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Corrosion in Aluminium Cans with Grape Juice – Influence of Mechanical Damage

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The consumption of canned food products from dented cans is not recommended by surveillance and consumer protection agencies due to the possibility of aluminium pick up, which may migrate from package to food/beverage. However, it is necessary to raise scientific data that will support any decision concerning the consumption of this kind of food, especially when the percentage of undernourished persons all over the world is considerable. Drawn and wall ironing–type aluminium cans with 330 ml of ready-to-drink grape juice, under three different controlled conditions of can damage as well as without damage, were evaluated for 1 year at 35°C. Aluminium migration, internal pressure and can internal surface appearance were periodically evaluated in order to monitor the package/beverage interaction. The results showed very small variation on the can internal surface appearance and pressure. Even after storage for 365 days, no can presented perforation, although the aluminium migration was increased. The highlight of this work is that after 1 year, for all the evaluated damage conditions, the ready-to-drink grape juice in aluminium cans could be considered adequate for human consumption in terms of metal migration from packaging. Copyright © 2013 John Wiley & Sons, Ltd.

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KEY WORDS: dented can; aluminium migration; corrosion; DWI aluminium cans; grape juice

INTRODUCTION

When cans are transported and distributed, they are subject to mechanical deformations. However, due to different factors such as their apparent high mechanical resistance and their design, which is not always suitable for stable stacking and handling at the sales outlet, aluminium cans are often submitted to abusive conditions that result in a high incidence of crushing.

Research institutions and health surveillance agencies[1] often point out the risk of drinking from crushed cans made of aluminium or steel, considering the possibility of lacquer peeling and the development of internal corrosion of the cans due to interaction with foodstuffs. Damage to the can body may lead to changes in the internal lacquer, whereas deformations at the seam region may result in corrosion development or leakage, and even in microbiological contamination of its content.

Waste reduction, hunger-fighting and environmental impact programmes stimulate the search for information on food safety. It is necessary to reinforce the main purpose of packaging, which is to protect and distribute products in good condition to consumers.[2] In Latin America, the losses in processing, packaging and distribution in food chains may affect 32% of fruits and vegetables,[3] which represent the major loss among different segments of food chains.

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The actual consequences of damage in metal packaging for foodstuffs should be assessed in more depth to check if deformation really affects the can contents, resulting in food inappropriate for human consumption.

Taking this into consideration, the purpose of this study was to verify the effect in the foodstuff–container interaction and to survey information on aluminium migration to food that originated from packaging. Thus, grape fruit juice was selected for this study because it is a favourable medium for the development of aluminium corrosion, such as acidity and other compounds. The development of internal oxidation was assessed in comparison to control cans to evaluate whether it was appropriate for human consumption.

METHODOLOGY

Material

Two-piece drawn and wall ironing (DWI)–type aluminium cans with 330 ml of ready-to-drink grape juice were assessed. They were submitted to three conditions of controlled damage to obtain three intensities of crushing, identified herein as I, F_1 and F_2, as described below.

Crushing conditions

Before carrying out this work, a survey was made as to the type and intensity of crushing in cans donated to some food banks located in São Paulo State, Brazil. Based on the data collected, three conditions of crushing were determined, as described below and illustrated in Figure 1, to represent the types of crushing commonly observed in the donated crushed cans.

- I: Impact to the double seam, made by a Pendulum Impact Tester (Agr International Inc., Butler, PA, USA). The impact tip corresponded to a steel device with a rectangular section measuring

