Ecotoxicological Percentage Assessment of Spent Mobile Phone Batteries (Samsung, Tecno and Nokia) to *Aspergillus Nidulans* in Freshwater

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Abstract
Three brands of spent mobile phone batteries (lithium-ion and Li-Polymer) were used as toxicant in freshwater sample with Aspergillus nidulans. The 24h Median Lethal Concentration (LC_{50}) was used as indices for ecotoxicological assessment. Aspergillus nidulans survive and multiply in the Samsung contaminated freshwater with median lethal concentration (LC_{50} = 84.5659%) which is higher than the maximum toxicant concentration of 75%. Nokia (LC_{50} = 73.0401%) which is slightly lower than the maximum toxicant concentration showing that Aspergillus nidulans is slightly susceptible to the toxicant in fresh water. Tecno mobile phone battery is a Li-Polymer battery (LC_{50} of 66.3615%) which is lower than the maximum toxicant concentration showing that Aspergillus nidulans is susceptible to the toxicant in fresh water. Cumulative analysis of mean % mortality showed that Aspergillus nidulans is ***not susceptible*** *to spent Samsung battery,* ***slightly susceptible*** *to spent Nokia battery and* ***susceptible*** *to spent Tecno phone battery. Mean % log mortality at different dose 0%, 5%, 15%, 25%, 50% and 75% revealed Samsung: 0, -5.618, 1.18, -1.87, -19.822, -17.042; Nokia: 0, 4.642, 3.974, -0.156, 4.018, 1.366; Tecno: 0, 4.59, 8.072, 4.458, 11.394, 17.23 [Note: the negative % log mortality values indicates growth above % control]. There were significant differences in the toxicants at 95% probability level; showing that Tecno battery is more toxic than Nokia and Samsung mobile phone battery. Samsung mobile phone battery might have been manufactured with green awareness. Spent mobile phone batteries should be handled as toxic materials that require special treatment. Implementation of a well-coordinated management strategy for spent batteries is urgently required to check the dissipation of large doses of toxic chemicals and rare heavy metals into the environment. However, the ability of Aspergillus nidulans to utilize battery chemical component for growth up to 45% concentration shows that this organism is a very potential tool for biodegradation of spent mobile phone batteries, thus industries concerned should mix broth cultures of Aspergillus nidulans with spent chemicals of phone batteries before discharge into the environment. It can also be used as a bio-marker to detect low and high level pollution in freshwater.*

Keywords*: Spent mobile phone batteries, Samsung, Nokia, Tecno, Median Lethal Concentration (LC_{50}), Aspergillus nidulans*

1.0 Introduction

The management of spent primary and secondary batteries has been an issue of environmental concern in developing countries especially considering the absence of basic waste collection and management infrastructure (Abdel-Ghani *et al.*, 2007; Daryabeigi and

Abduli, 2008; Rabah *et al.*, 2008). Batteries represent a large volume of toxic and hazardous materials in common use (Lankey and McMicheal, 1999; Nrior and Owhonda, 2017). Waste management in general has emerged as a major problem for urban cities (Aina *et al.*, 2009). Adopting inappropriate mean in the management of wastes could result in environmental pollution (Giri *et al.*, 2007; Ogundiran and Afolabi, 2008; Wemedo and Nrior, 2017).

Batteries contain a wide variety of materials such as carbon, steel, plastic, heavy metals and salts (electrolytes). While materials such as carbon are not so aggressive to the environment and can quickly merge into the eco-system without noticeable impacts, others such as heavy metals pose threat to the ecosystem and man (Nnorom and Osibanjo, 2006a,b; Nrior and Gboto, 2017). The fate of spent rechargeable batteries is an important and timely issue, primarily because of the toxic and hazardous materials they contain. The consumption of portable rechargeable batteries in Nigeria has been phenomenal since the introduction of mobile telecommunication in the country in 2000. For instance, in 1999, about 179,295kg of portable rechargeable batteries was imported into Nigeria. Consumption of portable rechargeable batteries has also increased with increase in subscription of mobile telecommunication from a mere 30,000 subscribers in 1999 to more than 40 million subscribers in 2007. As at April 2009, the teledensity in Nigeria was 47.98 with 67 million active lines and an installed capacity of 133million lines.

