kondensat in Gemüseschalen von Kältegeräten

Kurzfassung

Gemüseschalen in Kältegeräten verfügen häufig über Feuchtekontrollfunktionen, die Transpirationsprozesse und damit den Frischmasseverlust von gelagertem Obst und Gemüse reduzieren. Infolge der Feuchtekontrolle auftretendes Kondensat ist als relevanter Performanceparameter von Kältegeräten zu berücksichtigen, da Kondensat den Produktverderb beschleunigen kann. Zur Kondensatbewertung wird ein qualitatives Prüfverfahren mit einem Lebensmittelsimulanzsystem konzipiert, das die Kondensatbildung nachstellt und die Kondensatkategorisierung gemäß definierter Intensitätsstufen ermöglicht. Das Verfahren wird für unterschiedliche kältetechnische Systeme und Feuchtekontrollmechanismen erprobt und erweist sich als umsetzbar.

Schlagworte: Kondensat, Kondensatbewertung, Feuchtekontrolle, Gemüselagerung, Gemüseschale

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Introduction: Food preservation performance analysis in refrigerator storage

Consumers have to consider various factors when purchasing a new refrigerator. Freshness performance is getting more important, next to design criteria, volume and energy efficiency.

Freshness performance in cold storage is currently not considered in the global standard for refrigerating appliances (IEC 62552: Household refrigerating appliances - Characteristics and test methods). Some reference to the importance of freshness performance is provided by the definition of chill compartments and the respective requirements. Chill compartments provide enhanced storage conditions intended to preserve the quality of particular foods: The current eco-design regulation (DIRECTIVE 2009/125/EC) defines a chill compartment as "a compartment intended specifically for the storage of highly perishable foodstuffs", which should maintain storage temperatures between -3 and +3 °C.

Next to that, no test design is available to evaluate the preservation of food quality in refrigerating appliances. To make reliable statements on the food quality retention in refrigerator storage compartments, reproducible test standards have to be developed. Such standards have to take into account the different storage climate parameters that have an impact on freshness retention. The main extrinsic parameters that influence foods in storage are temperature, relative humidity, atmospheric gases and microbial cross-contamination (Krämer 2006).

Evaluation methods analysing the freshness performance of refrigerators are currently in discussion within the International Electrotechnical Commission (IEC), in order to define next steps for a consensus-based International Standard on “freshness performance”. A first focus has been placed on humidity control features, providing a test method that simulates weight loss of vegetables that are stored in refrigerator vegetable drawers (IEC FDIS 63169).

Next to proper temperature management, weight loss is the major parameter determining freshness retention and thus shelf life in fruit and vegetables. Weight loss in cold storage mainly results from transpiration losses and - to lower extents- from product respiration. Water deficit stress results in discolouration, wilting and texture loss, along with a loss in flavour and aroma (Kays & Paull 2004).

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Weight loss is decisively contributing to food loss along the whole supply chain, including private home food storage (Johnson et al. 2008). Properly designed and operated refrigerated storage systems, providing a low temperature and high humidity storage climate, reduce weight loss by transpiration and respiration processes. Thus the storage life of fresh produce is extended and food loss is reduced (Chakraverty & Singh 2014, Bartz & Brecht 2003).

The number of humidity-controlled storage systems in refrigerator launches is increasing since several years: Vegetable storage zones frequently come along with humidity control options to increase or reduce the humidity level within the storage zone, depending on the individual use case or load.

The Committee Draft IEC 63169 ED1, "Household refrigerating appliances – Characteristics and test methods – Food preservation", provides a standardized test procedure based on an artificial food system to simulate weight loss of fresh produce. The test system consists of a tray with 18 cellulose sheets, into which a defined amount of water is filled. The cellulose sheets absorb water from the reservoir and act as an active evaporation surface. The weight loss of the tray system is measured after a test cycle of at least 24 h and the weight loss rate is derived accordingly (Figure 1).

