Effect of microplastics and nanoplastics on cereal crops

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Abstract:

Plastic is a type of organic compound of synthetic or semi-synthetic material. From the last two decants the use and application of plastic were increasing rapidly. Plastic when accumulated in the terrestrial environment they further breakdown into micro and nano plastics. Both micro and nano plastics are more hazardous. Microplastics are further classified as polypropylene, polyethene, polystyrene, and polyethylene terephthalate etc. A trace amount of microplastic has a serious impact on the ecosystem while they are released into the environment. In several countries, cereal crop and cereal products are the major staple food, which contains carbohydrate, sucrose, sodium. It also contains dietary nutrients like protein, iron, phosphorus, copper, fibre, riboflavin, vitamins B6 and E. Exposure to micro and nanoplastics are reported to have a significant impact on both germinations as well as root growth of the cereals crops. This review article mainly discusses the toxic effect of micro and nano plastics in three major cereal crops, paddy, wheat and maize on its growth and production. Understanding the impact of micro and nano plastic on the cereal crops can help the stakeholders to prevent the damage that could affect the food for humans in the uncertain future.

Keywords: Microplastic; Nano plastic; Cereal crops; toxicity.

1. INTRODUCTION

Plastic is an organic compound and usually synthetic or semi-synthetic. From the last two decades, the use and application of plastics have increased rapidly. Plastic, when accumulated in the terrestrial environments, further breakdown into micro and nano plastics. Micro and nano plastics are known to be more hazardous. Microplastics are further classified into polypropylene, polyethene, polystyrene, and polyethylene terephthalate etc. In several countries, cereal crops and products are major staple foods which contain carbohydrate, sucrose, and sodium. They also contain dietary nutrients like protein, iron, phosphorus, copper, fibre, riboflavin, vitamins B6 and E. Understanding the impact of micro and nano plastic on the cereal crops can help the stakeholders to prevent the damage effects of these foods on humans in the uncertain future. The presence of plastic is the ubiquitous environment has become a major problem globally. Plastic occurs in the environment globally. The world level quantity of plastic has steadily expanded during the last decades, because of its widespread use and durability of synthetic polymers. Reports have suggested that terrestrial plants receive much more plastics wastes as compared to their oceanic counterparts. For instance, in 2017, the terrestrial environment was roughly deposited with 34.8 million metric tons of plastic wastes, 80% of which pollutants to the terrestrial ecosystem (Jiapan, et al., 2019). Much scientific research information reveals that degeneration of plastic and plastic products results in the release of nanoplastics into the natural environment (Hernandez et al., 2017). Plastic application and production were rose from 1.5 million tons in the 1950s to 335 million tons in 2016 (Chibuisi et al., 2019). The term plastic was derived from the Greek word “platikos” which means "able to be shaped". It is a man-made material and the current major pollutant. Plastics are the current major pollutants (**Figure-1**) of the world because they are ubiquitous hence have become an environmental issue. A single product of plastic can consist of hundreds of chemicals (Zimmermann et.al 2019), which binds to the polymers with weak Vander walls forces. There are different types of microplastics such as polypropylene, polyethylene, polystyrene, and polyethylene terephthalate.

Very trace quantities of microplastic have a serious impact when they are released into the environment. Ecological effect on terrestrial plants is still under investigation. Comprehensive studies have been done by kind courtesy, scientists as well as government and non-government organizations, on their occurrence and impacts to the environment. Scientific reports have suggested that terrestrial plants are probably receiving much more plastic waste as compare than that of oceans which were roughly 34.8 million metric tons was in landfills in 2017 and 80% of them pollutes the terrestrial ecosystem. In the 1950s the world production of plastics was around 1.7million tons; which rose to about 200 -299 million tons in 2013, and 322-355 million tons in 2015/2016 (Plastics-The Facts in 2017). Given this, it can be deduced that the production rate of plastics has been increasing rapidly. Particles of plastics are found from different sources in the environment which include various pathways. Plastics are further classified by size into macro, meso, micro and nano. Plastic has been found in distinct terrestrial environments form (**Figure-2**), including biomedical equipment, agricultural farmland bio-solids such as fertilizers, synthetic polymers, daily-using cosmetic products, tooth-brush, tooth-paste, road constructions, tyres, municipal wastes, plastic pellets, industrialized emission of plastic-based raw material, soil, and also from several regions. In agriculture, sewage sediment was granted as a major hazardous cause for the terrestrial ecosystem as it contains a very high amount of fibres with nano plastic beads from clothing and different cosmetic products which affecting soil and its fertility. Once polystyrene nanoparticles (PSNPs) are absorbed by terrestrial plants, its effects the entire