The NiMH and Li-ion batteries do not contain cadmium, which is highly toxic and are therefore considered environmentally acceptable. This and the better performance offered by these batteries led to the replacement of NiCd in many application by the NiMH and Li-ion batteries. These new types of batteries make up about 10- 30 % portable sources of energy depending on the region (Gega and Walkowiak, 2001). In 2002, out of the total rechargeable batteries available in the market for use in mobile phones and communication devices 66 % is Li-based batteries while the rest used nickel-based batteries (Arora and Zhang, 2004). The NiMH batteries are not only Cd-free, but also can store more energy than their NiCd of comparable size (Rydh and Svard, 2003). However, NiMH batteries are not as environmental friendly as presented as they contain toxic materials such as Ni, a toxic and carcinogenic material (Lankey and McMicheal, 1999). Also the Li-ion and NiMH batteries contain metals (such as La, Nd and Co) for which only a few have their toxicological or ecotoxicological data available. As a result, Rydh and Svard (2003) opined that the production and consumption of batteries containing these ‘new’ metals is associated with uncertainties regarding their environmental impact and could result in a change from one problematic metal to another should be reviewed. Meanwhile, the potential environmental impact of spent batteries depends on the disposal options adopted. The use of portable rechargeable batteries represents a true ‘source reduction’ since this reduces the amount of batteries consumed and the volume of waste spent batteries generated over time. This is the case considering that majority of these portable rechargeable batteries can be recharged and reused as many as one thousand times (Lu and Chung, 2003). They have better performance characteristics (such as high energy density) which are desired in many applications (Moshtev and Johnson, 2000). NiMH and Li-ion batteries are special purpose rechargeable batteries used in cell phones, iPods and PDAs. Li-ion battery is the fastest growing battery technology today (Castillo *et al.*, 2004). It has significant high energy density and twice the life cycle of a NiMH battery. Nevertheless, they can be more expensive than NiMH batteries and unsafe when improperly used or disposed (Lankey and McMicheal, 1999; Castillo *et al.*, 2004). At the global level, battery manufacturers produced 1.4 billion NiCd batteries, ~1 billion NiMH batteries.

Ecotoxicity involves the identification of chemical hazards to the environment, measures the effect of chemicals on aquatic organisms (fungi, bacteria, virus, lower and higher organisms), and terrestrial animals. The specific properties of a chemical are used to describe the potential hazard to the aquatic environment (UNECE, 2004).

Aspergillus nidulans(also called *Emericella nidulans* when referring to its sexual form, or teleomorph) is one of many species of filamentous fungi in the phylum Ascomycota. Scientific classification; Domain: Eukarya, Kingdom: Fungi, Phylum: Ascomycota, Class: Eurotiomycetes, Order: Eurotiales, Family: Trichocomaceae, Genus: Aspergillus, Species: A. nidulans, Binomial name: *Aspergillus nidulans*. It has been an important research organism for studying eukaryotic cell biology for over 50 years, being used to study a wide range of subjects including bioremediation, biodegradation, recombination, DNA repair, mutation, cell cycle control, tubulin, chromatin, nucleokinesis, pathogenesis, metabolism, biodegradation and experimental evolution. It is one of the few species in its genus able to form sexual spores through meiosis, allowing crossing of strains in the laboratory. *A. nidulans* is a homothallic fungus, meaning it is able to self-fertilize and form fruiting bodies in the absence of a mating partner. It has septate hyphae with a woolly colony texture and white mycelia. The green colour of wild-type colonies is due to pigmentation of the spores, while mutations in the pigmentation pathway can produce other spore colours. Fresh water reflects perturbations in the environments. So microorganisms can often be used to indicate the health of an aquatic system because chemicals can accumulate in the organism from the water and sediment. To test the toxicity, they can apply bio-markers to detect low-level pollution in the fresh water.

The aim of this study is to evaluate and compare the ecotoxicological percentage assessment of spent Mobile Phone Batteries (Samsung, Tecno and Nokia) to *Aspergillus nidulans* in freshwater.

