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THE IMPACTS OF COMBAT OPERATIONS ON THE ENVIRONMENTAL CONDITION OF SUNFLOWER CULTIVATION, OIL PRODUCTION, AND STORAGE IN UKRAINE

Introduction. Military operations have a devastating impact on the environment, causing severe damage to natural ecosystems, accelerating land degradation, and contributing to biodiversity loss.

Problem Statement. The contamination of agricultural land and industrial facilities involved in sunflower cultivation, storage, and processing has become a critical issue. This challenge is associated with the need to ensure the production of environmentally safe raw materials and products for both technical applications and the food industry.

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Purpose. This study aims to analyze the environmental consequences of contamination affecting crop production areas and industrial facilities of the oil and fat sector, as well as to examine the stratification of oilseed raw material quality, particularly in sunflower oil stored in tanks damaged by missile strikes.

Materials and Methods. The study has employed methods of scientific and technical literature review, analysis, classification, systematization, and generalization of available data on military operations in Ukraine. Laboratory analyses have also been conducted to determine the composition and quality characteristics of sunflower oil before and after exposure to explosive impacts.

Results. The study has identified ammunition residues and rocket fuel as the principal sources of environmental contamination during hostilities, as they contain toxic heavy-metal compounds and hazardous combustion products. During the first 214 days of the war, 6,215 fires have been recorded across an area of 486,162 ha, including 371,715 ha of agricultural land, while total greenhouse gas emissions have reached 23,764 million t of CO₂ equivalent. Laboratory analyses of sunflower oil have shown that, although the basic quality indicators remained relatively stable (acid value: 2.12 mg KOH/g; peroxide value: 10.8 meq/kg), concentrations of polycyclic aromatic hydrocarbons increased critically to 794.3 µg/kg, exceeding the regulatory limit more than fifteen times. In addition, the concentration of dioxin-like polychlorinated biphenyls increased significantly, with toxic equivalency values rising from 0.339 to 0.594 pg TEQ/g fat. These findings have confirmed severe contamination of the oil and have demonstrated substantial risks to food safety.

Conclusions. The findings have substantial practical significance for the development of environmental monitoring systems, the improvement of food safety standards, the planning of contaminated land remediation, and decision-making regarding the potential technical use of contaminated agricultural products.

Keywords: sunflower oil, military pollution, ecological consequences, port infrastructure, laboratory research, computer data processing, certification.

On the initiative of the UN General Assembly, the International Day for the Prevention of Exploitation of the Environment during War and Armed Conflict is celebrated annually on November 6 [1, 2]. Its purpose is to draw attention to the ecological consequences of war and the importance of refraining from senseless damage to ecosystems in pursuit of military objectives. The United Nations emphasizes that environmental damage caused during armed conflicts affects the state of natural resources long after their end and often goes beyond national territories and the lifetime of one generation [3]. Military operations lead to serious environmental problems that arise in the territory where they take place — these are the disruption of ecosystems, the destruction of environmentally dangerous industrial facilities, the deterioration of the sanitary and hygienic indicators of drinking water, the violation of the activities of nature conservation areas, soil pollution, etc. [4—7]. As a result of hostilities in Ukraine, the ecological condition of its south-eastern part with the corresponding representatives of flora and fauna suf-

fers significantly. The occupation of fields, forests, and territories by the military leads to considerable damage. The movement of heavy equipment, the construction of fortifications, and combat operations damage buildings and ground cover, which makes it impossible to grow a large number of crops and conduct agriculture in general.

Before the armed conflict, Ukraine had been steadily increasing its sunflower cultivation, which was due to the high profitability of this crop and significant demand on the world market. In 2015, the profitability of seed production reached over 80%, which made sunflower one of the most attractive areas for agrarian business. The crop occupied at least 15% of all sown areas in the country, which provided Ukraine with a leading position in the world — every fourth ton of sunflower seeds on the planet was of Ukrainian origin. At the same time, the country established itself as a major player in the sunflower oil market, accounting for almost a quarter of its global production. Domestic consumption of sunflower oil in Ukraine does not exceed 10%, so most of the production is

exported, mainly to Europe, Asia and the Middle East. Such a high level of exports requires compliance with international standards of quality and environmental safety, in particular control over pesticide residues, GMOs and heavy metals. In the EU countries, sunflower oil ranks second in popularity after rapeseed oil, ahead of soybean oil, and covers approximately 23% of the market. Such demand creates significant prospects for the development of the agro-processing industry, but at the same time requires a deep adaptation of Ukrainian production to modern European environmental standards. Currently, against the backdrop of the war, these positions are under threat due to the loss of crops, the destruction of infrastructure and logistics channels. The restoration of the industry will require not only technical resources, but also international support and modernization for the new conditions of the global market. However, from a unit of area, sunflower yields the highest yield of oil among other oil crops. The seeds of its zoned varieties and hybrids contain 50—52% of oil, and the seeds of selected varieties — up to 60%. The content of oil in seeds and its quality depends on the species, characteristics of the variety (hybrid) of plants, fertilizer, water regime, soil and other conditions. The introduction into the production of high-oil varieties and hybrids and the use of a perfect seed production system are of decisive importance in increasing the oil content in seeds [8—13].

Given the fact that the oil and fat industry has an important strategic importance for the country's economy, the issue of providing it with high-quality raw materials in the necessary volumes is urgent. Every enterprise of the food industry takes care of the quality of its products, as the main part of it is exported. In addition, the safety of food products and edible oil raw materials are among the main factors that affect the health of consumers. More than 70% of all pollutants enter the human body with food. Product safety is a guarantee that products will not harm the consumer and the environment during their production, preparation or consumption in accordance with their inten-

ded purpose. This applies to the presence of residues of mycotoxins, pesticides, pollution of a military nature (growing on contaminated areas), etc. Environmental friendliness is a guarantee of certain properties of the product, its characteristics and properties, the presence of appropriate proteins, fats, carbohydrates, vitamins and trace elements in the product without harmful impurities [14]. Nowadays, many scientists study the issue of processing of secondary raw materials [15—17], as well as obtaining environmentally safe agricultural products and practical aspects of environmentally safe sunflower production.