consumers through major physical, metabolic and physiological hazards that happen to their bodies, like rate of respiration, reduce their growth rate, and also oxidative stress, This is because microplastics can easily be transferred and bio-accumulated through various food chain along with food web. It can be easily transported by wind because of their small size and low density. When macro and microplastics are directly inhaled by the humans, body it further causes several serious health risks. These PSPNs was uptake via several cereals crops. Once microplastics had deposited at the soil surface via a variety of source like certain pathways, which including biological activity and contribute to the incorporation of microplastic into the soil. The deposition rate of microplastics and nano plastic on the soil is currently unknown.

1.1. Microplastics

The term was first introduced by Thompson and his colleagues, while they were working on beach sediments around Plymouth in the UK in 2004. Four years later in 2008, International research workshop on the occurrence, effects and fact of microplastics in marine debris held in Tocom, USA. Microplastics are present everywhere in nature and various research studies have suggested that they can induce a wide range of negative impacts on cereal crops (**Figure-3**). Plastic undergoes abiotic and biotic weathering process that results in disintegration, degradation and fragmentation, resulting in smaller particles known as microplastics. Microplastics are smaller pieces of plastic fragments having sizes nearly about less than 5mm in length. Microplastics are not identical (Lambert et.al 2017) since they arise from many different product types composed of various polymers (Rochman et.al). Some studies have highlighted the heterogeneity of microplastic. They are further classified into primary and secondary microplastics based on their size. Primary microplastics are formed small piece of plastic formed during the manufacture of industrial products like cosmetics, and also form the drug production. Secondary microplastics are results from the large plastic debris. Secondary microplastics were results when its exposure to various physical, chemical and photo-degradation caused by sunlight, can reduce its structural integrity by the process of disintegration, fermentation and eventually become un-visualised to the naked eye. Microplastic will subsequently degrade further to form nanoplastics.

1.2. Nanoplastics

Nanoplastics (NPs) are becoming a developing global pollutant. Potential liability is that NPs may distribute as the carrier to increase the spreading of coexisting contaminants. Nanoplastics mainly consist of carbon which is inert, and not easily decomposed. Nanoplastics are classified based on their size as primary and secondary. Primary nano plastic includes nanoplastics which are released from industrial products such as cosmetics, paints, medicinal drugs and more. Other sources of primary nanoplastics are plastic-packaging producing crops (Falco et al., 2018). Secondary sources of nanoplastics are plastic particles which are disintegrated to form miniature particles under various physical and chemical systems. The discharge of nanoplastics from the weathering and degradation of plastics is an important environmental concern. Continuing release of nanoplastics to the terrestrial ecosystem is recognized as major potential health and environmental problem because nanoplastics can transport through the food chain and food web. Production abundance of nanoparticles was largely underestimated, as the production of secondary nanoparticles is not being monitored but many consumer products contain primary nanoparticles. Amount of concentration, particle size and shape, surface area, magnetic forces and their chemical properties plays

a key role in the toxicity manifestation of PSNPs (Joanoviv, 2018). There has been a considerable expanded of the ecological consequences of polystyrene nano plastic discharged into the environment because of their nano-sized particles of polymer-based materials. Nanoplastics are small inert particles and they will nevertheless degrade in the environment by both biotic and abiotic mechanisms. Considering the toxicity of nanoplastics to the terrestrial ecosystem further detailed and molecular studies are required to evaluate and review the effects of nanoplastics. The presence of nanoplastics is problematic to adequately ascertain, due to various technical difficulties for their confinement and measurement. Nano plastic having a special feature such as large specific surface area is relatively more reactive compared to microplastics. Nanoplastics are being widely used in various consumer products such as cosmetic, textiles, rood manufacture, building construction, agricultural land and are expected to be leached into the aquatic and terrestrial environment.