2.0 Materials and Method

Sample Collection

Three brands of battery Samsung, Nokia and Tecno were collected form a recycle bin in a phone shop. Samsung mobile phone battery is a Li-ion battery with a voltage supply of 3.8V and a charging voltage limit of 4.23V. Nokia mobile phone battery is a Li-Polymer battery with a voltage supply of 3.7V and a charging current limit of 2.6wh. Tecno mobile phone battery is a Li-Polymer battery with a voltage supply of 3.7V and a charging voltage limit of 4.2V. Fresh water was gotten from a local Stream in Asarama community, Andoni Local Government Area, Rivers state, Nigeria.

Preparation of *Aspergillus nidulans* Broth Culture

A laboratory prepared fresh potato broth was made by using the following formula; *Composition*: Potato infusion 200g, Dextrose 20g, pH 5.6 ±0.2 at 25^{o}C, Distilled water 1000ml. *Preparation*: The potato is boiled and 200g of the infusion is collected and poured into 500ml conical flask. 20g of Dextrose sugar is added to the potato infusion and 1000ml of distilled water is added to the mixture, it pH is check to obtain 5.6 ±0.2 at 25^{o}C. A pure culture of *Aspergillus nidulans* was scrapped into broth culture

Preparation of Potato Dextrose Agar

Potato Dextrose Agar (PDA) medium was prepared by weighing 78g PDA, then mixed thoroughly with 360ml of distilled water in a conical flask. The medium was sterilized by autoclaved 121^{o}C for 15minutes at 15psi.

Set-up and Monitoring Procedure

A total of eighteen (18) set-up were done, six (6) for each spent mobile phone battery; Samsung, Nokia and Tecno. The batteries were separately soaked in a sterile container containing autoclaved habitat water (freshwater) for three weeks. The set-up with toxicants (spent mobile phone battery- Samsung, Nokia and Tecno) concentrations 0, 5, 15, 25, 50 and 75% were prepared in test tubes as shown in table 1-3. The test tubes were then covered with cotton wool; the control (0%) consists of freshwater from the habitat and the organism only. About 1ml of the test organism was added to separate toxicant concentrations in test tubes containing (5%, 15%, 25%, 50%, 75% and control respectively) (Table 1-3), and an aliquot (0.1ml) was plated out immediately after inoculation on Potato Dextrose Agar. This is known as zero-hour count plating. And then was incubated at room temperature (28± 2°c). Aliquot (0.1ml) of each of the concentrations of the effluent was then plated out after 4h, 8h, 12h and 24h on Potato Dextrose Agar and was incubated for 72hours. After which the plate were counted.

Table 1: Toxicity Set-up of the different concentrations of spent Samsung battery with *Aspergillus nidulans* in freshwater

Concentration	Test Tube No.	Set-up Label	Sterile (Autoclaved) habitat water	Toxicant (Samsung battery solution)	Test organism (*Aspergilus nidulans*) broth
	-	-	ml	ml	ml
Control 0%	1	Samsung 0%	10.0	0.0	1.0
5%	2	Samsung 5%	9.5	0.5	1.0
15%	3	Samsung 15%	8.5	1.5	1.0
25%	4	Samsung 25%	7.5	2.5	1.0
50%	5	Samsung 50%	5.0	5.0	1.0
75%	6	Samsung 75%	2.5	7.5	1.0

Table 2: Toxicity Set-up of the different concentrations of spent Nokia battery with *Aspergillus nidulans* in freshwater

Concentration	Test Tube No.	Set-up Label	Sterile (Autoclaved) habitat water	Toxicant (Nokia battery solution)	Test organism (*Aspergilus nidulans*) broth
	-	-	ml	ml	ml
Control 0%	7	Nokia 0%	10.0	0.0	1.0
5%	8	Nokia 5%	9.5	0.5	1.0
15%	9	Nokia 15%	8.5	1.5	1.0
25%	10	Nokia 25%	7.5	2.5	1.0
50%	11	Nokia 50%	5.0	5.0	1.0
75%	12	Nokia 75%	2.5	7.5	1.0