Summarizing the above, it should be noted that the deterioration of ecological conditions due to hostilities, the strengthening of soil degradation processes, problems with the production of safe food products require a detailed study of the impact of polluting factors on the processes of growing and storing sunflower and its oil raw materials. Therefore, the purpose of this study is to analyze the ecological consequences of the pollution of the territory of sunflower fields and to consider the issue of stratification of the quality of oil raw materials that underwent combustion changes in the chemical composition of soil and sunflower oil after a missile strike at the fat-oil complex enterprise.

THE MAIN SOURCES OF POLLUTANTS ENTERING THE ENVIRONMENT DURING HOSTILITIES

The full-scale war has led to the massive destruction of the infrastructure of Ukrainian cities and villages, but less obvious, although no less dangerous, are its long-term environmental consequences. The fighting has covered all climatic zones of Ukraine, causing the destruction of unique natural biosystems and ecosystems [18—21]. Areas of mass use of munitions have suffered chemical contamination, which threatens with toxic consequences for decades. Of particular danger are strikes on critical infrastructure — energy, chemical and industrial facilities — which provoke man-made disasters. Agricultural lands, which occupy

more than 70% of the country's territory, have suffered from physical destruction, mining and poisoning with heavy metals from ammunition and military equipment [22]. This not only reduces soil fertility, but also threatens the safety of food products and water resources. Sources of pollution, from explosive remnants to burned-out equipment, already pose a persistent threat to the environment. Before analyzing the impact of war on air, water, or soil in isolation, it is important to understand the scale and depth of these threats as a whole.

Chemical composition and features of use of some types of ammunition. Ammunition contains a wide range of toxic components that cause long-term environmental pollution. The initiating mixtures in the capsules — both in cartridges and in grenade detonators — usually consist of toxic substances such as lead azide ($\text{Pb}(\text{N}_3)_2$), lead trinitroresorcinate, antimony (Sb_2S_3), mercury and potassium chlorate (KClO_3). For example, a UZRG type primer contains about 200 mg of lead [23]. Explosives included in ammunition are often supplemented with compounds of tin, bismuth, strontium and magnesium, which increases the toxic load on the environment.

Armor-piercing shells with depleted uranium cores pose a separate threat. During impact, up to 70% of the uranium is converted into an aerosol of oxides (U_3O_8 , UO_2), which form finely dispersed radiotoxic dust. These particles remain in the air, settle on the soil and penetrate into groundwater, forming persistent pollution [24].

Understanding the chemical composition of modern ammunition allows us to predict the main sources of pollution, especially in areas of destruction of warehouses or massive use of weapons. The greatest risks are associated with heavy metals and radiotoxic elements that have a long period of decay and accumulation in ecosystems.

Missile weapons and their use. Among the weapons actively used in Ukraine, missiles of various types are especially dangerous — from multiple launch rocket systems to long-range cruise missiles. In addition to the destructive power of warheads, missiles pose a threat due to the use of toxic fuels —

both solid and liquid. For example, the Kh-101 cruise missile has a liquid turbojet engine, a warhead of up to 400 kg and a total mass of over 3.5 t. Its emissions during launch and explosion leave behind thousands of kilograms of harmful chemicals.

The remains of missiles that have not been completely burned pollute the soil, water and air, leaving behind heavy metals and toxic compounds. Solid fuel is considered less toxic in a stable state, but during combustion it releases hazardous substances, in particular CO, NO, NO_2 , Pb and PbO . The combustion of one ton of such fuel produces hundreds of grams of carbon monoxide, nitrogen oxides and lead, which settle in the environment. Modern precision missiles also use ammonium perchlorate (NH_4ClO_4), which releases chlorine, hydrogen chloride, nitrogen dioxide, and other toxic products when burned.

Added to this are the remnants of initiating explosives and materials from the missile's burned electronics, which form a complex toxic cocktail. All of these compounds have the potential to have long-term impacts on ecosystems and human health, especially in areas of mass missile damage.

OIL ASSESSMENT OF ENVIRONMENTAL IMPACT OF WARFARE ON SUNFLOWER CULTIVATION AND OIL PROCESSING AREAS

There are 32 large enterprises and almost 1,000 small oil mills operating in the Ukrainian oilseed market. The industry is characterized by a high level of production concentration. In 2019, 6,536 million t of unrefined sunflower oil were produced in Ukraine. According to industry associations, the market leaders occupy from 6 to 7% each, and in general, the top ten producers provide almost 49% of the total volume. As for refined sunflower oil, production reached 364.8 thousand t during the first six months of the marketing season, representing a 9.1% increase compared with the corresponding period of the previous year. This segment is also characterized by a relatively concentrated

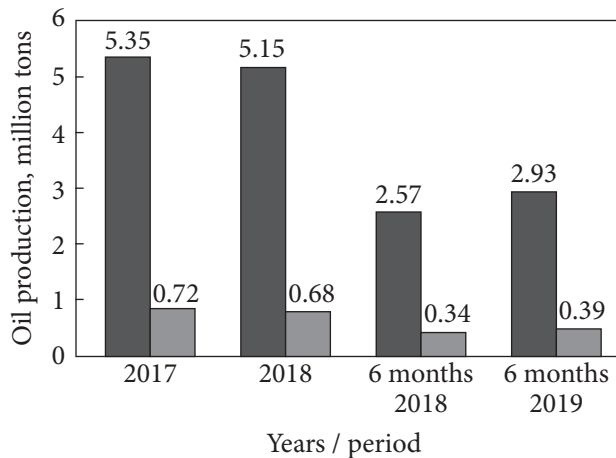


Fig. 1. Production of sunflower oil: ■ — unrefined sunflower oil and its fractions (except chemically modified); ■ — refined sunflower oil and its fractions [25]

market structure, with several leading enterprises each accounting for approximately 11% to 15% of total output. The production volumes of sunflower oil in Ukraine are presented in Fig. 1.