2. Materials and methodology

It is important to identify the routes biological response of macro and microplastic in cereal crops. the toxicity effect of micro and nano plastic in major cereal crops such as paddy, wheat and maize crop has been studied. This review seeks to describe the toxic effect of macro and microplastics cereal crops by characterization of micro and nanoplastics, plant cell response towards microplastics and nanoplastics, seed germination essay, pot study, cytotoxicity and genotoxicity tests.

2.1. Characterization of Micro and nanoplastics

To know the actual effect of micro and nano plastics the morphology and particle size must be focused on. Here, the particle sizes of both micro, as well as nanoplastics, were observed. For determining the morphology and particle size of micro and nano plastic, scanning electron microscope which operates at 10kV is used. The composition and surface functional groups are analyzed by Laser Confocal Raman Spectrometer (LCRS). By using two culture media i.e. deionized water & 25% of Hoagland solution, their colloidal nature could be determined. Ultrasonication is done for 10min and hydrodynamic size distribution of microplastic and nanoplastics are noted by using Dynamic Light Scattering instrument. The sizes of microplastics (less than 5mm in length) and nanoplastics (10-100nm in length) are observed.

2.2. Plant cell response towards micro and nanoplastics

Plastic is ubiquitous and present in both terrestrial and aquatic environments. To identify the response of micro and nanoplastics in cereal plants, carbon and nitrogen concentrations need to be observed as well as recording the airway micro and nano plastics in the leaves of paddy, wheat and in maize plant. Uptake of both micro and nano plastics via root system pathway or by cellular respiration is also observed. Here, paddy, wheat and maize leaves and root systems under-treated with micro and nano plastics were examined.

2.2.1. Foliar carbon and nitrogen contents

Essential nutrients, carbon and nitrogen play a vital role in the cellular mechanism and metabolic pathways of plants. In this, the effect of micro and nano plastics on the concentrations of carbon and nitrogen in the leaves are identified and analysed. For this, ball mill freeze-dried paddy, wheat and maize leaves are ground into a fine

powder. The Carbon and Nitrogen content in the leave are observed under EA3000 automatic elemental analyzer. By using this automatic elemental analyzer, carbon and nitrogen contents in the leaves of cereal plants can be measured. It was observed that micro and nano plastics affect the concentration of both carbon and nitrogen in the leaves of paddy, wheat and maize plant.

2.2.2. Response to air mediated pollution

Airborne microplastics and nanoplastics can be found in various forms like vehicle tyres, clothes, industry production, dried sludge, cosmetic products and agriculture. Atmospheric fall out of microplastic and nano plastic was reported from more pollutant areas in paddy, wheat and maize plants. The scanning electron microscope was used to identify the presence of macro and nano plastics in the paddy, wheat and maize plants. It was shown that plastic particles, both macro and nano were found on the epithelial surface of the leaves, which causes premature cell death and yellowing of the mature leaves. It was observed that airborne micro and nano plastics pose chlorosis to the respective crop plants.

2.3. Seed germination assay

Seed germination plays a major and vital role in every plant and for that reason, seed germination assay of the cereal crops is performed. Seeds of paddy, wheat and maize are surface-sterilized by 2% hydrogen peroxide solution for about 30min and rinsed with distilled water afterwards. The next step is to soak the seeds with SDS solution (0.0012, 0.012, 0.12, 1.2mL) for about 2hrs at room temperature followed by ultrasonication for 10 minutes. 25 seeds of each crop plant are taken into a Petri dish which is incorporated with filter paper, and a gap should be maintained between them. 5ml of test medium is placed on Petri dish and incubated in a growth chamber under the dark condition at 25 °C. All germinating seeds are evacuated, blotted dry and then their weight also measured. Micro and nano plastic effects on the seed germination of paddy, wheat, and maize crop were observed.

