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IMPACT OF URBAN WASTEWATER ON HEAVY METALS ACCUMULATION IN CEREALS : A CASE STUDY

“From Soil to Plate: Heavy Metals in the Food Chain”

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ABSTRACT: This abstract provides a comprehensive overview of the complex journey of heavy metals from soil to the ultimate destination-our plates. “From Soil to Plate: Heavy Metals in the Food Chain” offers insight into the sources, transmission mechanism, health implication and mitigation strategies related to heavy metals in the food chain.The abstract commences with an exploration of heavy metals find their way into agricultural soils, primarily through contaminated irrigation water, fertilizers, and atmospheric deposition. It then traces the pathways by which these toxic elements are taken up by plants, subsequently making their way up the food chain.The potential health implication of consuming heavy metal-contaminated foods are thoroughly examined, highlighting the dangers of chronic exposure to elements like lead, cadmium, and mercury. Emphasis is placed on the risks associated with these exposures, including neurological and development disorders, organ damage, and an increased risk off certain cancers.The abstract also discusses mitigation and preventive measures, addressing the importance of soil testing, crop selection, and the implementation of good agricultural practice to reduce heavy metal uptake. Furthermore, it delves into regulatory standards and monitoring systems that help ensure food safety.Hence “From Soil to Plate: Heavy Metals in the Food Chain” underscores the need for vigilance and action at every stage of the food production process to safeguard human health. It serves as a vital resources for policymakers, agricultural stakeholders, and consumers, promoting awareness and offering solution to mitigate the risks associated with heavy metals in our daily diet.

KEYWORDS- heavy metal, food chain, toxic, food, policy, fertilizers, irrigation

I. INTRODUCTION

Actually, the accumulation of heavy metals by crops irrigated by wastewater has considered a serious environmental problem in many countries . In this study, we were interested in highly toxic metals such as zinc (Zn), copper (Cu), lead (Pb) and cadmium (Cd) in water, agricultural soils and crops and their possible risk on human health. The physicochemical parameters pH, electrical conductivity, organic carbon and organic matter, were determined for the samples. Irrigated water, soil and vegetable samples for Zn, Cu, Pb and Cd concentrations and transfer factor from soils to plants (TF) were analyzed, daily intake of metals (DIM) and health risk index (HRI) were calculated.

The irrigated soil was contaminated with Zn (112.71 mg/kg), Cu (17.70 mg/kg), Pb (57.36 mg/kg) and Cd (11.22 mg/kg). The trend of heavy-metal concentrations in all samples was Zn > Pb > Cu > Cd. The daily intake (DIM) for Cd and Pb exceeded the permissible limits. The Health Risk Index (HRI) varied from 0.054–0.174 for Zn, 0.031–0.242 for Cu, 2.407–7.973 for Pb and 0–5.059 for Cd. The HRI was >1 for Cd and Pb indicating a potential health risk.
Our results revealed high risks indexes, heavy metal contaminated food crops in our study area, and consequently, a great health risk to the local human and animal populations. Thus, preventive measures must be taken to reduce heavy metal pollution of irrigation water and soils to protect both, human and animal health.

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The permanence and environmental toxicities of heavy metals have been reported as the most important reasons for their investigation in aquatic environments [1, 2]. Industrial and domestic wastewater discharges, uncontrolled and overuse of heavy metal containing pesticides and fertilizers [3], atmospheric deposition, surface runoff, dissolution from sediment [4] are known as the most important anthropogenic sources of heavy metal pollution in river water. Metals in water structures are found in colloid, particulate and dissolved form or adsorbed to the sediment [5]. The transport of metals in aquatic environments depends on dissolution, precipitation and sorption processes [6], which affect their bioavailability [7]. After a certain period of time, heavy metals mixed with the river precipitate to sediment by various mechanisms (sedimentation, complexation and adsorption of clay particles) and accumulate there then, they reach high concentration in the food chain [8]. This results in a higher concentration of heavy metals in the sediment than in the water column. Furthermore, these metals deposited in the sediment can be re-mixed into the water column by resuspansion, desorption, oxidation or reduction processes and can be more hazardous for aquatic organisms, animals and humans [9, 10]. Therefore, sediment is suitable for monitoring heavy metal pollution in aquatic environments [11]. When these metals reach high concentrations, they pose a serious danger to the ecosystem and humans [12, 13]. Therefore, heavy metal concentrations determined in water and sediment can be used to evaluate the anthropogenic and industrial impacts and risks caused by wastewater discharges in the rivers [14].