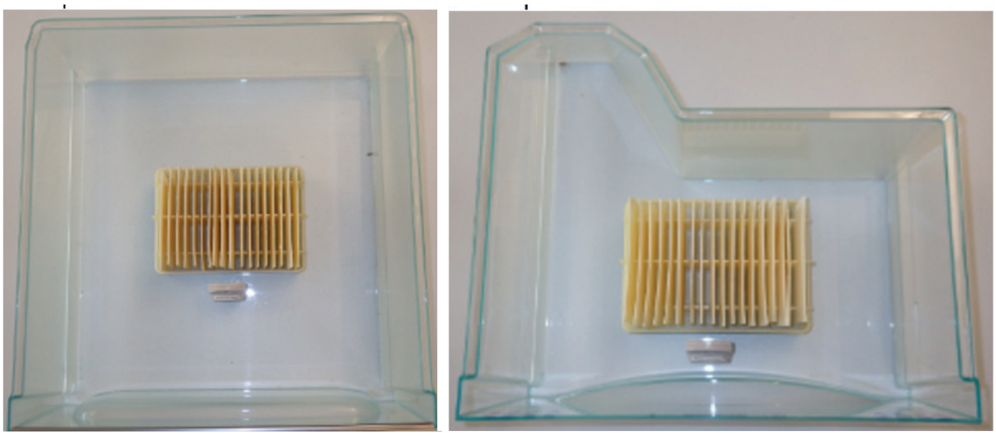

Figure 1: Test system "nonwoven tray" for the simulation of vegetable weight loss in refrigerator storage (IEC 63169 ED1)

The analysis of weight loss provides essential information on the performance of humidity-controlled storage systems, yet it cannot be regarded in isolation: As soon as proper humidity control is provided, condensate formation within a storage zone is inevitable. As condensate in storage may enhance microbial growth and may negatively impact texture and colour, condensate management is a crucial storage performance parameter.

A test procedure that considers condensate-related effects on freshness retention has to include the analysis of condensate occurrence and distribution patterns. Breaking-down condensate analysis to these two parameters makes it possible to further evaluate the impact of condensate impact on stored goods.

Theoretical background: Impact of condensate on freshness retention in cold storage

Condensation in cold storage occurs when the temperature of the surface of the stored food product or storage compartment is lower than the dew-point temperature of the surrounding air. When the surface temperature of the product or storage container is above 0 °C, condensate forms as liquid water (Heiss & Eichner 2014, Benamara et al. 2010).

Water vapour in the air of a refrigerated space migrates to the coldest surface, which will most frequently be the surface of the evaporator in refrigerating appliances. In enclosed storage compartments the humidity will be trapped within and will condense at the coldest surface areas or the stored product.

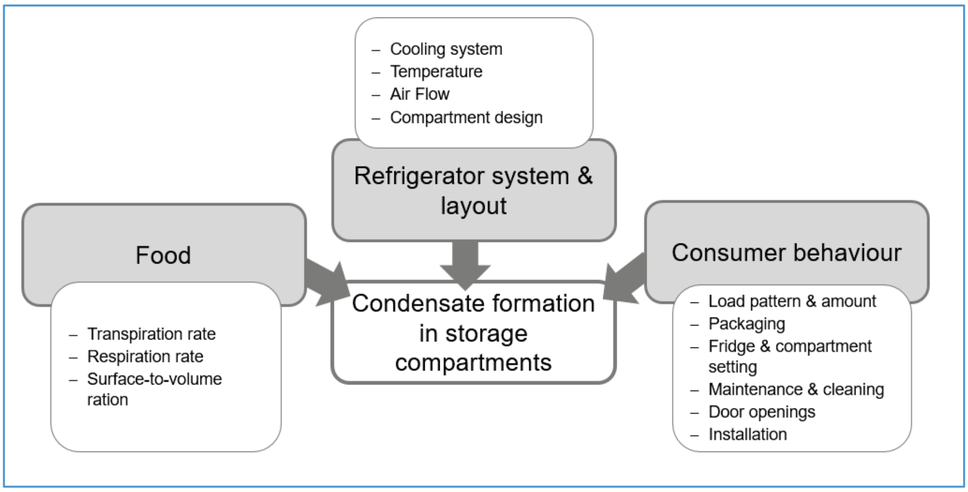

Figure 2: Parameters influencing condensate formation in refrigerator storage

The quantity and distribution of condensate in refrigerators is influenced by three parameters: The refrigerator itself, the consumer and the stored food (Figure 2).

