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An Approach to Accelerated Measurement of Dehydration (Freezer Burn) in Beef Patties in Household Freezers

Beate Kölzer, Jasmin Geppert, Harald Wucher, Astrid Klingshirn, Lilla Brugger, Thomas Ertel, Thomas Gindele, Antje Engstler, Jochen Härlen, and Rainer Stamminger

Abstract

Freezer burn is a damage that occurs on the surface of frozen foods. To develop an accelerated method to measure the ability of different freezers to prevent freezer burn, the weight loss of beef patties, stored for 4 months in different freezers designed for household usage, is measured. These values act as a reference for accelerated tests (72 h instead of 4 months) with food simulants. Tests with wet cellulose sheets show a high correlation between experiments with foods and simulants, which suggests the potential for the material used to be utilised in the future.

Keywords: freezer burn; weight loss; household freezer; standard method

Ein Ansatz zur beschleunigten Messung von Austrocknung (Gefrierbrand) von Rindfleischbuletten in Haushaltsgefriergeräten

Kurzfassung

Als Gefrierbrand wird die Austrocknung der Oberfläche von Lebensmitteln bezeichnet. Um eine Standardmessmethode für Gefrierbrandbildung in Haushaltsgeräten vergleichbar messen zu können, wird der Gewichtsverlust von Rindfleischbuletten bei vier Monaten unverpackter Lagerung in unterschiedlichen Haushaltsgefriergeräten aufgezeichnet. Die Ergebnisse dienen als Richtwerte für beschleunigte Tests (72 Stunden anstatt 4 Monate) mit Ersatzlebensmitteln. Die Untersuchung der Austrocknung von Zellulosevliesen zeigt eine hohe Korrelation mit der der Buletten und zeigt das Potenzial, in Zukunft für Messungen eingesetzt zu werden.

Keywords: Gefrierbrand, Gewichtsverlust, Haushaltsgefriergerät, Standardmethode

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Introduction

Freezing is a preservation method for perishable foods, such as meat, bakery goods and certain types of fruit and vegetables. The extended shelf life can come at a price regarding food quality, depending on the surrounding parameters in the freezer and initial food quality (Evans 2009).

Frozen storage

Perishable foods, such as fruit, vegetables and meat, often contain a high proportion of water (~ 90 % in produce, 60–80 % in meat) (Kurzhals 2007: 15). Free water is essential for food spoilage and plays a major role in the determination of the shelf life. Thus, the main strategies to extend the storage period, such as curing, sugaring and smoking, have the inactivation of the water contained in common. The lower the water activity level (a_w-value), the lower the microbial growth (Evans 2009: 1; Rödel 1977) besides the microbial spoilage, enzymatic reactions are known to lead to molecular changes inside the food; changing the taste, colour and texture. This, as well as non-enzymatic oxidation reactions resulting from air contact, are slowed down drastically by freezing (Sun 2006: 26). As a general formula, the preservation is better at lower temperatures and low temperature fluctuations and shorter storage times (Evans 2009: 144).

In addition to molecular changes, physical changes also take place (Sun 2006: 21). Some of these are due to the volume increase of 9 % when liquid water solidifies to ice. Fibres, cell membranes and walls and their functionality can be destroyed as a result. This damage can cause lower water-holding capacity and therefore higher drip loss when thawed, which lowers the quality of the product (Kurzhals 2007: 127; McGann et al. 1988).

Another problem is the formation of frost in the freezer, on packaging and food. Fluctuating temperatures, such as those that occur in refrigerators when the compressor is switched on and off, promote the formation of frost (Laguerre, Flick 2007; Martins et al. 2004). The moisture for this can come from the ambient air of the freezing appliance which can enter the appliance via the sealing due to pressure drop when the compressor is working. Another water source for frost is water e.g. ice (from ice layers or food) inside the freezer. Ice sublimes, evaporates from solid to gaseous phase, and re-condenses on cold surfaces inside the freezer (Kurzhals 2007: 127; Laguerre & Flick 2007).

Freezer burn and moisture migration

Freezer burn is another type of food damage which occurs exclusively with frozen food. Some sources refer to freezer burn as desiccation (Schmidt & Won Lee 2009), as an irreversible desiccation (Heiss & Eichner 2002: 178) or as a consequence of desiccation (Johnston et al. 1994). In agreement, it can be said that dehydration and freezer burn are directly connected (Kurzhals 2007: 127).

When water sublimes from the surface of a food, small dried-out cavities remain. This is visible as dull, pale, greyish parts on the product. Taste and texture are deteriorated by the drying process, and the higher surface area makes the food more vulnerable (Meat and Livestock Australia = MLA 2016) to oxygen and accelerates the oxidization, which can make food rancid more rapidly (Evans 2009: 146). Freezer burn occurs mostly on food rich in protein, such as fish and meat, but can also affect other foods like (cut) vegetables (Kurzhals 2007: 127).

Freezer burn can be prevented by a tight-fitting packaging impermeable to air and water, which inhibits sublimation (Ashby et al. 1973; Kaess & Weidemann 1971). This kind of packaging is practicable for industrial purposes but rather difficult and unusual in everyday use for consumers at home. A German consumer survey revealed that consumers normally use the original packaging, freezer bags or plastic containers to store frozen foods, around 5 % stated packing their food in aluminium foil, in a container or not at all (Kölzer et al. 2020).

