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Environmental Impact on Biodegradation Speed and Biodegradability of Polyethylene and *Zea Mays* Starch Blends

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ABSTRACT
Several studies projected that by year 2025, 4.3 billion urban residents will be generating about 2.2 billion tonnes of municipal solid waste per year, over 10% of which will be plastics. The landfills in Nigeria are uncontrolled and do not conform to the international standards of similar operations elsewhere in the world; this makes the disposal of synthetic polymers in the soil even more hazardous. Due to the availability and relative inexpensiveness of *Zea mays* in Nigeria, this study explores the use of this natural polymer, blended with low density polyethylene (LDPE) as an alternative to synthetic plastics. Biodegradability of the biopolymer blend was observed while buried in loamy sand soil with properties similar to the soil found in the general area of the study. The results showed that a polymer blend with 50% LDPE (50 CoS) by weight had the most uniform weight loss over the period of the study. Under the soil conditions given in the study, 50 CoS also had the steadiest rate of degradation. Hence 50% LDPE (wt.%) blended with *Zea mays* starch is the optimal ratio with regard to the degradability of biopolymer in loamy sand soil Ota, Ogun State, Nigeria.

Keywords: biodegradable; biodegradation rate; biopolymer; loamy sand; *Zea mays*

INTRODUCTION

In 2002, there were 2.9 billion urban residents who generated about 0.64 kg of municipal solid waste (MSW) per person per day (0.68 billion tonnes per year). Ten years after, the statistics show an increase to about 3 billion residents generating 1.2 kg per person per day (1.3 billion tonnes per year). It is estimated that by 2025, there will be about 4.3 billion urban residents generating about 1.42 kg/capita/day of MSW (2.2 billion tonnes per year) according to Hoornweg and Bhada-Tata (2012). Currently, over 10 percent (10%) by weight of municipal garbage content in the world are plastics (D'Alessandro, 2014).

Recently, plastics have been in the public eye for potentially dangerous human exposure to such toxic components as bisphenol A(BPA) and di-(2-ethylhexyl) phthalate (DEHP) as stated by Halden (2010) and Gilpin *et al* (2003). As a result, an effort is currently being made to reduce to barest minimum (or even phase out), the presence of these toxic components from plastics by exploring biodegradable options for plastic packaging, opportunities for reducing plastic waste, and recycling in the quest to reap maximum benefits from polymers without compromising the human health or the environment in the process (North and Halden, 2013; Westblad *et al.*, 2002; Gregory, 2009).

Research has shown that plastics make up the second highest percentage by weight (18%) of the MSW composition in Nigeria after organic waste (57%). Paper makes up 11%, glass 5%, metal 5% and others (textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other

inert materials) 4%. There are four major options for the disposal of plastics: landfilling, incineration, recycling, and biodegradation (Hoornweg and Bhada-Tata, 2012).

All plastics can be disposed of in landfills or incinerated. However, landfills require space. Moreover, the chemical constituents and energy contained in plastic materials is typically lost in this disposal route (Hopewell *et al*, 2009). In Nigeria, landfills are uncontrolled and do not conform to international standards of similar operations elsewhere in the world (Olorunfemi, 2011).

Several researchers have studied MSW collection and management crisis in Nigerian cities. The majority of this literature revealed the basis for high waste generation, inefficient waste collection and management in urban areas (Agwu, 2012; Igbinomwanhia and Ohwovoriole, 2012; Kayode and Omole, 2011; Ofuani, 2011). Some of the challenges facing waste management in Nigeria have been attributed to lack of awareness, poor public enlightenment, inappropriate technology, education and poverty, among others (Olorunfemi, 2011; Achi *et al*, 2012; Momoh and Oladebeye, 2010).

This study shows that *Zea mays* starch, which is a relatively cheap and easy to obtain natural polymer, could be blended with synthetic polymer to enhance degradation. In the event of the disposal of this biopolymer blend in the earth, this study also examines the impact of the soil kind present in the southwestern region of Nigeria (particularly Ogun State) on the biodegradability and rate of biodegradation of *Zea mays* starch biopolymer blend. Maize is the second most cultivated crop in Nigeria in terms of area harvested (over 5.8 million Ha, second to Cassava with 7.1 million Ha). Nigeria is the second largest maize producer in Africa, after South Africa, with an estimated 10.79 million MT produced in 2014 (Liverpool-Tasie *et al.*, 2017; FAO, 2017; Lamidi, 2013).

