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Steel Packages 10 Years After Being Disposed as Litter in a Tropical Environment

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A study considering Brazilian environmental conditions was carried out aiming to obtaining the development of data on the metal packaging performance when discarded in different natural conditions instead of an adequate disposal. The behaviour of steel packages in four local tropical environments during the time of 10 years was studied: on the ground at an industrial site, on the seashore, buried in the ground and immersed in a riverbed. Four different kinds of steel cans were used (plain powdered milk and soybean oil three piece tinplate cans and lacquered soft drink DWI tinplate can and tomato sauce tinplate three-piece cans). Alternative packages containing the same products—PET bottles for soybean oil, DWI aluminium cans for soft drinks, laminated plastic bags for powdered milk and carton-based multilayer packaging for tomato sauce—were used as control. Annually, samples of all packages were removed from the studied sites and visually analysed. Powdered milk and soybean oil cans were completely degraded in the industrial and marine environments between 6 and 7 years. Tomato sauce can sample was totally degraded between 7 and 8 years in the industrial environment. However, although some important surface damage was observed, none of the studied types of steel cans was completely degraded in both conditions: buried in the ground and immersed in a riverbed during the 10 years of study. Alternative packaging showed smaller alteration than steel cans in the studied period and conditions. Copyright © 2015 John Wiley & Sons, Ltd.

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INTRODUCTION

Any solid waste that is indiscriminately disposed in the open can cause physical and biological environmental changes over time, therefore changing the landscape condition and adversely affecting existing ecosystems.[1,2]

A study by Troschinez and Mihelcic[3] focusing on recycling as a sustainable way of diverting the maximum fraction of solid urban waste to be disposed in landfills identified three main contributing elements that can influence the sustainable recycling in developing countries, including the waste collection and separation system, planned management of solid urban waste and the presence of a local market for the recycled material. It was also concluded that the type of solid urban waste management, sustainably performed, is collaborative, where all the sectors of a society and government should engage.

Langley *et al.*[4] carried out an extensive research in a specific region of the UK to identify the features of the packages that encouraged consumers to treat it as waste after product use, or segregate

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it for recycling. The established features and categories were materials, geometry, contents and information. In terms of materials, plastic and cardboard packing, along with thin plastic films, were the most frequently items found in litter bins; however, in some cases, glass or metal packages were also found in bins of compostable food products. It was also seen that even people who claimed that they recycled everything and in large quantities had some items in their general waste bins that they could have segregated for recycling. It was not clearly seen any special relation between the package shape and the possibility of larger containment of food waste. It terms of contents, it was seen that one of the key obstacles to recycling and one of the reasons for the item not to be recycled by recycling companies is the containment of waste that are repugnant, such as blood and mouldy food. The storage area of packages sent for recycling was often located away from the living room for reasons of hygiene, resulting in a proximity conflict between the bin of general waste from the kitchen and the bin for recycling. In terms of information, it is evident that people do not always understand the symbols used for recycling.

In general terms, the research showed that even in more developed regions, some of the materials that could be sent for recycling or energy recovery are sent to landfills.

Wever *et al.*[5] defined litter as things that, at the end of their useful life, are thrown away or left behind and end up being disposed in places that are not officially intended for this purpose, mixing with other things that are disposed in these places because of an indirect action or omission by consumers. These authors studied the influence of packaging design in the way people behave when they dispose their waste and litter, seeking to use packaging design as an additional tool for reducing litter. Four tests were performed, which showed that different design solutions lead to different behaviours towards waste. In tests where the package displayed anti-littering warnings, waste was effectively reduced. It was also seen that the peel-off type of lid are easily disposed as litter, therefore supporting the already known information about the tendency of disposing small things randomly (as litter), while screw caps are apparently considered to reseal the package after product use, although this does not mean that a sealed package cannot become litter. In one of the experiments, excerpts from proverbs were printed in candy wrappers, where the proverb would only be fully understood after the collection of all the excerpts, leading consumers to keep the wraps with them. Because these packages were not properly disposed along with the product that was used, they eventually became litter, unlike paper[6] without such proverbs, which were disposed in litter bins immediately after product use. In another study, it was shown that packaging of a premium brand can be treated differently than a non-branded product, with a higher probability of appropriate destination.

The management of solid urban waste in many developing countries, including Brazil, continues to show below optimal conditions, because much of the collected waste is inappropriately disposed, with a portion not being collected at all. According to data collected by ABRELPE[6] in 2013, 58.26% of solid urban waste collected in Brazil (90.4% of SUW generated) were sent to landfills (110,232 tons/day), while 41.74% (78,987 tons/day) were sent to controlled landfills or disposed in open dump sites. The portion that is not collected is disposed indiscriminately in the open.