The demand for raw sunflower oil, both on the world market and within the country, remains high, which is why manufacturers actively compete in the raw material market. The main production facilities are located in regions with de-

veloped agricultural infrastructure, which often coincide with crop growing zones. The largest concentration of enterprises is in several eastern, southern and central regions of the country, where, unfortunately, a significant part of industrial facilities was damaged due to hostilities, which caused serious environmental pollution. According to environmental organizations, a large number of cases of potential environmental damage have been recorded, in particular due to violations of nuclear and energy safety, destruction of industrial enterprises, pollution of water resources and soils, which negatively affects ecosystems.

As for agriculture, sunflower is one of the leading industrial crops, which is grown mainly in the northern and central regions of the steppe zone of the country. The areas under this crop make up a significant part of all industrial and agricultural lands. In other natural zones — forest-steppe, southern steppe, as well as Polissia and the foothills of the Carpathians — sunflower is cultivated much less. In recent years, the area under sunflower has increased significantly, which indicates a high level of its economic attractiveness for agricultural producers in Ukraine and in the world as a whole. Detailed dynamics of sunflower cultivation in Ukraine are presented in the relevant statistical materials [26]. In table the trend of sunflower cultivation in Ukraine is shown (Table 1).

The impact of hostilities on sunflower sowing areas. The beginning of a significant increase in sunflower production in the steppe zone of Ukraine has been noted since the mid-2010s. During this period, the cultivation of this crop expanded in traditional regions, and also began to gain popularity in the northern and western regions, where its cultivation was previously limited due to climatic conditions, the lack of adapted varieties and the spread of diseases. A particularly noticeable increase occurred in the forest-steppe zone, where the area of crops increased significantly. Even in the Polissya zone, experiments with sunflower cultivation began, despite natural limitations. Relevant data on the structure of sown areas by region and natural zones are given in statistical materials. It should

Table 1. The Status of Sunflower Cultivation in Recent Years, 2011—2019

Year	Collected area, thousand ha	Output, thousand cwt	Yield, ts from 1 ha of harvested area
2011	4534.3	86974.6	19.2
2012	4868.3	83283.3	17.1
2013	4581.7	103583.0	22.6
2014	4987.1	99952.3	20.0
2015	4962.0	110871.1	22.3
2016	5756.8	131905.5	22.9
2017	5779.6	119377.5	20.7
2018	5923.4	138827.1	23.4
2019	5759.9	149234.4	25.9

Source: The authors' own analysis based on [26].

also be noted that some of these regions subsequently suffered significant damage due to hostilities, which is indicated in the relevant reports.

Data on sunflower acreage and their share in the overall structure of agricultural land by regions and natural zones of Ukraine for 2016 are provided in the relevant statistical materials (Table 2). It is important to note that as of 2022, some of these regions have experienced significant destruction and damage to agricultural land due to hostilities, which has affected production potential and the environmental situation. These regions are identified as areas with a particularly high level of risk for the agricultural sector and the environment.

Significant fires occurred in the south and east of Ukraine, which is marked on the map in (Fig. 2) In addition to agricultural fields, unique nature conservation areas were damaged and may not be able to be restored.

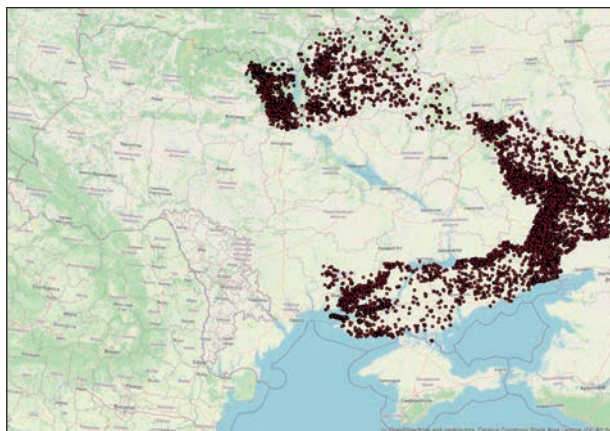


Fig. 2. Approximate map of fire sources [27]

Analysis of fire maps shows that the foci of ignition traditionally coincide with the areas of hostilities in the east, south and north of the country. Even in regions where active hostilities have ceased,

Table 2. Sunflower Cultivation Area*

Region	Total sown area, thousand, ha	Sown area under sunflower, thousand ha	Share in the structure of cultivated areas, %	Region	Total sown area, thousand, ha	Sown area under sunflower, thousand ha	Share in the structure of cultivated areas, %	Region	Total sown area, thousand, ha	Sown area under sunflower, thousand ha	Share in the structure of cultivated areas, %
Steppe	11621.2	3893.1	33.5	Forest steppe	10820.3	1822.2	16.8	Forested	4334.1	371.4	8.57
Dnipro	1892.5	631.4	33.3	Vinnitsia	1640.0	266.7	16.3	Volyn	550.9	6.4	1.16
Donetsk	978.7	332.5	33.9	Kyiv	1154.9	165.6	14.3	Zhytomyr	836.8	91.9	10.9
Zaporizhzhia	1606.7	601.9	37.4	Poltava	1714.1	312.5	18.2	Rivne	546.0	13.2	2.42
Kirovohrad	1683.9	577.4	34.3	Sumy	1114.9	196.9	17.7	Chernihiv	1183.1	207.3	17.5
Luhansk	772.6	339.5	43.9	Ternopil	810.3	55.1	6.80	Iv. Frankivk	369.6	23.1	6.25
Mykolaiv	1509.9	558.5	36.9	Kharkiv	1738.1	486.6	28.0	Lviv	660.5	26.3	3.98
Odesa	1839.1	468.6	25.5	Khmelnysk	1149.5	115.8	10.1	Zakarpattia	187.2	3.2	1.71
Kherson	1337.8	383.3	28.6	Cherkassy	1193.0	203.4	17.1				
				Chernivtsi	305.5	19.6	6.42				

* Sunflower cultivation regions that may be at risk of poisoning from hostilities are indicated in red.