Several researchers (Mostafa *et al.*, 2018; Cho *et al.*, 2011; Makhtar *et al.*, 2013) have carried out studies on production and analysis of biodegradable polymers as well as their impact on the environment. Plastics are typically organic polymers of high molecular mass, most commonly derived from petrochemicals, thus making them synthetic (Andrej, 2012). Conversely, a range of variants are made from renewable stock such as polylactic acid from corn or *Cellulosics* from cotton linters (Mostafa *et al.*, 2018; Axel, 2009). People have been utilizing naturally derived plastics for far longer than one might envision. For instance, medieval artisans made lantern windows from translucent slices of animal horn, which is composed of keratin – a blended carbon-nitrogen polymer – a similar material that skin and hair, as well as fleece, is made of (Norbert, 1968).

In this research, polymer blend samples from LDPE and *Zea mays* starch were produced at different compositions and their biodegradation ratio and rate were analysed in sandy loam soil in Ota, Ogun State, Nigeria, over the period of 28 days in order to determine the effect of the soil on the biodegradation properties of the blends.

METHODS

Materials and apparatus

About 12kg of Low-Density Polyethylene (LDPE) was sourced for this research. The starch used in this project was made from *Zea mays*. Glycerol was used as the plasticizer. Other materials used included distilled water, paper tape and thread. The utilized cleaning materials included iron sponges and detergent.

The apparatus used for the study comprised; a crucible furnace, stirrer, the OHAUS digital weighing scale (Model PA214), stainless steel wire mesh sieves (Ø 0.08 mm/80 μm and Ø 0.2 mm/200 μm), Winkworth Z Blade Sigma industrial blender, beakers, plastic bottles, cutter, trays and aluminium foil sheets.

Soil analysis

A soil sample from the study area was taken at a depth of 10.16 cm to determine the particle size composition. Organic matter content (OMC) was determined using the ASTM D-2974- standard test method. The soil temperature was measured by inserting digital thermometer with sensor to obtain precise temperature measurement.

Soil temperatures at a depth of 10.16 cm were observed twice a day; soil temperature per day was within the range of 23- 35°C.

