Jurnal Ilmiah Pertanian
Article
https://journal.unilak.ac.id/index.php/jip/
J | I | P

# A comparative study on pesticide residue profiles in locally grown rice from conventional and sustainable agricultural methods

# Studi perbandingan residu pestisida di dalam beras lokal petani dari lahan dengan budidaya konvensional dan pertanian berkelanjutan

Indra Purnama[1,4]*, Farag M. Malhat[2], Anisa Mutamima[3], Fikratul Ihsan[5], Amalia[6]

[1]Department of Agrotechnology, Faculty of Agriculture, Universitas Lancang Kuning, Pekanbaru, Indonesia
[2]Central Agricultural Pesticide Laboratory, Agriculture Research Center, Giza, Egypt
[3]Department of Chemical Engineering, Faculty of Engineering, Universitas Riau, Pekanbaru, Indonesia
[4]Graduate School of Environmental Sciences, Universitas Lancang Kuning, Pekanbaru, Indonesia
[5]Department of Agricultural Product Technology, Faculty of Agriculture, Universitas Lancang Kuning, Pekanbaru, Indonesia
[6]Department of Agribusiness, Faculty of Agriculture, Universitas Lancang Kuning, Pekanbaru, Indonesia

ARTICLE INFO

***Article History***
**Received:** Nov 20, 2023
**Accepted:** Dec 22, 2023
**Available Online:** Dec 24, 2023

***Keywords**:*
*pesticide residue,*
*rice cultivation,*
*green economy,*
*environmental impact,*
*food safety*

**Cite this:**
*J. Ilm. Pertan.*, 2023, 20 (3) 219-231
**DOI:**
https://doi.org/10.31849/jip.v20i3.17122

*Corresponding author*
*E-mail: indra.purnama@unilak.ac.id*

## ABSTRACT

Amid escalating concerns about pesticide residues in agricultural product, this study conducts a meticulous comparative analysis of pesticide residue profiles in locally grown rice, aiming to contribute essential insights for informed decision-making in agriculture. The overarching problem addressed involves identifying pesticides in rice from conventional and sustainable farming and understanding their potential environmental and health implications on food safety. Utilizing HPLC/MS-MS, the research discerns a notable absence of over 500 pesticide types in rice cultivated according to good agricultural practices (GAP). Conversely, rice from fields deviating from GAP guidelines reveals the presence of 7 pesticide active ingredients, with 2 exceeding globally established residue limits by twice the recommended amount. Notably, bifenthrin and tebuconazole, uncommonly used in the last one years, are identified. This study underscores the urgency of adhering to sustainable agricultural practices for the safety and quality of rice, offering critical insights for future research. It not only contributes to current knowledge but also emphasizes the global necessity of safe agricultural practices to safeguard our food supply.

## ABSTRAK

Dalam menghadapi kekhawatiran meningkatnya residu pestisida dalam produk pertanian, penelitian ini dilakukan dengan menganalisis perbandingan yang cermat terhadap profil residu pestisida pada beras lokal, dengan tujuan memberikan wawasan penting untuk pengambilan keputusan yang berbasis informasi dalam pertanian. Permasalahan utama yang diatasi adalah mengidentifikasi pestisida dalam beras dari pertanian konvensional dan berkelanjutan, serta memahami potensi dampak lingkungan dan kesehatan mereka terhadap keamanan pangan. Dengan menggunakan HPLC/MS-MS, penelitian ini mengungkap ketiadaan mencolok lebih dari 500 jenis pestisida dalam beras yang ditanam sesuai dengan praktik pertanian yang baik (GAP). Sebaliknya, beras dari lahan yang menyimpang dari panduan GAP menunjukkan keberadaan 7 bahan aktif pestisida, dengan 2 melebihi batas residu yang ditetapkan secara global sebanyak dua kali lipat dari jumlah yang direkomendasikan. Hal mengejutkan lainnya, bifenthrin dan tebuconazole, yang sudah tidak lagi digunakan dalam satu tahun terakhir, teridentifikasi. Studi ini menekankan urgensi untuk mematuhi praktik pertanian berkelanjutan demi keamanan dan kualitas beras, memberikan wawasan kritis untuk penelitian masa depan. Studi ini tidak hanya memberikan kontribusi pada pengetahuan saat ini tetapi juga menekankan kebutuhan global akan praktik pertanian yang aman untuk melindungi pasokan pangan kita.