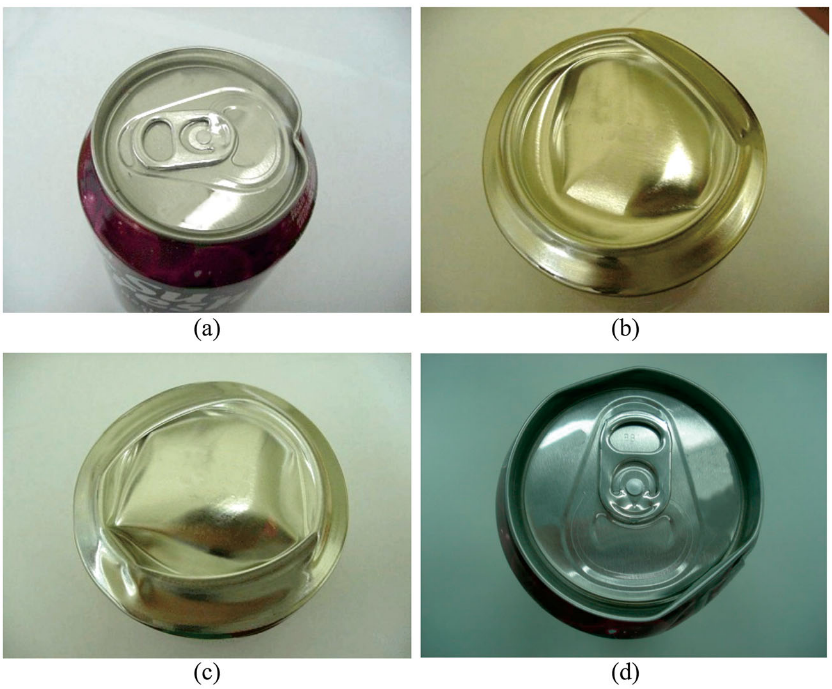

Figure 1. Photographs of the grape juice cans after impact: (a) I, (b) F_1 bottom, (c) F_2 bottom and (d) F_2 top.

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approximately 3.10^{-3} m × 5.10^{-3} m. The cans were arranged on the support surface, and an impact of 1.4 J energy was applied to the can double seam.

- F_1: An impact resulting from free fall of the can made with a free fall test instrument built by CETEA/ITAL, consisting of two movable platforms with an electro-pneumatic release system, with variation and millimetre indication of fall height and with a base of impact made of a steel plate. The cans were placed at an angle of 45° and a height of 1.80 m.
- F_2: Two impacts by free fall of the can made as described for condition F_1, but with the can positioned on the surface diametrically opposite the first one.

Cans that were not damaged, identified as ND, were used for comparison with the crushed ones.

After damaging the cans, crushing intensity was determined in five units of cans for each crushing condition with a dial indicator with a 10^{-5} m resolution (Mitutoyo America Corporation, Aurora, IL, USA). The greatest crushing was considered to be in cans with more than one crushed area.

Periodical Assessments

Dented and undented cans belonging to the same batch were stored at a temperature of 35°C ± 2°C. They were assessed, in terms of the parameters described below, at the start and after 45, 180 and 365 days of storage. All measurements were performed in five replicates.

Aluminium content in the beverage. The aluminium content (Al) was determined by taking a 10.0 ml sample of grape juice, which was acidified with 1 ml of concentrated hydrochloric acid reagent grade in a 50 ml volumetric flask. The mix was stirred for 3 h in an orbital stirrer, and then the volume was topped up with distilled water.[4]

After the treatment, the aluminium content was quantified by plasma-induced atomic emission spectrometry with an optical detector – ICP OES, using a Perkin Elmer instrument, model OPTIMA 2000DV (PerkinElmer, Waltham, MA, USA), using an appropriate calibration curve for analysis. The operating conditions and instrument parameters of ICP OES listed in Table 1 were used.

Visual assessment. The inner surface of the cans (top, body and bottom) was visually assessed to ascertain changes to the metal sheet over the course of the period of storage. Oxidation intensity was rated by comparison to the G-scale of standard ASTM D 610 (2008).[5]

Determining the internal pressure. The internal pressure was determined with Ashcroft vacuum pressure meter (Ashcroft Inc., Stratford, CT, USA), with a 0.01 psi resolution and a capacity range of 0 to 100 psi, after storing the cans at 23°C for at least 8 h.[6]

RESULTS AND DISCUSSION

Crushing Condition

The can crushing intensity of each crushing condition evaluated in this study is shown in Figure 1. This figure presents photographs of grape juice cans identified as I (a), F_1 (b) and F_2 (c, d) after being crushed, while Table 2 shows the results of the determination of deformation intensity under the three crushing conditions applied to the cans.