Source: The authors' own analysis based on [27].



Fig. 3. Maxar satellite imagery (May 2022) illustrating the condition of arable land in southeastern Izium, Kharkiv Oblast, before and during military operations [29]

the risk of fires due to the remnants of hostilities remains high. Most of the territories are still mined, and the clearance process can last for years or even decades. Due to the intensity of hostilities, the number of fires caused by shelling, bombing and explosions on the territory of Ukraine has significantly increased.

In conditions of limited access to the affected areas, especially in combat zones, one of the most effective methods of fire control is satellite monitoring. Remote sensing is used to collect data on the number of fires, the time of their start and end, the boundaries of the foci, the area of affected land and their categories. This information is obtained from open information systems, which allow for a prompt assessment of the scale and consequences of fires. Generalized data on the im-

pact of fires on the territory are given in the relevant statistical materials (Table 3).

A comparison of satellite images (Fig. 3) of agricultural lands in one of the districts of Kharkiv Oblast before and after the fighting indicates that the further use of such lands will be extremely difficult and dangerous. Specialists have developed a methodology for assessing the impact of shelling on the condition of soils in the eastern regions of the country. On the example of an area of one square kilometer, hundreds of explosions of various calibers were recorded, which led to the ingress of a significant amount of metal and chemical pollutants into the soil. In addition, the explosions caused mechanical destruction and movement of large masses of soil, which significantly complicates the restoration of soil fertility and structure. The resto-

Table 3. Fires in Ukraine During the 214 Days of the War (with an area of more than 1 ha)

Distribution of fires on the territory of Ukraine	Number of fires	Total area of fires, ha	Area of fires on agricultural land, ha	Emissions from fires on agricultural land, thousand t CO ₂ eq.	General amount emissions, thousand t of CO ₂ eq.
Zone inactive hostilities to the front line	2,066	122,693	94,656	1,068	3,780
Near-front and front-line zones	3,724	315,046	234,002	2,640	18,736
Zone inactive hostilities from the opposite front line	425	48,423	43,057	486	1,248
Together	6,215	486,162	371,715	4,194	23,764

Source: The authors’ own analysis based on [28].

ration of such territories will require significant resources and time, including a large amount of fuel and equipment for leveling and cleaning.

Combat operations leave hundreds of wounds on the earth's surface, causing short-term destructive effects of the blast wave and long-term chemical pollution. During the explosion of ammunition of various calibers, a partial chemical reaction occurs, polluting the soil and air. In addition to relatively safe CO₂ and water vapor, toxic gases are released into the atmosphere — SO₂, NO_x, CO and aromatic hydrocarbons, which are especially dangerous. Sulfur dioxide and nitrogen oxides return to the soil with acid rain, changing its pH and causing plant burns. Thus, the soil becomes the final element of chemical pollution from ammunition. In addition, the soil is compacted, its structure and natural processes are disturbed — humification, weathering, moisture movement. The restoration of such soils is extremely slow, because the natural increase in soil thickness is on average only about 0.06 mm per year. There is often no vegetation near explosion sites, and the destruction of the impermeable rock layer accelerates the penetration of water into the soil horizons, leading to erosion and acidification of the soil instead of enriching it. Aggressive pollutants enter groundwater and rivers, which can spread far beyond the combat zone.

The impact of hostilities on industrial facilities of the fat-oil complex. Ukraine has territories saturated with industrial facilities. A significant part of them are potentially dangerous enterprises related to the production, processing and storage of highly toxic, explosive and fire-hazardous substances. To date, the State Register of PNO contains detailed information on more than 23,000 objects, which include industrial enterprises, mines, quarries, main gas, oil, and food pipelines, hydro-technical structures, hub railway stations, bridges, tunnels, accumulators and landfills of industrial waste, places of storage of dangerous substances, etc. The majority of these are located in the Donetsk, Dnipropetrovsk, Zaporizhzhia, Kharkiv, and Lviv Oblasts. Basically, these are fire hazar-

dous (41%), explosive (37%), chemically hazardous (7.9%), radiation hazardous (2.1%), hydrodynamically hazardous (1.85%) and biologically hazardous (1.8%) objects.

Many cases of shelling and airstrikes have damaged storage facilities for fuel, chemicals, food, medicine and paints. The destruction of industrial facilities causes fires, which further pollute the air, soil and water. The products of combustion contain toxic gases and particulates that harm the environment. Particularly serious pollution is observed in storage and production areas, where toxic substances enter the soil and water resources. Another source of increased danger for the environment is the destruction of facilities of the metallurgical and chemical industry, which leads to explosions of warehouses and storages of toxic or potent poisonous substances and their release into the environment. The consequences of the destruction during hostilities of such industrial giants as Azovstal, Avdiiv Coke Plant, Lysichan Oil Refinery, Sumykhimprom and other industries pose a serious threat to the environment.

As for the industrial objects of the oil and fat complex of Ukraine, the enterprises are conventionally divided into several categories: the first — enterprises that produce oil (oil and fat and oil extraction plants); the second — small oil producers (for which this is not the main type of activity); the third — producers of oil and fat products (margarine factories, soap factories); the fourth — warehouse impurities for storing sunflower components for transportation and sale. Regardless of the category, these objects can be classified as potentially dangerous, accidents at which can be the source of local emergency situations associated with the release of combustion products on a significant scale.