Prior research has shown an increased weight loss at fluctuating temperatures compared to steady temperatures, provoking minimal phase changes by thawing and refreezing food, enabling water loss (Laguerre & Flick 2007; Rahman 2007). The longer an unprotected product is exposed, the more severe the dehydration is. Water from deeper layers of the food will migrate towards the dry surface and sublimate into a gas state after a while (Mascheroni 1998; Williams et al. 1981).

To make matters worse, the dry air in a freezer can absorb moisture from the surface of the food, carrying it to the coldest place in the freezer, where it condenses and forms an ice layer on the evaporator or packaging material (Evans 2009: 311 ff). Since freezers with automatic defrost (NoFrost freezers) force more air movement, dehydration is expected to be higher at the same temperatures (Mascheroni 1998) than static freezers that run without ventilation. The only air movement in static freezers is a result of natural convection (Johnston et al. 1994; Sun 2006: 265).

There are a few studies on the topic of freezer burn apart from the investigations of Kaess (Kaess 1969; Kaess & Weidemann 1962; Kaess & Weidemann 1963; Kaess & Weidemann 1967a; Kaess & Weidemann 1967b; Kaess & Weidemann 1971), which were carried out in the 1960–70s. His meat tests investigated the influence of the age of the animal, the fat content of the meat, packaging, freezing rate, mean storage temperature and storage time. A high dependency on the packaging (no burn after 380 days in polyethylene packaging, Kaess & Weidemann 1971) and on the mean storage temperature was found and confirmed by others (Ashby et al. 1973). Contrary to general recommendations, slow freezing was found to be more beneficial than fast freezing (Kaess 1969).

There are some models to calculate mass transfer (i.e., water loss, weight loss) in freezers based on the dependency on temperature, air velocity and the food product itself (Campañone et al. 1998; Martins & Silva 2004; Mascheroni 1998; Pham & Willix 1984; Tocci & Mascheroni 1995). Many of which utilized meat (pork, minced beef) as reference food and utilized cold chambers with adjustable temperatures and air flow rates to verify their mathematical models. However, none specifically relates to freezer burn.

As mentioned above, freezer burn can be detected as pale, dry, greyish areas on food surfaces, but no general scaling is used in the literature. Only a comparative, subjective determination of the visual difference is possible, as Kaess did in his studies. The more objective and widespread method seems to be the indirect determination via the weight loss.

Unlike the prior research, this study aims to provide an accelerated measuring method as a standard procedure for dehydration of food in household freezers. Although the models in the above literature seem to make precise calculations, the measurement of all parameters (temperature, air flow) in all compartments is time-consuming and requires relatively expensive equipment. In addition, the air speed values may differ greatly depending on the location of the measuring point. Therefore, a weight loss test with simulant food should deliver accelerated results. As reference food beef patties shall be used since their surface/volume ratio can easily be reproduced and the material is more homogenous than non-minced meat. For the simulation of moisture migration, starch gels have been used in the past (Reid & Perez-Albela Saettone 2006) but since a standard procedure for weight loss for vegetable drawers in refrigerators already exists (IEC 05/2020), it is convenient to utilize it for both purposes.

Key focus is the development of a method that is possible to reproduce in different laboratories and avoiding the variance of foodstuffs. Therefore a simulant should be used and examined for its suitability of making accelerated dehydration measurable.

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Material and Methods

Five different household appliances were used for this study, including static and NoFrost freezers with different numbers of compartments. Tab. 1 shows the details for each freezer including the set temperature and the mean temperature measured in the top compartment of each appliance. Appliance 5 takes a special position because the average temperature is set to -26 °C in contrast to -18 °C in the others.

The tests including real food were carried out with beef patties made of 100 % ground beef with no salt or other additives. The ground beef was divided into portions of 50 g ± 1 g and each portion moulded into a patty with the help of a petri dish (Ø 9 cm). As mentioned above, most consumers pack their food in plastic bags or containers. Non-airtight packaging methods might be acceptable for short storage periods but do not ensure protection from freezer burn over longer periods of time. Even though food sold frozen has been frozen and packed according to best practice, it can be assumed that users at home have to open packages and leave the leftovers in the freezer, since the food often comes in large batches. Bags and cartons of frozen foods might be opened and re-stored for an indefinite period and the insufficient packaging cannot keep the moisture as it should. For this reason, a "worst case" approach was chosen by using unpacked foods with high surface/volume ratio and low freezer load.

So, after being removed from the petri dish, the patties were placed individually on stackable circular stainless-steel grids to obtain as much air contact as possible.

The dry mass of the starting material was determined by drying five portions, 5 g each, at 80 °C to constant weight, leaving behind around 33 % of the fresh weight.

Regarding the experiments with food simulants, the tests were adapted from the IEC 63169:2020 "*Electrical household and similar cooling and freezing appliances – Food preservation*" where cellulose sheets (= non-wovens) made for air humidification are used to maximize the evaporation surface of a water source. In this case it consists of study trays with 18 slots each are applied, where the sheets of the non-wovens (12.5 x 7.5 cm) can fit in (fig. 1).

