



## Toxicity, Biodegradability and Detection Methods of Glyphosate; the Most Used Herbicide: A Systematic Review

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### ABSTRACT

**Introduction:** Glyphosate is known as the most used world's herbicides and contradictions exist over its classification as a probably carcinogenic for the human. This study aimed to review the newest evidences in toxicity, biodegradability and detection methods of glyphosate.

**Materials and Methods:** To conduct this systematic review, databases such as Scopus, Web of Science, PubMed, and Google Scholar were searched to extract studies on the non-target toxicity, biodegradability and detection methods of glyphosate from 2000 to 2018. The applied key words included glyphosate, herbicide, biodegradation, and bio decomposition. The number of articles retrieved and reviewed was 84 and 23, respectively.

**Results:** Glyphosate could cause endocrine disrupting effects, dermal irritation, embryo toxicity, electrolyte abnormalities, apoptosis, cardiovascular collapse, teratogenicity, and mutagenic effects. High-performance liquid chromatography, UV-visible spectroscopy, gas chromatography/ mass spectrometry, and ion-exchange liquid chromatography were techniques used for detecting glyphosate in soil and water. The biodegradation of glyphosate was performed by various bacteria and fungi microorganisms.

**Conclusions:** Given the high consumption and low rates of biodegradation of glyphosate, more attention should be paid to its toxicity potential in the human's environment and health.

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### Introduction

Annually, two million tons of pesticides are consumed only in 10 top pesticide consuming countries in the world<sup>1</sup>. Worldwide, 40 percent of pesticides are used as herbicides. Glyphosate is known as the most concerned herbicide in some countries such as Iran. Glyphosate has the chemical name of Glyphosate; N-(phosphonomethyl) glycine; 1071-83-6; Glyphosphate; Pondmaster; Roundup

with the molecular formula of C<sub>3</sub>H<sub>8</sub>NO<sub>5</sub>P, vapor pressure of 0.01 mPa at 25 °C, and the water solubility of 12000 mg/L at 25 °C.

Glyphosate is a systemic, non-selective, and acidophilic herbicide used to control weeds<sup>2</sup>. Glyphosate was widely used to control agricultural weeds in many areas such as the north of Iran<sup>3</sup>. Some important properties of glyphosate are known as an enzyme inhibitor, 5-

enolpyruvylshikimate-3-phosphate (EPSP) synthase<sup>4, 5</sup>, antifungal agents,<sup>6</sup> and as an uncoupling agent. In terms of health aspects, the U.S. Environmental Protection Agency (USEPA) classified glyphosate originally as a carcinogen (Class C, possible human carcinogen) because of the increased incidence of renal tumours in the studied mice. Furthermore, the International Agency for Research on Cancer (IARC) announced that glyphosate was a plausible agent for human cancer. From the perspective of environmental issues, continued extensive use of glyphosate components in agricultural activities is a cause of fundamental risks such as bioaccumulation, biomagnification, and toxicity for the environment<sup>7, 8</sup>. These risks potentially effect soil biological cycles<sup>9</sup>, non-target organisms, subsequent pollution of groundwater<sup>10, 11</sup>, runoff,<sup>12</sup> and the residues on agricultural crops. Recently, researchers showed an increased interest in related issues such as toxicity, degradation, biodegradation, fate, pathways, and health risks of glyphosate herbicides. However, toxicity, biodegradability, and detection method of glyphosate has been discussed rarely.

The aim of this paper was to review the newest evidences in toxicity, biodegradability, and detection methods of glyphosate.