Table 1. Operating parameters of ICP OES.

Wavelength (nm)	**Gas flow rate (l/min)**			**Sample aspiration**
Al	Plasma	Auxiliary	Gem cone nebulizer	Gas flow rate (ml/min)
396.153	15	0.2	0.55	1.5
Radiofrequency power	**Observation height**			**View**
1300 W	15 mm			Axial

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Table 2. Determination of deformation under each condition of can crushing, in % of the initial dimension reduction.

	Impact condition		
	I	F_1	F_2
Mean	5.9	6.5	14.7
Standard deviation	0.34	0.42	1.4
Minimum	5.2	5.9	11.9
Maximum	6.3	7.3	16.0

Impact condition I caused medium intensity deformation to the can top in the form of a crease, which may lead to the loss of the can's airtightness, whereas fall conditions F_1 and F_2 resulted in medium and intense damage, respectively, to the bottom of the can. Cans submitted to free fall also showed changes in the top. The deformation measurements indicated a similar condition in terms of intensity of crushing between samples I and F_1.

The Food Products Association[7] has guidelines to assess dented metal containers in which the mechanical damage can be rated as a critical, major or minor defect. The recommendation is that products in cans with critical defects should not be consumed. They should be disposed of. Cans with major defects should be segregated for critical assessment of their suitability for consumption. They may be sold under specific conditions, provided that they are identified as dented. Consumption of products in cans with minor defects has no restrictions.

Although the document mentioned above does not include cans of carbonated and alcoholic drinks (note that, on account of the similarity, this restriction must be extended to the product under study), when we compare the results of impact crushing obtained for the grape juice cans to the guidelines, we can observe that they could be rated as cans with major defects. Moreover, the damage to the top of the cans in fall condition F_1 is also similar to a condition of minor defect presented by the Food Products Association.[7]

It should be pointed out that preserving closing integrity should be taken into consideration so that the internal pressure of the can is not lost. Therefore, under the conditions to which the cans were exposed, no loss of package integrity was verified in this study.

Visual assessment of the inside of the cans

The visual assessment was conducted in accordance with the classification of surface alteration per standard ASTM D 610 (2008),[5] which presents a scale that ranges from 9-G to 1-G, where 1-G represents the worst state of surface alteration.

The degree of surface oxidation of the body, top and bottom of uncrushed cans was assessed at the start of the study, and it was also assessed for crushed and uncrushed cans after 45, 180 and 365 days at 35°C.

The visual assessment in the regions that did not have mechanical damage, such as in condition ND, was carried out to ascertain the surface alteration intrinsic to the normal product/packaging interaction of canned products.

It can be seen that the different regions and packaging presented the same level of performance, i.e. there was no significant alteration in the appearance of the internal surface over the period of 365 days at 35°C, with the mean overall classification of the cans remaining at 9-G in all evaluation periods, corresponding to up to 0.03% of the surface having some alteration. It should be noted that a largely uniform condition was observed between the units assessed for each condition of crushing.

Figure 2 illustrates the condition of the internal surface observed in the cans of grape juice after storage for a period of 365 days at 35°C.

Internal pressure

In the DWI-type can, by virtue of the low wall thickness resulting from the production process, when the product to be canned is not carbonated, the addition of liquid nitrogen is deliberately carried out in

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(a) (b) (c)

Figure 2. Example of the surface of cans of grape juice: (a) region with crushing but no alteration, (b) small perforation of the lacquer on the can's body in a region in the vicinity of the crushing, and (c) bottom with intense crushing but no alteration to the lacquer.

order to provide positive internal pressure, which results in the mechanical resistance improvement of the cans. It can be seen that conditions ND and I do not, in practice, alter the can's internal pressure in relation to the beginning of storage in the different periods assessed. However, under conditions F_1 and F_2, there was a reduction in internal pressure caused by the deformation arising from the crushing, observed from the variation in the value between the conditions with and without crushing (computed after 45 days of storage).