Fig. 1: Non-woven tray with cellulose sheets

One tray was needed for each compartment /drawer, and each tray equipped with six sheets of non-woven material, distributed as evenly as possible over the 18 slots. The weighing accuracy of the balance used was ± 0.01 g and the compartments were numbered from top to bottom.

Storage of beef patties for four months

Regarding the storage for four months, six of the prepared patties on grids were placed in each drawer/compartment of each appliance. The patties were weighed when frozen solid, around 3 h after storage, put back and then left untouched until sampling. Pre-freezing was necessary because the patties (still unmarked, see below) lost about 0.5 g while freezing regardless of the storage place, as also observed by other authors (Campanone et al. 2001).

After 2, 4, 6, 8, 12 and 16 weeks, one marked with the date of exchange patty was removed from each drawer/compartment and replaced by a fresh one. These subsequently frozen samples were all removed together at the end of the experiment after 16 weeks, resulting in storage times of 4, 8, 10, 12 and 14 weeks. Since these patties were all made from different batches of meat, the focus of this evaluation is on the original patties made from the same batch of raw material.

The result was calculated as the residual weight in % from the initial frozen weight. Due to limited storage space and the intention to monitor behaviour over four months, it was not possible to use enough samples to provide standard deviation in this experiment.

Tab. 1: Appliances and temperatures used

Appliance	Model description	Set temperature	Mean temperature in the top compartment	Freezer capacity	Size [cm] h x w x d
1	Refrigerator-freezer combination, 3 compartments, static	-18 °C	-19.8 °C	115 l	201x66x66,5
2	Refrigerator-freezer combination, 3 compartments, NoFrost	-18 °C	-21.0 °C	101 l	201x66x66,5
3	Upright freezer, 8 compartments, No-Frost	-18 °C	-22.0 °C	257 l	184x60x63
4	Upright freezer, 7 compartments, No-Frost	-18 °C	-19.5 °C	237 l	186x60x65
5	Upright freezer, 7 compartments, static	-26 °C (not adjustable)	-27.8 °C	296 l	170x70x75

Acceleration approach with food simulants over 72 h

The trays containing six sheets of the non-woven material were filled with deionized water and left to rest at room temperature for about 3–5 min until the sheets were fully soaked. The residual water was discarded and the trays dried by patting from the outside. One tray per compartment was then placed in the freezer for 3 h until the weights of the patties were taken at the start. The trays were put back to the geometrical centre of the respective compartment. After 72 h ± 2 h the trays were weighed again and the weight loss ratio in g/24 h was calculated. The 72 h test with non-wovens was performed in triplicate.

Statistical analysis

Basic statistics were calculated in Microsoft Excel 2013, including the mean value and standard deviation, and the Pearson's correlation coefficient was calculated using IBM SPSS 25.0. The strength of the correlation will be defined as "medium" at a value of 0.5 to 0.7, "high" from 0.7 to 0.9 and "very high" from 0.9 to 1 (Zöfel 2001: 120).

Results

Storage of beef patties for four months

Fig. 2 to 6 show the residual weight in % of unpacked beef patties that was observed in the respective appliance and compartment over a period of four months.

The data of the appliance 1 (fig. 2) shows a linear tendency with the highest dehydration in compartment (= drawer) 1, followed by 2 and 3. The residual weight after four months lies between 67 and 82 %.

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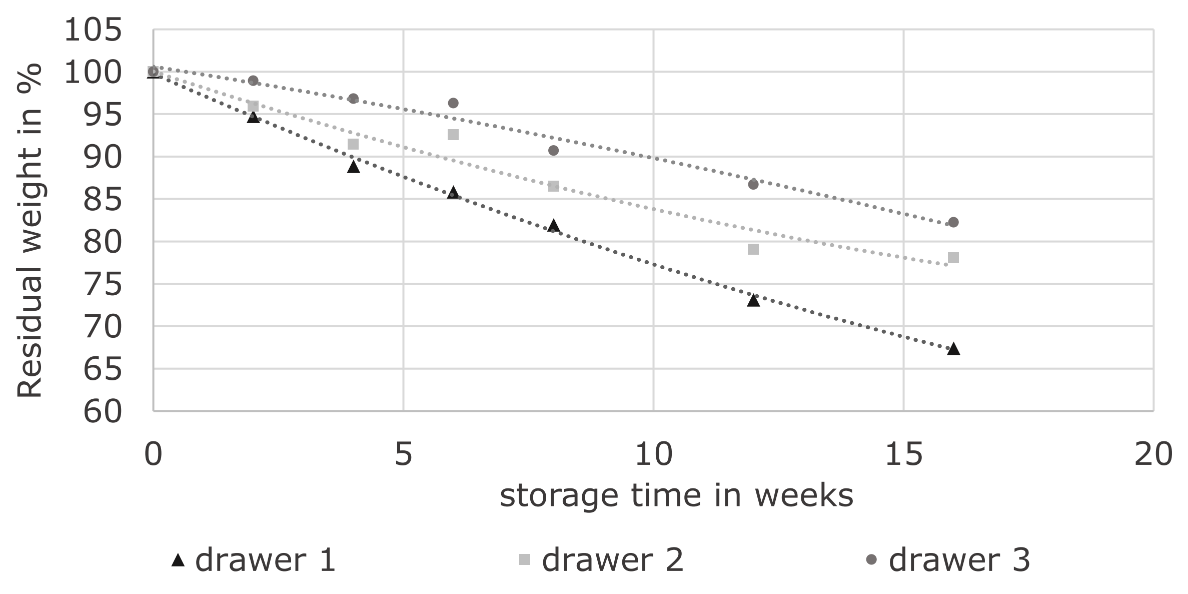