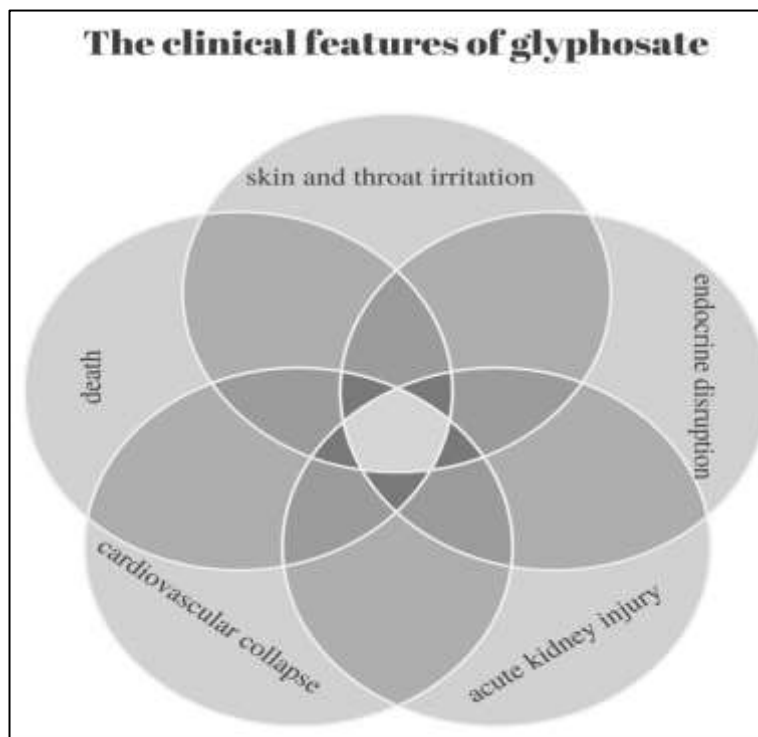
### Materials and Methods

This review was conducted using key terms of toxicity, biodegradation, and detection methods of glyphosate. In this regard, databases including Scopus, Web of Science, PubMed, and Google Scholar along with related published books in this filed were investigated. Considering the study aims, more detailed references with technical explanation and clarification on glyphosate toxicity, biodegradability, and detection method

in soil and water were included; whereas, the unrelated articles and references were excluded. Some of the excluded articles were on other aspects of glyphosate, such as its removal or were published before year 2000. In addition, the articles published in languages other than Persian or English were excluded. Finally, in the biodegradation section, 14 articles were included for further investigation.

### Results

Figure 1 shows the clinical features of glyphosate mentioned in the literature. As Figure 1 represents, human health risks caused by glyphosate exposure ranged from skin irritation to death. On the other hand, in the absence of human data, studies on experimental animals can provide the most reliable tools for detecting the important toxic properties of chemical compounds and for estimating the risks for human and environmental health. In addition, the experimental animals that received glyphosate through a variety of ways were at the risks of glyphosate toxicity<sup>13</sup>. In the literature, many animal toxicity studies were conducted to survey the toxicity of glyphosate. The results of animal toxicity studies are summarized in Table 1. Previous glyphosate biodegradation studies identified different species of microbial. Table 2 represents the microbial species and their isolation environments. These microbial species are isolated based on the morphology differences from a various glyphosate-contaminated environment. Moreover, Table 3 illustrates some of the main characteristics of glyphosate biodegradation. So far, different methods have been applied to measure glyphosate in different environments. Table 4 shows the detection methods and techniques of glyphosate in several environments.



**Figure 1:** The clinical features of glyphosate

**Table 1:** The newest toxicity profiles of glyphosate against different animals

Host	Duration of exposure	Concentrations of glyphosate	Biochemical test	Observed disorders	Ref.
Adult offspring	1-5 Day	1% in drinking water	Glutamate excitotoxicity / oxidative stress	Oxidative stress, affects cholinergic and glutamatergic neurotransmission	14
Immature rat	Pregnancy and lactation	0.38% orally	$^{45}\text{Ca}^{2+}$ uptake, oxidative stress parameters, (14) C- $\alpha$ -methyl-amino-isobutyric acid ((14) C-MeAIB) accumulation, as well as glutamate uptake, release and metabolism	Oxidative stress and neural cell death	15
Odontesthes humensis	48-96 h	0.36-5.43 mg/L	Embryonic development and the number of somite pairs	Produce morphological alterations in fish embryos	16
Guppies	96 h	35 mg/L	The histopathological assessment	Tissue and gender-specific histopathological response	17
Zebrafish	96 h	1, 5, 10 and 100 mg/L	Enzyme activity, Reactive oxygen species, Apoptosis,	Body malformations with cellular apoptosis caused by ROS and inhibition of carbonic anhydrase,	18
Anuran	48 h	100, 1000, and 10,000 $\mu\text{g/g}$	The histopathological assessment	Increased the melanin area in MMCs, hepatic metabolism	19

