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EXPOSURE TO PHARMACEUTICALS AFFECTS NUTRIENT AND METAL UPTAKE BY WHEAT, *Triticum aestivum* L.

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Abstract

Interest in water recycling has provided opportunities to evaluate the potential impact of pharmaceuticals and personal care products (PPCPs) on plants where recycled wastewater is used for watering and irrigation. Most researches have focused on the impact of pharmaceuticals on seed germination and plant physiology or the uptake of pharmaceuticals into plants. We sought to find out whether nutrient and metal uptake into wheat plants were affected by the presence of PPCPs (acetaminophen, caffeine, β-estradiol, and gemfibrozil) in soil. As acetaminophen, caffeine, β-estradiol, and gemfibrozil concentrations in soil increased, plant physiological parameters such as electrolyte leakage and lipid peroxidation also increased significantly over levels in control plants grown in parallel. Furthermore, increasing PPCP soil concentrations led to decreasing element concentrations in wheat plants, suggesting a reduction in uptake of nutrients and metals in the presence of pharmaceuticals. Our short-term observations suggest plants irrigated with recycled wastewater containing PPCPs experience stress which is ultimately reflected in a reduction of nutrient and metal uptake by wheat plants.

Key words: acetominophen, metal, personal care products, pharmaceuticals, wheat

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1. Introduction

Continuous discharge of pharmaceuticals in the environment in different ways can cause serious health problems and also affect plants and aquatic organisms, even at lower concentrations. Therefore, it is important to raise awareness of drugs and environmental problems. Considering the environmental problems caused by pharmaceuticals and their effects on organisms and transformation in plants becomes indispensable. In addition, some pharmaceuticals also enter the food chain through plants (Al-Farsi et al., 2017; Karnjanapiboonwong et al., 2011). The products are metabolized by plants, which can affect organisms including humans (Bartrons and Penuelas, 2017). Pharmaceuticals and personal care products include a wide range of chemicals, including prescribed and non-prescribed medicine used by humans and animals. They also cover products used by individuals for health or cosmetic reasons (Wu et al., 2015). Environmental pollution caused by widespread use of pharmaceuticals and personal care products becomes an issue to be solved (Wang and Wang, 2016).

Human activities and the waste deriving from those activities contribute to environmental degradation and reductions in water quality. The presence of pharmaceuticals and personal care products (PPCPs) is a current example of an issue affecting surface water quality across the globe. PPCPs include a large variety of chemicals compounds differing in terms of physicochemical properties. Many PPCPs have the ability to exist as ions at environmental pH, so that their environmental behavior can be affected by this dissociation. The behavior of the ionized form of PPCPs is more difficult to predict compared to the neutral form. Thus, in order to have better tools for assessing the behavior of PPCPs, the dissociation process should be well understood (Wu et al., 2012). Discharge of

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pharmaceuticals into the environment occurs in different ways. In a cycle beginning with humans and livestock animals, many excreted pharmaceuticals can pass through wastewater treatment plants or enter soils and surface waters directly through runoff. In cases where waste treatment is inadequate or absent (Halling-Sorensen et al., 1998; Ternes, 1998; Topal et al., 2012; Türkdoğan and Yetilmezsoy, 2009; Wang and Wang, 2016), mixtures of PPCPs continuously enter surface water environments. As water supplies become more limited and water re-use practices increase, the presence of PPCPs in treated wastewater that is being recycled and used for other purposes will continue to be of interest. Studies suggest that PPCPs can be taken up by plants as a result of biosolids reuse (Eggen et al., 2011; Karnjanapiboonwong et al., 2011; Wu et al., 2012) or irrigation of crops with recycled wastewater containing PPCPs.