Existing studies indicates that heavy metal pollution in surface waters is generally investigated in areas where the industry is developed and the population is very high [15–18]. On the contrary Bartın River is located in a place where industry and population are not developed. Although the domestic wastewater treatment plant is being operated since February 2017, wastewater discharge is still present at some points due to the lack of collection system. In addition, as the river is located in a rainy region, stormwater runoff from the mountains especially in winter causes an increase in the water level and flow in the river. Also stormwater runoff causes changes in the physical properties of the river water like color, turbidity, suspended solids etc. For this reason, in this study, it was aimed to 1) investigate the effect of stormwater runoff on the concentration and distribution of metals in river water and sediment. 2) determine the effect of wastewater discharges on heavy metal concentration and diversity 3) evaluate the heavy metal pollution in river water and sediment by calculating the pollution index methods defined in the literature

The impact of heavy metal presence in soil on cereal crops is a growing concern, posing significant challenges to global food security and environmental sustainability. Cereal crops, vital sources of nutrition, face the risk of contamination with toxic heavy metals released into the environment through human activities. This paper explores key aspects requiring thorough investigation to foster innovation and understand intricate interactions between heavy metals and cereals. Visible symptoms and physiological changes resulting from heavy metal contamination, such as chlorosis and stunted growth, demand further research to devise targeted mitigation strategies and sustainable agricultural practices. Root barrier formation, mycorrhizal symbiosis, and metal-binding proteins emerge as critical defence mechanisms for combating heavy metal stress, offering opportunities for developing metal-tolerant cereal varieties. Research on metal bioavailability and food safety implications in cereal grains is vital to safeguard human health. This paper reveals that multidisciplinary collaboration and cutting-edge technologies are essential for promoting innovation beyond the state of the art in elucidating and mitigating the impacts of heavy metals on cereal crops. Genetic and breeding approaches show promise in developing metal-tolerant cereal varieties, while agronomic practices and soil amendments can reduce metal bioavailability and toxicity. Unravelling the complex mechanisms underlying heavy metal uptake and tolerance is essential for sustainable cereal agriculture and worldwide food sustainability. Embracing the challenges of heavy metal pollution through proactive research and collaboration can secure a resilient future for cereal crops amid evolving environmental conditions. Cereal crops (wheat, rice, maize, and barley), are of paramount importance for food accessibility since they serve as the cornerstone of the world's food supply, providing a substantial portion of the essential nutrients required for human sustenance [9,10]. These crops are extensively cultivated and consumed worldwide, accessible to millions of farmers and communities. Their adaptability to diverse climates and growing conditions ensures food availability across regions and demonstrates remarkable resource efficiency, producing significant grain harvests per unit of land,

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water, and energy invested [11,12,13,14]. This efficiency is particularly vital in regions with limited arable land and resources, as it supports sustainable food production without straining the environment.

Furthermore, cereal crops possess exceptional storage capabilities, allowing grains to be preserved for extended periods with minimal loss of nutritional value. This characteristic is crucial for regions facing erratic weather patterns, natural disasters, or disruptions, as stored grains serve as a buffer during food scarcity [15,16,17]. These crops are also rich in carbohydrates, proteins, fibres, vitamins, and minerals essential for human health, forming the foundation of a balanced and nutritious diet, especially in areas with limited food diversity. Additionally, cereal crops play a key role in supporting livelihoods and economic stability, contributing to income and employment opportunities for farmers, workers, and traders, thus fostering agricultural development and rural prosperity [18].