**Table 2:** Microorganisms involved in the biodegradation of glyphosate Microbial Species

Microorganisms	Isolation environment	Region	Year	Ref.
<i>Trichoderma viride</i> strain FRP3	Agriculture land	Indonesia	2016	20
<i>Pseudomonas</i> sp. GA07, GA09 and GC04	Herbicide manufacturer	China	2015	21
<i>Bacillus subtilis</i> Bs-15	Pepper plant	China	2015	22
Actinomycetes	Apple orchards	Brazil	2014	23
<i>Trichoderma viride</i> strain FRP3	Malt extract agar	Japan	2013	24
<i>O. anthropi</i> GPK 3 and <i>Achromobacter</i> sp. Kg 16	Contaminated soil	Russia	2012	25
<i>Stenotrophomonas maltophilia</i> , <i>Providencia alcalifaciens</i> , <i>Pseudomonas asplenii</i> .	Oil palm plantation	Malaysia	2012	26
<i>Pseudomonas (Aeruginosa)</i>	Citrus garden	Iran	2012	27
<i>Penicillium oxalicum</i> ZHJ6	Abandoned pesticide factories	China	2010	28
<i>Escherichia</i> sp, <i>Azotobacter</i> sp., <i>Alcaligenes</i> sp., <i>Acetobacter</i> sp. <i>Pseudomonas fluorescens</i> )	Rice fields	Nigeria	2010	29
<i>Nocardioideis</i> sp.	Synthetic	Russia	2008	30
<i>Filamentous fungi</i> (91148 and 55.1)	Sugar cane	Brazil	2007	31

**Table 3:** Biodegradation characteristics of glyphosate

Study No.	Optimum pH	Temperature (°C)	Initial concentration (mg/L)	Degradation rate (%)		Degradation media		Time (d)	Ref.
				Minimum	Maximum	Soil	Medium		
1	5.5	25	70	21.42	78	*		28	20
2	7	19-26	50	22.8	82	*		18	21
3	8	35	3800	19	71.57	*		4	22
4	6-8	60	1940	98.5	98.5	*		32	23
5	6.8-7.2	28	100	10	99		*	0.62	26
6	5	25	500	NA	52		*	4	28
7	7-8	NA	NA	NA	85	*		44	32
8	6	30	22	31.8	40	*		5	31

**Table 4:** Analytical techniques applied for detection and quantitative estimation of glyphosate residues

Study	Detection method	Detection technique	Environment	Ref.
1	Derivatization with fluorenylmethyl chloroformate	(LC-MS/MS)	Water	33
2	Stable isotope co-labeled <sup>13</sup> C <sup>3</sup> <sup>15</sup> N-glyphosate	UPLC-MS i-Class system	Water	34
3	Direct detect	HPLC	Soil	35
4	Derivatization with Fluorenylmethyl chloroformate (FMOC-Cl)	UV-visible spectroscopy (265 nm)	Soil	36
5	Vanadate-molybdate	UV-visible spectroscopy (880 nm)	Soil	37
6	Derivatization reaction with Acetic Acid/TMOA	GC/MS	Soil	26
7	Methamidophos assay	GC	Soil	38
8	Determination of turbidity	UV-visible spectroscopy (660 nm)	Soil	39
9	NA cycled derivatives	Ion-exchange chromatography	liquid Soil	40

NA: Not Available

## Discussion

### Toxicity of glyphosate against living organisms human health effects evidence for carcinogenicity

The evidences over carcinogenicity of glyphosate in humans were reported by several national and international agencies <sup>41</sup>. The IARC's study showed

a limited evidence on carcinogenicity of glyphosate in humans <sup>42</sup>. However, in some case-control studies, a positive evidence association was observed between occupational exposure to glyphosate and non-hodgkin lymphoma <sup>43, 44</sup>. Therefore, IARC interpreted all the evidences in order to justify the theory of glyphosate carcinogenicity <sup>45</sup>. The theory of

glyphosate carcinogenicity was confirmed, although it has limited evidences in humans. In fact, IARC relied on the evidences of carcinogenicity in animals and strong mechanistic evidences of genotoxicity and oxidative stress as a reasonable reason to accept carcinogenicity in humans. In another study, the Environmental Protection Agency (EPA) conducted a systematic review study over the carcinogenicity of glyphosate based on the Agency's own Cancer Guidelines and other related papers. It finally reported that glyphosate was not carcinogenic to humans<sup>46</sup>.