On the part of the refrigerator, cooling technology, temperature as well as the design of storage compartments have an impact on condensate formation. Consumer behavior contributes to condensate formation by storage load, storage time, the packaging status of stored food, cleaning activity, frequency of door openings and ambient conditions of the room, in which the appliance is located.

Condensate constitutes a hygienic problem and a food safety problem: If in contact with food condensate may cause swelling and may support microbial growth. One of the key parameters that enables microbial growth is freely available water in foods or at food surfaces. Freely available water that is not bound to food molecules can support the growth of bacteria, yeasts and moulds. Furthermore it participates in and supports chemical and enzymatic reactions and thus spoilage processes.

The term water activity (a_w) refers to this freely available, unbound water. Water activity or a_w is the partial vapour pressure of water in a substance divided by the standard state partial vapour pressure of water (Krämer 2006). With $a_w < 0.75$ bacterial growth is inhibited but some yeasts and moulds may grow. At less than 0.6, all microbial growth is inhibited. As the water activity in condensate is typically > 0.99, the growth of all kinds of microorganisms will be supported (Krämer 2006).

Most critical is condensate formed on the surface of stored products or at contact surfaces, especially underneath stored products. Vegetable storage compartments are especially critical: Highest microbial counts have been found in vegetable storage compartments of refrigerators, next to defrost water drain outlets (Carpentier et al. 2012). This can be explained by the fact that unprocessed produce is frequently stored w/o packaging in vegetable storage compartments (Plumb et al. 2013).

Even though no significant correlation between the amount of bacteria and relative humidity in storage has been shown, the impact of condensate may not be neglected: Condensate provides excellent conditions for microbial growth (Carpentier et al. 2012). Most relevant in cold storage are psychrophilic and psychrotrophic microorganisms, having the ability to grow at 0 °C. Psychrotrophic microorganisms have a maximum temperature for growth above 20 °C. Psychrophilic microorganisms have a maximum temperature at 20°C or below (Gounot 1986). Table 1 provides an overview on typical spoilage microorganisms and pathogens that are relevant in cold storage (Betts & Everis 2000).

Table 1: Minimal growth temperatures of typical spoilage microorganisms and food pathogens

Microorganism	Minimum growth temperature [°C]
Pathogen microorganisms	
Salmonella	7
Staph.aureus	6
Bacillus cereus	< 4
Listeria monocytogenes	0
Escherichia coli	7,0
Vibrio parahaemolyticus	5
Yersinia enterocolitica	-2
Escherichia coli O157	-6,5
Spoilage microorganisms	
Pseudomonas	< 0
Enterobacter aerogenes	2
Lactobacilli	2
Yeasts	-5
Moulds	<0

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The growth of moulds such as grey, black and black bread mould (*Botrytis cinerea, Aspergillus niger* and *Rhizopus stolonifer*) strongly increases with rising humidity levels and increasing amounts of condensate (Benamaraet al. 2010), which may counteract the benefits of high humidity storage (Carpentier et al. 2012, Beuchat 2002). *Bacillus cereus* and *Staphylococcus aureus*, representing the food pathogens most frequently occurring in cold storage, may be further promoted in case of condensate occurrence (Carpentier et al. 2012). Contamination of fresh fruit and vegetables with pathogenic bacteria such as *Listeria*, *Yersinia* and *Campylobacter* represents a potential risk for human health, especially related to cross-contamination effects (Beuchat 2002). Furthermore, fresh produce is frequently subject to mechanical stress, which further promotes microbial growth: Damaged produce surfaces provide entry points for bacteria; escaping cell sap provides optimal nutrient sources for the growth of microorganisms (Geyer & Hassenberg 2009). A further proliferation – especially in combination with condensation - is enhanced. Next to that, condensate on fruit and vegetable surfaces may have an impact on colour, structure and texture (Linke & Geyer 2012).

Materials and Methods

To derive a reproducible test method for the evaluation of condensate in refrigerating appliances, a multi-stage approach is followed (Figure 2). Firstly, condensate amounts and patterns are analysed, based on a real vegetable load, to derive quantitative and qualitative reference values. Based on these reference values, a suitable food substitute is identified, that comes up to the condensate amounts and distribution patterns of the real vegetable load. The application of a substitute is inevitable as fresh produce shows high variations in humidity loss and thus as well in resulting condensate amounts. The parameters driving humidity loss of fresh produce in storage are complex, showing a high variance even within one species and due to the impact of pre- and post-harvest handling parameters. Especially water stress, respiration and ripening- induced changes, senescence and decay drive the kinetics of the humidity loss rate (Kays & Paull 2004, Chakraverty & Singh 2014, Bart & Brecht 2003).