Wheat is grown in nearly all parts of the world; it is considered as an important product based on its production as well as its use in flour for baking bread, in addition to the fact that it is a staple food of nearly all people. Minerals and trace elements are essential to maintain the productivity of agricultural crops such as wheat (Kızılaslan, 2004). These elements, in general, play a key role in the emergence of metabolic events such as oxidation and reduction reactions, energy transfer, enzyme activities, and electron transport, as well as organic matter production (Kacar and Kattat, 2006). Interactions of pollutants like PPCPs and metals, and their potential impact on plants are logical scenarios that should also be evaluated. While there are metal concentrations, each plant needs to develop (Brady and Weil, 2008; Kızılgöz et al., 2011), metal levels above or below these concentrations can damage agricultural plants and/or reduce crop yields (Mahmood and Malik, 2014). Furthermore, humans and livestock may be harmed due to consumption of contaminated food (plants). Plants which are subjected to various negative environmental conditions affecting their growth and development during all periods of their life are stressed. This stress damage is initially manifested as various disorders in plant metabolism, and subsequently causes serious decreases in growth, development, and productivity of the plant. Plants can respond to stress by activating several biochemical/physiological mechanisms (Bhattacharjee and Saha, 2014; Hale and Orcutt, 1987). In the present study, electrolyte leakage, MDA, H_2O_2 and carotenoid concentration and mineral element uptake in wheat were measured and negative effects of PPCPs on wheat were found.

2. Case studies

In this paper, wheat (*T. aestivum* L.), which is of economic value as plant, and acetominophen, caffeine, β-estradiol, and gemfibrozil consumed in large quantities in daily life were used as plants. Gemfibrozil is generally used in the treatment of glyceride and cholesterol as an active substance in lipid regulation while β-estradiol is a sex hormone. Being sex hormone, β-estradiol has also serious effects on other tissues and organs, especially on bones. On the other hand, caffein is a herbal alkoloid which has been taken with tea and coffee for ages. Caffein is present in many prescribed and non-prescribed medications as an active substance that stimulates the central nervous system, analgesics and relieves respiratory problems. Acetaminophen, on the other hand, is a pharmaceutical that has analgesic and antipyretic effects. It is also effective and widely used in our daily life for headache, migraine, menstrual pains, cold, toothache, influenza, neuritis, neuralgia, muscle and joint pain, middle ear pain, sinusitis and surgical operations or painful injuries (Osma et al., 2017).

Firstly, 25% of the sown soil is made up of fertilizer and 25% of it is made up of perlite. Acetominophen, caffeine, β-estradiol, and gemfibrozil were mixed into 650 g soil in different concentrations. 7 g of wheat was planted in the prepared 100 g of soil. Then, 250 mL of water was put into the pots. To the extent of the field capacity, the soil was watered. Following germination, the temperature of the environment was adjusted to 10-15 ^oC and the humidity reached to 60%. The wheat was harvested at the end of the 15th day and the samples were stored for experiments. 3 replicates were prepared for each application and enough readings were made in all parameters studied (Osma et al., 2018).

2.1. Nutrient and metal determinations

During the harvest, samples were collected by hand and packed into polyethylene bags. Only the leafs of each plant were analyzed. In addition, soil samples from each treatment were also collected. Plants and soils were dried in oven at 80 ^0C for 24 hours then plant samples were milled in a micro-hammer cutter, sieved through a 1.5-mm sieve, and transferred to a clean polyethylene bag. After each milling, the mortar was cleaned with ethyl alcohol and distilled water to prevent cross-contamination of samples (Aksoy et al., 2012; Barbeş and Bărbulescu, 2017). Samples for metal analysis (0.5 g dry weight) were digested with 10 mL HNO_3 using a CEM MARS 5 (CEM Corporation Mathews. NC. USA) microwave digestion system. Digestion conditions were as follows: maximum power was 1200 W, the ramp was set for 20 min, the pressure was 180 psi, temperature was 210^o C, and the hold time was 10 min. After digestion, solutions were evaporated to near dryness in a beaker. The volume of each sample was adjusted to 10 mL using 0.1 M HNO_3. Determination of elements in all samples was carried out using a Varian Inductively Coupled Plasma–Optical Emission Spectrometry (ICP–OES) (Aksoy et al., 2012; Matache et al., 2018).

2.2. Plant physiology assays

The modified method developed by Heath and Packer (Ananieva et al., 2002) was employed to assess

the amount of lipid peroxidation (as indicated by the presence of the end product malondialdehyde, MDA). We homogenised sample leaves with a mass of 0.5 g in 3 mL of 0.1% trichloroacetic acid (TCA). We centrifuged the material at 15,000 g for 30 min at 4° C. 1 mL reagent (0.5% thiobarbituric acid (TBA) in 20% TCA w/v) was supplemented into an aliquot of the supernatant. 0.5 mL of 0.1% TCA and 1-mL reagent was added for a negative control. At 95° C for 30 min, test tubes were heated and then cooled down in an ice bath. Following centrifugation and cooling in order to obtain a clear supernatant, absorbance at 532 nm was determined. Non-specific binding measured at 600 nm was subtracted from total absorbance. MDA concentrations were measured using mmol/L extinction coefficient of 155 $mmol/L^{-1}$ cm^{-1} (Osma et al., 2014).