2.4. Pot study

Pot study is one of the best experiments to identify the toxic effect of macro and nano plastic in the cereal crops. Seeds of paddy, wheat and maize are surface sterilized by using 2% of hydrogen peroxide solution for 30min. Sterilized seeds are placed on Petri dish which is lined with cotton gauze for germination to occur within 5 days under the condition of 25 °C in a dark growth chamber. Germinated seeds are placed separately in a pot containing different concentration of PSNPs (0, 0.01, 0.1, 1.0, 10mg) for a week. The seedlings are cultured at room temperature for 21 days. Nutrient concentration is changed regularly. After that, seedlings are washed with distilled water. Shoot and root tissues are removed and weights are analyzed subsequently. The isolated roots are scanned and the morphological traits of root parameters are calculated with WinRHIZO Pro. Poorly developed rhizoids and root hair in paddy, wheat and maize are also observed.

2.5. Cytotoxicity and genotoxicity Test

To identify the effect of micro and nanoplastics on cereal crops, studies at the molecular level need to be encouraged. Seeds of Paddy, wheat and maize are kept in the dark at 24°C with 200µl of distilled water and

polystyrene microspheres with different concentration of 0.01, 0.1, and 1g for around 72 hours. After that, germinated seedlings are washed thoroughly by distilled water. 10 roots are fixed in ethanol acid with the ratio 3:1. Root tips are squashed and stained by using the Feulgen technique to identify chromosomal materials like DNA and RNA in the specimen. In this technique, a large number of nuclei are analysed with a light microscope. Level of cytotoxicity is predicted by knowing the mitotic index. Genotoxicity levels are also measured by calculating micronucleus frequency assay and mitotic aberrations.

3. RESULTS AND DISCUSSION

Plastics break down into small fragments which results in micro and nanoplastics and these are more hazardous. This micro and nanoplastics travel cross different channels but finally accumulate in soils, affecting terrestrial plants. Experimental observation suggested that small-sized micro and nano plastics can rapidly toxify the environment. Cereal crops are the source of energy and staple food in the entire world. Both cereal and cereal products provide a major proportion of nutrition as well as dietary energy. They are rich in carbohydrates lipids, protein (mostly gluten), antioxidants, fibres, calories, nutrients, fats, and minerals. Microplastic and nano plastic affect the growth and production of cereal crops because their population rate increases day by day while the production rate of these crops reduces as they come into contact with microplastics and nano plastic. Characteristics of both macro and nanoplastics are analyzed by using Laser Confocal Raman Spectrometer (LCRS) and hydrodynamic size distribution of microplastics and nanoplastics are recorded by using the Dynamic Light Scattering instrument. In this article, the carbon and nitrogen concentrations in the leaves of the three cereal crops have also been elaborated. Atmospheric macro and nano plastic on the upper surface of the epithelial region of the leaves have also been detected. In pot study, cereal crops were treated with different concentration of PSNPs (0, 0.01, 0.1, 1.0, 10mg) for a week. After 21 days, poor development of seedlings and root hairs were observed. Different concentrations of micro and nano plastics also tend to affect root and seedling development. In Paddy plant, micro and nanoplastics increase arsenic toxicity to rice seedlings, decreasing root length and seedling growth of the plants in that effect (**Figure-5**). In wheat, it significantly reduces the total plant biomass, chlorophyll content of leaves, reduces the carbohydrate and amino acid and also has an impact on seed germination of the plants. Microplastics and nanoplastics on the rhizosphere are taking up to the root level, and also induce the phytotoxicity of the plant. High concentrations of micro and nano plastics have more impact on the environment and cereal crops as compare to low concentrations. Germination of seed is a primary step in every cereal crop life cycle. Therefore, seedling stages of cereal crops were examined, and their phytotoxicity as well as cytotoxicity evaluated by using different chemicals such as Hoagland solution, and pyridines. Effect on macro and microplastics, Hoagland solutions and different chemicals on cereals crop seedlings depends on several factors such as chemical surface area, the particle shape, and concentration which had been taken. When a cereal crop is treated with nanoplastics like polystyrene, it affects both root elongation and seed germination, which indicates toxicological effects on the cereal crops. When a low or environmentally relevant concentration of polystyrene was applied, it enhanced root elongation hence was concluded that polystyrene could not affect the root development of cereal crops negatively. However, when the concentration was increased gradually, the root elongation of cereal crops reduced, which indicates that polystyrene could affect the cereal crops. During seedling development, starch granule which has generated via α-amylase penetrated to the interior and hydrolyzed the granule from the inside out. The pitted starch