Table 3: Toxicity Set-up of the different concentrations of spent Tecno battery with *Aspergillus nidulans* in freshwater

Concentration	Test Tube No.	Set-up Label	Sterile (Autoclaved) habitat water	Toxicant (Tecno battery solution)	Test organism (*Aspergilus nidulans*) broth
	-	-	ml	ml	ml
Control 0%	13	Tecno 0%	10.0	0.0	1.0
5%	14	Tecno 5%	9.5	0.5	1.0
15%	15	Tecno 15%	8.5	1.5	1.0
25%	16	Tecno 25%	7.5	2.5	1.0
50%	17	Tecno 50%	5.0	5.0	1.0
75%	18	Tecno 75%	2.5	7.5	1.0

Percentage log survival of *Aspergillus nidulans* in spent mobile phone batteries in freshwater

The percentage log survival of the *Aspergillus nidulans* in the mobile phone batteries effluent used in the study was calculated using the formula adopted from Williams and Johnson (1981), Odokuma and Nrior (2015). The percentage log survival of the bacteria isolates in the effluent was calculated by obtaining the log of the count in toxicant concentration, dividing by the log of the count in the zero toxicant concentration and multiplying by 100. Thus:

$$\text{Percentage (\%) log survival} = \frac{\text{LogC}}{\text{Logc}} \times 100$$

where:
LogC=log of the count in each toxicant concentration
Logc=log of count in the control (zero toxicant concentration).

Percentage (%) log mortality of *Aspergillus nidulans* with spent mobile phone batteries in freshwater

The study was carried out to assess the probable toxic effect, cell batteries could have in fresh, marine and brackish water (aquatic environment). The formula for calculation of percentage mortality was adopted from APHA (1992), Nrior and Obire (2015). And the percentage log mortality was done by subtracting percentage (%) log survival percentage log control (100).

Percentage (%) log mortality = 100 - % log survival

3.0 Results and Discussion

The percentage (%) log survival of the test organism *Aspergillus nidulans* to the toxicants; spent Samsung, Nokia and Tecno phone batteries at concentrations (%) 5, 15, 25, 50, 75; exposure time 0, 4, 8, 12, 24h were shown in Fig. 1-3. The results obtained during this research revealed that certain substances in lithium battery used to power mobile phones are relatively toxic at certain concentrations; and stimulatory at alternate concentrations to *Aspergillus nidulans*. Similar observations have been reported (Wang, 1984; Nrior and Gboto, 2017; Nrior and Owhonda, 2017). A good increase in the loss of *Nitrobacter* with increasing exposure time was observed in the media as the concentration of the battery cells are increase.

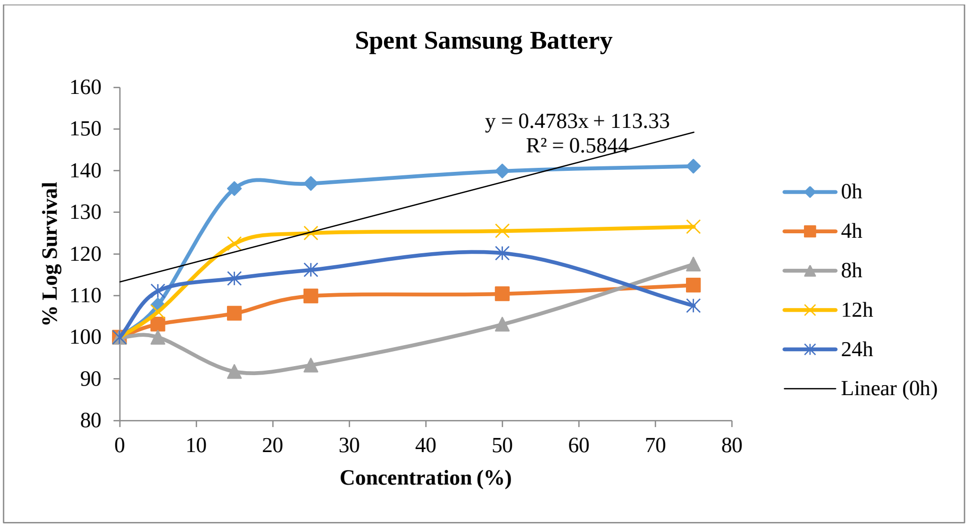

Fig. 1: Percentage (%) Log Survival count of *Aspergillus nidulans* in fresh water using Samsung mobile phone battery