Changes in the internal pressure of the cans reveal that the structure of the packaging was altered, although there was no important variation in internal pressure, in either condition, throughout the storage in the periods assessed, demonstrating that there was no adverse effect on the packaging's airtightness.

Figure 3 shows the results of the computation of internal pressure in the cans of grape juice at the beginning of storage and after 45, 180 and 365 days of storage at 35°C.

Quantification of aluminium in the product

The grape juice revealed a small concentration of aluminium in the various impact conditions throughout the duration of the storage, as per the results shown in Figure 4, showing itself to be on average less than 2.5 mg/kg (ppm) in all cases. After 365 days in storage at 35°C, the product revealed an increase in the concentration of aluminium of 18%, 5% and 98% under conditions I, F_1 and F_2, respectively, when compared to the product in the can with no impact (ND). Mean and standard deviation of I, F_1, F_2 and ND samples are shown as follows: 1.45 mg/kg (±0.49 mg/kg), 1.29 mg/kg (±0.46 mg/kg), 2.44 mg/kg (±1.08 mg/kg) and 1.23 mg/kg (±0.47 mg/kg). Fall condition F_2 proved to be far more aggressive than F_1.

As Brazilian legislation[8,9] does not establish a maximum limit for the concentration of aluminium in food and beverages, the content of this element in the grape juice does not infer that it no longer has a

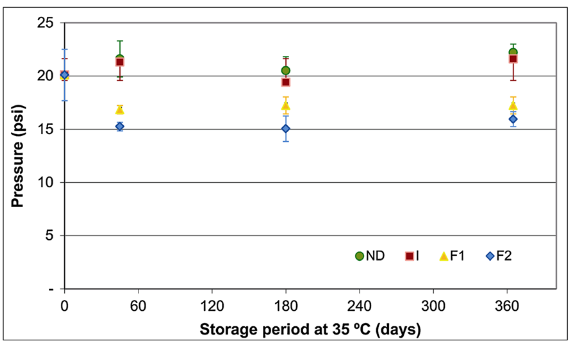

Figure 3. Internal pressure inside cans of grape juice over the course of 365 days of storage at 35°C under the different impact conditions: no damage (ND), impact I, fall condition F_1, and fall condition F_2.

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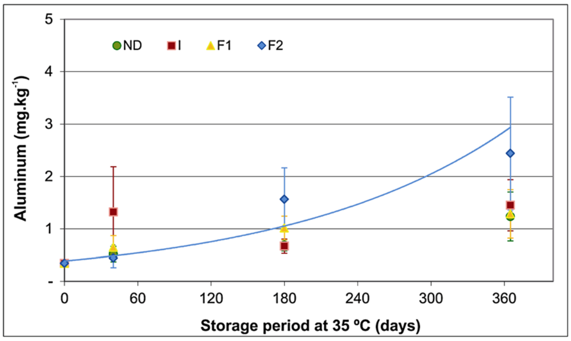

Figure 4. Concentration of aluminium in the canned grape juice with no damage to the packaging and submitted to different impact conditions during a storage period of 365 days at 35°C: ND – no damage, I – impact on the double seam, F_1 – fall condition 1, and F_2 – fall condition 2.

useful life, indicating that, in terms of metal contamination, the canned product that suffered the three types of damage could not be rejected for human consumption based on national law.

In industry in general, an average content of 2 mg/kg is adopted as the maximum limit for aluminium content in beverages, which is set at 4 mg/kg for individual cans. The values found in cans of grape juice that were submitted to different crushing conditions, except for the F_2 condition, even after remaining at a temperature of 35°C for 1 year, were lower than this limit, proving that the crushing did not result in a significant acceleration of aluminium dissolution. Nevertheless, for the F_2 damage condition, the mean value determined was less than 2.5 mg/kg, that is, superior to the industrial practice, although the upper value was 3.67 mg/kg, which means that it is below the maximum individual limit adopted by the industry.