Starch extraction process

The process followed for extracting starch from Zea mays is shown in Figure 1

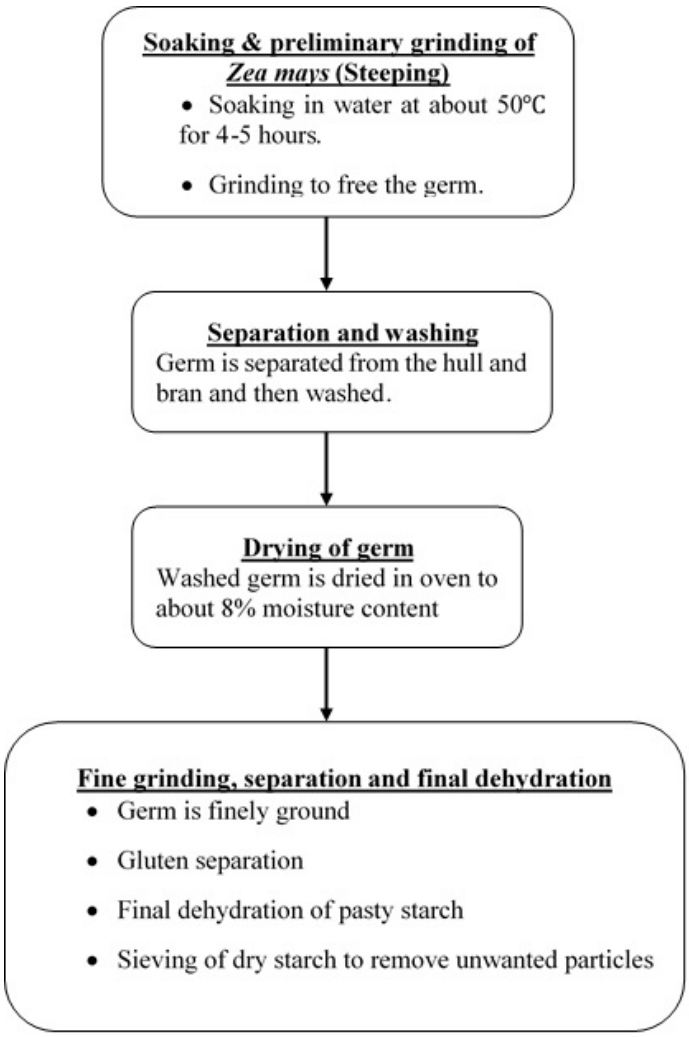

Figure 1. Flow chart for *Zea mays* starch production

Plastic blend production

One percent (1%) concentration of glycerol was produced by diluting 10 ml of pure glycerol with 1000 ml of distilled water as plasticizer. The crucibles were prepared by coating them with coconut oil to avoid sticking of polymer blend to the surface of the crucibles. A total of 6 sample blends containing 5%, 10%, 15%, 20%, 40% and 50% by weight of Zea mays starch was prepared by weighing LDPE and the prepared starch using the OHAUS digital weighing scale (Model PA214). The weighed LDPE and starch were mixed with the glycerol (plastici-zer) for each percentage composition, as shown in Table1. These mixtures were poured into the prepared crucible as well as allowed to melt and blend properly by mechanically stirring at temperatures above 120°C. The molten polymer blends were then poured on aluminium foil and allowed to cure at room temperature (25°C) for 24 hours. This procedure was repeated for all 6 blend formulations as shown in Table 1. A pure LDPE sample (i.e. 100% LDPE), which served as the control sample, was also prepared as well. Each produced polymer blend was weighed using the OHAUS digital weighing scale (Model PA214) to determine the initial weight.

Table 1. LDPE/*Zea mays* starch formulations

Sample name	LDPE (wt.%)	*Zea mays* starch (wt.%)
5 CoS	95	5
10 CoS	90	10
15 CoS	85	15
20 CoS	80	20
40 CoS	60	40
50 CoS	50	50

Note: CoS – *Zea mays* starch

Biodegradation analysis

The weighed samples were buried in sandy loam soil at a depth of about 10.16 cm (4 in.) for a period of 28 days in an uncontrolled environment. The biodegradation of the polymer blend samples was monitored by excavating them from the soil every seven days for a period of four weeks and the degradation was calculated by measuring the weight loss per week using equation 1. This method is commonly known as "degradation by weight loss" (Yang *et al.*, 2006; Dong *et al.*, 2008; Maryam and Hadi, 2016; Mostafa *et al.*, 2018). This procedure was repeated for all the produced samples for this period of time.

$$D = \frac{w_0 - w_1}{w_0} \times 100\% \quad (1)$$

Where D = Degradation Ratio (%)
w_0 = initial weight (g)
w_1 = current weight (g)

The degradation rate was determined using equations 2 and 3 for all the buried samples for the given period. The degradation rate was calculated by finding the instantaneous degradation ratios as follows:

$$D_i = \frac{w_x - w_y}{w_x} \times 100\% \quad (2)$$

$$D_t = \frac{D_i}{N} \quad (3)$$

Where D_i = [Instantaneous Deg] radation Ratios
w_x = Former weight
w_y = New weight
D_t = Degradation Rate (% per day)
N = Number of days

RESULTS AND DISCUSSION

The result of particle sizes classification is shown in Table 2. The particle size, organic matter composition and salinity analysis indicates that the soil where the biodegradable samples were buried corresponded to Loamy Sand.

The results of the biodegradation ratio and biodegradation rates for the 6 LDPE/*Zea mays* blends are shown in Figures 2 to 7.

Figure 2 shows a relatively steady increase in weekly degradation ratio for sample 5 CoS. Degradation by 10.73% occurs after 7 days, 17.94% after 14 days, 23.03% after 21 days and then finally by 27.08% after 28 days. Conversely, degradation rate for 5 CoS saw a decline from 1.53% per day during the first week to 1.15% per day during the second week then 0.89% the third week and finally 0.75% in the final week.