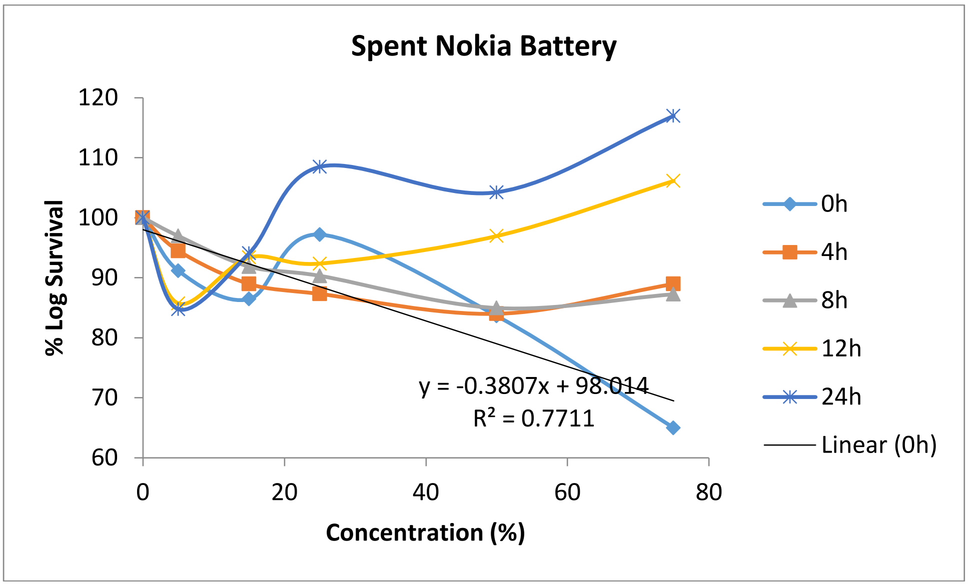

Fig. 2: Percentage (%) Log Survival count of *Aspergillus nidulans* in fresh water using Nokia mobile phone battery

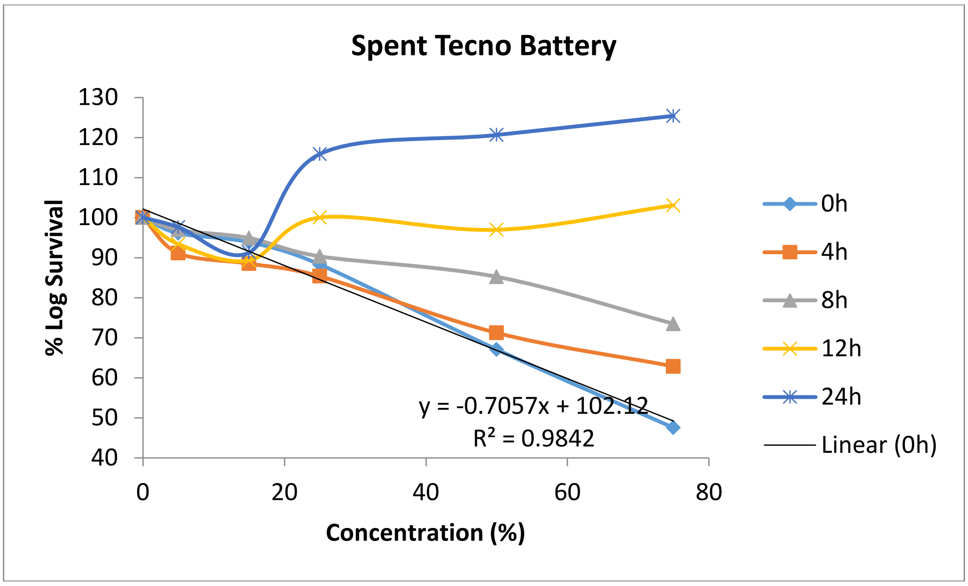

Fig. 3: Percentage (%) Log Survival count of *Aspergillus nidulans* in fresh water using Tecno mobile phone battery