Consequently, cereal crops are irreplaceable in ensuring planetary food due to their extensive cultivation, resource efficiency, storage stability, nutritional value, and socio-economic significance. As the world's population continues to grow, the sustainable production and availability of cereal crops remain critical in addressing hunger, malnutrition, and food insufficiency on a global scale

Heavy metals have a high degree of persistence in the environment. Once introduced into the soil, they tend to accumulate over time due to their low mobility and limited degradation. Consequently, areas subjected to prolonged exposure to heavy metals face increasing contamination levels, posing long-term threats to agricultural productivity [31]. Crops can absorb heavy metals from contaminated soils through their root systems. Some metals, like cadmium and lead, have a high affinity for root surfaces and can be readily taken up by plants, even in trace amounts [22,23]. These metals then get translocated to various plant parts, including edible portions, making them potential pathways for human exposure [24,25]. Therefore, heavy metals are toxic to both plants and humans. In plants, they can disrupt essential physiological processes, leading to reduced growth, chlorosis (yellowing of leaves), and nutrient imbalances [36,37]. Heavy metal contamination negatively impacts crop yield and quality. High levels of metals in the soil can lead to reduced plant productivity, stunted growth, and lower yields. Additionally, crops exposed to heavy metals may show a decline in nutritional quality, with decreased levels of essential nutrients like iron and zinc. Consequently, heavy metals can adversely affect soil fertility and microbial activity [26,27]. Soil microbes play a vital role in nutrient cycling and organic matter decomposition. Heavy metals can disrupt microbial populations and impair their metabolic processes, leading to imbalanced nutrient availability and degradation of soil health [28,29].

Obviously, the issue of heavy metal contamination extends beyond crop plants. Grazing animals consuming contaminated crops can experience the bioaccumulation of metals in their tissues. Humans consuming meat and dairy products from these animals also face exposure to heavy metals. Consumption of crops and food of animal origin contaminated with heavy metals can lead to a range of health issues in humans, including kidney and liver damage, neurological disorders, developmental problems in children, and an elevated risk of certain cancers [30].

In light of these considerations, heavy metal contamination poses significant food safety concerns. Regulatory bodies worldwide set maximum allowable limits for heavy metals in food products to safeguard public health [11,12,13]. Exceeding these limits can result in the recall of food products and substantial economic losses for farmers and the food industry

II. DISCUSSION

Wastewater irrigated fields can cause potential contamination with heavy metals to soil and groundwater, thus pose a threat to human beings . The current study was designed to investigate the potential human health risks associated with the consumption of okra vegetable crop contaminated with toxic heavy metals. The monitored heavy metals included Cd, Cr, Cu, Pb and Zn for their bioaccumulation factors to provide baseline data regarding environmental safety and the suitability of sewage irrigation in the future. The pollution load index (PLI), enrichment factor (EF) and contamination factor (CF) of these metals were calculated. The pollution load index of the studied soils

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indicated their level of metal contamination. The concentrations of Ni, Pb, Cd and Cr in the edible portions were above the safe limit in 90%, 28%, 83% and 63% of the samples, respectively. The heavy metals in the edible portions were as follows: Cr > Zn > Ni > Cd > Mn > Pb > Cu > Fe. The Health Risk Index (HRI) was >1 indicating a potential health risk. The EF values designated an enhanced bio-contamination compared to other reports . The results indicated a potential pathway of human exposure to slow poisoning by heavy metals due to the indirect utilization of vegetables grown on heavy metal-contaminated soil that was irrigated by contaminated water sources. [14,15,16]The okra tested was not safe for human use, especially for direct consumption by human beings. The irrigation source was identified as the source of the soil pollution in the study.

