Effects of Milk and Cream Residual Contents in Beverage Carton Packaging Used for Recycling

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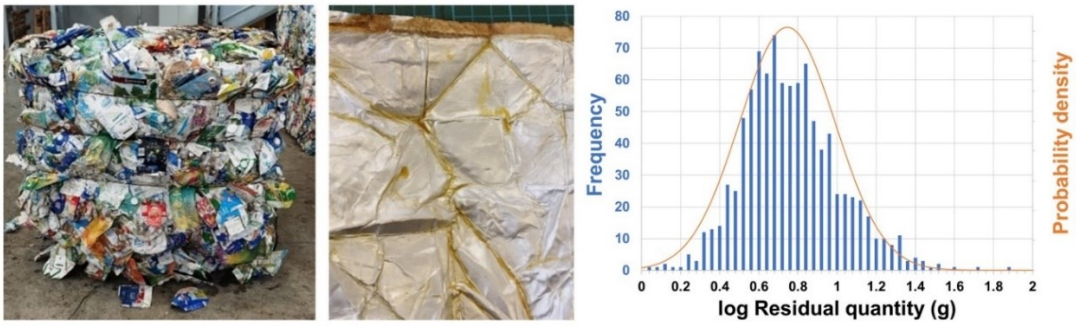
GRAPHICAL ABSTRACT



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Jürgen Belle [a,*] Jonas Rittler,[a] Bastian Küppers,[b] and Sven Sängerlaub [a,*]

Milk and cream are often sold in beverage carton packaging. After use, the unconsumed liquid residues and adhering content remain in this packaging. These food residues end up in the recycling cycle, where they pose troubles in the aqueous processing. The aim of this empirical study was to quantify milk and cream residues in beverage carton packaging from recycling streams. 949 recovered cartons that had been filled with milk or cream and consumed in Germany, Austria, and the Czech Republic were analyzed by gravimetric measurement. For 1-liter cartons, the mean value of the residual quantity was 6.6 g residue for every liter filling quantity, with a range of 1.0 to 71.9 g/L. This corresponds to 0.66% residual quantity by mass, with an assumed density of 1.0 g/cm³. Considering a mean value for all the carton weights with residual quantity of 35.8 g for 1-liter cartons, here some cartons without closures, and 29.2 g without residual quantity, this results in a packaging material content of 81% by mass for recycling. The rest is food waste that ends up in the recycling stream. This can be a task for packaging designers to further improve easy-to-empty solutions.

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Keywords: Diary; Food loss; Emptying behavior; Pulping; Circular economy; Paper recycling

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INTRODUCTION

Beverage carton packaging is one of the most prevalent types of packaging for liquid food. The recyclability of this packaging is becoming increasingly important. Initiatives such as the European Green Deal and the legislation and measures derived from it create the framework conditions for a circular economy (European Commission 2019). Recycling is increasingly legally required. In Germany, for example, 80% of beverage carton packaging must be recycled (Bundesministerium der Justiz 2017).

Beverage carton composite packaging is processed during recycling by wet processing in a similar or identical way to other fiber-based packaging and recovered paper due to longer defibering time for example, although a pre-shredding step may be applied to allow for decreased residence times in the pulper (Martens and Goldmann 2016; Robertson 2021). To the authors' knowledge, beverage cartons are not always shredded before recycling. Plastic and, if present, aluminium foil layers, are removed in a pulper or a drum, and the cellulose fibers are dispersed and recovered. The processes themselves have not been scientifically described, but the principle have been discussed at specialized symposia (Hankaniemi 2025; Neumüller 2025). Residual amounts of food in the packaging end up in the recycling process, and these can cause problems during

reprocessing such as deposits and microbial growth. It has been reported that "the increased amount of recycled fibers significantly increased the amount of bacteria in the paper samples" (Hladíková *et al*. 2015). Higher amounts of recycled fibers positively correlate with the concentration of endotoxins in paperboard samples (Johansson *et al*. 2001). Food residues on the surface of packaging could act as a substrate for microorganisms and exacerbate problems with microbiological contamination.

Laboratory emptying tests performed on beverage carton packaging with milk showed a residual amount of milk between 0.04% and 0.53% (Meurer *et al*. 2017; Wohner *et al*. 2019; Klein *et al*. 2024). Dairy products with a higher viscosity, *e.g.*, yoghurt and buttermilk, lead to larger residual quantities in beverage carton packaging (Cragnell *et al*. 2014; Wohner *et al*. 2019; Klein *et al*. 2024).