The values of percentage (%) log survival and mortality of *Aspergillus nidulans* at different concentration of test toxicants (spent mobile phone batteries – Samsung, Nokia and Tecno) 0, 5, 15, 25, 50, 70% at 0, 4, 8, 12, and 24h duration of exposure in freshwater were shown in Table. 4-6. The percentage log survival count of *Aspergillus nidulans* were checked by setting a biomarker which is the log survival count of *Aspergillus nidulans* in the control. The percentage log survival was calculated by dividing the contaminant at a particular time interval divided by the control log survival count of that same time interval. This shows a significant rate at which there is an inhibitory activities or tolerance to the toxic chemical discharged from each spent mobile phone battery. Mean % mortality at different dose 0%, 5%, 15%, 25%, 50% and 75% revealed Samsung: 0, -5.618, 1.18, -1.87, -19.822, -17.042; Nokia: 0, 4.642, 3.974, -0.156, 4.018, 1.366; Tecno: 0, 4.59, 8.072, 4.458, 11.394, 17.23 (Fig. Table 4-9).

Table 4: Lethal toxicity of spent mobile phone battery, Samsung, using *Aspergillus nidulans* in freshwater

Conc. (%)	**5**	**15**	**25**	**50**	**75**
Control (%)	100	100	100	100	100
Start (0h)					
% Log Survival	107.74	135.71	136.90	139.88	141.07
% Log Mortality	-7.74*	-35.71*	-36.9*	-39.88*	41.07*
Start (4h)					
% Log Survival	103.13	105.73	109.90	110.42	112.50
% Log Mortality	-3.13*	-5.73*	-9.9*	-10.42*	-12.5*
Start (8h)					
% Log Survival	100	91.75	93.30	103.09	117.53

% Log Mortality	0	8.25	6.7	-3.09*	-17.53*
Start (12h)					
% Log Survival	106.12	122.45	125	125.51	126.53
% Log Mortality	-6.12*	-22.45*	-25*	-25.51*	-26.53*
Start (2h)					
% Log Survival	111.11	114.14	116.16	120.20	107.57
% Log Mortality	-11.11*	-14.14*	-16.16*	-20.2*	-7.57*

**Indicates non % log mortality rather there is growth above control.*

Table 5: Lethal toxicity of spent mobile phone battery, Nokia, using *Aspergillus nidulans* in freshwater

Conc. (%)	**5**	**15**	**25**	**50**	**75**
Control (%)	100	100	100	100	100
Start (0h)					
% Log Survival	91.15	86.44	97.18	83.62	64.98
% Log Mortality	8.85	13.56	2.82	16.38	35.02
Start (4h)					
% Log Survival	94.48	88.95	87.29	83.98	88.95
% Log Mortality	5.52	11.05	12.71	16.02	11.05
Start (8h)					
% Log Survival	96.94	91.84	90.31	84.94	87.24
% Log Mortality	3.06	8.16	9.69	15.06	12.76
Start (12h)					
% Log Survival	85.71	93.37	92.35	96.94	106.12
% Log Mortality	14.29	6.63	7.65	3.06	-6.12*
Start (24h)					
% Log Survival	84.75	94.07	108.47	104.24	116.95
% Log Mortality	15.25	5.93	-8.47*	4.24*	-16.95*

**Indicates non % log mortality rather there is growth above control.*

Table 6: Lethal toxicity of spent mobile phone battery, Tecno, using *Aspergillus nidulans* in freshwater