Despite provisions of Federal Law 12305/2010, which instituted the National Solid Waste Policy (PNRS) and established August 2, 2014 as the deadline for the environmentally appropriate disposal of waste and rejects to be implemented in the country, solid waste management in Brazil is still

Table 1. Soybean oil cans.

			Organic Coating	
Can[(1)]	Component	Material	Internal	External
Cylindrical (900 ml)	body	Tinplate – E2,0/2,0	absent	Printing ink + Finishing Lacquer
	top/bottom	Tinplate – D2,0/1,0	absent	High solids sanitary (food grade lacquer)
Cylindrical (900 ml)	body	Tinplate – E2,0/2,0	absent	White enamel + Printing ink + Finishing Lacquer
	top[(2)]/bottom	Tinplate – D2,0/1,0	absent	High solids sanitary (food grade lacquer)

[1]Two commercial type trademark cans were used, with different design printing.
[2]Conventional tops, opened with a home type opener.

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Table 2. Milk powdered cans.

Can[1]	Component	Material	Organic Coating	
			Internal	External
Not labelled (diameter 99 mm and height 122 mm)	body	Tinplate – E2,8/2,8	Absent	Absent
	bottom and ring	Tinplate – D2,8/5,6	Absent	Absent

[1]Three piece cans without the aluminium membrane and fitted top.

insufficient and with a need for adequacy, which deadline was extended by up to 6 years, according to the number of people living in a city.

In general, what is seen is that even in developed countries, for different reasons, recyclable materials are thrown in the open, losing their characteristics by the environmental action and causing other types of issues.

In 2012, according to CEMPRE,[7] a total of 47% of steel packaging consumed was recycled in Brazil, although the country already had installed capacity to absorb 100% of this form of scrap. Around 300 000 tons of post-consumption steel cans were returned for the process of recycling in the country. This rate has been rising thanks to the expansion of the programmes of selective waste collection, environmental education and the trend towards significant growth following the implementation of the National Solid Waste Policy, forecast for 2014. The difficulties, however, lie in the structuring of the recycling chain because of various factors affecting the return of this packaging for a new cycle of production, such as the low rate of selective collection or collection on an economically appropriate scale and low prices in comparison with other materials. Moreover, the logistics of this process, which is fundamental, is a challenge as a result of the geographical dimension of the country and the various social, cultural, political and economic differences, where the regional profiles, in terms of waste generation and management, are still quite trenchant.

When steel packaging is incorrectly disposed of in the environment, its metal constituents present significant potential for degradation, reverting to the chemical forms in which they are to be found in nature, though not in the original conditions, as they cannot be reused as if they had just come out of the mines. This ultimately represents a dissipation of natural resources. Furthermore, it is necessary to understand the environmental impact of the indiscriminate release of the other components of the packaging, besides the metals. However, the timeframes for these reactions are not well quantified. The information published by the media is contradictory and without scientific vindication. Bromander[8] conducted a study in Norway with the aim of surveying the degradation time of this form of packaging when disposed into the environment; however, the climatic conditions of that country are very specific and completely different from those to be found in a tropical country like Brazil.

By taking into account the Brazilian reality and the lack of reliable scientific information about the performance of steel packaging and other materials when disposed in the environment, CSN, the

Table 3. Tomato product cans.

Can	Component	Material	Organic Coating	
			Internal	External
Tomato sauce (340 g)	body	Tinplate – D2,8/2,0	Epoxi-urea lacquer + White epoxi enamel	Polyester enamel + Printing ink + Ester-epoxi lacquer
	top[1]	Tin free steel – 60/60	Organosol lacquer with aluminium	Printing ink + Epoxi-phenolic lacquer
	bottom	Tin free steel – 60/60	Epoxi-urea lacquer + White epoxi enamel	Epoxi-phenolic lacquer
Tomato paste (350 g)	body	Tinplate[2]	Present [2]	Present [2]
	top[3]/bottom	Tin free steel – 60/60	Present [2]	Present [2]

[1]Easy-open top.
[2]Parameters not informed by packaging manufacturer.
[3]Conventional top opened with a home type opener.

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Table 4. Two piece steel cans (Draw and Wall Ironing – DWI).