The residual quantities of milk in composite beverage packaging in real recycling loops have not yet been sufficiently analyzed. The aim of this study was therefore to quantify real residual quantities of milk packaging for recycling.

EXPERIMENTAL

Materials

The beverage carton samples used for milk and cream cartons were collected at two different times and locations (Fig. 1).

The first batch of about 500 beverage carton packaging samples was received from GWV Wertstoffvermarktung Austria GmbH (Hörsching, Austria) near Linz in Austria on November 15th, 2023. The carton packaging received had been compressed into bales. The bales had been compressed at a force of 150 tonnes and secured by four metal straps. One bale weighed approximately 200 to 400 kg with an edge length of 1.0 m. The bales were stored outdoors for approximately 2 to 3 months before being inserted into the recycling plant. These beverage carton samples were primarily sourced from Austria, with some originating from the Czech Republic.

The second batch of around 500 beverage carton samples was supplied by Veolia Umweltservice West GmbH (Hamburg, Germany) near Ochtendung in Germany on February 20th, 2024. The packages are usually not compressed, and these are recycled a few weeks after sorting.

Fig. 1. Bales of carton samples and opened bale on conveyor belt

Methods

After conditioning at room temperature (23 °C) and climate (50% relative humidity) the beverage carton samples had been brushed off with a scrubbing brush to remove outside sawdust and other waste. Afterwards they were weighed, cut open and cleaned with soap and water (Fig. 2). Clean samples were left to air-dry at ambient temperature and climate for 7 days. Subsequently the samples were weighed again.

Gravimetric measurements were performed using a calibrated analytical balance (model BP 221 S, Sartorius, Göttingen, Germany), with a capacity of 220 g and an accuracy of 0.1 mg. The instrument's linearity is specified at 0.2 mg.

The collected data were taken from the package-printing that included the brand and the type of packaging, the fat content and the expiration date, as well as the classification of the milk as either fresh or long-life.

Fig. 2. Samples with residues before cleaning of inner surface (left and middle) and after cleaning (right)

RESULTS AND DISCUSSION

Sample Structure

In Table 1 the sample structure is shown. The samples were discriminated against their country of sale, fat content, and whether milk or cream were fresh or preserved (long-life milk). Most of the samples were milk cartons with a fat content of 3.5%, and second most contained 1.5% fat. Long-life milk and cream dominated over fresh milk by factor of almost 6. From Czech Republic only packages with long-life milk were available, and therefore those were analyzed.

Description of Distribution

The remaining food quantity in the cartons is displayed as a histogram (Fig. 3). As food residues might get dry slightly in the used cartons, the residual quantities of fresh milk and cream tend to be underestimated in the results shown. Furthermore, bales had been pressed, and residue might had been squeezed out, which also contributes to under-estimation.

Table 1. Distribution of Samples (Fat Content, Fresh or Long-life, Country); Information Taken from Package-Printing; Numbers: Amount of Samples

	All Samples		Austria		Czech Republic	Germany	
Fat (%)	Fresh	Long-Life	Fresh	Long-Life	Long-Life	Fresh	Long-Life
0.1		2					2
0.5		13		13			
0.8		1					1
0.9		2		2			
1		1			1		
1.5	31	199		8	58	31	133
1.8	2	4		2	1	2	1
2.1		1					1
3		1		1			
3.5	76	505	36	289	34	40	182
3.6	4	13	4	13			
3.7	1					1	
3.8	29	31		1		29	30
7.5		1					1
10		1					1
29	1					1	
32		24		23			1
36		6		6			
Total	144	805	40	358	94	104	353

In Table 2 the distribution between the package producers ELOPAK, SIG, and Tetra Pak is shown. These results were later compared with regard to their residual contents. Samples from Austria and Germany dominated.