Conc. (%)	**5**	**15**	**25**	**50**	**75**
Control (%)	100	100	100	100	100
Start (0h)					
% Log Survival	96.09	93.85	88.27	67.04	47.49
% Log Mortality	3.91	6.15	11.73	32.96	52.51
Start (4h)					
% Log Survival	91.10	88.48	85.34	71.20	62.83
% Log Mortality	8.90	11.52	14.66	28.80	37.17
Start (8h)					
% Log Survival	96.94	94.90	90.31	85.20	73.47
% Log Mortality	3.06	5.10	9.69	14.80	26.53
Start (12h)					
% Log Survival	**93.37**	89.29	100	96.94	103.06
% Log Mortality	6.63	10.71	0	3.06	-3.06*
Start (24h)					
% Log Survival	**97.62**	91.27	115.87	120.63	125.40
% Log Mortality	2.38	8.73	-15.87*	-20.63*	-25.40*

**Indicates non % log mortality rather there is growth above control.*

The 24h Median Lethal Concentration (LC_{50}) of the sensitivity of the fungi *Aspergillus nidulans* to the toxicity of mobile phone battery (Samsung, Nokia, Tecno) with Fresh water samples from Andoni LGA, Rivers state, Nigeria for Samsung, Nokia and Tecno respectively are: 84.5659, 73.0401 and 66.3615. The toxicant with the lowest LC_{50} has an higher inhibitory substance to *Aspergillus nidulans* while the toxicant with the highest LC_{50} have shown that *Aspergillus nidulans* is tolerant to the toxicant in the fresh water (Table 7-9).

Table 7: Median lethal concentration (LC_{50}) of Samsung mobile phone battery on *Aspergillus nidulans*

Dose	%Mortality	Mean %Mortality	Dose Difference	∑dose diff. x Mean %Mortality
0%	0	-	-	-
5%	-28.09	-5.618	5	-28.09
15%	5.9	1.18	10	11.8
25%	-9.35	-1.87	10	-18.7
50%	-99.11	-19.822	25	-495.55
75%	-85.21	-17.042	25	-426.05
				∑= -956.59

$$LC_{50} = LC_{100} - \frac{\sum \text{dose diff. x mean \%Mortality}}{\text{\%Control}}$$

$$= 75 - \frac{-956.39}{100}$$

$$= 75 - -9.5659$$

$$= 75 + 9.5659$$

$$\mathbf{= 84.5659}$$

Table 8: Median lethal concentration (LC_{50}) of Nokia mobile phone battery on *Aspergillus nidulans*

Dose	%Mortality	Mean %Mortality	Dose Difference	∑dose diff. x Mean %Mortality
0%	0	-	-	-
5%	23.21	4.642	5	23.21
15%	19.87	3.974	10	39.74
25%	-0.78	-0.156	10	-1.56
50%	20.09	4.018	25	100.45
75%	6.83	1.366	25	34.15
				∑= 195.99

$$LC_{50} = LC_{100} - \frac{\sum \text{dose diff. x mean \%Mortality}}{\text{\%Control}}$$

$$= 75 - \frac{195.99}{100}$$

$$= 75 - 1.9599$$

$$\mathbf{= 73.0401}$$

Table 9: Median lethal concentration (LC_{50}) of Tecno mobile phone battery on *Aspergillus nidulans*

Dose	%Mortality	Mean %Mortality	Dose Difference	∑dose diff. x Mean %Mortality
0%	0	-	-	-
5%	22.95	4.59	5	22.95
15%	40.36	8.072	10	80.72
25%	22.29	4.458	10	44.58
50%	56.97	11.394	25	284.85
75%	86.15	17.23	25	430.75
				∑= 863.85

$$LC_{50} = LC_{100} - \frac{\sum \text{dose diff. x mean \%Mortality}}{\text{\%Control}}$$

$$= 75 - \frac{863.85}{100}$$

$$= 75 - 8.6385$$

$$\mathbf{= 66.3615}$$

Aspergillus nidulans survive and multiply in the Samsung contaminated freshwater with median lethal concentration (LC_{50} = 84.5659%) which is higher than the maximum toxicant concentration of 75%. Nokia (LC_{50} = 73.0401%) which is slightly lower than the maximum toxicant concentration showing that *Aspergillus nidulans* is slightly susceptible to the toxicant in fresh water. Tecno mobile phone battery is a Li-Polymer battery (LC_{50} of 66.3615%) which is lower than the maximum toxicant concentration showing that *Aspergillus nidulans* is susceptible to the toxicant in fresh water (Fig. 4). Cumulative analysis of mean % mortality showed that *Aspergillus nidulans* is **not susceptible** to spent Samsung battery, **slightly susceptible** to spent Nokia battery and **susceptible** to spent Tecno phone battery.