The electrolyte leakage (Griffith et al., 1992) was determined using test tubes containing 0.1 g of fresh leafs. 4 mL of distilled water being added to each test tube was incubated at 4° C for 24 h. The amount of ions present in water was determined using an electrical conductivity meter (Osma et al., 2018). The Lichtenthaler and Buschmann (2001) method was used to estimate carotenoid content in fresh leaves. 0.5 g of fresh leaf tissue was ground using a mortar and pestle containing 5 mL of 80% acetone. The optical density of the solution was measured at 470 nm to determine carotenoids.

Photosynthetic pigments were taken for granted as mg/g fresh weight (Osma et al., 2014). Hydrogen peroxide (H_2O_2) was determined by measuring absorbance (410 nm) of the titanium-peroxide complex following methods developed by He et al. (2005). Plants (six replicates) were extracted in cold acetone; a portion of the extract was added to 0.1 mL of 20% titanium reagent and 0.2 mL of 17 M ammonia.

After centrifugation at 3000 × g for 10 min at 4° C, the supernatant was discarded. 3 mL of 1 M sulfuric acid was used to dissolve the pellet, and absorbance of the solution was measured at 410 nm. The absorbance values were converted using a calibration curve based on known concentrations of H_2O_2 (Osma et al., 2018).

2.3. Statistical analysis

For statistical analyses, p-values ≤ 0.05 were significant; the average value of samples was within the 95% confidence interval (Demirezen and Aksoy, 2006).

3. Results

As acetominophen, caffeine, β-estradiol and gemfibrozil concentrations in soil increased, the element concentrations in wheat plants generally decreased, suggesting a reduction in uptake of metals in the presence of pharmaceuticals. In our study, it was found that the stem length of the wheat compared with the pharmaceuticals was shorter, undersized. This was more evident in specimens in which gemfibrozil was employed. After harvesting, the root of wheat was shorter, weaker and thinner in the samples where pharmaceuticals were used. However, it was also observed that wheat root biomass and its spread in soil decreased with increasing concentration of pharmaceuticals. When the tested PPCPs were compared to each other, the reduction in element concentrations in wheat plants was determined to be of greater magnitude in the β-estradiol and gemfibrozil treatments. Statistical analysis performed for each element supported the findings. Namely, that PPCPs at different concentrations had metal uptake effects on wheat plants significantly different from control plants grown in the absence of PPCPs. When mineral element concentrations were examined, it was found that element concentrations generally decreased as the pharmaceuticals increase ed. While the lowest amount of mineral element concentrations of Fe (16.1±11.0 µg/g dry weight), Cu (48.2±0.6 µg/g dry weight), B (6.0±1.8 µg/g dry weight), Mn (14.7±1.0 µg/g dry weight), Mg (604.9±20.8 µg/g dry weight), K (29792.9±785.6 µg/g dry weight) Ca (272.2±21.5 µg/g dry weight), P 4(663.8±40.9 µg/g dry weight) were found in the samples in which gemfibrozil pharmaceuticals were introduced, the lowest concentrations of Zn (29.1±3.5 µg/g dry weight) and Na (380.1±4.2 µg/g dry weight) were found in the samples where β-estradiol was used (Tables 1-2).