granule of cereals, when interacts with polystyrene, changes its pitted shape into rough. This indicates that polystyrene reduces the α-amylase activity which results in the decomposition of a high amount of starch. According to the phytological and cytological studies, a large amount of polystyrene has been found in the root tips to the epidermis of cereals, which shows a lignified epidermis pathway. Translocation mechanism of cereal crops was observed through 3D LCSM and SEM. Water uptake by rhizodermis of root cell to the chlorophyll of leave cell through xylem pathway was also observed by using SEM. The major effect of polystyrene in cereal crops was the blockage of essential nutrients like carbon, oxygen, hydrogen, phosphorus, potassium, calcium, sulphur, nitrogen, magnesium uptake and transport. Nutrients including both major and minor elements are used by the plant for their survival, growth and seed germination. It has been experimentally observed that four micronutrients; iron, magnesium, copper and zinc become decreased. Cytological analysis reveals that polystyrene could significantly regulate growth by modulating plant nitrogen and carbon amount and regulating various metabolic pathways such as tricarboxylic acid cycle which is a series of enzyme-catalyzed chemical reaction in the plant cells, starch and sucrose metabolism, galactose metabolism which is metabolised from lactose and milk sugar, and dicarboxylate and glyoxylate metabolism. Global food security largely depends on both cereal and cereal products, approximately 2600 million tons per year. For this review, three types of cereal crops (maize, wheat, and paddy) are focused on. Cereal crops are a source of staple food for countless people in the world since they are a good source of energy. Both cereal and cereal products provide a major proportion of nutrition as well as dietary energy. They consist of carbohydrate, mainly in the form of starch, protein, other nutrients and vitamins like B6 and E.

3.1. Paddy crop

Paddy (*Oryza sativa*) (**Figure-4A**) is an important food grain crop has been traditionally grown and cultivated all over the world. It is the most important human food crop in the entire world. In 2012, more than half of the world population, nearly about 3 billion people relied on paddy every day. East and Southeast Asia mainly rely upon Paddy as a staple food. Nearly about 95% of the global rice crop was consumed by human beings. It is also a valuable crop for the farmer since it is an assured source of income for them. Paddy is an edible starchy cereal grain and belongs to the Poaceae family. Nearly one-half of the global population depends on it. In India, paddy production occupies the first position for its huge annual production. Since time immemorial, paddy has fed many people than any other crop because of its special diversity. It has grown in a wet environment. The domestication of paddy ranks as one of the most important developments in history and nowadays there are thousands of paddy varieties being cultivated. Paddy provides instant energy as it contains a huge amount of carbohydrates which is found in the form of starch. Paddy is used in different forms such as making of bread, cookies, snacks, biscuits and also used in the brewery industries to make alcohol.

3.2. Wheat crop

Wheat (*Triticum spp*) is one of the oldest cereal crops in existence and one of the major cereal crops in India. In India, nearly about 29.8million hectares of the wheat crop is cultivated. It mainly occupies the prime position in the world but in India, it is the second most important crop next to Paddy. It is mostly consumed by people in the northern and north-west region of India. Wheat grain is a rich source of carbohydrates, vitamins, proteins antioxidants, fibre, carbs, calories, fats, and minerals. Wheat flour is used to make various food items like cake,

crackers, bread, cookies and more. It is having a high fibre diet which helps in reducing some diseases like heart diseases, reduce inflammation relating to cancer and also lower the high risk of type-II diabetes.