Fig. 2: Storage of beef patties for four months in appliance 1, weight in % of starting weight (frozen), R^2 of polynomial trend lines between 0,959 and 0,997

The residual weights in appliance 2 reveal a slight difference. Dehydration starts linearly with storage time but seems to run into some exhaust after 12 weeks especially in the first and the third drawer. Possibly the effect might be due to the different cooling methods in appliance 1 (static) and appliance 2 (dynamic), but this does not come out significantly because of the considerable spread of the values measured, and is disproved by fig. 4-6. The residual weight after 4 months lies between 35 and 43 % - close to the dry mass determined beforehand.

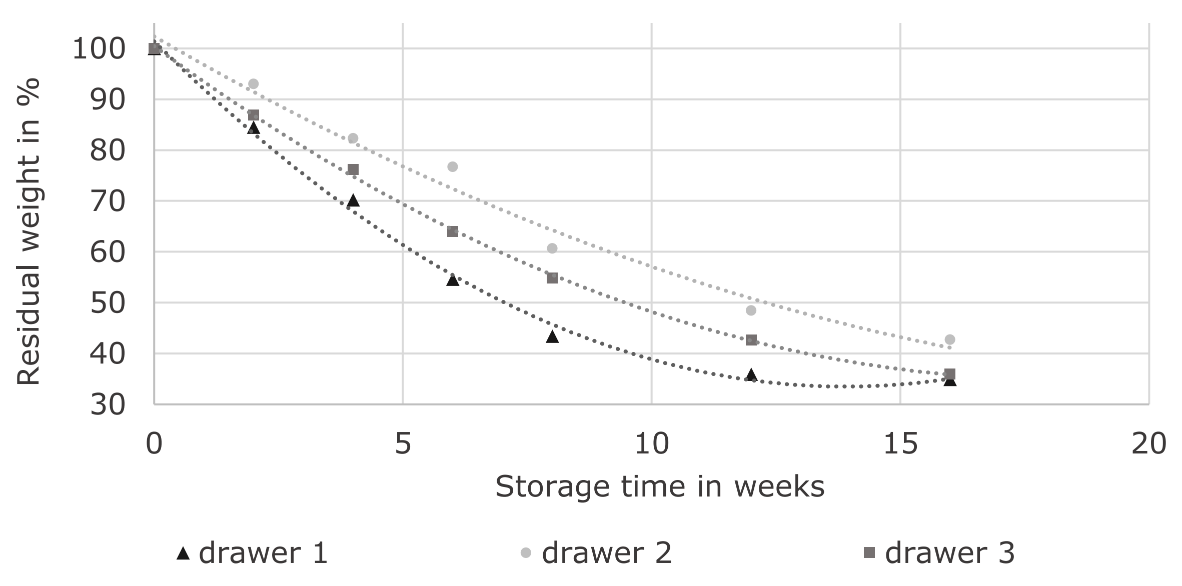

Fig. 3: Storage of beef patties for four months in appliance 2, weight in % of starting weight (frozen); R^2 of polynomial trend lines between 0,983 and 0,999

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Fig. 4 shows the dehydration curves of appliance 3. All compartments show comparable tendencies, with number 3 and 4 presenting the highest weight loss (~45 % residual weight after four months) in this appliance. The curves run almost on top of each other.