Next, a reproducible test procedure that evaluates condensate occurrence and intensity is identified. The test procedure applies a qualitative analysis approach.

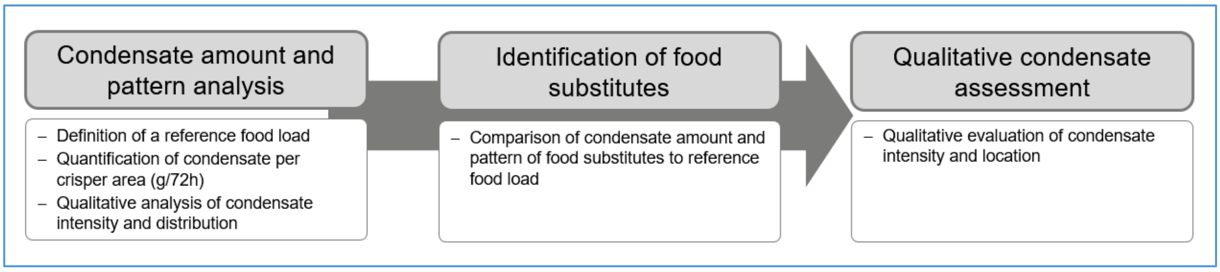

Figure 2: Overview of the condensate evaluation approach

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All tests are performed in three different refrigerators to be able to evaluate the applicability of the test procedure to different cooling technology layouts, storage zone designs and volumes. The appliances include dynamic (No Frost / Full No Frost = NF) and static cooled (SC) refrigerators, with and without chill compartments (Table 2).

Table 2: Refrigerators used for the condensate analysis

Appliance code	**No Frost Solo (NF Solo)**	**Full No Frost Combi (FNF Combi)**	**Static Cooled Combi (SC Combi)**
Appliance type & cooling system	No Frost refrigerator, vegetable storage compartment in chill compartment	Full No Frost Fridge-Freezer	Static Cooled Fridge-Freezer, vegetable storage compartment in chill compartment
Refrigerator net capacity (l)	187	237	242
Test zone net capacity (l)	18.90	34.50	38.10
Humidity control feature	Tightly sealing top, two humidity settings	Tightly sealing top, two humidity settings	Tightly sealing top, three humidity settings

Each test run is performed in triplicate within each vegetable storage compartment. All test compartments are set to the high humidity setting. The refrigerators are located in an air-conditioned laboratory with an ambient temperature set to 22 °C ± 2 °C. The refrigerator temperature is set to 4 °C in the refrigerator compartment and -18 °C in the freezer compartment. All refrigerator compartments and sub-compartments are free from load. As soon as the refrigerator has reached steady state conditions, the test load is added. Each test run takes 72 h. Relative humidity and temperature values within the test zones are logged by mobile temperature and humidity loggers on a minute-by-minute base.

Condensate generation by reference food load and substitutes

An average vegetable food load is defined, based on a reference load that has been in discussion for the test standard evaluating the weight loss rate in vegetable storage compartments (IEC TC 59/SC 59M/WG 4 2017). The test load considers vegetables with different transpiration rates. The reference values for the food substitutes are derived from the resulting condensate amounts and patterns the reference values. The food load is adapted to the volume of the vegetable storage compartments, being increased if the net volume is > 20 L (Table 3).

Cellulose sponges and a nonwoven cellulose fabric ("nonwovens") are qualified as suitable food substitute materials in pre-tests (Table 3). Most important selection criteria are availability, costs, ease of application and handling, the possibility of repeated application and a high repeatability in condensate generation. The nonwoven sheets are already defined as the food substitute material in the Committee Draft on weight loss analysis (IEC 63169 ED1, PNW 59M-76: Household refrigerating appliances – Characteristics and test methods – Food preservation).