For sample 10 CoS, Figure 3 shows that degradation ratio increased rapidly for the first three

Table 2. Soil sample analysis

Soil Depth	Organic Matter	Salinity	Sand	Slit	Clay	pH Value	Textural Class
10.16 cm	35.65	1.05	75.68	5.80	18.52	4.20	Loamy Sand

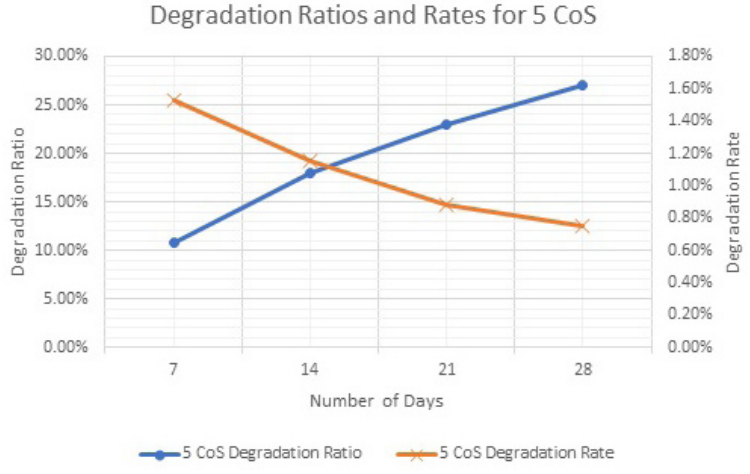

Figure 2. Biodegradation ratios and rate of 5 CoS

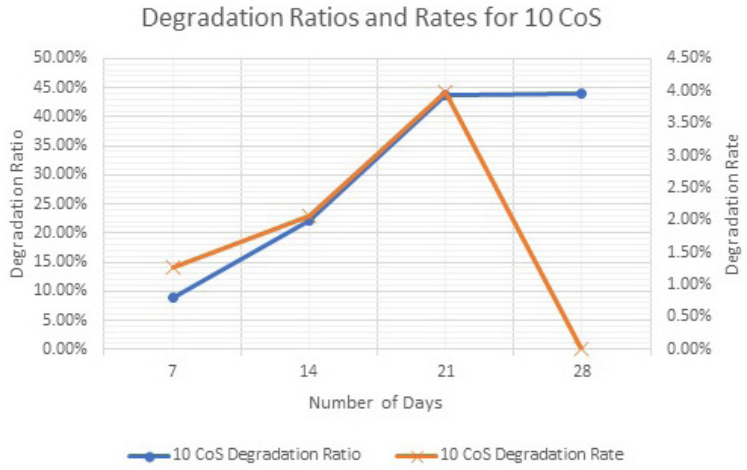

Figure 3. Biodegradation ratios and rate of 10 CoS

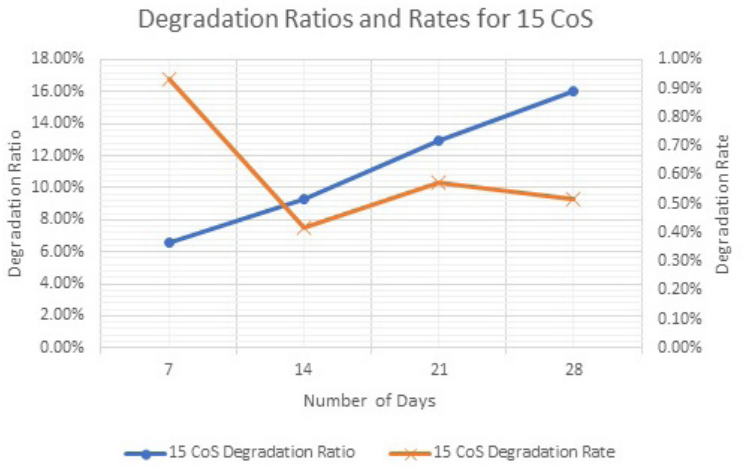

Figure 4. Biodegradation ratios and rate of 15 CoS

weeks; 8.91%, 22.12% and 43.87%; then 43.94% degradation ratio was recorded after the fourth week. However, the values obtained for the degradation rate was erratic. An increase in the degradation rate per day for the first (1.27%), second (2.07%) and third (3.99%) weeks was noted, then a large decrease occurred during the fourth (0.02%) week.