Studies have shown that cereal crops can absorb heavy metals from contaminated soils through their root systems. The extent of metal uptake varies among different cereal species, with some crops exhibiting higher metal accumulation than others [17,18]. Several factors influence the uptake process, including soil pH, metal concentration, soil organic matter content, and the presence of other elements that can compete for absorption sites on the root surface [19,20,21]. For example, certain cereal crops like rice and barley are known to have a higher affinity for the uptake of heavy metals like cadmium and arsenic. In contrast, other cereals, such as wheat and corn, have been found to accumulate lower levels of these metals under similar soil conditions [22,23,24]. Once taken up by the roots, heavy metals can be transported within the cereal plant through the translocation process [6,7,8]. This movement of metals from the roots to other plant organs is a critical aspect of the metal's behaviour within the plant. In some cases, heavy metals may be translocated to above-ground parts of the plant, such as leaves, stems, and grains [1,2,3,4,5]The translocation to the edible portions of the plant is of particular concern as it can lead to contamination of the human food chain. For instance, in rice, which is a staple food for nearly half of the world's population, heavy metals like cadmium and arsenic have been found to accumulate in the grains [25,26,27]. This accumulation can have severe health implications for consumers, as prolonged exposure to elevated levels of these toxic metals may lead to various health problems, including organ damage and increased cancer risk [9,10,11]. The translocation process is not uniform across all heavy metals and cereal crops. Some metals, like lead, tend to remain concentrated in the roots and are less efficiently transported to the above-ground plant parts. However, lead contamination in soils can still impact the quality of agricultural products and pose health risks to the ecosystem [60,61].

Therefore uptake and translocation of heavy metals in cereal crops are complex processes influenced by various environmental and plant-related factors. Elucidating the mechanisms of metal uptake and translocation in cereals is vital for developing strategies to minimize heavy metal accumulation in edible portions of crops and mitigate health risks associated with food consumption [26,27]. This is all the more complicated since certain cereal species show a greater propensity to accumulate heavy metals, while understanding these mechanisms and their variation is essential for safeguarding both crop productivity and human health. Implementing responsible soil management practices and exploring innovative approaches to reduce heavy metal uptake in cereals are essential steps toward ensuring food safety and promoting sustainable agriculture in a metal-contaminated world [28,29,30].

One notable metal-tolerant cereal crop is barley, which has been extensively studied for its ability to accumulate and sequester heavy metals, particularly cadmium and zinc, in its above-ground tissues [3]. Barley utilizes various strategies to cope with metal stress, including enhanced metal chelation by metal-binding compounds like phytochelatins and metallothioneins [11,12]. These compounds play an essential role in sequestering and detoxifying heavy metals, thereby protecting the plant from metal-induced oxidative damage. The metal tolerance and capacity to accumulate metals of barley make it a promising candidate for phytoremediation efforts in cadmium and zinc-contaminated soils. Similarly, rye has also exhibited exceptional metal tolerance properties, particularly in response to nickel and copper stress. Rye plants have been shown to accumulate elevated levels of these metals in their shoots without significant adverse effects on growth and yield [13,14]. This metal accumulation ability stems from the activation of various metal transporters and detoxification mechanisms that help rye plants cope with metal toxicity.

By leveraging the natural metal-accumulating abilities of barley, rye, and other tolerant cereals, it is possible to harness their potential to reduce metal levels in contaminated soils and restore ecological balance [15,16]. In

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addition to their applications in phytoremediation, these metal-tolerant cereal crops may also play a central role in sustainable agriculture practices. Cultivating these crops in metal-contaminated regions can not only help remediate the soil but also enable food production without compromising crop yield or quality. Utilizing metal-tolerant cereals for animal fodder or bioenergy production further expands their utility in a circular economy approach [17,18,19]. However, ensuring that the accumulated metals do not enter the food chain or pose health hazards is of utmost importance.