Prior to each test, the food substitutes are charged with pre-cooled distilled water (4 °C ± 2 K):

- The cellulose sponges are watered and wrung out. 75 g water is subsequently poured on each sponge. After measuring the initial weight of each sponge, the sponged are placed horizontally on top of plastic rings (plastic ring height: 2 cm) in the vegetable storage compartment, to allow for proper air circulation. Each test zone is completely covered with sponges.
- The nonwoven fabric sheets are placed within a plastic box with a water reservoir, allowing for 6 (small trays) or 18 (large trays) vertically inserted sheets. The boxes are charged with 200 g +/- 50 g (small trays) or 700 g +/- 50 g (large trays) of pre-cooled water. The nonwovens, being instantly soaked with water, are then inserted into the test zones. The tray load is calculated in proportion to the volume of the test zone. A ratio of one small tray per 3 litres of test zone volume is applied, with three small trays corresponding to one large tray.

Table 3: Reference and food substitute load definition

Appliance code	**No Frost Solo (NF Solo)**	**Full No Frost Combi (FNF Combi)**	**Static Cooled Combi (SC Combi)**
Reference food load (according to IEC TC 59/SC 59M/WG 4 2017)	4 carrots 2 broccolis (small) 2 lettuce heads (small) 2 red radish bunches (small)	7 carrots 1 broccoli (large) 1 lettuce head (large) 1 red radish bunch (large)	
Cellulose sponge load (Spontex Bloc R3 wet, 880 x 160 x 123 mm / sponge)	5 sponges	7 sponges	8 sponges
Nonwoven tray load (Brune Humidifier Filter Pads, 125 x 75 x 1.5 mm / sheet)	3 large trays	3 large trays 1 small tray	3 large trays 2 small trays

Quantitative condensate assessment

The quantification of the resulting condensate is assessed by wiping all surfaces of the test zone with paper towels after the test has been finished. The paper towels are weighed separately before and after the wiping process: The total weight increase of all paper towels per test zone amounts to the total condensate amount for the respective drawer.

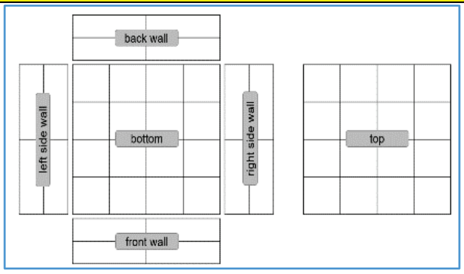
Qualitative condensate assessment

The qualitative condensate evaluation is based on the visual assessment of the occurring condensate. The method considers the intensity of occurring condensate along with the condensate pattern.

The condensate intensity is rated by a 4-point scale. The evaluation of the condensate pattern includes an evaluation of each test zone surface area. The values for each surface are recorded on a data report sheet. The data report sheet provides a sketch of the test zone, including a subdivision of each surface area in single evaluation grids (Table 4). The highest occurring condensate intensity per evaluation grid is the valid evaluation for the single grid, which is then transferred to the overall evaluation scheme. The sum of all evaluated grids per area amounts to the overall qualitative condensate evaluation of the test zone.

All tests are done in triplicate by three trained panellists.

Table 4: Condensate intensity scale and condensate pattern analysis in qualitative condensate analysis

Condensate intensity scale	Rated surface areas	Area subdivision	Report sheet with subdivision grids per area
0: No condensate	Top	16	
1: Fog	Bottom	16	
2: Small drops	Two side walls	4	
3: Big drops	Front	4	
	Back	4	

Results and discussion

Identification of a suitable food substitute system for condensate generation

The storage climate parameters are comparable in all test runs. Even though all test zones provide high humidity values > 97% rH (Table 5), the total weight loss and condensate amount vary (Figure 3).

Table 5: Temperature and humidity values within analysed vegetable drawers

	NF Solo		**FNF Combi**		**SC Combi**	
	T [°C]	**rH [%]**	**T [°C]**	**rH [%]**	**T [°C]**	**rH [%]**
Reference food load	0.7	99.0	3.8	98.0	1.2	97.0
Cellulose sponges	0.8	98.0	3.4	97.0	1.1	97.0
Nonwoven trays	0.9	99.0	3.9	98.0	1.2	98.0

As none of the test zones is completely airtight, water vapour transfer to the surrounding refrigerator compartment is possible. Both substitute systems come up to the total weight loss and condensate amounts of the reference food load. Cellulose sponges show the best match to the reference load.