Data on aluminium dissolution in beverages were obtained by Saron et al.,[10] who studied the interaction of carbonated drinks and aluminium cans for 6 months, determining the migration of this element to the beverage. These authors found mean values for aluminium content of less than 1 mg/kg, which is in accordance with values determined in the present study.

According to Lopez,[11] the average intake of aluminium corresponds to around 30 mg per day. According to the World Health Organization (WHO),[12] the daily aluminium intake in adults varies between countries, namely 1.9 to 2.4 mg in Australia, 3.9 mg in the UK, 6.7 mg in Finland and between 8 and 11 mg in Germany. In children aged between 5 and 8 years, this bibliographical reference quotes an intake of 0.8 mg per day in Germany and 6.5 mg per day in the USA. Similar data were presented in a separate WHO document.[13]

The natural concentration of aluminium in food is, generally speaking, low, at around 5 mg/kg, although certain additives do contain high concentrations of this element, thereby increasing the total amount in the processed product.[14] Vegetables and salads contain around 5 to 10 mg/kg, while some dehydrated condiments and tea leaves have aluminium content in the tens or even hundreds of ppm (mg/kg).[15]

In 1989, the FAO/WHO published a report, produced by the Expert Committee on Food Additives, recommending the establishment of a maximum limit for the provisional tolerable weekly intake (PTWI) of aluminium for humans, corresponding to 7 mg of aluminium per kilogram of body mass.[16] Recently, the WHO Expert Committee on Food Additives established a provisional tolerable weekly intake of 2 mg/kg body weight for aluminium.[17]

Assuming the maximum value determined in the canned grape juice studied at this work, which is 3.67 mg/kg for the content of aluminium in product stored for 1 year at a temperature of 35°C, at the worst crushing condition (fall condition F_2), and estimating an intake of one can (330 ml) of drink per day, we would obtain an aluminium intake of 1.21 mg per day. Considering an individual with a body mass of 60 kg, the aluminium migrated from the crushed can would represent 7% of the daily aluminium intake limit, taking the most recent limit[17] as a baseline (2 mg of Al per kg of body weight, per week).

Equation 1 was obtained from the regression of the data presented in Figure 4 for condition F2, representing the evolution of the most intense dissolution of aluminium in the grape juice. It is useful

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to estimate the aluminium content over the storage period and relate it to the maximum level of aluminium admissible in the product for human consumption. Based on the aluminium content results of the sample submitted to condition F2, an exponential equation was determined (regression is significant at the 95% confidence level).

$$\mathrm{Al}\ [\mathrm{mg/kg}] = 0.3873.e^{0.0055.t\ [\mathrm{days}]}\ \left(R^2 = 0.922\right) \tag{1}$$

Accordingly, 516 days (or 1 year and 7 months) will be the time estimated for aluminium migration to achieve the maximum admissible content, under the worst crushing condition (more intense damage), considering the product and packaging evaluated in this study. It means that, taking into account the metal migration, the product, at the end of the shelf life determined by the producer, will have an aluminium content lower than the PTWI estimate for an individual with a body mass of 60 kg. Thus, even if the date of occurrence is not known by the final consumer, it is not unsafe for use.

CONCLUSION

Cans of grape juice submitted to the three crushing conditions applied in this work and stored for 1 year at a temperature of 35°C, for the purposes of assessing the impact of mechanical damage on the increase in packaging–product interaction, did not reveal a loss in the packaging's airtightness. The denting did not result in any alteration to the internal surface, and the dissolution of aluminium was found to be low in all damage conditions. Assuming that the crushed cans were also kept for 1 year at a temperature of 35°C before the contents were consumed, the aluminium content present in the consumption of one can of grape juice would represent, for an individual with a body mass of 60 kg, 7% of the recommended daily intake limit. Although the consumer does not have the expertise to assess the can integrity and degree of crushing, food banks' staff can establish usage conditions for damaged cans prior to its distribution.

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