According to the plot in Figure 4, sample 15 CoS showed relatively lower, but steadily increasing values for degradation ratio: 6.54% for the first week, 9.72% the second week, 12.91% the third and finally 16.07% after 28 days. The degradation rate for 15 CoS followed a more erratic (zig-zag) pattern than 10 CoS; 0.93%, 0.42%, 0.57% and 0.52% during the first to fourth weeks, respectively.

In Figure 5, it can be seen that there is another steady increase in the degradation ratio of sample 20 CoS over four weeks – 4.27%, 5.76%, 6.83% and 7.47%. Conversely, average degradation rates per day: 0.61%, 0.22%, 0.16% and 0.10%, decreased steadily for the first to fourth weeks, respectively.

The degradation ratios and rates for sample 40 CoS are presented on the chart in Figure 6. It reveals another steady increase in the degradation ratio – 29.15%, 50.97%, 68.08% and 75.41%. The highest values for the degradation rate per day were recorded for this sample. The values were also close together – 4.16%, 4.40%, 4.99% and 3.28%.

Figure 3.6 indicates that the degradation ratio of sample 50 CoS had an increasing pattern similar to the other samples. 13.77%, 23.23%, 32.64% and 40.89% after the first, second, third and fourth weeks, respectively. The degradation rates per day were relatively close together – 1.97%, 1.57%, 1.75% and 1.75%.