### Human toxicity

The most glyphosate toxicity studies were conducted on patients who ingested the commercial product "Round-up" consisting of a mixture of glyphosate (as an isopropylamine salt) and a surfactant (polyoxyethyleneamine). The U.S. Environmental Protection Agency (USEPA) reported that the chronic Reference Dose (cRfD) of glyphosate was 1.75 mg of glyphosate in mg/kg/day<sup>47</sup>. However, several studies showed potential adverse health effects on humans. According to Figure 1, glyphosate is known as an endocrine disruptor<sup>48, 49</sup>. Considering this reason, the level of testosterone, 17 $\beta$ -estradiol, and total protein, as indexes of endocrine disreputability, significantly decreased ( $p \leq 0.05$ ) by exposure to glyphosate<sup>50</sup>. In addition, the concentrated solutions of glyphosate can also cause dermal irritation<sup>51</sup>. Most human cases were intoxicated through ingestion, inhalation, and skin contact in the previous studies. Ingestion of glyphosate can result in acute kidney injury, electrolyte abnormalities, acidosis<sup>52</sup>, and cardiovascular collapse<sup>53</sup>. Human lymphocytes, with or without metabolic activation, were proved by negative genotoxicity of glyphosate<sup>54</sup>. A number of modern diseases are associated with exposure to the glyphosate toxicity. Gluten sensitivity or intolerance, as a known Celiac disease, is a complex disorder affected by a variety of risk factors. Exposure to glyphosate can be considered as an environmental factor<sup>55</sup>. The mechanism of glyphosate toxicity appears intricate and complicated. In this regard, Zhan et al. reported that presence of surfactants in the

glyphosate compound aggravated this complexity<sup>56</sup>. Weng et al. showed that the surfactant component of glyphosate was contributed by rhabdomyolysis (a serious syndrome can lead to serious complications such as renal (kidney failure) and compartment syndrome<sup>57</sup>. In addition, Sribanditmongkol et al. described that the toxic effects of the surfactant polyoxyethylene amine (POEA) and glyphosate were caused by their capability to erode tissues<sup>58</sup>. Although glyphosate toxicity related to the central nervous system is still unknown, Malhotra et al. showed that its probability was a reversible encephalopathy to the direct neuronal toxic effects of glyphosate<sup>59</sup>. The toxicokinetics properties of glyphosate are also complicated. Respiratory failure, metabolic acidosis, tachycardia, elevated creatinine level, and hyperkalemia are known as sings of the refractory cardiopulmonary failure<sup>60</sup>. Moon et al.'s pathological findings in glyphosate fatality indicated that the gastric mucosa of anterior fundus showed hemorrhage and the small intestines identified the bowel obstruction<sup>61</sup>. The ingestion of glyphosate can result in acute kidney injury. Garlich et al. showed that hemodialysis should be considered because ingestion of glyphosate is associated with severe acidosis and acute kidney injury<sup>62</sup>. The results of Mink et al.'s epidemiologic review showed no significant positive correlation and causal relation between exposure to glyphosate and diseases of non-cancer respiratory debases, diabetes, myocardial infarction, reproductive and developmental outcomes, rheumatoid arthritis, thyroid, and Parkinson's disease (PD)<sup>63</sup>. Chen, et al.'s surveillance study indicated that Paraquat (one of the most widely used herbicides) and glyphosate are known as mild caustic agents that can injure the oesophagus. Injuries of the oesophagus caused by glyphosate have only grades 1, 2a, and 2b. The glyphosate commercial formulation was more cytotoxic than the only active component; this condition implies that the additive plays the main role in the glyphosate toxicity when the additive was added to the glyphosate commercial formulation<sup>64</sup>. However, glyphosate induces some adverse formations in the structure of micronucleus and some risky modification in the chemical