III. RESULTS

Indiscriminate industrialization and urbanization have negatively impacted our environment. One of the common environmental problems in semi-urban areas in India is the discharge of inefficiently treated municipal, industrial and domestic wastewater into the environment, resulting in the degradation of soil and water qualities.[25,26,27] Depleting freshwater resources have led Indian farmers to look for easily available, cheaper, and nutrient-rich sources of irrigation water in the form of wastewater; however, this also led to increased pollutant transfer to the soils. Known as persistent pollutants, heavy metals such as cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), mercury (Hg), and a few others are potentially hazardous due to their non-biodegradable nature, extended biological half-lives, and biological interactions. These heavy metals can bind to soil surfaces and then be absorbed by plant tissues. Vegetables supply micronutrients, antioxidants, vitamins, and other nutrients essential for human growth. Therefore, the consumption of vegetables/crops grown in wastewater-irrigated land poses a potential threat to humans. Since wastewater irrigation cannot be eliminated in the Indian (semi-)urban areas because of the ever-increasing demand for irrigation water, it is important to assess the impact of wastewater irrigation. This review article congregates the findings of studies from India [28]wherein heavy metal contaminations in vegetables have been reported. An attempt was made to estimate the risk to human health because of the long-term consumption of vegetables cultivated in wastewater-irrigated lands from the Indian sites. In addition to impairing enzymatic activities, heavy metals in the soil can interfere with nutrient uptake, posing another challenge to cereal crop physiology. Essential nutrients such as iron, zinc, and manganese are essential for various plant functions, and their uptake can be hindered in the presence of toxic heavy metals [20,22]. For instance, cadmium can compete with iron and zinc for uptake by plant roots, leading to nutrient imbalances and deficiencies. This interference disrupts vital cellular processes and can result in symptoms such as chlorosis (yellowing of leaves) due to reduced chlorophyll production [88].

Cereal crops often exhibit different responses to heavy metal stress, depending on the specific metal, its concentration, and the crop species, manifested by direct effects (as physiological responses) and indirect effects (as molecular and biochemical responses) [29,30]. For example, rice plants have been found to be particularly susceptible to cadmium accumulation in the grain, which can lead to significant human health concerns when consumed [90]. In contrast, barley and certain wheat cultivars have shown better tolerance to heavy metals, enabling them to survive and produce acceptable yields in metal-contaminated soils.

IV. CONCLUSION

The negative impact of heavy metal exposure on cereal crop yield and quality is a significant concern for worldwide food plenty. Elevated concentrations of heavy metals in the soil can have detrimental effects on various aspects of crop production, leading to compromised yields and altered nutritional composition in harvested grains .

Heavy metals in soil can affect various growth indicators in cereal plants, with the degree of impact varying depending on factors such as the metal type, concentration, exposure duration, and the cereal species involved . Some of the key growth indicators affected by heavy metals in soil

Heavy metals can also affect reproductive processes, leading to smaller seed size and reduced grain yield. For example, cadmium exposure has been linked to decreased pollen viability and lower seed production .Moreover, heavy metal contamination can alter cereal nutritional composition, potentially leading to micronutrient deficiencies

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in populations reliant on cereal-based diets [27,28]. The resultant decrease in essential nutrients like iron, zinc, and manganese can impact human and animal health [26]. Food products derived from these cereals, such as bread, pasta, and breakfast cereals, may consequently have compromised nutritional value .