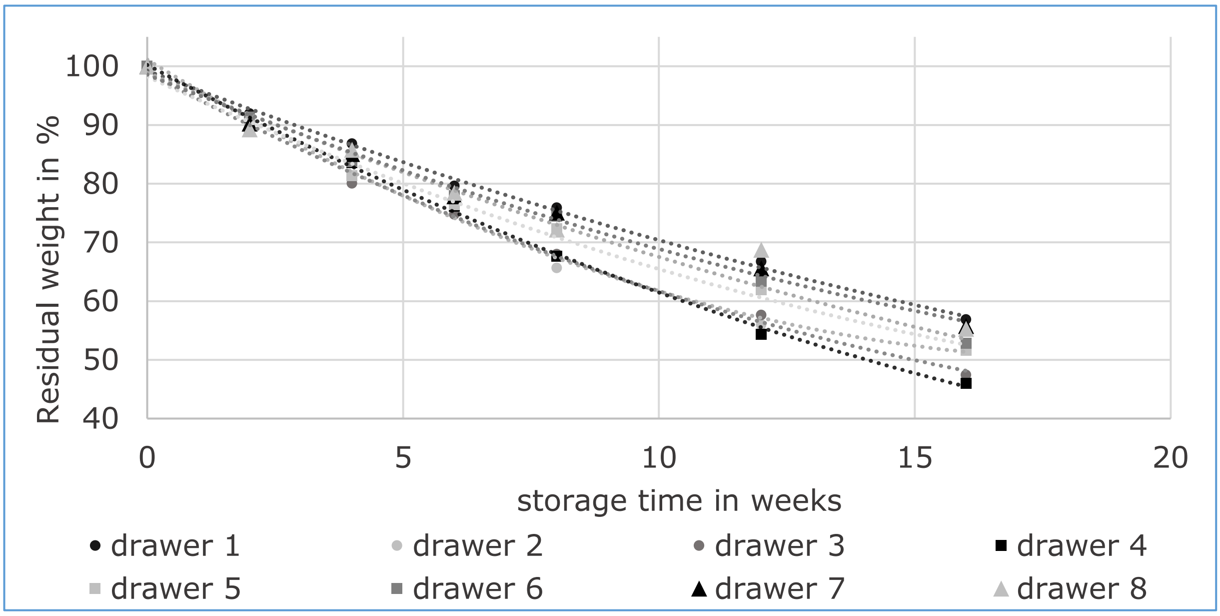

Fig. 4: Storage of beef patties for four months in appliance 3, weight in % of starting weight (frozen) R^2 of polynomial trend lines between 0,992 and 0,999

The dehydration curves of appliance 4 are presented in fig. 5. The residual weights after four months vary between 36 and 48 %.

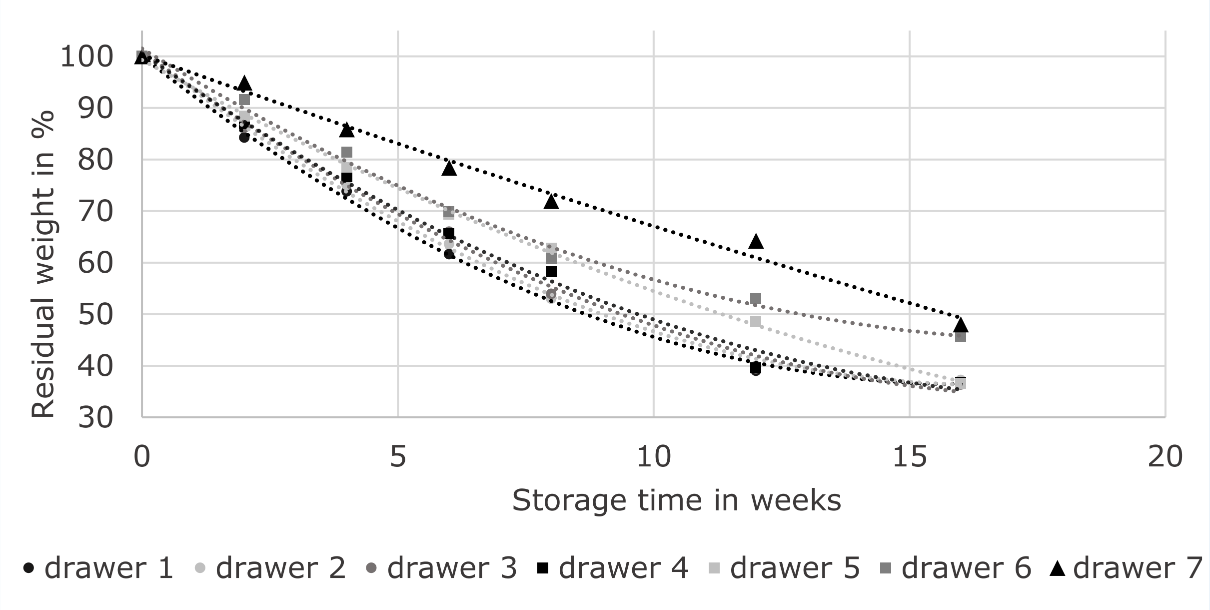

Fig. 5: Storage of beef patties for four months in appliance 4, weight in % of starting weight (frozen) R^2 of polynomial trend lines between 0,990 and 0,999

The dehydration in the upright, static freezer, appliance 5 is presented in fig. 6 below. Unlike the others, the appliance operates at -26 and not -18 °C. Six out of seven compartments show a slow and even dehydration, resulting in residual weights around 76 to 91 % after four months. The first compartment, however, deviates highly from the other compartments, showing a notably greater decrease down to 60 % of the initial weight.

It appears plausible that for appliance 5 with static cooling the evaporation rate in the uppermost drawer may be considerably higher than in the other compartments, due to the non-uniform temperature distribution. Different compartments of the same appliance showed different dehydration behaviour.