			Organic Coating	
Can	Component	Material	Internal	External
Soft drink (350 ml)	Body	Tinplate - D3,0/2,0[(1)]	Modified epoxi lacquer	White enamel + Printing ink -polyester
	Bottom	Tinplate - D3,0/2,0	Modified epoxi lacquer	Lacquer: acrylic –epoxi
	Top[(2)]	Aluminium	Epoxi lacquer	Lacquer: amine-epoxi

[1]After stretching, the tin coating is reduced to about 25% of initial value.
[2]Aluminium ends, stay on tabs opened.

national tinplate and chromium plate producer, in conjunction with CETEA Packaging Technology Centre, conducted a study in order to gather information on the average degradation time of several types of packaging under specific, tropical environmental conditions. In addition to steel cans, a number of packages produced from other materials were placed in the same experimental fields, to be used as benchmarks. The packaging was left in the experimental fields from 2002 to 2012.[9–11]

Riverbed, marine and industrial environments and the soil were the experimental fields. This paper presents the results obtained after 10 years of exposure of the samples in the various environments. This approach did not include an investigation into the effect of the degraded material on the environment, which should be the focus of consideration in future studies.

MATERIALS AND METHODOLOGY

Materials

The following items of steel packaging were analysed:

- Steel can for packing of powdered milk, unused, without its fitted lid and with a non-varnished material
- Steel can for packing soft drinks, unused, closed with stay on tab easy-open end
- Steel can for packing tomato products (purée or sauce), unused, with seamed lid opened, tomato sauce with easy-open lid and tomato purée with a conventional lid opened using a household can opener
- Steel can for packing soybean oil, unused, with seamed lid opened with a household can opener

Tables 1, 2, 3 and 4 describe the steel packaging studied, according to information from the manufacturers.

In addition to the steel cans, some packages manufactured from other materials were placed in the same experimental fields to be used as a benchmark, namely,

- Laminated plastic bag for 400 g modified powdered milk, used, empty and unwashed.
- Carton packaging for 520 g tomato paste, used, empty and unwashed.
- PET bottle for 900 ml soybean oil, used, empty and unwashed.
- Two-piece aluminium cans, for packing 350 ml soft drinks, used, empty and unwashed.

(a) (b) (c) (d)

Figure 1. Steel packaging used in the study, before being exposed in the monitoring fields (reference samples): (a) soybean oil cans, (b) milk powdered cans, (c) tomato product cans and (d) soft drink DWI steel cans.

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Figure 2. Packaging used in the study, produced with other materials, before being exposed in the monitoring fields (reference samples): (a) PET bottle for soy oil, (b) laminated plastic bag for milk powdered, (c) carton packaging for tomato paste, (d) DWI aluminium can for soft drinks.

The steel packaging used in the study is exemplified in the photos presented in Figure 1, and the other packages produced from different materials are presented in Figure 2.

Monitored fields and methodology for exposure of samples

Soil—The soil around the CSN research centre in Volta Redonda, Rio de Janeiro, Brazil, was used and the arrangement of the samples followed the procedure described later, illustrated in Figure 3.

1. preparation of 45 pits, sufficiently deep to accommodate 45 plastic basins (36 basins, 25 l capacity, and 9 rectangular, 56 l containers);
2. perforations on the sides and bottoms of the 36 basins and 9 rectangular containers;
3. numbering the basins and rectangular containers and filling then with a layer of earth, installing them in the pits;
4. placing the test packaging in the 45 plastic containers, according to the following distribution: 9 basins, containing 5 milk powdered cans and 1 laminated milk powder bag; 9 basins containing 5 tomato product cans and 1 tomato product carton packaging; 9 basins containing 5 two-piece steel cans; 9 rectangular containers containing 5 soybean oil cans and 1 soybean oil PET; 9 basins containing 5 two piece aluminium cans;
5. all 45 plastic containers were completely filled with earth after being installed in the pits.

Open-air industrial environment–experimental station located at the ‘Presidente Vargas’ plant close to the coke production unit in Volta Redonda, Rio de Janeiro, Brazil

Sample arrangement was made in a system of 7 modules, using plastic covered wires, whose ends were fixed in the soil of an experimental station located inside the ‘Presidente Vargas’ mill, next to the coke production unit (Figure 4).

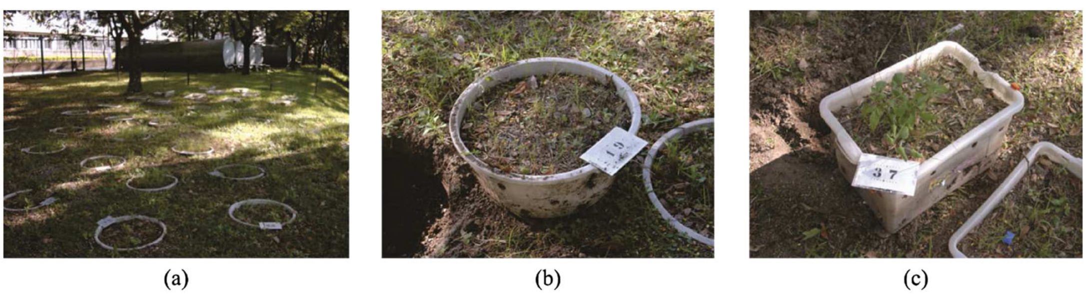

Figure 3. Sample arrangement of the packaging for the study on degradation buried in the soil: (a) partial view of the basins and containers installed inside the excavated pits, (b) basin and (c) container, both with perforated walls and bottom containing the packaging after unearthed.