Table 2. Distribution of Samples (Packaging Producer, Country), Information Taken from Package Printing, Numbers: Amount of Samples

	All samples	Austria	Czech Republic	Germany
ELOPAK	448	329	56	63
SIG	340	47	36	257
Tetra Pak	161	22	2	137

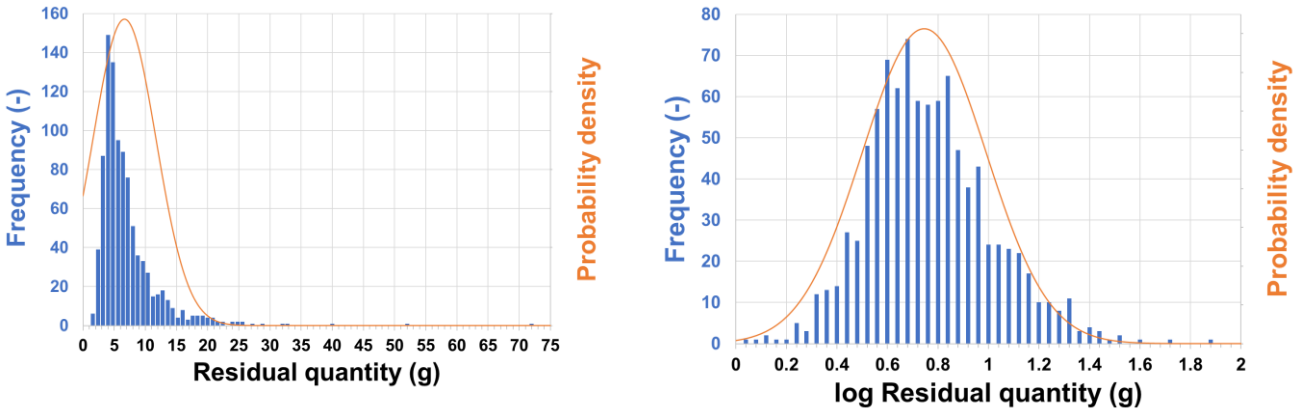

Fig. 3. Histogram of residual quantity in 1-liter beverage carton packaging for milk and cream; left: amount, right: log of amount; in red: Gaussian curve

It was found that smaller residual quantities dominate, and that the histogram of the residual quantity distribution was asymmetrical (Fig. 3). The Gaussian curve calculated from the mean value (6.65 g) and standard deviation (5.07 g) was not congruent with the histogram. The graphical representation of the logarithmical quantities as a histogram corresponded closely to a Gaussian distribution (log-normal distribution) and can therefore be described as such. The Gaussian curve calculated from the mean value (0.745) and standard deviation (0.245) of the logarithmic residual quantities described the histogram much better.

Cartons with above-average residual food quantities contributed disproportionately to the total residual quantity (Fig. 4). Half of the total residual quantity was caused by 75% of the beverage cartons with low residual quantities and the other half by 25% of cartons with higher residual quantities. To reduce the amount of residue entering the recycling system, the need to reduce the cartons with above-average amounts of residue is therefore obvious.

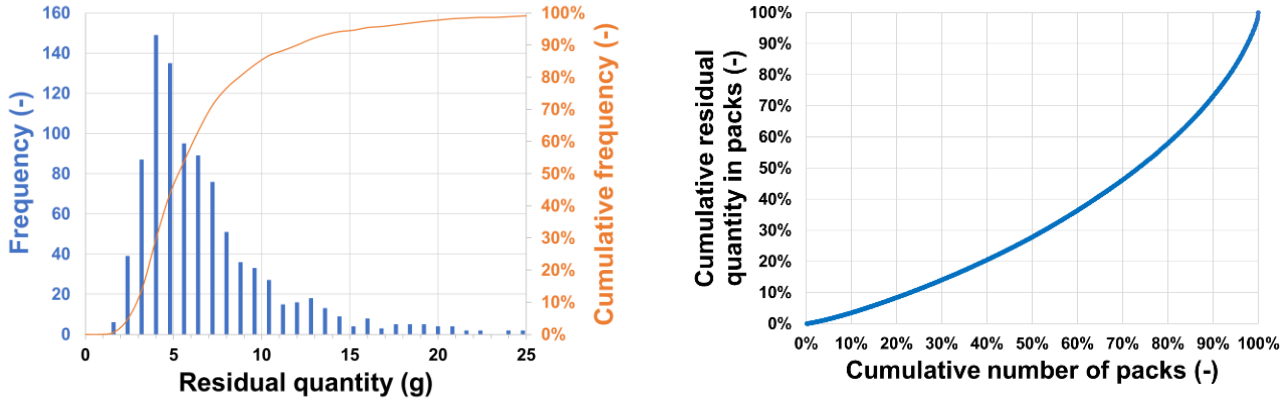

Fig. 4. Left: Histogram of residual quantity in 1-liter beverage carton packages for milk and cream (same as in Fig. 3, left) with cumulative frequency; right: Cumulative quantity in wt% over cumulative number of cartons in %, cartons are shown cumulatively from low to high residual quantity