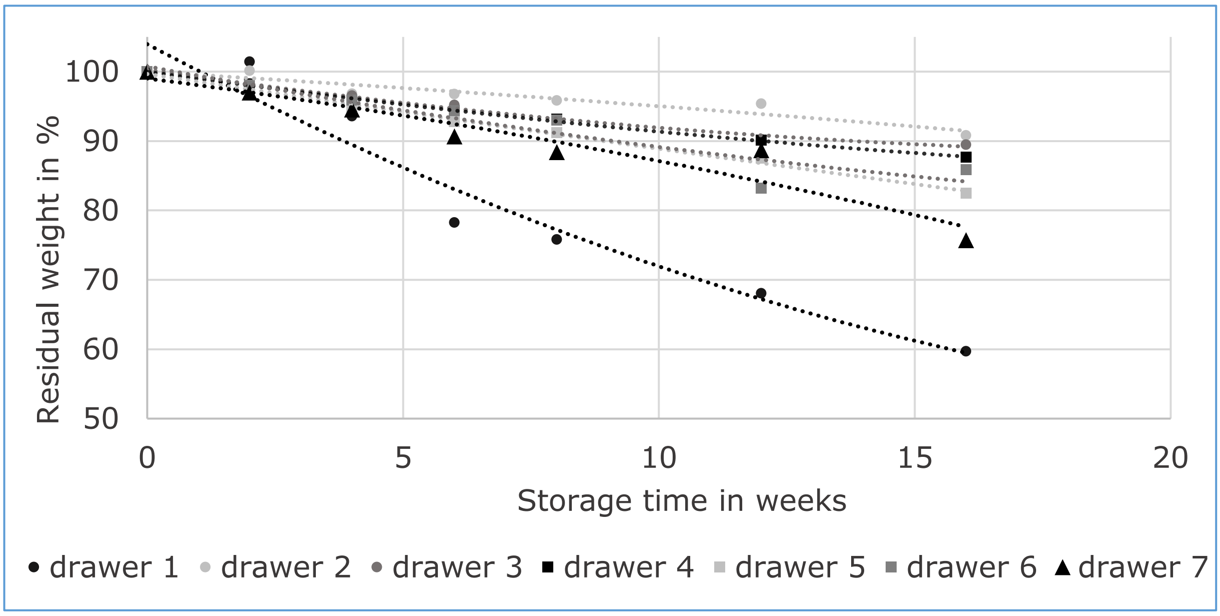

Fig. 6: Storage of beef patties for four months in appliance 5, weight in % of starting weight (frozen) R^2 of polynomial trend lines between 0,892 and 0,997

In conclusion, different compartments in one appliance showed different dehydration behaviours, resulting in some unexpectedly retaining more moisture than others. The end of the linear dehydration curve can be seen in some curves and maximum weight loss is also reached in some drawers in the period examined.

Acceleration trial with food simulants over 72 h

The results of the weight loss rates in g/24 h of the non-wovens are indicated in fig. 7, showing mean values and standard deviations of three trials each. Appliance 5 shows a negative mean value, caused by a weight gain in compartment 2. The compartments for each appliance are pictured from top to bottom (left to right). The tendencies inside the appliance are not similar, and there is no overall rule for the weight loss rate distribution.

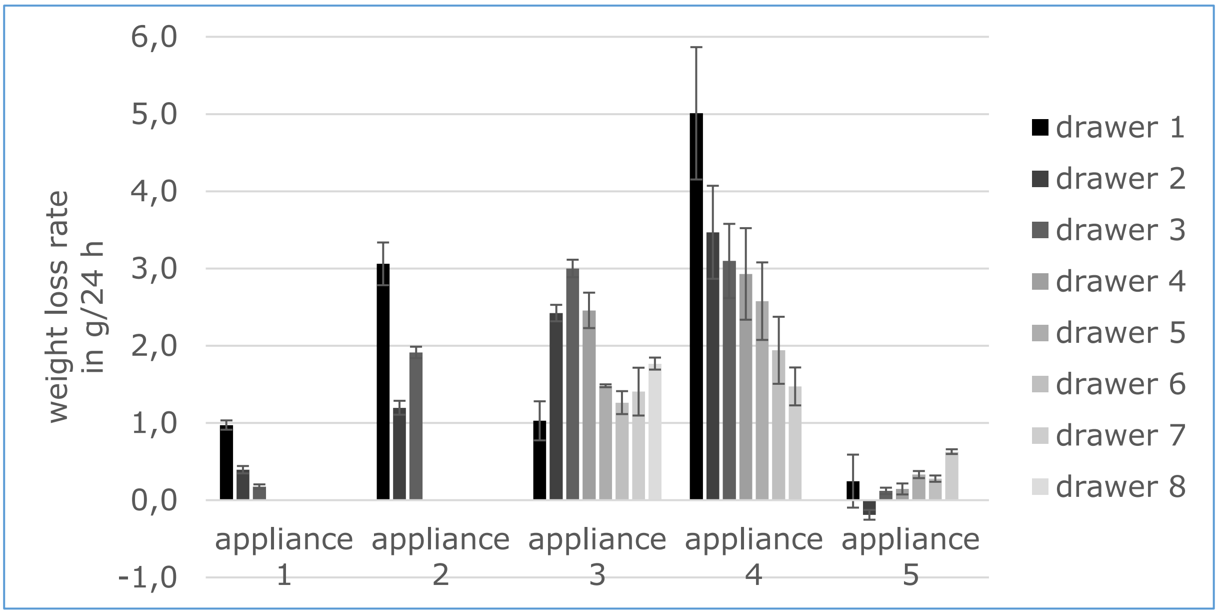

Fig. 7: Weight loss rate in g/24 h of non-wovens in five appliances; compartments shown from top (drawer 1) to bottom

To illustrate the connection between the acceleration trial and the meat storage tests fig. 8 shows the percentual weight loss (100 % - residual weight in %) in the individual compartments plotted for all five appliances tested. For this purpose, the residual weights after 8 weeks storage time (instead of 16 weeks) were used to eliminate the nonlinear part of the dehydration curves (fig. 1- 5) for the beef patties. The 8 week values were taken as single data points and not as mean values since only one sample was analysed per compartment. The central question is whether this dehydration behaviour can be modelled by a quick simulation method.