structure of DNA in a buccal epithelial cell line (TR146). In addition, glyphosate can alter some functional activity of human placental JEG3 cells<sup>65</sup>. The glyphosate exposure and risk of lymph hematopoietic cancer (LHC) including non-Hodgkin lymphoma (NHL), Hodgkin lymphoma (HL), multiple myeloma (MM), and leukemia were assessed by Chang and Delzell<sup>66</sup>. They found that Meta-relative risks (meta-RRs) were statistically positive for the association between the contrast without facing and risk of NHL and MM. These associations were statistically null for HL, leukemia, and NHL subtypes except B-cell lymphoma. Sorahan conducted a re-analysis of US Agricultural Health Study (AHS) data to find the relation between multiple myeloma and glyphosate use. According to Sorahan's study, positive association confirmed in some previous can be rejected due to their limited data. In this regard, their results showed no statistically significant trends for multiple myeloma risks in relation to application of the glyphosate<sup>67</sup>.

### **Animal toxicity studies**

#### **Rats and mice**

Rats and mice are the most studied experimental animals in glyphosate toxicology. So far, many types of the immunological, biochemical, genetic, and histopathology examinations have been carried out on rats and mice. The results reported that exposure to glyphosate did not affect the uterine weight, but could modulate the expression of estrogen-sensitive genes<sup>68</sup>. The EPA screening assay results (in the Endocrine Disruptor Screening Program) for 52 pesticide chemicals showed no detectable evidence of disruption in the thyroid pathway. In contrary, de Souza et al.'s showed that by glyphosate exposure to thyroid-stimulating hormone (TSH), expression of genes associated with thyroid hormone was disrupted during the perinatal period in male rats. Oxidative stress is one of the most frequently used biochemical examinations in analysing the potential cytotoxicity of chemical compounds and refers to the difference between existence of free radicals and body ability in detoxifying the risky effects of free radicals<sup>69</sup>. In

rats, the lipid peroxidation (LPO) level is considered as an oxidative stress response<sup>70</sup>. In rats, roundup is probably a better antioxidant disruptor than an active ingredient glyphosate. Hence, a typical response to stress and inflammation is increased by exposure to a sub-lethal concentration of glyphosate<sup>71</sup>. Consequently, the antioxidant defence system is activated due to the increase in hydrogen peroxide generation. Therefore, the glyphosate-contained herbicides disrupts the normal biochemical function of liver and kidney<sup>72</sup>. Enzyme assay measures either the consumption of substrate or by-product for the whole time of cell's life. Therefore, this assay can help to have a better understanding of the chemicals' toxic effects. The results of enzymatic activity in the pregnant rats and their foetuses who were exposed to glyphosate showed that maternal exposure to glyphosate during pregnancy caused some functional abnormalities. The abnormalities were observed in isocitrate dehydrogenase-NADP dependent glucose-6-phosphate dehydrogenase and malic dehydrogenase affected liver, heart, and brain of the pregnant rats and their foetuses<sup>73</sup>. In a study by Ait Bali et al., mice were subjected to behavioural and immunohistochemical tests to investigate their sub-chronic and chronic exposure to glyphosate. The results showed that unlike acute exposure, both sub-chronic and chronic exposure to glyphosate induced a decrease in body weight gain and locomotors activity, while they increased anxiety and depression-like behaviour levels. In addition, the immunohistochemically findings showed that the chronic treatment induced only a reduction of TH-immunoreactivity. However, both sub-chronic and chronic exposure reduced serotonin-immunoreactivity in the dorsal raphe nucleus, basolateral amygdala, and ventral medial prefrontal cortex<sup>74</sup>. Cattani et al. studied exposure to glyphosate herbicide and depressive-like behaviour by developed the glutamate excitotoxicity and oxidative stress tests in adult offspring. The results of Cattani et al.'s study showed that glyphosate exposure caused oxidative stress and affected cholinergic and glutamatergic neurotransmission in offspring hippocampus from immature and adult rats<sup>14</sup>.

### Rabbits

A few glyphosate toxicity studies were conducted on rabbits. However, some results indicated that glyphosate toxicity had some effects on sperm quality. The adverse effects may be caused due to the cytotoxic effects of glyphosate on spermatogenesis directly and/or via hypothalamic-pituitary-testis axis indirectly, which controls the reproductive efficiency<sup>75</sup>. Prenatal development of rabbits' cardiovascular status was affected when glyphosate posed a risk for cardiovascular malformations<sup>76</sup>.