3.3. Maize crop

Maize (*Zea mays*) (**Figure-4B**) is a versatile crop which shows acclimatization in various agro-climatic conditions. It has the highest genetic yield potential among all cereal crops hence maize is considered as the "queen of cereals". Maize is also known as corn. In the entire world, the United State occupies the first position for the production of maize of nearly about 345.89 million metric tons every year.

Fig 1: Plastic wastes on land.

Fig 2: Different sources of plastics to the environment.

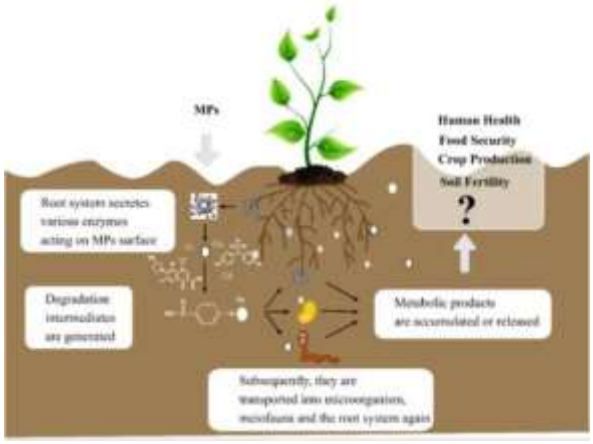

Fig 3: Effects of microplastics to the environment.

Fig 4: Paddy (A), and maize (B).

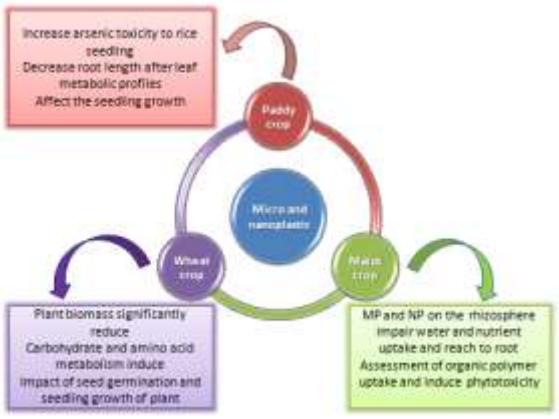

Fig 5: Effects of microplastics and nanoplastics on paddy, wheat, and maize.

CONCLUSION

Plastic particle, when released into the environment, further breaks down into micro and nanoplastics to the ecosystem. These macro and nanoplastics are non-degradable hence cause a negative impact to both terrestrial as well as the aquatic environment. Micro and nanoplastics are producing from industrial processes as a result of the breakdown of large plastics (Prosper et.al 2020). Microplastics have been found in distinct terrestrial environment areas including agricultural farmlands, synthetic polymers, daily-using cosmetic product, road constructions, tyres,

municipal wastes, plastic pellets, industrialized soil, and also from several regions. More research and studies are required on short and long term effects of macro and nano plastic to cereal crop. Plastic pollution is an emerging problem in an environment which requires a quick redress. It is not specific to a particular region or a country.

The whole world is suffering from a huge and growing range of plastic pollution. Everywhere in the surrounding environment, the presence of plastic and plastic products is abundant. Plastic and plastic products are easy to carry, store and dispose of. Plastic is a major issue affecting cereal crops in the terrestrial environment. In our daily lives, we use plastic and its products for various purposes like storage materials, water bottles, chairs, polythene, plastic wires, plastic pipes, motorbike, cars, tyres, bags, toys, not forgetting different medical equipments. The recent rise in plastic pollution is a worldwide concern. All the major toxicity effects observed were mainly based on short-term polystyrene exposure test.

Conflicts of interest

Authors declare that no conflicts of interest exist.

Compliance with Ethical Requirements: This article does not contain any studies with animals performed by any of the authors.

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