The patterns per appliance seem comparable, however the relation between different appliances is a little bit different. The appliances 1 and 5 achieved the lowest weight loss rates when tested via Nonwoven material. Compartment 1 in appliance 5 barely showed dehydration when tested with nonwovens, but a medium high value (25 %) after the 8 weeks storage of beef patties.

The patterns of the dehydration of beef patties after 8 weeks in appliance 3-5 are similar to the ones obtained by the accelerated tests with the nonwovens, however the differences in one appliance seem smaller. The relation between appliance 3 and 4 remain similar, but appliance 2 shows medium weight loss rates when tested with the nonwovens and high values when tested with the beef patties.

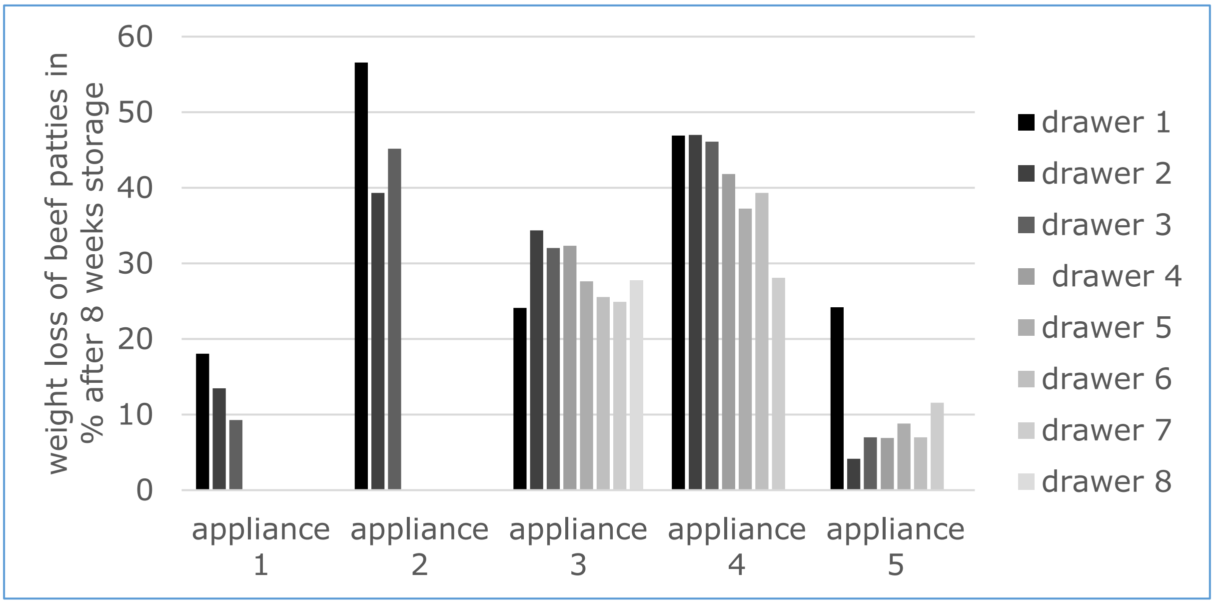

Fig. 8: Weight loss in % after 8 weeks storage of beef patties

The correlation between the long-term storage of beef patties and the 72 h storage of non-wovens is pictured in fig. 7 and the Pearson's correlation coefficient gives a factor of r = 0.879 with high significance. Values of the residual weight after 8 weeks were used here as well instead of 12 weeks to eliminate the nonlinear dehydration curves of the beef patties.