e-ISSN: 2502-5988
p-ISSN: 1829-8346

## INTRODUCTION

Pervasive concerns regarding the existence of pests in agricultural ecosystems have propelled the extensive use of pesticides, presenting a double-edged sword. While these chemical interventions aim to protect crops and secure food supplies, their indiscriminate application raises profound environmental and public health apprehensions (Purnama and Mutamima, 2023; Tudi et al., 2021; Damalas & Eleftherohorinos, 2011). According to Sharma et al. (2019), approximately 2 million tons of pesticides are utilized globally each year, with 50% constituting herbicides (such as glyphosate, paraquat, and other active ingredients for weed control), 30% insecticides (including neonicotinoids and other active insecticidal compounds), 18% fungicides, and the remaining portion comprising rodenticides and nematicides, as illustrated in Figure 1.

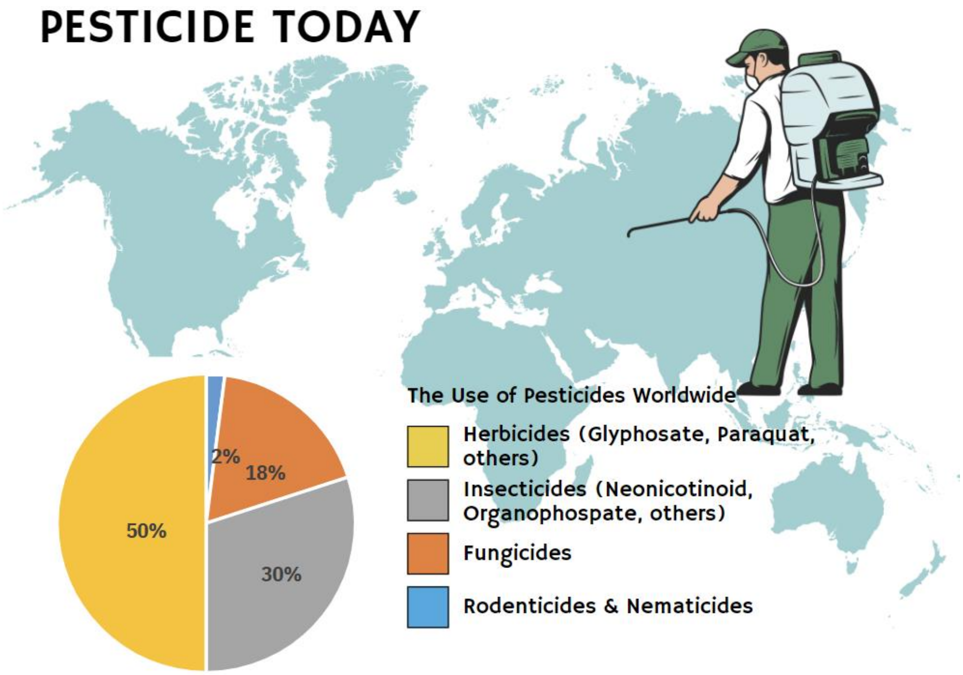


**Figure 1**. Global distribution of pesticide utilization by type. Reproduced with permission from Purnama & Mutamima (2023)

According to research by the Food and Agriculture Organization (FAO, 2019), pesticide residues in agricultural products can impact human health. If consumed over an extended period, pesticide residues can lead to various health issues, including disruptions in organ function, hormonal imbalances, and, in some cases, may even contribute to the development of cancer (Lushchak et al., 2018). In this context, consumers often emerge as the most vulnerable group to health risks associated with pesticide residues, considering they are at the end of the food chain.