### Fishes

The glyphosate embryotoxicity was not well known as its oxidative stress effects. Therefore, Zebral et al. estimated the effect of exposure to glyphosate on the odontesthes humanises embryonic development. They found that exposure to concentration for 96 h (0.36-0.54 mg/L) reduced the eye diameter and the distance between eyes of odontesthes humanises. In addition, main result of Zebral et al.'s study indicated that exposure to glyphosate (0.54mg/L) caused high mortality rates of fish embryos<sup>16</sup>. Sulukan et al. assessed body malformations during embryonic development on zebra fishes. Their results determined that glyphosate decreased CO<sub>2</sub> extraction and subsequently led to developing respiratory acidosis condition. In this condition, reactive oxygen species (ROS) level, as a carbonic anhydrase (CA) inhibitor increased. Finally, embryonic malformations were caused by ROS and inhibition of CA<sup>18</sup>.

### Other animals

McVey et al. conducted an exposure study to find the adult nervous system disorder in relation to *Caenorhabditis elegans* eggs exposed to glyphosate-containing herbicide. McVey et al.'s study showed that eggs from *Caenorhabditis elegans* exposed to glyphosate resulted in larva with abnormal neuronal cell bodies<sup>77</sup>.

### Glyphosate biodegradation

Table 2 shows that bacterial species were used in most glyphosate degradation studies. These microbial species had the ability to grow on media containing glyphosate as carbon, nitrogen, or phosphorus

sources. Furthermore, Table 3 indicates that the minimum value of pH for optimum glyphosate degrading is 5 and *Penicillium oxalicum* is responsible for it. Table 3 also indicates that the minimum and maximum required temperature for optimal glyphosate biodegradation were recorded at 19 and 60 °C, respectively. In addition, the highest and lowest removal rates of glyphosate were 58.8 and 33.92 percent, respectively. The time required for maximum glyphosate removal was calculated between 0.62 and 32 days with a mean of 16.9 days. The strain could grow well in a wide range of pH (4 to 6.5) and the optimum growth was observed at pH range of 5-5.5. The results of kinetic investigation showed that the kinetic data of the glyphosate biodegradation process were characterized by the rate constants (k) of 0.0740, 0.0434, and 0.0946/day for strains GA07, GA09, and GC04, respectively<sup>21</sup>. Nourouzi et al. observed that with increase in initial glyphosate concentration, the percentage of glyphosate degradation decreased from 100 to 98 percent and from 20 to 10 percent when the pH and initial inoculums size were constant, respectively. Nourouzi et al. suggested that the Haldane model was more suitable for prediction of the growth inhibition kinetic of glyphosate<sup>26</sup>. Bacteria and fungus microorganisms were studied in glyphosate biodegradation due to their ability to degrade glyphosate as carbon or phosphorus or nitrogen sources. Accessibility to carbon, phosphorous, and nitrogen (CNP) sources is a significant issue in determining the biodegradation capability of pesticides in the soils. Moreover, due to high requirement of nutrients, microorganisms have to adapt themselves to the alternative nutrient sources when certain nutrients are deficient in the medium<sup>78</sup>. In the biodegradation studies, glyphosate was added to the cultivation medium as carbon, phosphorous, or nitrogen sources by bacteria and fungi<sup>79</sup>. Arfarita et al. reported a continuous tense increase in the growth of utilizing bacterial species when glyphosate was used as a phosphorus source and glucose was applied as the carbon source<sup>24</sup>. Castro et al. reported the glyphosate biodegradation as a sole source of phosphorous by fungal strains. Castro et al.'s study elaborated that the filamentous fungi belonging to the