This research revealed that substances found inside the mobile phone batteries can be toxic and affect the test organism *Aspergillus nidulans* at certain concentration. This result confirms similar observation made by Hermann and Urbach on substances electronics (Hermann and Urbach 2000; Nrior and Gboto, 2017). Some advantages observed in the use of microbial bioassay organism include; low cost, small space, simplicity and rapidity. Mortality of the test organism expressed as Median Lethal Concentration (LC_{50}) was used as indices to monitor toxicity (Odokuma and Nrior, 2015; Nrior and Owhonda, 2017).

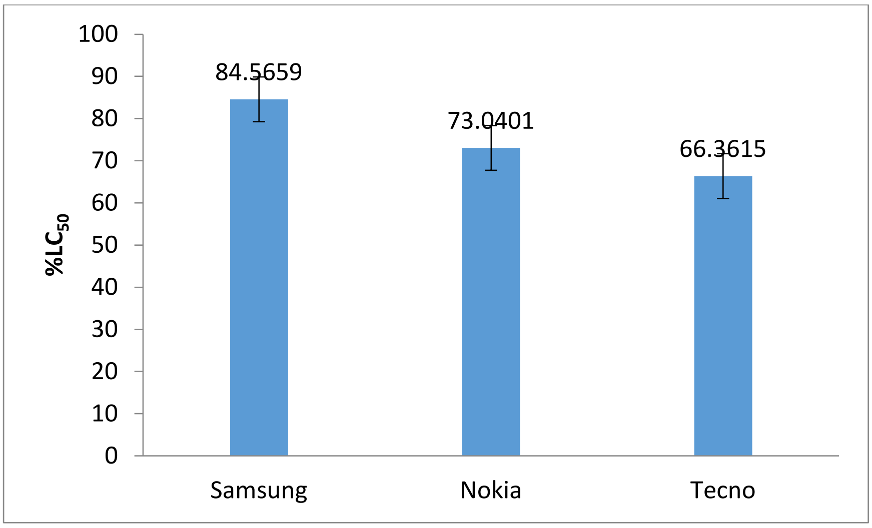

Fig 4: Median lethal concentration (LC_{50}) of mobile phone battery on *Aspergillus nidulans*

The results shows *Aspergillus nidulans* is able to survive in fresh water contaminated by mobile phone battery leading to the deterioration of the fresh water for plants and animal consumption either domestic, agricultural and industrial use. Using the results from the ANOVA there is a significant difference among the toxicants in fresh water.
During this research spent Tecno mobile battery proves to be more lethal to *Aspergillus nidulans* than the Nokia and least with Samsung; the longer these organisms are being exposed to these toxicants the more lethal it becomes to them as shown in the results obtained.

Conclusion
Tecno battery is more toxic than Nokia and Samsung mobile phone battery. Samsung mobile phone battery might have been manufactured with green awareness. Spent mobile phone batteries should be handled as toxic materials that require special treatment. Implementation of a well-coordinated management strategy for spent batteries is urgently required to check the dissipation of large doses of toxic chemicals and rare heavy metals into the environment. However, the ability of *Aspergillus nidulans* to utilize battery chemical component for growth up to 50% concentration shows that this organism is a very potential tool for biodegradation of spent mobile phone batteries, thus industries concerned should mix broth cultures of *Aspergillus nidulans* with spent chemicals of phone batteries before discharge into the environment. It is therefore recommended that; Spoilt mobile phone batteries should be recycled or dumped at an appropriate dumpsite or landfill to avoid the aforementioned environmental hazards. Implementation of extended producer responsibility, introduction of an effective collection system and the introduction of environmentally sound material recovery strategy is required in handling this issue. Landfills should be covered with a thin layer or clay to avoid chemicals in the battery to leak into groundwater thereby leading to pollution.

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