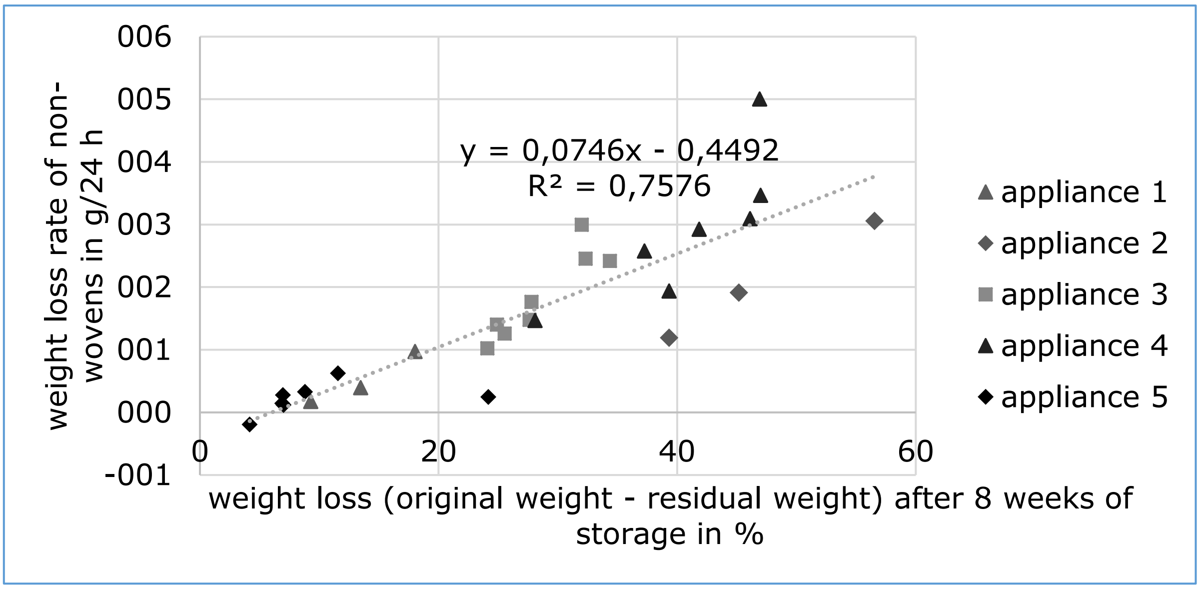

Fig. 9: Correlation between the residual weight in % of beef patties after 8 weeks and weight loss rates of non-wovens in the respective drawer (R^2 = determination coefficient)

Discussion

The main question to answer is whether the non-wovens can simulate the behaviour of the food inside the freezers or not. The high correlation factor of r = 0.879 shows the possibility of using the non-wovens as a simulant for the dehydration of food. Despite some of the absolute values measured of the dehydration for the non-wovens being low, a good repeatability is found. The acceleration effect is a definite improvement on the part of the storage time, in terms of the applicability in standard tests. For this goal it is also important to note, that the trays are easy to handle and the actual working time is short, a relative small part of the storage time.

Also, it is particularly important to note that the experimental setup of the storage tests is designed as a worst-case scenario. The influencing factors "packaging" and "load of the freezer" are intentionally chosen to be as harmful as possible in terms of freezer burn development.

With unpacked food a first acceleration is achieved compared to packed food. The low load (only 300 g per drawer/compartment) is meant to create an even more harmful environment since fully loaded drawers prevent quick air movement by blocking the free space in the drawer.

Studies upon this effect (Pham & Willix 1984, Mascheroni 1998) indicate that air velocity has a noticeable impact when increased from 0 to 0.1 m/s, but not beyond. The experiments in this study show that NoFrost freezers generally provoke higher weight loss rates than static models but since the humidity and air velocity are not be measured the crucial parameter cannot be determined. NoFrost appliances 2, 3 and 4 show mostly higher dehydration rates than appliances 1 and 5, and appliance 5 occupies a special position. Its mean temperature is around -27 °C, unlike the other freezers which operate aiming at a temperature of -18 °C. The lower the temperature, the lower the water-holding capacity of the air, thus, less molecular movement and less dehydration occur. An increase of weight can be observed for some non-woven samples in appliance 5. Since the amount is very small (< 0.1 g/24 h), it is possible that these changes are caused by scale uncertainty and frost adhesion. This could be a result of the unusual construction of the compartments 1 and 2 in appliance 5 which are not shaped as drawers but as simple shelves with plastic lids covering the front. As bottoms of these compartments serves the evaporator pipes directly, quasi forming a grid which is covered by an ice layer as a result of condensation, so some crystals may have stuck to the trays unnoticed. It could be beneficial for static models in the future to increase the non-woven test duration to obtain higher absolute values, which can be weighed more accurately, and it would be better to place trays on a flat surface to prevent ice crystals on the stands.

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Despite the arguments above, some compartments in NoFrost appliances reach levels of dehydration as comparably low as in static models (compare compartment 1 in appliance 1 to compartment 2 in appliance 2), which proves that an excellent compromise can be found by good construction.

The results show not only a difference between specific appliances but also between the drawers of the same appliance. A range from 1.03 to 3.00 g/24 h in appliance 3 and from 1.47 to 5.01 g/24 h in appliance 4 is observed and the tendencies within an appliance show individual patterns. This indicates that there is no general recommendation possible regarding the storage of opened packages in a certain compartment (e.g. top or bottom) because each appliance has individual properties.

It should be noted that the values generated are tested with unpackaged foods, but it can be assumed that packaging would have slow down the dehydration in all appliances equally and, thus, would have change only the absolute values.

Conclusion

The short-term tests with the non-wovens present overall repeatable data, which have a high correlation to the results of the long-term tests with beef patties. This suggests the use of non-wovens as food simulants for an accelerated measurement method in freezers. Some additional advantages of non-wovens over real food are reusability, incorruptibility, and seasonal and regional independent availability. The differences in dehydration revealed for various models of appliances and for the individual compartments show the need of determining dehydration experimentally to find out optimum conditions.

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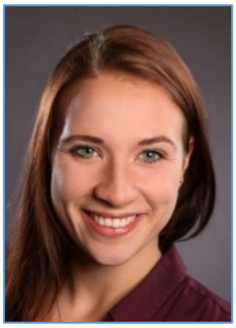

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Conflict of interest and acknowledgement

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