*Fusarium* genre consumed glyphosate effectively as the source of phosphorous by increasing the biomass observed during the assay; even at a high concentration this compound supported the growth of *Fusarium*<sup>31</sup>. Shushkova et al. added the glyphosate to MS1 medium, instead of  $\text{NH}_4\text{Cl}$ , as a source of nitrogen and phosphorus. Shushkova et al. provided a further support for the hypothesis that changing the type of phosphorus source in the inoculum medium affected both the growth of culture and the decrease of glyphosate concentration. Furthermore, the highest level of biomass production and the maximum amount of utilized glyphosate were observed when the glyphosate was used as a phosphorus source<sup>25</sup>. Moneke et al. explained the effect of adding glyphosate, as a carbon and phosphorous sources in sole or combined forms on the glyphosate biodegradability. Moneke et al.'s study showed that glyphosate degradation by *Pseudomonas fluorescens* was significantly more than *Acetobacter* sp., while glyphosate was used as carbon and phosphorus sources. The isolated *Acetobacter* sp., *Azotobacter* sp., and *Alcaligenes* sp. bacteria were grown on the salt medium containing glyphosate as a sole phosphorus source. However, *Escherichia* sp. did not have any noticeable growth on the medium<sup>29</sup>. Finally, biodegradation was categorized under the two terms of bio-mineralization and biotransformation. In the bio-mineralization process, the organic compounds are completely degraded and converted to an inorganic material such as water and carbon dioxide<sup>80</sup>. However, in biotransformation, a part of the organic compounds is degraded and the remaining is converted into other simple organic compounds<sup>81</sup>. By reviewing related studies, it can be concluded that the glyphosate biodegradation is not classified in the bio-mineralization process.

### Environmental detection of glyphosate

Depending on soil composition, glyphosate persists in soil for a long time (a few days to several months, or even one year)<sup>82</sup>. However, the average of glyphosate's half-life in water may differ from a few days to 91 days<sup>83</sup>. The mentioned half-life indicates that glyphosate has a good detection capability. Therefore, different methods were used

to measure glyphosate in different environments. Table 4 represents analytical techniques applied for detection and quantitative estimation of glyphosate residues include derivatization with fluorenylmethyl chloroformate, stable isotope co-labeled  $^{13}\text{C}_3$   $^{15}\text{N}$ -glyphosate, direct detect, derivatization with fluorenylmethyl chloroformate (FMOC-Cl), vanadate-molybdate, derivatization reaction with acetic acid/TMOA, methamidophos assay, determination of turbidity, N -acylated derivatives. Glyphosate detection in various media was performed through complex analytical procedures. As shown in Table 4, liquid chromatography-tandem mass spectrometry (LC-MS/MS), UPLC-MS i-Class system, high-performance liquid chromatography (HPLC), UV-visible spectroscopy (in 265 nm), UV-visible spectroscopy (in 880 nm), gas chromatography mass spectrometry, gas chromatography, UV-visible spectroscopy (in 660 nm), and Ion-exchange liquid chromatography are techniques coupled with the above methods. Table 4 highlights that the spectroscopy measures were the major instrumental methods for detecting residue glyphosate. Another detection method was the separation processes such as chromatography. Application of appropriate methods in pesticide detection can provide more precision for the analyser and saves time, cost, and energy to improve the performance of integrated pesticide management<sup>84</sup>. Sun et al. and Al-Rajab et al. used high-performance liquid chromatography to separate, identify, and quantify glyphosate and its product amino methyl phosphoric acid (AMPA) in a mixture form<sup>35, 85</sup>. Moreover, Zhao et al. detected the glyphosate in the culture liquid and soil by HPLC<sup>21</sup>. Nourouzi et al. and Zhao et al. used chromatography technique for detecting the glyphosate in soil environment<sup>26, 86</sup>. Further research is required to develop ultrasensitive, real-time, and robust detection methods to detect and measure glyphosate and its production.

### Conclusion

Environmental pollution, bioaccumulation, bio-magnification, and hazard effects on living organisms are the inevitable results of glyphosate



increased use. A crucial need exists to restrict the global use of herbicides and their impacts on the living organisms, water, and soil should be equally recognized. The expected glyphosate biodegradation depends on several key factors such as pH, temperature, and CNP values. The optimum condition of glyphosate biodegradation was obtained when pH was at 5 and temperature was from 19 to 60 °C. Accessibility to carbon, phosphorous, and nitrogen (CNP) is considered as a life crucial factor for microorganisms' growing. Therefore, glyphosate surfactant herbicides, which contains CNP in its composition can be degraded easily by microorganisms. The field and concentration monitoring of glyphosate and its derivatives are facilitated mainly by high-performance liquid chromatography, UV-visible spectroscopy, gas chromatography/mass spectrometry, and ion-exchange liquid chromatography techniques.

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### Conflict of Interest

Authors declare no conflict of interests.

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