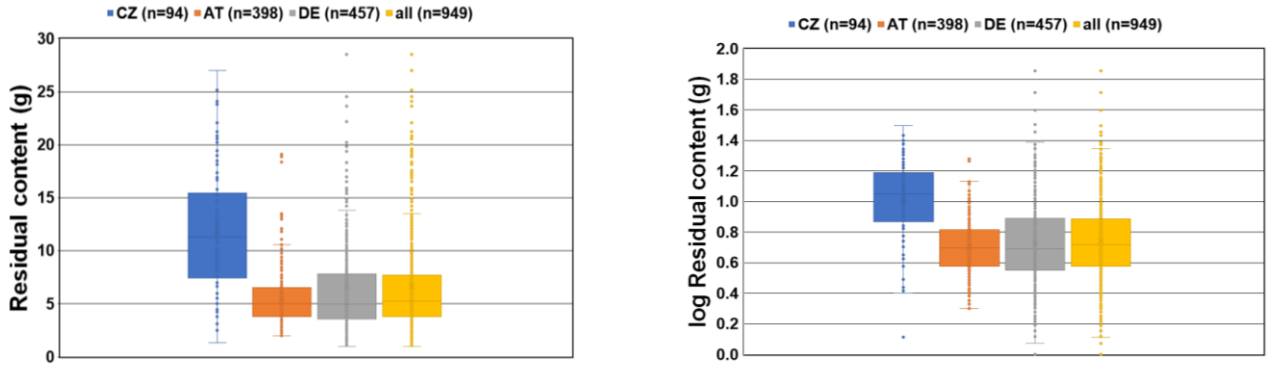

Fig. 5. Residual quantity in 1-liter beverage carton packaging with milk and cream from different countries; left: amount, right: log of amount; n: Number of samples with different fat contents; CZ: from Czech Republic, AT: from Austria, DE: from Germany

Residual Quantity Depending on Country of Consumption

Figure 5 shows the residual contents categorized by their origin. In cartons from the Czech Republic, more residues were found in the cartons (mean value of 11.8 g) than in the cartons from Austria (mean value of 5.5 g) and Germany (mean value of 6.7 g). The reasons are unknown. Because the most cartons in the samples were from Germany and Austria, the residual amount of all cartons (mean value of 6.6 g) was almost identical to their residual content. The quartiles of the box plot of all samples, samples from Germany and Austria overlapped, and these results could therefore not be statistically discriminated.

Residual Quantity Depending on the Fat Content

In general, the viscosity and composition of liquid foods influence their emptying behavior (Cragnell *et al*. 2014; Wohner *et al*. 2019; Klein *et al*. 2024). As there were cartons in which milk and cream with different fat contents was packed, the residual quantity was analyzed with regard to the fat content (Fig. 6). Only cartons with a fat content of at least 10 samples were analyzed. Unexpectedly, no correlation was found between the residual quantity in the cartons and the fat content. It is possible that the scattering of the residual contents primarily occurred that the influence of the fat content was not recognizable. For the evaluation of the samples, this means that it is not necessary to differentiate between the samples in terms of their fat content.