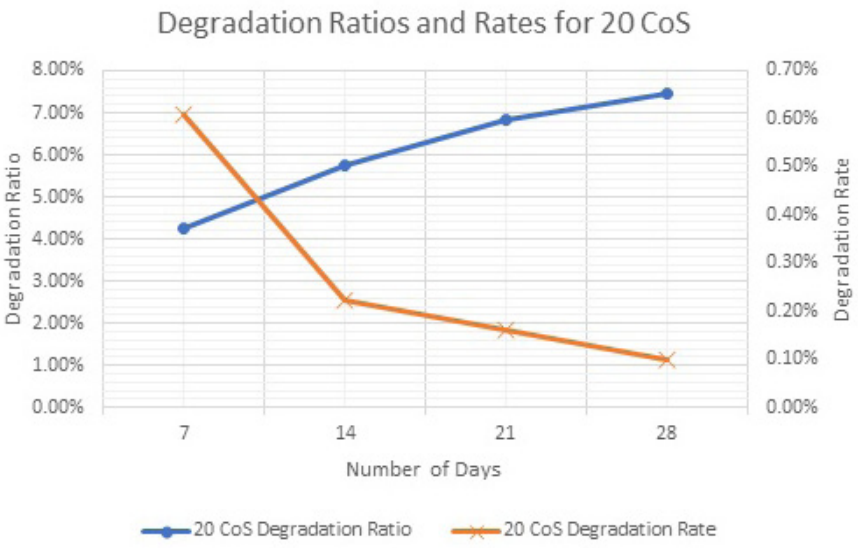

Figure 5. Biodegradation ratios and rate of 20 CoS

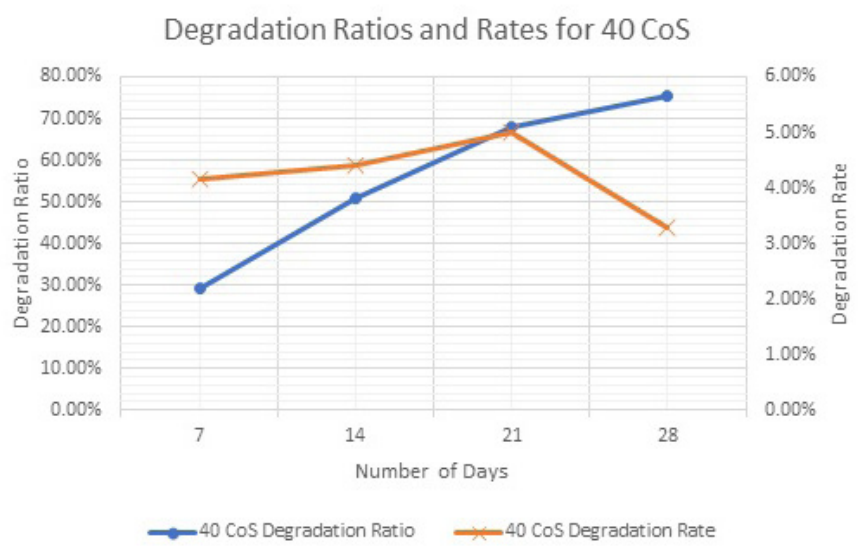

Figure 6. Biodegradation ratios and rate of 40 CoS

Figure 8 shows a pattern in the relationship between the biodegradability ratio and biopolymer blend composition recorded for the 6 blends of LDPE/*Zea mays*; 40 CoS had the highest values for degradability ratio. However, 50 CoS showed the steadiest biodegradation over the four weeks. Almost constant values for biodegradation rate were recorded for 50 CoS (from Figure 7). This implies that under the soil conditions *Zea mays*/LDPE biopolymer blend was buried and studied, the blend with 50% LDPE and 50% *Zea mays* showed the most optimum biodegradation properties.

CONCLUSION

All formulated blends have proven to be biodegradable and can be selected for various applications based on the required properties However, the polymer blends with 50% LDPE (50 CoS) by weight had the most uniform weight loss over the period of the study. Under the given soil conditions, polymer blend 50 CoS also had the steadiest rate of degradation. Hence 50% LDPE (wt.%) blended with *Zea mays* starch is the optimal ratio with regard to the degradability of biopolymer in loamy sand soil of Ota, Ogun State, Nigeria.

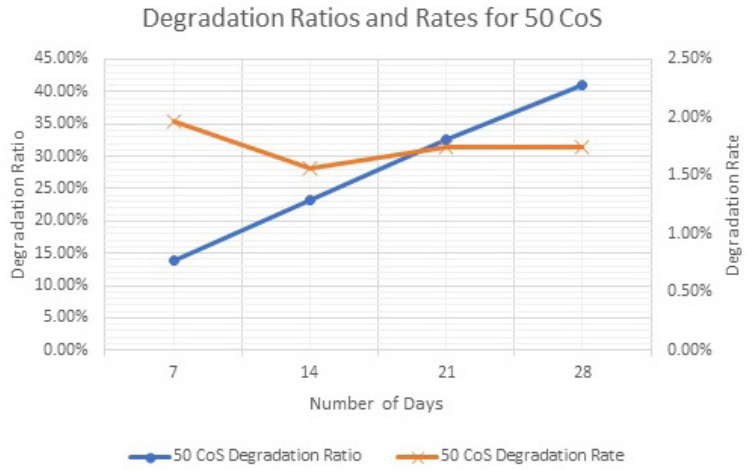

Figure 7 Biodegradation ratios and rate of 50 CoS

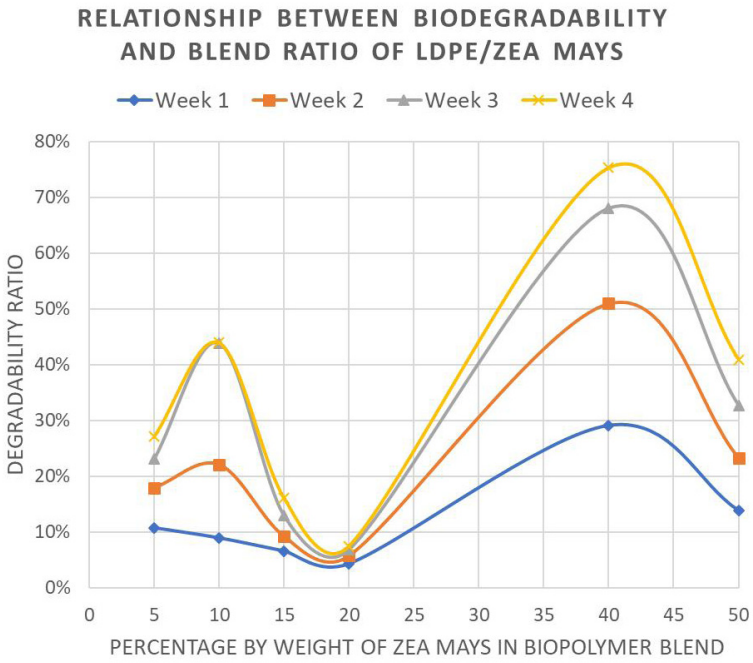

Figure 8. Relationship between biodegradability and blend ratio of LDPE/*Zea mays*

Acknowledgements

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