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(a) (b)

Figure 4. Samples exposed in an industrial environment (CSN coke oven): a) view of the corrosion station and b) module containing the various packaging.

Each module comprised

1. 5 cans and 1 PET bottle for soybean oil;
2. 5 cans and 1 laminated bag for milk powdered;
3. 5 cans and 1 carton package for tomato products;
4. 5 two piece steel cans for soft drink;
5. 5 two piece aluminium cans for soft drink.

Open-air marine environment – experimental station located at the Restinga da Marambaia beach in Rio de Janeiro, Brazil.

The samples were mounted in the same arrangement described for the industrial environment, and the modules were fixed to the soil at an experimental station located in Marambaia Beach, West district of the city of Rio de Janeiro (Figure 5).

Riverbed – experimental station (floating boathouse) built on the Paraíba do Sul River, where it cuts across the property of the 'Presidente Vargas' plant in Volta Redonda, Rio de Janeiro, Brazil

A floating boat garage was built on the Paraíba do Sul river, where it crosses the 'Presidente Vargas' mill property. Sample arrangement followed the procedure described later:

1. perforate the side walls, bottoms and tops of 35 rectangular plastic containers, 28 l capacity;
2. mount 7 modules, 5 containers each. This mounting involved the use of PVC pipes to support the containers;

(a) (b)

Figure 5. Samples exposed to a marine environment (Marambaia Beach – *Restinga de Marambaia* - RJ): a) modules containing the various packaging and b) view of the corrosion station, showing details of the device to monitor atmospheric chloride.

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Figure 6. Samples exposed in the riverbed: (a) modules of 5 containers accommodating the different types of packaging and (b) modules after removal from Paraíba do Sul river.

3. place the test packaging in each one of the 5 plastic containers in each module;
4. complete the module tying system to the PVC supports, using plastic-coated wires;
5. immerse the modules inside the floating garage, at about 1 m depth. Welded steel rods held the modules to the two floating platforms.

Each module had 5 containers:

1. containers in the soybean oil series: 5 cans and 1 PET bottle;
2. containers in the milk powdered packaging series: 5 cans and 1 laminated bag;
3. containers in the tomato product series: 5 cans and 1 tomato product carton package;
4. containers in the 2 part steel can series: 5 two-piece steel cans;
5. containers in the 2 part aluminium can series: two-piece aluminium 5 cans.

Figure 6 shows photos of the arrangement of samples and the system used to immerse them in the riverbed.

Description of the parameters monitored in each testing environment

For each testing environment, some parameters were selected for analysis, to physically and chemically characterize the conditions to which the samples would be exposed. These parameters are described later:

1. Soil: organic matter, pH, phosphorus, potassium, calcium, magnesium, sulfur, electrical conductivity and chlorides. These analyses were made only once, in the beginning of the study;
2. Open air, industrial environment: temperature, relative humidity, rain fall, total particles in suspension and sulfur dioxide (monthly monitoring), solar radiation and nitrogen dioxide;
3. Open air, marine environment: temperature, relative humidity, rain fall and chlorides (monthly monitoring);
4. River water: temperature, magnesium, calcium, chemical oxygen demand (DQO), total alkalinity, electrical conductivity, pH and chlorides (monthly monitoring).

Table 5. Characteristic parameters of the soil in the CSN Research Centre.

Parameter	Value measured
Organic matter	32 g/dm^3
pH	6.8
Phosphorus	61 mg/dm^3
Potassium	2.5 mmol/dm^3
Calcium	118 mmol/dm^3
Magnesium	22 mmol/dm^3
Sulfur	9 mg/dm^3
Electrical condutivity	170 μS/cm
Chloride	18.5 mg/dm^3

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Table 6. Parameters obtained while monitoring the air in the industrial environment during the 10 year exposition of the samples.