Table 1. Mean (±standard deviation) metal concentration (Fe, Cu, B, Zn, Mn) (µg/g dry weight) in wheat grown in the presence of PPCPs. Treatment I=15 mg (50 mg for caffeine). Treatment II=50 mg (100 mg for caffeine). Treatment III=200 mg (300 mg for caffeine). NS=not statistically significant from control; *=statistically significant from control at p<0.05; **=statistically significant fom control at p<0.01; ***=statistically significant from control at p<0.001

PPCPs	*Concentration*	*Fe*			*Cu*			*B*			*Zn*			*Mn*		
Acetominophen	I	72.9	±	25.4	95.4	±	12.3	50.3	±	8.6	39.7	±	7.5	41.4	±	1.7
	II	165.3	±	95.3	88.3	±	12.0	14.5	±	3.1	37.2	±	2.0	58.6	±	6.6
	III	55.9	±	5.0	84.7	±	23.3	21.9	±	2.4	37.9	±	6.4	69.1	±	11.5
	Control	92.8	±	1.0	139.7	±	0.9	97.7	±	0.7	49.6	±	0.3	57.8	±	0.9
Caffeine	I	73.0	±	14.5	83.7	±	20.9	19.1	±	0.3	49.4	±	9.1	43.9	±	2.4
	II	70.9	±	13.5	77.7	±	5.4	11.0	±	0.6	40.1	±	8.1	42.0	±	4.5
	III	63.3	±	7.2	59.2	±	7.8	11.8	±	2.2	29.9	±	1.2	33.6	±	1.2
	Control	92.8	±	1.0	139.7	±	0.9	97.7	±	0.7	49.6	±	0.3	57.8	±	0.9
β-Estradiol	I	87.7	±	44.2	55.3	±	14.4	10.8	±	2.6	29.1	±	3.5	33.6	±	4.9
	II	284.0	±	17.6	52.2	±	14.0	13.2	±	3.8	32.7	±	5.7	37.2	±	3.5
	III	59.8	±	4.0	49.3	±	10.3	10.5	±	2.5	34.2	±	3.5	37.9	±	1.9
	Control	92.8	±	1.0	139.7	±	0.9	97.7	±	0.7	49.6	±	0.3	57.8	±	0.9
Gemfibrozil	I	68.2	±	25.2	119.8	±	19.9	8.4	±	1.7	55.0	±	9.6	30.1	±	2.5

	II	16.1	±	11.0	98.3	±	1.8	12.6	±	3.0	60.0	±	16.2	27.3	±	0.9
	III	45.8	±	14.4	48.2	±	0.6	6.0	±	1.8	40.6	±	15.9	14.7	±	1.0
	Control	92.8	±	1.0	139.7	±	0.9	97.7	±	0.7	49.6	±	0.3	57.8	±	0.9
Soil		20872	±	959	42.75	±	2.14	40.817	±	1.165	46.56	±	1.89	661.7	±	43.85
Significance	Acetominophen	***			***			***			*			***		
	Caffein	**			***			***			***			***		
	β-Estradiol	***			***			***			***			***		
	Gemfibrozil	***			NS			***			NS			***		

Table 2. Mean (±standard deviation) metal concentration (Na, Mg, K, Ca, P) (μg/g dry weight) in wheat grown in the presence of PPCPs. Treatment I=15 mg (50 mg for caffeine). Treatment II=50 mg (100 mg for caffeine). Treatment III=200 mg (300 mg for caffeine). NS=not statistically significant from control; *=statistically significant from control at p<0.05; **=statistically significant from control at p<0.01; ***=statistically significant from control at p<0.001