As a result of hostilities, explosions at industrial enterprises of the oil and fat complex are accompanied by the collapse and deformation of buildings, fires, and power system failures. Moreover, the striking factor of any explosion is the shock wave that occurs as a result of a sudden increase in pres-

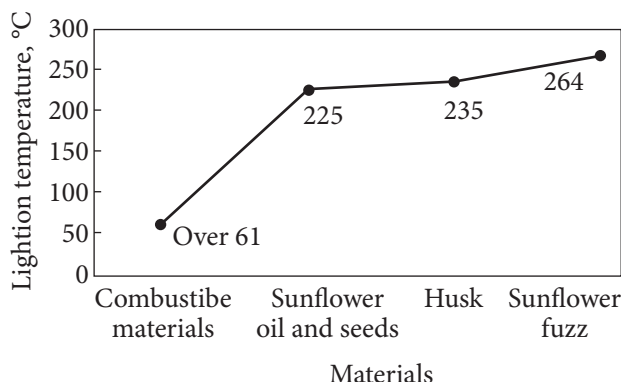


Fig. 4. Ignition temperature of sunflower components, °C

sure. The impact of the shock wave on building elements is characterized by a complex set of loads: direct pressure, reflection pressure, flow pressure, flow pressure, load from seismic blast waves.

The main raw material for oil production enterprises is sunflower seeds. As a result of the processing of oilseeds, products of primary processing (oil and meal), products of deeper processing (mayonnaise, margarine, soap, confectionery fats, oils), sunflower flour and protein acids are obtained. According to fire-explosive properties, raw materials, semi-finished products and finished products located in the premises of oil and fat industry enterprises are all combustible (Fig. 4). Since sunflower oil refers to substances that can catch fire from an ignition source and burn independently after its removal.

Some repair work takes place during wartime, but most rebuilding or reconstruction will take place after hostilities have ended. These restoration works will require a significant amount of construction materials, and transporting these materials to the construction sites and carrying out the construction work will require energy. In general, the reconstruction of Ukraine will lead to significant emissions of greenhouse gases. An approach based on taking into account the “carbon footprint” of construction materials is used to determine greenhouse gas emissions due to the reconstruction of civil infrastructure. According to this approach, all emissions, both direct and indirect, are assessed throughout the life cycle of the facility, excluding,

however, operational emissions. An assumption has been made that completely destroyed facilities will be fully restored, and therefore a 100% “carbon footprint” factor for the materials is applied. A factor of 33% was adopted for damaged objects. Thus, during the reconstruction of residential buildings, emissions will amount to 28,432 t of CO₂ eq., and for industry and business services — 3,615 t of CO₂ eq.

ENVIRONMENTAL CONSEQUENCES OF A ROCKET STRIKE ON TANKS WITH SUNFLOWER OIL AS A FOOD PRODUCT

As a result of the hostilities in Ukraine, the CWG discussed the impact of weapons use on goods grown and/or processed in Ukraine, in addition to all other supply/pesticide/labeling impacts. First, the CWG issued a general surveillance to monitor sunflower seeds and crude sunflower oil originating in Ukraine for a number of “known” contaminants, including dioxins, petroleum products, heavy metals, PAHs — in September 2022. In addition, general vigilance for unknown substances due to war was also emphasized. This topic was further discussed at the SAFCO meeting in October 2022, where it was decided to collect information from FEDIOL members on such “unknown” pollutants.

Nowadays, more and more people pay attention to the naturalness of manufactured products and their environmental friendliness. In order to meet consumer requirements, large producers of sunflower oil increasingly use the DSTU ISO 14024 standard in production. This certification is already recognized in more than 60 countries worldwide, including the countries of the European Union and the USA. Considering the fact that Ukraine is a large producer of sunflower oil, it simply obliges it to diligently monitor and constantly improve the quality of its products supplied to the world and local markets. This trend is ensured by the majority of Ukrainian manufacturers who want to bring their products to the world market and strive to fulfill their obligations to foreign partners. This is confirmed by an inspection carried out by the Euro-

pean Commission (EC) after detecting mineral oils in sunflower oil exported from Ukraine to EU countries. Based on the commission's findings, a report was drawn up on the prevention of mineral oil contamination of sunflower oil intended for export to EU countries. Following the recommendations of this report, the Ministry of Health of Ukraine developed and agreed with the Ministry of Agrarian Policy of Ukraine the Action Plan for the implementation of EC recommendations, which was sent to the European side. According to this plan, the Ministry of Health of Ukraine recommends the introduction of the HACCP international food safety system (Hazard analysis and critical control point) at oil and fat industry enterprises. The presence of HACCP systems in food industry enterprises becomes a mandatory requirement when entering the European market. This requirement is dictated by EU Council Directive 93/43/EEC of 14.07.1993 "On Food Hygiene." Article 20 of the Law of Ukraine "On the Quality and Safety of Food Products and Food Raw Materials" also stipulates that "subjects of entrepreneurial activity are physical and legal entities of all forms of ownership engaged in development, production, transportation, storage, import, as well as sale, use, utilization or destruction of food products and food raw materials, are obliged to implement measures for the step-by-step implementation at food industry enterprises of the international system for ensuring the safety of food products of HACCP."

The main guarantee of the safety of oil and fat products produced in Ukraine is the control of oil seeds and their processing products according to the main quality indicators: fatty acid composition, group composition of phospholipids, content of fat-soluble vitamins, content of sterols, content of wax-like compounds, presence of transisomers of fatty acids, residual amount of ecotoxins (organochlorine derivatives), namely pesticides, the content of polycyclic aromatic hydrocarbons (benz(a)perene), polychlorinated biphenyls, etc.

For producers and consumers of vegetable oils, phyto-oils and modified fats, the problem of im-

proving product quality and improving methods of its control is relevant. An important aspect of modification process management is the need to formulate a generalized indicator that uniquely characterizes the quality of modified oils and fats. Their quality according to state standards is determined by several indicators. Of these, melting point and hardness are mainly used to control the process. But these, as well as other regulatory indicators, do not sufficiently characterize the nutritional and biological value of modified products. For oil and fat raw materials and finished products of domestic production, reliable information on the fatty acid composition is necessary in accordance with the requirements of international standards of the ISO 9000 series. Therefore, modern methods of physicochemical analysis (chromatographic, spectrometric and other) are used to assess the quality of sunflower oil.