The condensate share of the totally occurring weight loss is comparable for the reference load and the substitute load, being ~30 % for NF Solo and ~15 % for SC Combi. Thus, humidity loss from the test zones succeeds the amount of condensate in the test zone. In the FNF Combi the share is ~50%. The differences can be traced back to the different cooling technologies of the appliances as well as the different test zone sealing: The FNF Combi provides lowest humidity values in the surrounding refrigerator compartment (~ 40 % rH), thus the water vapour transfer from gaps in the test zone sealing to the refrigerator compartment is increased.

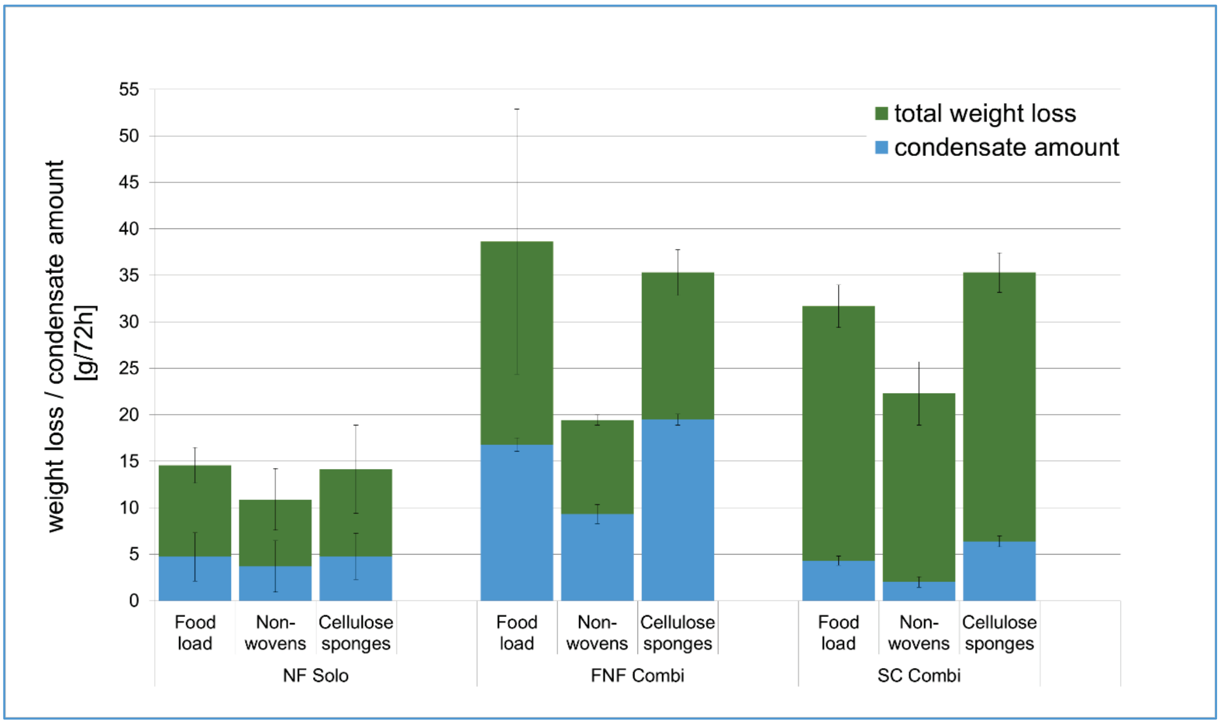


Figure 3: Quantification of total weight loss and condensate amount of the reference food load and food substitutes

The quantitative analysis of total humidity loss and condensate shows high standard deviations, especially in the NF Solo test zone, in which humidity and condensate amount show the lowest levels.

The results underline the fact, that even though a quantitative approach is necessary to set up the basis for a condensate evaluation method, the occurring variations are too high to justify a quantitative approach as a standard evaluation method. The major problem of the quantitative analysis is the retrieval of condensate with paper towels, which is highly error-prone: Condensate is easily transferred from one surface area to another during wiping and upon opening and moving of the test zone.

The analysis of condensate distribution within the test zones shows a good fit for both food substitutes: Condensate locations and intensity levels can be retrieved. The best matches are found for cellulose sponges (Figure 4). Due to the fact that the nonwoven fabric has already been defined as the food substitute material in the Committee Draft on weight loss analysis (IEC 63169 ED1, PNW 59M-76), the follow-up analysis, focussing on the qualitative condensate analysis, is just pursued with nonwovens.