PPCPs	*Concentration*	*Na*			*Mg*			*K*			*Ca*			*P*		
Acetominophen	I	574.5	±	81.5	1072.7	±	93.6	65825.6	±	2022.7	1473.0	±	178.5	9019.3	±	772.5
	II	515.8	±	121.5	1101.8	±	93.0	60328.0	±	4131.8	1375.6	±	156.8	8884.9	±	335.8
	III	471.4	±	102.8	1062.3	±	179.0	58331.9	±	8558.0	1370.9	±	256.9	8206.4	±	1297.5
	Control	663.3	±	10.8	1230.1	±	6.7	70828.9	±	1124.1	1526.9	±	18.4	9932.5	±	48.0
Caffeine	I	536.4	±	22.0	1199.7	±	44.6	53578.8	±	6422.7	1488.0	±	119.4	9754.2	±	112.2
	II	617.8	±	28.0	1141.4	±	30.8	55159.1	±	7368.0	1466.0	±	86.3	9295.7	±	53.3
	III	434.2	±	32.6	1045.5	±	12.3	52417.9	±	1182.9	1322.8	±	92.6	8043.9	±	94.4
	Control	663.3	±	10.8	1230.1	±	6.7	70828.9	±	1124.1	1526.9	±	18.4	9932.5	±	48.0
β-Estradiol	I	462.2	±	30.5	1081.2	±	125.2	39159.1	±	5937.5	1283.1	±	222.4	8229.9	±	682.3
	II	482.0	±	90.8	1184.7	±	61.6	52616.7	±	4489.1	1245.6	±	71.5	8519.2	±	664.7
	III	380.1	±	4.2	1105.4	±	70.8	68057.1	±	3386.0	1230.6	±	116.8	8716.4	±	320.7
	Control	663.3	±	10.8	1230.1	±	6.7	70828.9	±	1124.1	1526.9	±	18.4	9932.5	±	48.0
Gemfibrozil	I	468.2	±	89.3	950.0	±	83.3	55307.0	±	4539.4	1198.6	±	152.9	7109.4	±	629.4
	II	478.1	±	18.1	895.3	±	13.7	50563.1	±	527.9	725.5	±	78.8	6361.8	±	119.5
	III	531.1	±	73.1	604.9	±	20.8	29792.9	±	785.6	272.2	±	21.5	4663.8	±	40.9
	Control	663.3	±	10.8	1230.1	±	6.7	70828.9	±	1124.1	1526.9	±	18.4	9932.5	±	48.0
Soil		1075.6	±	213.9	24410.2	±	993.0	14312.1	±	1409.0	28748.6	±	846.3	2272.6	±	138.7
Significance	Acetominophen	*			NS			***			NS			*		
	Caffein	***			***			NS			**			***		
	β-Estradiol	***			*			***			**			**		
	Gemfibrozil	***			***			***			***			***		

Apart from the differences in element concentrations we observed in leaves of wheat plants, lipid peroxidation levels as one of the biochemical parameters and electrolyte leakage as an important indicator of cellular injury were also affected by the test PPCPs in soil. It was observed that depending on the concentrations of PPCPs applied, there was an increase in the concentrations of carotenoid and hydrogen peroxide in wheat. The statistical evaluation showed that the differences between the control sample and the sample treated with different concentrations of PPCPs were significant.

As concentrations of PPCPs increased, electrolyte leakage and lipid peroxidation were found to increase at a significant rate over control samples grown in parallel (Fig. 1 and 2). Electrolyte leakage in control samples (59±9.8 $\mu S \cdot cm^{-1}$) was lowest, and was highest in the caffeine treatments (104±7.6 $\mu S \cdot cm^{-1}$). Lipid peroxidation was the lowest in control samples (1.63 $nmol \cdot g^{-1}$±0.72) and highest in the caffeine treatment (14 $nmol \cdot g^{-1}$±1.56). Carotenoid levels were the lowest in control samples (8.16 mg/g±0.52) and the highest in the gemfibrozil treatment (15 mg/g±1.21) (Fig. 3). H_2O_2 was the lowest in control samples (440 ng/g±56.6) and highest in the gemfibrozil treatment (822 ng/g±76.6) (Fig. 4). Decrease in mineral element intake and increase in MDA, H_2O_2 and carotenoid were observed in the samples where gemfibrozil was used. The pollutants found in soil and wastewater affecting wheat was examined and important results were received. This study conducted to evaluate the ecological risk of pharmaceuticals transmitted to agricultural ecosystems was compared with previous studies.

Wu et al (2012) detected some PPCPs such as carbamazepine, diphenhydramine, triclocarban in leaves and roots of vegetables like pepper, lettuce, radish, and tomato. In addition, they found a significant difference in the amount of PPCPs in soil samples that were taken before planting and after harvesting. Therefore, based on these studies, it is clearly seen that PPCPs could be easily taken up by plants.

4. Discussions

Karnjanapiboonwong et al. (2011) found that the concentrations of 17α-ethinylestradiol and triclosan in pinto bean increased over time, suggested that these substances could have negative effects on human and animal health. Frederick et al. (2012) presented data regarding the presence of triclosan and triclocarban in roots and stems from three different plants. Pietrini et al. (2015) investigated the effect of ibuprofen on *Lemna gibba* L. and found that there were differences in the levels of carotenoids and chlorophyll in exposed plants. The PPCPs concentrations used in this study represent soil concentrations above what would be considered environmentally relevant. However, accumulation of PPCPs in soil is relevant under certain water recycling plans (Carr et al., 2011a; 2011b).