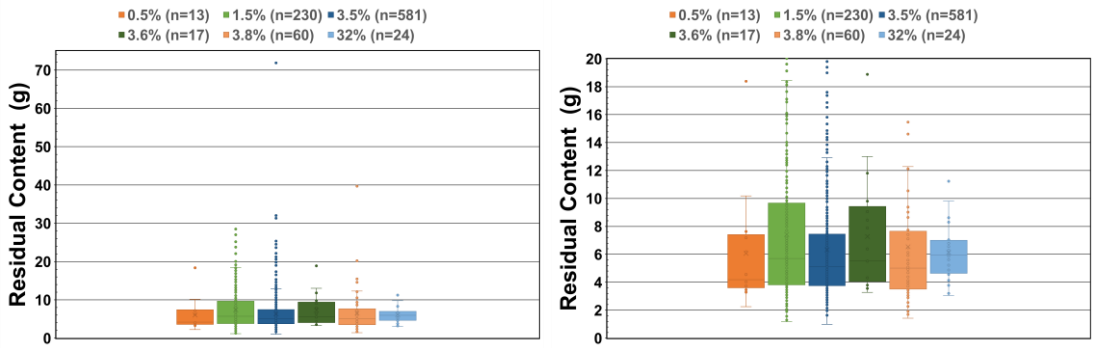

Fig. 6. Residual quantity in 1-liter beverage carton packaging with milk and cream with different fat contents; left: All measuring points, right: scaling up to 20 g; n: Number of samples with different fat contents.

Residual Quantity Depending on Producer of the Beverage Carton

Figure 7 shows the residual contents discriminated against by their producer. No statistical relevant differences could be identified.

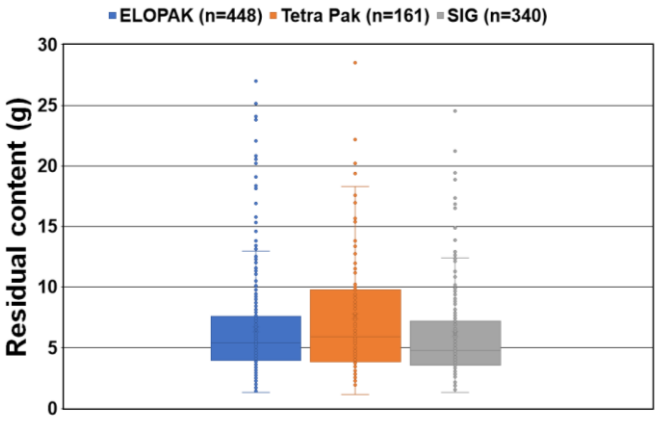

Fig. 7. Residual quantity in 1-litre beverage carton packaging with milk and cream from different producers; n: Number of samples with different fat contents

Comparison of the Residual Quantities from this Study with Other Reported Results

It is obvious that the milk or cream residue weight would become a part of the packaging waste, The mean value of the residual quantity in this study was 6.6 g/L. The weight in g refers to the residual contents as measured in the packaging, whereas the volume in liter (L) refers to the filling amount printed on the packaging. This corresponds to 0.66 wt% residual quantity, at an assumed density of 1 g/cm³. Other researchers found in laboratory emptying tests on beverage carton with milk a residual amount of 0.04% and 0.53% (Meurer *et al*. 2017; Wohner *et al*. 2019; Klein *et al*. 2024;). The results of this empirical study were therefore similar to laboratory tests from other studies. The cited researchers found larger residual amounts in foods having higher viscosity.

The mean value for the packaging weight with residual quantity was 35.8 g for one-liter cartons (some of them without closures), and is 29.2 g without residual quantity. Thus, this results in a packaging material content of 81 wt% for recycling. A comparison with other packaging types revealed that packaging waste for recycling consists of a different proportions of residual food waste: The polypropylene (PP) cups with various filling goods have 10 wt% approximately, the polyethylene (PE) tubs amounts to 50 wt%, PE-HD bottles with shower gel approx. 25 wt%, PP bottles with shower gel approx. 15 wt%, and PET bottles with various filling goods approx. 7 wt% (Schinkel *et al*. 2023). The rest is packaging material that can be supplied to recycling. Although these results have the character of random samples, the results show that the residual food waste in packaging for recycling accounts for significant quantities.

CONCLUSIONS

1. Residual quantities of milk or cream in beverage carton packaging can be described by log-normal distributions. Cartons with larger residual quantities are disproportionately included in the total residual quantity.
2. An influence of the fat content and the manufacturer of the packaging material on the residual quantity could not be determined.

3. The average residual quantity of milk and cream in the packaging was low. Nevertheless, these residual quantities (19% by weight of the beverage carton fractions on average) are large. This should be an incentive for all consumers to make full use of product content and for packaging designers to further improve easy-to-empty solutions. This obviously would reduce issues with food residues in recycling such as microbial growth and depositions at recycling equipment surfaces, and the amount of commercially attractive fibers in such recycled material would be increased.

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