Parameter	General Mean	Monthly Minimum Mean	Monthly Maximum Mean
Temperature (C)[(1)]	22.7	14.8	27.8
Relative Humidity[(2)]	77.8	61.0	93.0
Sulfur Dioxide ($\mu g/m^3$)[(3)]	11.9	1.9	58.1
Nitrogen Dioxide ($\mu g/m^3$)[(4)]	18.9	5.6	36.2
Total particles in suspension ($\mu g/m^3$)[(5)]	55.8	32.5	85.7
Solar Radiation (W/m^2)[(6)]	164.9	69.1	268.6
Rainfall Accumulated Monthly (mm)[(7)]	121.8	0.5	482.6

[1]Results of 102 determinations
[2]Results of 96 determinations
[3]Results of 98 determinations
[4]Results of 106 determinations
[5]Results of 109 determinations
[6]Results of 73 determinations
[7]Results of 91 determinations

RESULTS AND DISCUSSION

Soil analysis was performed in the beginning of the study, and the results are described in Table 5:

Table 6 presents the results obtained by monthly monitoring of the characteristic parameters of the air in the industrial environment where the packaging were exposed for the 10 years.

Table 7 presents the atmospheric parameters monitored on the Marambaia Beach, RJ (*Restinga da Marambaia*) during the 7 years the samples were exposed.

Table 8 presents the characteristic parameter values of the Paraíba do Sul River water where the samples were exposed, obtained by monthly sampling and analysis.

Figures 7 to 10 display photographs illustrating the evolution of the degradation of cans buried in the soil and placed on the riverbed, in an industrial and in a marine environment, respectively, for a period of 10 years.

According to the photographs in Figure 7, an evolution can be seen in the degradation of the powdered milk cans buried in the soil, although they did not end up fully integrating into the environment in which they were enveloped. Ten years after placement, fragments were recovered of the body and/or base and the seaming with part of the material from the body and the base; one of the cans still preserved the body attached to the base. An evolution of the degradation was also observed with these cans when placed on the riverbed. However, after 10 years, one of the cans exhibited the base and approximately ¾ of the body still attached, although of the other cans, only fragments of seaming and the body/base had been located. In the industrial and marine environments, the evolution of the degradation of these cans occurred more quickly when compared with the cans placed in the soil and in the river, since 6 years after placement, only scattered fragments could be found in the areas where they had been placed.

Observing the photographs in Figure 8, it was found that the evolution of the degradation of the cans of tomato products, when placed in the soil, is the slowest of the four environments studied, followed

Table 7. Parameters obtained by monitoring the marine air during the 10 years the samples were exposed.

Parameter	Mean	Minimum Value	Maximum Value
Temperature (C)[(1)]	23.0	19.6	27.6
Relative Humidity (%)[(2)]	82.0	70.0	94.1
Chlorides (mg/m^2/dia)[(4)]	141.9	45.7	264.1
Rainfall Accumulated Monthly (mm)[(3)]	88.2	1.4	472.4

[1]Results of 80 determinations
[2]Results of 64 determinations
[3]Results of 79 determinations
[4]Results of 52 determinations

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Table 8. Parameters obtained by monitoring Paraíba do Sul River water for the 10 years the samples were exposed.

Parameter	Mean in the study period	Annual Minimum Mean	Annual Maximum Mean
Magnesium (ppm)$^{(1)}$	1.07	0.75	1.24
Chemical oxygen demand - DQO (mg/l)$^{(2)}$	11.83	7.54	17.67
pH$^{(3)}$	6.70	6.23	6.89
Electrical Conductivity (μS/cm)$^{(3)}$	82.22	66.63	99.95
Total Alkalinity (% $CaCO_3$)$^{(3)}$	0.01	0.00	0.05
Chlorides (ppm)$^{(3)}$	6.31	4.64	7.58
Temperature (C)$^{(4)}$	22.95	22.10	23.69
Organic Matter$^{(5)}$	3.56	2.49	4.89

[1]Results of 73 determinations
[2]Results of 72determinations
[3]Results of 78 determinations
[4]Results of 77 determinations
[5]Results of 58 determinations

by cans placed on the riverbed, the industrial environment and the marine environment. Ten years after placement, the cans of tomato products placed in the soil had slightly discoloured outer printing and were without their lids; they had corrosion on the seams, the welds, the body and the base, both outside and inside, as well as dirt stuck to them; however, none of the welds was completely opened; all the cans placed in the river had corrosion on the body and the base, and two of them had the side seam ruptured because of corrosion; one of the cans still had its lid attached to the body, but there was no base, which was separated from the body of the can. It was also noted that, on two of the lids that were loose, the centre had come apart from the remainder of the material; fragments of the cans of tomato products placed in industrial and marine environments were found, and it was still possible to observe the outer printing, after 7 years.