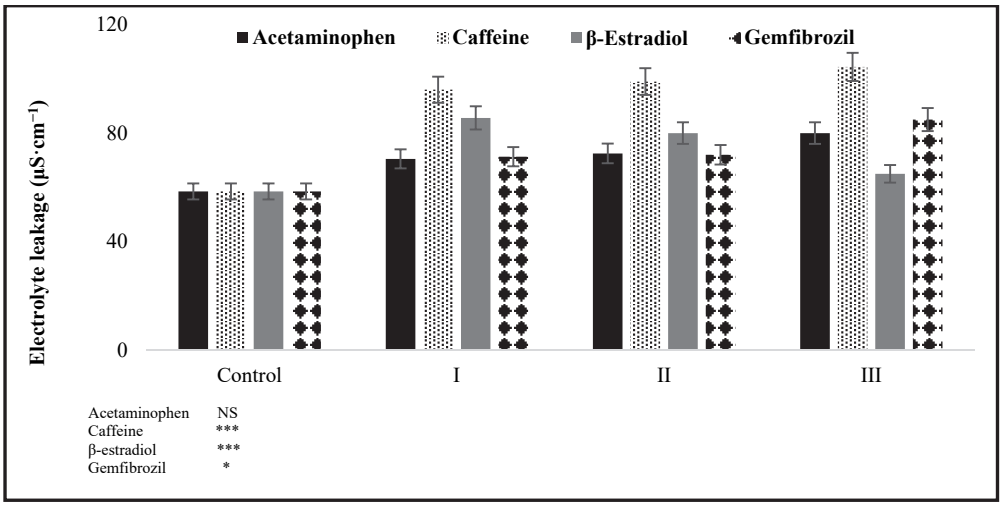

Fig. 1. Electrolyte leakage (%) in wheat after 15 days of growth in soil treated with PPCPs at different concentrations. Treatment I=15 mg (50 mg for caffeine). Treatment II=50 mg (100 mg for caffeine). Treatment III=200 mg (300 mg for caffeine). NS=not statistically significant from control. *=statistically significant from control at p<0.05. **=statistically significant from control at p<0.01. ***=statistically significant from control at p<0.001

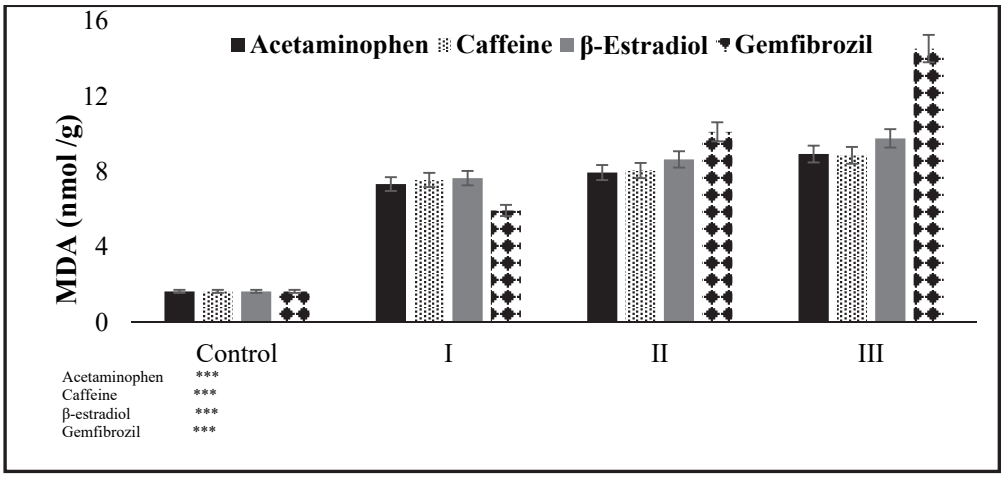

Fig. 2. MDA concentrations (nmol/g) in wheat after 15 days of growth in soil treated with PPCPs at different concentrations. Treatment I=15 mg (50 mg for caffeine). Treatment II=50 mg (100 mg for caffeine). Treatment III=200 mg (300 mg for caffeine). NS=not statistically significant from control. *=statistically significant from control at p<0.05. **=statistically significant from control at p<0.01. ***=statistically significant from control at p<0.001