Every company cares about the safety and quality of sunflower oil, which is transported to other countries through port elevators, so oil tests are constantly conducted. As a result of military actions, questions about reliability and ecology of port machinery and units are also of great importance [30, 31]. For example, at one enterprise where tanks with sunflower oil are mixed, scheduled sampling was carried out, but as a result of hostilities, several tanks with sunflower oil were damaged by a missile strike, which are shown in (Fig. 5). Moreover, according to fire and explosive classification, tanks with sunflower oil can be classified as category V (flammable).

When considering this case, it should be noted that unrefined sunflower oil was stored in shore tanks. Each such tank is designed for 6,800 t of raw materials. The condition of the oil was regularly monitored by the terminal staff for 3–4 months in accordance with ISO 5555, samples were taken weekly, the last sampling (before the explosion) was carried out on 20.06.2022. After the missile strike, two tanks were destroyed and the fire lasted for more than 48 hours, releasing large volumes of toxic combustion products into the air. After extinguishing the fire, some of the oil remained and



Fig. 5. Consequences of a missile strike on tanks with sunflower oil [32]

the next sampling of this contaminated substance took place on June 26, 2022.

The comparison of oil from intact and damaged tanks was carried out according to two main

criteria: quality parameters and safety parameters. The quality parameters of crude unrefined oil a few days before the missile attack are presented in Table 4.

Table 4. Quality Parameters of Crude Unrefined Oil a Few Days before the Missile Attack

Parameter	Standard	Unit	Shoretank #5	Shoretank #6	Shoretank #M3	Shoretank #M1
Acid value	ISO 660:2020	mgKOH/g	1.30	1.17	1.65	4.38
Acidity (FFA) expr. in oleic acid		% (m/m)	0.65	0.59	0.83	2.20
Moisture and volatile material content	ISO 662:2016	% (m/m)	0.05	0.06	0.15	1.03
Peroxide value	ISO 3960:2017	meq/kg	7.30	7.80	6.80	4.90
Peroxide value		mmol/kg	3.6	3.9	3.4	2.5

The results of the table correspond to the quality standards according to DSTU 4492:2005 and are as follows: moisture and volatile substances (ISO 662) — 0.05—1.03%; peroxide value (ISO 3960) 4.9—7.8 meq/kg; acid number (ISO 660) — 1.3—4.38 mgKOH/g.

After the missile attack, the sludge (a mixture of crude sunflower oil and water after extinguishing the fire) was tested for the same quality parameters as for the intact oil. The following results were obtained: humidity — 0.74%; peroxide number — 10.8 meq/kg; acid value — 2.12 mgKOH/g. These results correspond to the indicators of quality oil of the highest grade according to DSTU 4492:2005.

In addition to quality indicators, safety indicators were determined using the liquid chromatography method, according to which polyaromatic

hydrocarbons have significant differences before and after a missile strike (Table 5).

Norms for polyaromatic hydrocarbons are not clearly defined for crude unrefined oil, in comparison with refined. However, based on the standard GMP+ D 4.12 “Minimum specifications for feed fats,” which indicates that proposed action and rejection limit Action limit 15 µg BAPEQ/kg (on fat basis) Rejection limit 50 µg BAPEQ/kg (on fat basis) [33]. In our case, the PAH data significantly exceeded the norms almost 16 times, that is, such oil cannot be suitable for fodder purposes, let alone be used for the production of food products. In addition, using the gas chromatography method, Dioxins and PCBs on composite were determined, which are considered to be one of the most toxic substances, the obtained data are summarized in (Table 6).

Table 5. Polyaromatic Hydrocarbons (red color — parameters of contaminated oil)

Parameter	Method	Unit	LOQ	Shore-tank #5	Shore-tank #6	Shore-tank #M3	Shore-tank #M1	Damaged oil results
Benzo[a]anthracene	SGS-UA1-0026 (based on DFG S19/L00.00-34; ISO 15302:2007)	µg/kg	0.50	2.40	1.50	5.10	7.00	150.8
Chrysene	SGS-UA1-0026 (based on DFG S19/L00.00-34; ISO 15302:2007)	µg/kg	0.50	4.60	2.90	14.90	17.30	361.2
Benzo[b]fluoranthene	SGS-UA1-0026 (based on DFG S19/L00.00-34; ISO 15302:2007)	µg/kg	0.50	2.10	1.30	3.20	4.20	75.5
Benzo[a]pyrene	SGS-UA1-0026 (based on DFG S19/L00.00-34; ISO 15302:2007)	µg/kg	0.50	2.20	1.40	4.40	8.20	206.8
PAH Summation	SGS-UA1-0026 (based on DFG S19/L00.00-34; ISO 15302:2007)	µg/kg	0.50	11.3	7.1	27.6	36.7	794.3

Table 6. Dioxins and PCBs on the Composite

Parameter	Method	Unit	WHO-TEF	LOQ *	Intact oil results	Damaged oil results
2,3,7,8-TCDD	SGS-UA-0040 *	pg-TEQ/g fat	1	0.05	<0.05	<0.05
1,2,3,7,8-PeCDD	SGS-UA-0040 *	pg-TEQ/g fat	1	0.08	<0.08	<0.08
1,2,3,4,7,8-HxCDD	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.1	<0.01	<0.01
1,2,3,6,7,8-HxCDD	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.1	<0.01	<0.01
1,2,3,7,8,9-HxCDD	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.1	<0.01	<0.01
1,2,3,4,6,7,8-HpCDD	SGS-UA-0040 *	pg-TEQ/g fat	0.01	0.1	<0.001	<0.001
OCDD	SGS-UA-0040 *	pg-TEQ/g fat	0.0003	0.2	<0.00006	<0.00006