Observing Figure 9, after 10 years, it was found that all the units of cans of oil buried in the soil still had their base while two units had the lid attached to the body. It was possible to identify too the outer printing on the cans, although the corrosion was quite intensive and the body was already missing some parts. Two of the cans placed on the riverbed still had larger parts of the body intact, while only fragments of the other cans could be found. As for the cans placed in marine and industrial environments, after 6 years only fragments could be found spread out across the adjacent areas, but it was possible to identify two fragments of seam attached to the parts at the base of the cans of oil in the industrial environment; after 7 years, these fragments could no longer be located.

Observing Figure 10, after 10 years, it was found that 5 cans placed in the soil showed external printing with little discoloration and all the lids still had their hatches, although without the easy-open ring-pull tab. There were areas with corrosion over the entire body and less intensive corrosion on the base, mainly in the area of the dome. The module with 5 units of DWI steel cans had already been removed from the soil during a previous collection, as one of the cans was open. Intensive corrosion was observed in the open can as well as perforations in the body; the incidence of corrosion was also found on the base and the lid. All of the cans placed in the river still had their aluminium lid hatches and, on two of them, the base was separated from the body as a result of the intensive corrosion, while on another unit only a part of the body remained maintaining the join with the base, and the corrosion was less intensive in the other two units. The cans placed in the industrial environment were heavily oxidized, with lid and base separated, and both were still attached to the small part of the body. No body fragments were found in the experimental field after 10 years. In the marine environment, after 7 years, the cans had fragmented bases and bodies, and it was not possible to identify any printing. Some fragments were scattered in the soil. The aluminium lids exhibited some rust stains and still had their flaps.

Observing the photographs in Figure 11, it was found that

1. After being buried in the soil for 10 years, the plastic bag for the powdered milk remained intact (Figure 11a); the module with 5 units of DWI aluminium cans (Figure 11b) had already been removed from the soil at the time of a previous collection, so one of the cans was open, the outer

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Figure 7. Powdered milk cans: (a–c) covered with soil, (d–f) immersed in the river, (g–i) discarded in the open air, in an industrial environment and (j–l) discarded in open air, in a marine environment.

Figure 8. Tomato product cans: (a–c) covered with soil, (d–f) immersed in the river, (g–i) discarded in the open air, in an industrial environment and (j–l) discarded in open air, in a marine environment.

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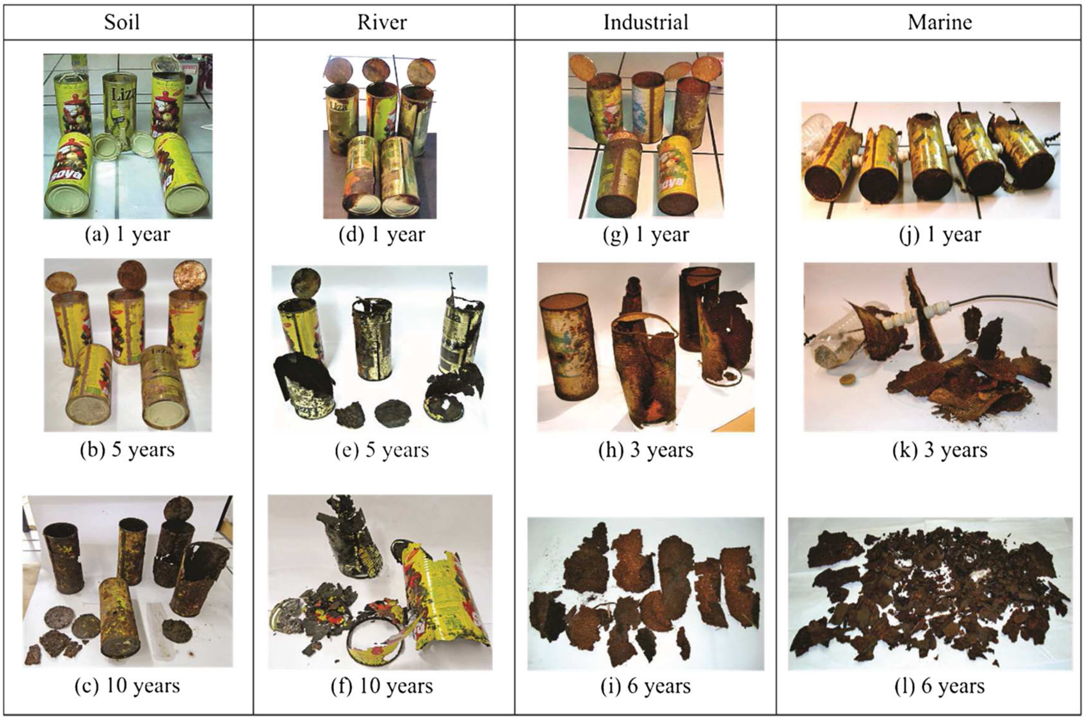

Figure 9. Soybean oil cans: (a–c) covered with soil, (d–f) immersed in the river, (g–i) discarded in the open air, in an industrial environment and (j–l) discarded in open air, in a marine environment.