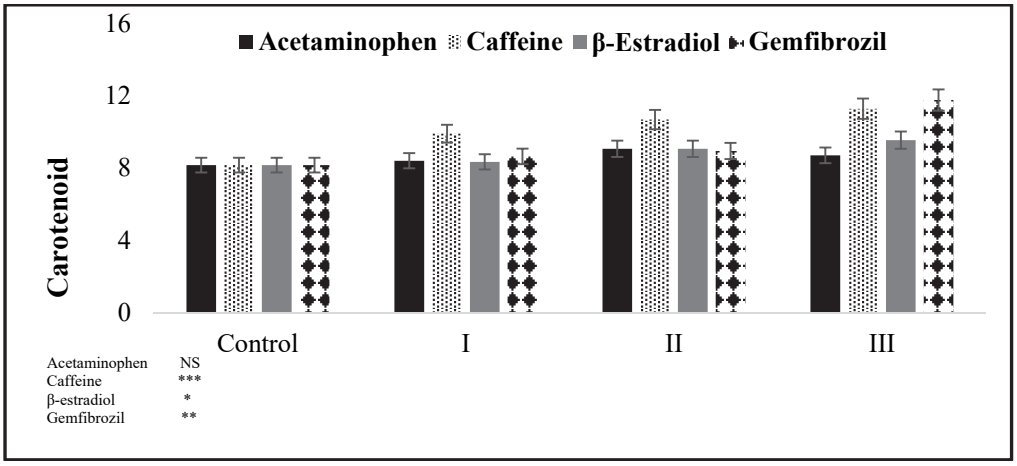

Fig. 3. Concentrations of carotenoid (mg/g FW) in wheat after 15 days of growth in soil treated with PPCPs at different concentrations. Treatment I=15 mg (50 mg for caffeine). Treatment II=50 mg (100 mg for caffeine). Treatment III=200 mg (300 mg for caffeine). NS=not statistically significant from control. *=statistically significant from control at p<0.05. **=statistically significant from control at p<0.01. ***=statistically significant from control at p<0.001

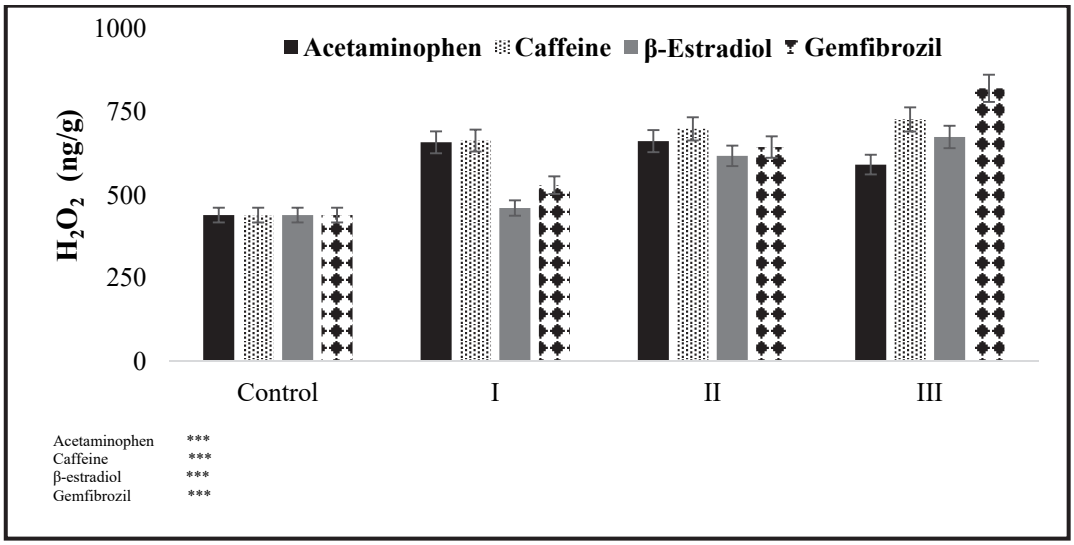

Fig. 4. Concentrations of hydrogen peroxide (ng/g) in wheat after 15 days of growth in soil treated with PPCPs at different concentrations. Treatment I=15 mg (50 mg for caffeine). Treatment II=50 mg (100 mg for caffeine). Treatment III=200 mg (300 mg for caffeine). NS=not statistically significant from control. *=statistically significant from control at p<0.05. **=statistically significant from control at p<0.01. ***=statistically significant from control at p<0.001