Addressing the impact of heavy metals on cereal crop productivity and quality demands a holistic approach that includes the remediation of heavy metals in soil, responsible soil management practices, and the cultivation of crop varieties resistant to metal exposure [69,99]. Ongoing soil testing and monitoring play a critical role in early intervention, and alleviating the adverse effects of heavy metal exposure on cereal yield, quality, and food safety can help reduce health risks associated with contaminated cereals [28,29,30]

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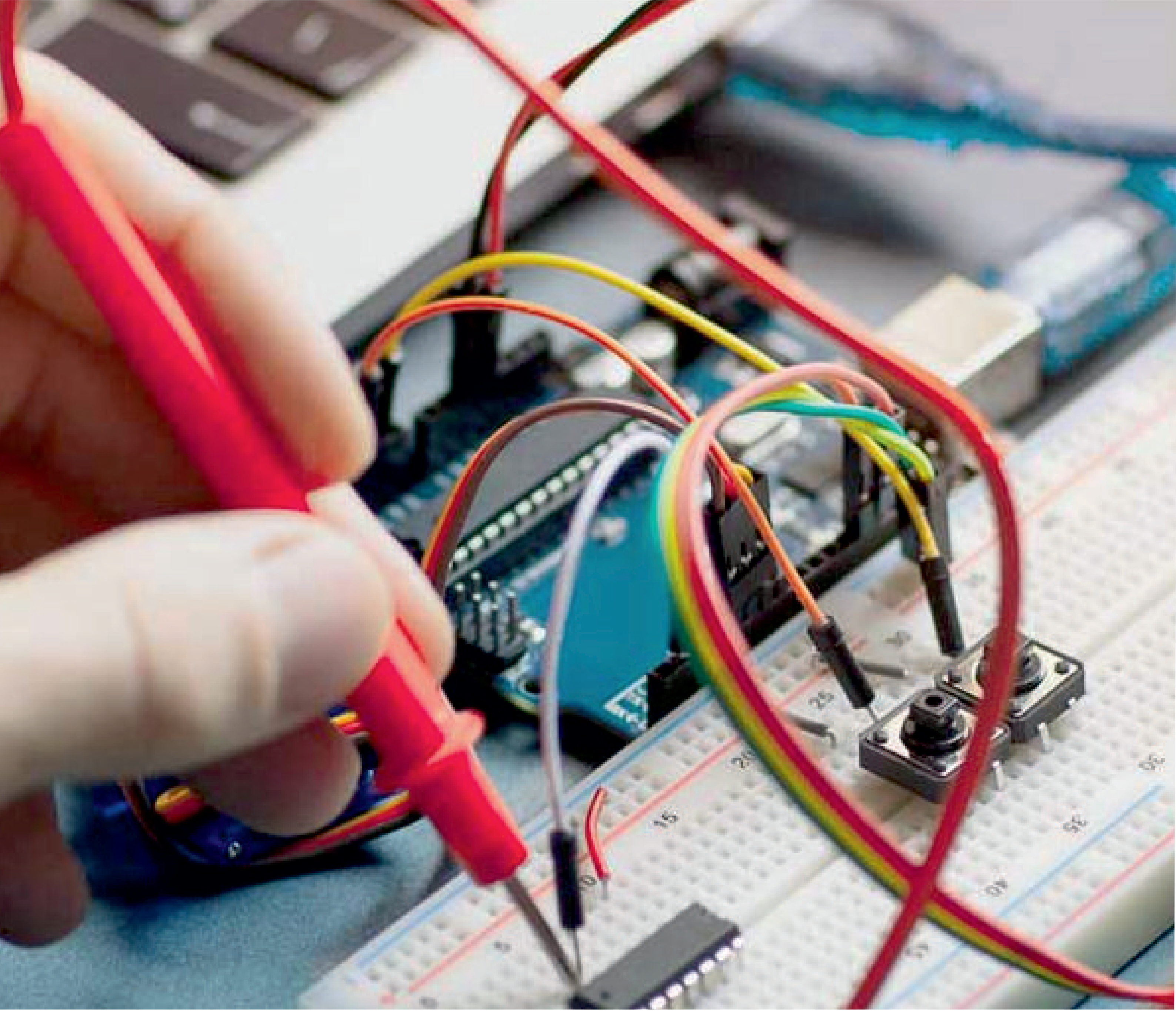

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