Figure 10. Steel DWI cans for soft drinks, (a–c) covered with soil, (d–f) immersed in the river, (g–i) discarded in the open air, in an industrial environment and (j–l) discarded in open air, in a marine environment.

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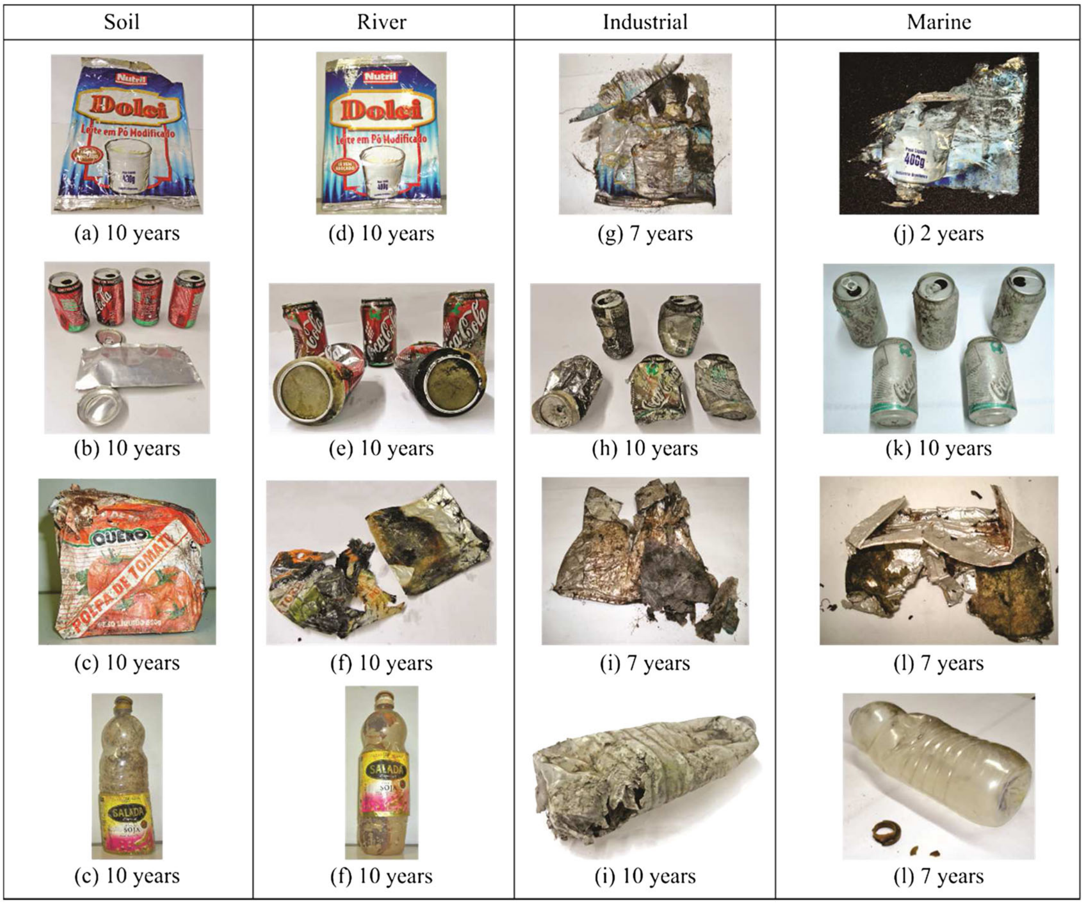

Figure 11. Packages produced with other materials: (a–d) covered with soil, (e–h) immersed in the river, (i–l) discarded in the open air, in an industrial environment and (m–p) discarded in open air, in a marine environment.

printing was a little discoloured and three of the lids still had their flaps, although without the easy-open ring-pull tab. The external part of all the cans had some form of stain on the body, lid and base, and heavy staining was noted on the base with the occurrence of surface corrosion, but without perforation. Inside the open can, small regions were found with the incidence of corrosion spread out over the body, lid and base, but without perforation. The carton packaging of the tomato pulp (Figure 11c) exhibited delamination with exposure of the aluminium in some areas, intense discoloration; however, the three materials (paperboard, aluminium and polyethylene) were preserved for the most part. The PET packaging for the soybean oil (Figure 11d) was intact, with cap, although the label had become separated;