An et al. (2009) in their study on the ecological risks of pharmaceuticals investigated the toxic effects of paracetamol on Triticum aestivum L. They found that root elongation and shoot height decreased significantly as paracetamol concentration increased. They also found that paracetamol inhibited chlorophyll. They observed that SOD activity in wheat increased with larger concentration and exposure time. In this study, we found that electrolyte leakage, MDA, H_2O_2 and carotenoid concentration increased and mineral element intake decreased in wheat on which acetominophen, caffeine, β-estradiol and gemfibrozil were applied in different concentrations.

Christou et al. (2016) in their study on the phytotoxic effects of pharmaceuticals introduced four pharmaceuticals (diclofenac, sulfamethoxazole, trimethoprim, 17a-ethinylestradiol) and their mixtures into alfalfa (Medicago sativa L.). They evaluated Lipid Peroxidation, Proline, H_2O_2, NO, antioxidant activity analyzes and gene expression levels, the markers of stress physiology. They found that lipid peroxidation and H_2O_2 and antioxidant enzyme activities increased after the mixtures of these substances. In this study, we observed that H_2O_2 and MDA increased with drug concentration in wheat leaves. Mordechay et al. (2018) examined the effects of carbamazepine, a non-ionic drug and personal care product, on the uptake, translocation and metabolism of tomato, wheat and lettuce. They discovered that carbamazepine reduced the bioavailability of plants from soil while we found that the amount of mineral element in wheat samples grown with the introduction of pharmaceuticals was lower compared to that of the control group. Sun et al. (2018a), in their study, grew cucumber seedlings with a mixture of 17 active substances of pharmaceuticals and personal care products obtained from other cucumber seedlings. They investigated the intake, transport, physiological responses and detoxification of these substances. As a result, they found that the production of reactive oxygen species (ROS) and lipid peroxidation increased with the increase of pharmaceutical concentration. Enzymes in various functions such as oxidative stress (superoxide dismutase and ascorbate peroxidase) and xenobiotic metabolism (peroxidase and glutathione S-transferase) were found to increase due to the intensive concentration of the abovementioned substances. In this study, electrolyte leakage, MDA, H_2O_2 and carotenoid concentration increased in wheat leaves into which acetominophen, caffeine, β-estradiol, and gemfibrozil were introduced. Sun et al. (2018b) examined the effect of commonly used Triclosan on plant growth. Theyshed light on the effects of Triclosan on root growth in wheat plants. In addition, they observed that after exposure to triclosan, root growth was inhibited, triggering H_2O_2 production and lipid peroxidation in the root. In this study, it was observed that acetominophen, caffeine, β-estradiol, and gemfibrozil increased the amount of H_2O_2 and MDA in wheat leaves. Similarities were observed between the results obtained in the previous studies and the findings obtained in this study.

5. Conclusions

Acetominophen, caffeine, β-estradiol, and gemfibrozil in soil may interact with elements in soil and affect their uptake into plants. Alternatively, these PPCPs influence plant physiology and growth, which may in turn reduce uptake of metals from soil. Either mechanism, in turn, would affect overall plant development. Further evaluation of the potential interactions of pollutants, with plants and the subsequent impact which has on plant productivity, is an important topic deserving of additional research efforts. Our short-term observations suggest plants irrigated with recycled water containing PPCPs

experience stress which is ultimately reflected in a reduction of metal uptake by wheat plants. To know how exactly these substances impact humans and animals, further studies should be conducted. In order to decrease the effects of PPCP on ecological system, various methods should be developed and awareness should be raised among people about their consumption and elimination.

In addition, the studies regarding the fate and transport of PPCPs should be considered. It is suggested that contamination of PPCPs in the environment should be revised, their formation mechanisms, interactions with each other in ecosystem, effects on organisms and transformation in plants should be monitored and precautions should be taken for these micro pollutants. New methods and technologies to remove and clean these pollutants from wastewaters could be tried considering the possibility of contamination into wastewater.

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