End of Table 6

Parameter	Method	Unit	WHO-TEF	LOQ *	Intact oil results	Damaged oil results
2,3,7,8-TCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.05	<0.005	0.044
1,2,3,7,8-PeCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.03	0.1	<0.003	0.022
2,3,4,7,8-PeCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.3	0.05	<0.015	0.030
1,2,3,4,7,8-HxCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.1	<0.01	0.01
1,2,3,6,7,8-HxCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.1	<0.01	0.06
1,2,3,7,8,9-HxCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.1	<0.01	0.10
2,3,4,6,7,8-HxCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.1	<0.01	0.05
1,2,3,4,6,7,8-HpCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.01	0.1	<0.001	<0.001
1,2,3,4,7,8,9-HpCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.01	0.1	<0.001	0.004
OCDF	SGS-UA-0040 *	pg-TEQ/g fat	0.0003	0.2	<0.00006	<0.00006
dioxin-like PCB 77	SGS-UA-0040 *	pg-TEQ/g fat	0.0001	2	0.0003	0.0005
dioxin-like PCB 81	SGS-UA-0040 *	pg-TEQ/g fat	0.0003	0.5	<0.00015	<0.00015
dioxin-like PCB 126	SGS-UA-0040 *	pg-TEQ/g fat	0.1	0.5	<0.05	<0.05
dioxin-like PCB 169	SGS-UA-0040 *	pg-TEQ/g fat	0.03	2	<0.06	<0.06
dioxin-like PCB 105	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	10	0.0005	0.0006
dioxin-like PCB 114	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	5	<0.00015	<0.00015
dioxin-like PCB 118	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	25	0.00133	0.00151
dioxin-like PCB 123	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	5	<0.00015	<0.00015
dioxin-like PCB 156	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	5	<0.00015	<0.00015
dioxin-like PCB 157	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	5	<0.00015	<0.00015
dioxin-like PCB 167	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	5	<0.00015	<0.00015
dioxin-like PCB 189	SGS-UA-0040 *	pg-TEQ/g fat	0.00003	5	<0.00015	<0.00015
non-dioxin-like PCB 28	SGS-UA-0040 *	ng/g fat	N/A	1	<1	<1
non-dioxin-like PCB 52	SGS-UA-0040 *	ng/g fat	N/A	1	<1	<1
non-dioxin-like PCB 101	SGS-UA-0040 *	ng/g fat	N/A	1	<1	<1
non-dioxin-like PCB 138	SGS-UA-0040 *	ng/g fat	N/A	1	<1	<1
non-dioxin-like PCB 153	SGS-UA-0040 *	ng/g fat	N/A	1	<1	<1
non-dioxin-like PCB 180	SGS-UA-0040 *	ng/g fat	N/A	1	<1	<1
TEQ (WHO) for PCDD/Fs including LOQs for non-quantified congener	SGS-UA-0040 *	pg-TEQ/g fat	N/A	N/A	0.22612	0.48072
TEQ (WHO) FOR DIOXIN-LIKE PCBs INCLUDING LOQS FOR NON-QUANTIFIED CONGENER	SGS-UA-0040 *	pg-TEQ/g fat	N/A	N/A	0.11310	0.11367
TEQ (WHO) FOR PCDD/F + DI-OXIN-LIKE PCBs INCLUDING LOQS FOR NON-QUANTIFIED CONGENER	SGS-UA-0040 *	pg-TEQ/g fat	N/A	N/A	0.33922	0.59439

Note: yellow color — changed parameters; red color — parameters of contaminated oil.

* Testing method SGS-UA-0040 according to Commission Regulation (EU) No. 1881/2006

Dioxins and PCBs were evaluated in accordance with the European directive [34] indicators of toxic groups (blue area in the table) of damaged oil did not exceed the maximum permitted levels, but significantly increased compared to oil whose tanks were not hit by a missile.

Therefore, the safety indicators vary significantly in the study of oil. Among the dangerous substances, PAHs are singled out due to their negative impact on human health, which is associated with cardiovascular diseases, cancers, etc. PAHs have contributed significantly to our understanding of the adverse health effects of exposure to environmental pollutants, including chemical carcinogenesis. On the other hand, dioxins and dioxin-like PCBs are toxic chemicals with carcinogenic and genotoxic effects, as well as endocrine disruptors. Their influence is associated with chronic effects on reproductive function and hormonal balance, immune and nervous systems. Currently, EU countries pay a lot of attention to the safety control of oil-fat products, including the content of benzo(a)pyrene in vegetable oils. EU Commission Directive 208/2005/EEC strictly regulates the content of polycyclic aromatic hydrocarbons in food products. In particular, the content of benz(a)pyrene in fat should not exceed 0.002 mg/kg (1 ppb in food products).

Considerable attention is paid to the control of vegetable oils for the content of organic ecotoxins — pesticides, polychlorinated biphenyls (PCBs), which belong to the class of organochlorine compounds and have a number of specific properties, namely bioaccumulation due to the fact that PCBs have a high solubility in fats, just like organochlorine pesticides. Therefore, the risk of toxic substances entering food and food raw materials increases, and operational management of the environmental situation as a whole becomes more difficult.

Today, in the conditions of hostilities, Ukrainian producers of sunflower oil generate the necessary search for new ways of developing ecologically safe approaches to sunflower cultivation. The production of sunflower oil plays an important role for Ukraine. First, it is the fastest and most eco-

nomical way to qualitatively improve the satisfaction of the population's needs with energy food products. Secondly, vegetable oil is gaining importance as a raw material, the production of which enables farms to solve the problem of providing fuel and lubricants, spare parts and other means of production. Thirdly, it is a solution to the acute problem of fodder for livestock. So, when processing seeds, valuable concentrated products (cake and meal) are obtained, in addition, cruciferous oilseeds (rapeseed, mustard seed, mustard) of universal use and give the opportunity to obtain up to 30—35 t/ha of high-protein green mass. The restraining factors of the development of the oil and fat complex of Ukraine today are not only the unsatisfactory material and technical base of agricultural enterprises, due to which, according to expert estimates, up to 10—15% of the harvest of oil crops is lost annually, but also a significant decrease in the acreage contaminated by hostilities on south and east of Ukraine.