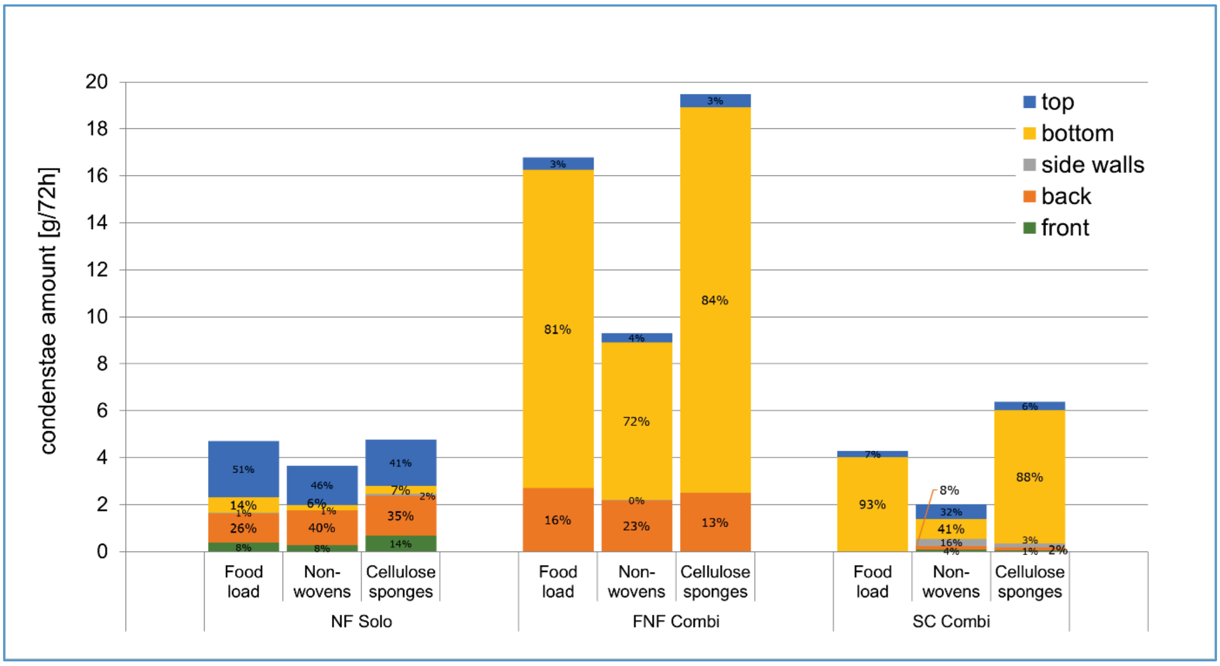


Figure 4: Condensate distribution per vegetable drawer area by food and food substitute application

Qualitative condensate evaluation test procedure: Test fit and explanatory power

The qualitative condensate analysis using nonwovens as a food substitute for condensate generation shows comparable condensate patterns for all test runs in all refrigerator test zones (Figure 5). The sketch approach, in which a direct quantification of condensate intensity for each surface area is done, shows good repeatability. The intensity scale including four intensity levels is easy to handle, even though the intensity evaluation shows some variation in SC Combi.