2. After being placed on the riverbed for 10 years, it can be seen that the plastic bag for powdered milk remained intact (Figure 11e). The printing on the aluminium cans showed little discoloration, although did have some corrosion and a presence of dark blotches all over; inside the body of the open can, there were areas with corrosion and perforation, as well as some points with corrosion at the base: all lids still had their flaps (Figure 11f). The carton packaging for tomato pulp (Figure 11g) had its plastic material separated from the structure of cellulose material with aluminium, and there was no discoloration of the printing on the cap or the label on the PET bottle (Figure 11h); both were stained but intact.
3. Seven years after being placed in the industrial environment, it can be seen that, as regards the laminated bag for powdered milk, only fragments of the plastic layer remained, practically without any metal coating and with the printing discoloured (Figure 11i). The aluminium cans had discoloured outer printing and corrosion over the whole surface, and perforations, but all the

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parts were still connected, 10 years after placement in this environment (Figure 11j). The remaining portion of the carton packaging for tomato pulp was composed of a plastic and aluminium material and did not exhibit any printing nor did it have its layer of cellulose material after 7 years (Figure 11k) and the PET bottle for soybean oil (Figure 11l) was without its cap and label and, in addition, had parts of its base and body missing, after 10 years.

4. The photograph displayed in Figure 11m is of the plastic bag for powdered milk, 2 years after being placed in the marine environment. After this period, only fragments of this packaging could be located, and they were not photographed. After 7 years, the printing on the aluminium cans was somewhat discoloured, two units still had their easy-open ring-pull tab and all the lids still had their flaps. The outer surfaces of the cans were very rough, probably as a result of generalized corrosion. Inside the open can, there was some corrosion on the lid and the base, but it was mostly found on the body; however, no perforations could be observed (Figure 11n). After 7 years, the carton packaging found, still presented fragments of paper, the majority being made up of aluminium foil and plastic already with delamination (Figure 11o), and the PET bottle for soybean oil did not have its label, and the cap was found in the vicinity (Figure 11p). It should be pointed out that the marine environment was decommissioned after this sample collection (after 7 years of exposure).

Table 9 shows a summary of the estimated degradation time of the steel packaging placed in the 4 experimental fields studied over a period of up to 10 years.

CONCLUSIONS

Considering as the criterion for the determination of packaging degradation time the impossibility to distinguish the fragments found in the experimental fields, by virtue of their appearance, after until 10 years of exposure to the different environments, it was found that the time required for corrosion to develop in steel containers that are indiscriminately disposed in the open in order to be considered fully degraded, depends on the environmental conditions to which they are exposed, the type of can used and the organic coating system used, where the shortest time is estimated to range between 6 and 7 years for milk powdered and soybean oil cans to degrade when they are disposed in marine

Table 9. Estimate of degradation time (years) of packaging placed in 4 experimental fields studied over a 10 year period.[11]

Estimate of degradation time (years)				
Packaging	Experimental field			
	Marine(1)	Industrial(2)	Riverbed(3)	Soil(3)
Steel can for powdered milk	6 < t < 7	6 < t < 7	>10	>10
Steel can for tomato products	>7	< t < 8	>10	>10
DWI steel can for soft drink	>7	>10	>10	>10
DWI aluminium can for soft drink	>7	>10	>10	>10
Steel can for soybean oil	6 < t < 7	6 < t < 7	>10	>10
PET bottle for soybean oil	>7	>10	>10	>10
Carton packaging for tomato products	>7	>7	>10	>10
Laminated plastic bag for powdered milk	>6	>7	>10	>10

(1) The marine environment was deactivated after the seventh evaluation as it was not possible to estimate the degradation time of the DWI steel and aluminium cans and the tomato products cans. Of the cans of tomato products, several fragments still remained with a part of the outer printing still visible, enabling us to make the assumption that the degradation time of this packaging was no greater than 7 years. Around 1/3 of the carton packaging was also removed, still with fragments of paper, the majority being represented by the aluminium foil and plastic already with delamination. The PET bottle for soybean oil was without its label and its cap and did not demonstrate any significant alteration. The cap was found in the vicinity. The plastic bag for powdered milk was not located;

(2) At the time of the seventh evaluation, pieces related to the aluminium foil and plastic film of the carton packaging were found and the bag for powdered milk showed intense delamination, some parts were missing and there was also discoloring; both sets of packaging were removed from the experimental station. After 10 years, the DWI aluminium cans, a part of the DWI steel cans and the PET bottle still remained.

(3) On the riverbed and in the soil, none of the packaging had fully degraded over the period of 10 years.

and industrial environments. None of the cans buried in the ground or submerged in a river bed were completely degraded after a period of up to 10 years of exposure.

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