Environmental pollution and the unfavorable ecological situation in the fields and in industrial areas necessitate constant environmental analytical control (EAC) of air pollution, water quality, and the accumulation of hazardous compounds in the soil and bottom sediments. In accordance with various international agreements, about 60 chemical substances (priority pollutants) have been included in the lists providing for the limitation of their distribution. Currently, the UNEP specifically singles out a group of 12 compounds that should be given priority attention in environmental studies. This so-called “dirty dozen” includes the following substances: polychlorinated biphenyls, polychlorinated dibenzo-p-dioxin, polychlorinated dibenzofurans, aldrin, dieldrin, dichloro-diphenyl-trichloroethane, endrin, chlordane, hexachlorobenzene, mirex, toxaphene and heptachlor. The accumulation of heavy metals in the soil disrupts its physicochemical properties: the structure changes, water permeability decreases, aeration worsens. This creates unfavorable conditions for the development of microorganisms responsible for the decomposition of organic matter and the circulation of nut-

rients. As a result, the humus content decreases, the activity of soil enzymes decreases, and the nitrogen, phosphorus, and potassium regimes deteriorate. Heavy metals can disrupt the functioning of the plant root system, block the absorption of nutrients and water. In high concentrations, they have a toxic effect, causing growth inhibition, reduced yield, and the accumulation of toxins in agricultural products, which is dangerous to human health. Soil restoration is possible through the use of biological (phytoremediation, green manure), chemical (liming, organic fertilizers) and agrotechnical methods (land reclamation, deep loosening). The effectiveness depends on the level of contamination, soil type and the correct selection of measures. An integrated approach allows for the gradual restoration of fertility and ecological safety of degraded lands.

However, based on the results of the analysis of regulatory documentation and monitoring of ecotoxicants, it can be concluded that the current regulatory documentation, which regulates the requirements for monitoring the safety indicators of raw materials and finished products of oil and fat enterprises, needs to be revised as a result of hostilities.

A possible solution for growing sunflowers in polluted areas could be the transition of the fat and oil industry to the processing of sunflowers for

technical purposes (biofuel, oil, etc.). However, but the situation with the possibilities of growing sunflowers for biofuel purposes on contaminated land is very similar to the situation with growing them for food. The issue of pollutant migration from soil to biofuel is poorly researched, and therefore it is difficult to guarantee adherence to biofuel quality standards.

To mitigate environmental risks in sunflower cultivation and processing areas affected by hostilities, a set of systemic measures is needed. Key among them is environmental monitoring of air, soil, water, seeds, and oil, followed by the creation of environmental passports for contaminated sites such as fields, warehouses, and processing facilities. Soil remediation should include phytoremediation using crops like rapeseed or mustard, and mechanical removal in cases of severe contamination. Damaged oil tanks require chemical or biochemical detoxification if the oil can be recovered; otherwise, it should be repurposed for technical use. Identifying undamaged zones for safe farming and ensuring buffer areas to prevent cross-contamination will help maintain production continuity. Mandatory certification of oilseeds from affected areas and compensation programs for agricultural recovery are also crucial. Finally, training farmers on safe practices and environmental compliance will support sustainable restoration.

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ВПЛИВ БОЙОВИХ ДІЙ НА ЕКОЛОГІЧНИЙ СТАН ВИРОЩУВАННЯ СОНЯШНИКУ, ВИРОБНИЦТВА ТА ЗБЕРІГАННЯ ОЛІЇ В УКРАЇНІ

Вступ. Військові дії мають нищівний вплив на довкілля, завдаючи непоправної шкоди природним екосистемам, що призводить до деградації земель та втрати біорізноманіття.

Проблематика. Питання забруднення і подальшого використання полів та підприємств з вирощування, зберігання та переробки соняшнику є актуальним, оскільки зумовлене потребою виробництва екологічно безпечної продукції технічного призначення і харчової промисловості.

Мета. Проаналізувати екологічні наслідки забруднення площ посівів і промислових об'єктів олійно-жирового комплексу та розглянути питання стратифікації якості олійної сировини, зокрема з пошкоджених після ракетних ударів резервуарів.

Матеріали й методи. Застосовано методи пошуку науково-технічної літератури, аналізу, класифікації, систематизації та узагальнення наявних даних про бойові дії на території України, а також лабораторні методи визначення складу соняшникової олії до та після впливу вибухових речовин.

Результати. Основними джерелами забруднення довкілля під час бойових дій є боєприпаси та ракетне паливо, що містять токсичні сполуки важких металів і продуктів згоряння. За 214 днів війни зафіксовано 6215 пожеж на площі 486 162 га, з яких 371 715 га — сільськогосподарські землі, а сумарні викиди становили 23 764 тис. т CO₂-еквіваленту. Аналіз соняшникової олії показав, що після ракетного удару при відносному збереженні базових показників якості (кислотне число 2,12 мг KOH/г, перекисне число 10,8 meq/kg) відбулося критичне зростання поліароматичних вуглеводнів до 794,3 мкг/кг (перевищення норми більш ніж у 15 разів) та збільшення діоксиноподібних поліхлорованих біфенілів (TEQ з 0,339 до 0,594 pg-TEQ/g жиру), що свідчить про небезпечне забруднення продукції.

Висновки. Отримані результати мають практичне значення для впровадження систем екологічного моніторингу, удосконалення стандартів безпеки харчових продуктів, для планування відновлення забруднених територій і прийняття рішень щодо можливого технічного використання забрудненої сільськогосподарської продукції.

Ключові слова: соняшникова олія, військове забруднення, екологічні наслідки, портова інфраструктура, лабораторні дослідження, комп'ютерна обробка даних, сертифікація.