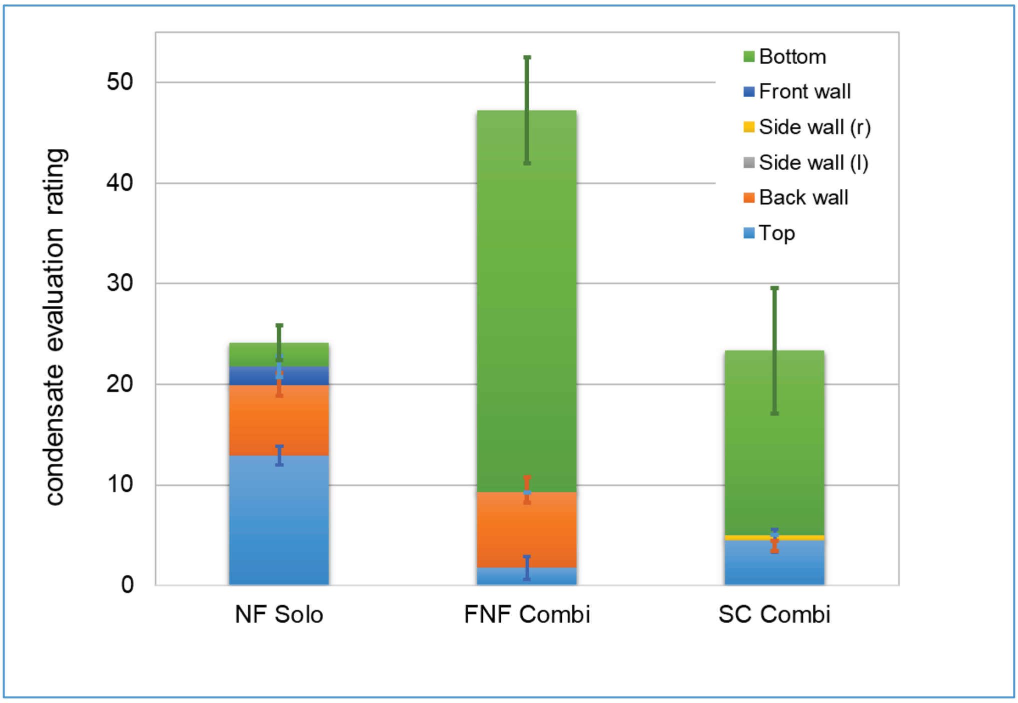


Figure 5: Qualitative condensate rating by application of nonwoven trays as food substitute

Still, further adjustments are required in the condensate test procedure. The qualitative test approach requires intensive training of test engineers and a more detailed information on the condensate intensity levels, supported by pictures and a more precise description, in a possible future test standard.

To further improve the qualitative condensate evaluation, the application of a grid sketch directly on the test zone surface has to be considered. Further evolvements have to provide solutions for the grid adaption to irregular shaped surface areas, as for example in test zones with cut-outs for the compressor niche.

Other follow-up issues are related to hygienic design evaluation. Incorporation of hygienic design into food storage compartments can decrease the risk of pest development and cross-contamination, and thus assure increased food safety. Yet hygienic design evaluation is complex: Material grades as well as the qualification of cleanability have to be included. This requires an extensive analysis of possible test zone layouts and designs along with a separate test procedure for a cleanability rating. As this complexity will hardly be manageable, just some parameters are to be followed. These might include special features for condensate control such as waved bottoms in the test zone by which food contact with occurring condensate will be limited. Further on, weighing factors of distinct surface areas posing higher risk of extended food contact, may be included.

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Conclusion

The qualitative condensate evaluation test procedure allows for a distinct analysis of condensate occurrence within vegetable storage compartments. Next to the information on the weight loss performance of a vegetable storage compartment, which evaluates the performance of humidity control, it provides additional crucial information on the freshness retention of fruit and vegetables: Just if a vegetable storage compartment provides both, a high humidity storage option, along with a proper condensate control option, a long-term freshness retention can be achieved. An enhancement of microbial growth by controlling possibly occurring condensate can be avoided.

Still, temperature control, as provided in chill compartments with temperature levels between -3 and +3 °C, is most decisive in microbial growth inhibition and thus food safety and food loss prevention. Yet, just if chill compartments can assure a supreme overall storage climate, including condensate control in high humidity storage, food safety benefits along with extended storage times can be achieved in the best possible way (Derens et al. 2001, Thomas 2007). An estimation study on storage time prolongation in best storage conditions, presuming a storage temperature close to 0°C and high humidity levels, without the impact of condensate, amounts to a factor of 4.2 for vegetables and 4.8 for fruit, giving the consumer more time to consume the products. This will reduce the expected food waste of not-used-in-time products, which is contributing most to food waste in fresh produce. Estimated reduction rates range from 12 down to 6 % for vegetables and from 7 down to 3.5 % in fruit (Kemna and van Holsteijn, 2017).

Additionally, the low cleaning activity of consumers has to be taken into account, which further promotes microbial growth, further emphasizing the necessity of a proper condensate management (Masson, Delarue and Blumenthal 2017).

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Die Autoren/innen erklären, dass kein Interessenkonflikt besteht.

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