Rice, serving as the primary dietary staple for over 50% of the global population and a majority in Indonesia, occupies a critical nexus at the confluence of agricultural practices, environmental conservation, and public health. Ardiwinata and Nursyamsi's (2012) research, conducted in the rice production hub of Central Java, revealed pesticide residues in all sampled rice, underscoring the pervasive presence of these contaminants. The prevalent use of pesticides in conventional farming, while a widespread practice, has inadvertently contaminated this essential food source. The implications of such contamination extend beyond fields, impacting the broader ecological equilibrium and, more crucially, the well-being of consumers. Prior research has highlighted the potential hazards associated with pesticide residues in agricultural products, prompting a nuanced exploration of cultivation practices to ensure food safety and sustainability (Ali et al., 2021; Kumari and John, 2019; Queirós et al., 2018; Lushchak et al., 2018). This study represents a pivotal contribution to existing knowledge, focusing on the comparative analysis of pesticide residue profiles in rice cultivated through conventional and sustainable agricultural methods. Given the scarcity of comparative studies addressing pesticide residues in rice with distinct cultivation techniques, particularly in Indonesia, where existing comparisons often on socio-economic and production aspects (Kılıç et al., 2020; Mahmood & Gheewala, 2023), or narrowly focus on a limited set of pesticide residues due to the constraints of pesticide standards in Indonesian laboratories (Andina, 2015; Nurjannah et al., 2020; Prabawardani et al., 2020).

At the global level, the use of pesticides and the issue of pesticide residues have become a serious concern, particularly due to the health risks they pose (Jepson et al., 2020). The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) have established maximum residue limits for various agricultural products circulating in the international market. However, monitoring and enforcing these pesticide residue limits often pose challenges, especially in developing countries with significant agricultural sectors and suboptimal surveillance systems, as is the case in Indonesia. By employing advanced analytical techniques (HPLC/MS-MS), this research aims to unravel the intricacies of pesticide residues, providing crucial insights for the development of evidence-based agricultural policies and sustainable farming practices. The findings of this study hold implications for future research on sustainable farming methods, emphasizing the necessity for global adherence to safe agricultural practices to safeguard our food supply.

## MATERIALS AND METHODS

### *Site description*

This study was conducted in Buantan Lestari Village, Siak District, Riau Province, Indonesia (0°56'56.9"N 102°01'54.5"E) (Figure 2). The location selection was carried out purposively with the consideration that the farmers in this village were already market-oriented and were one of the food centers in Riau Province, Indonesia. This region had a wet tropical climate, where the lowest temperature was 24°C, and the highest was 35°C. The soil type of paddy fields was classified as peatland or Organosol (USDA soil taxonomy). The area had been used for growing rice for more than 30 years, and the cropping system was twice a year. There were three farming systems developed by farmers in the area, organic planting (not using inorganic fertilizers and synthetic pesticides), conventional planting with integrated pest control management (IPM) principles, and conventional planting without IPM principles. Conventional planting without IPM principles directly used pesticides exceeding the recommended dose when attacked by a pest or disease.

### *Inventory of pesticides used and collecting rice samples*

This research employs a purposive sampling approach for the selection of rice fields to be used as sample sources. Sample collection was conducted by considering specific criteria, ensuring a significant difference between sustainable farming plots (adhering to Good Agricultural Practices – GAP, only two rice field) and conventional plots that excessively use pesticides. The analysis focused on four rice samples sourced from distinct farming practices. Two of these samples originated from fields cultivated by farmers abstaining from conventional pesticides, while the remaining two were obtained from lands where excessive pesticide application was a prevalent practice among farmers. This sampling strategy aimed to juxtapose the pesticide-free cultivation with the consequences of intensive pesticide usage, providing a nuanced perspective on the pesticide residue profiles in the examined rice samples. Meanwhile, the sampling technique followed the research conducted by Hamid et al. (2018) with several modifications. First, paddy samples were taken during the harvest season in each farmer's field from 5 plots, with the plot size being 1 × 1 $m^2$, then threshed and air-dried to a moisture content of 14%. The paddy seeds were then milled using a YMM 20 milling machine (Yanmar, Japan) to obtain rice. This rice was then taken 2 kg and stored in the refrigerator (-20 °C) until the time analysis was carried out.

### *Chemicals and reagents*

Acetonitrile (ACN) and methanol (MeOH) of HPLC grade, along with LC–MS grade formic acid, were sourced from Fisher Scientific in Loughborough, UK. Sodium chloride and magnesium sulfate anhydrous were supplied by Chem-Lab NV in Zedelgem, Belgium. Primary secondary amine (PSA) with a particle size of 40–60 μm was acquired from Agilent Technologies in DE, USA. Analytical reference standards, characterized by a purity exceeding 97.0% for 506 compounds, were obtained from various suppliers including Sigma-Aldrich in St. Louis, MO, USA, Chemservice in West Chester, PA, USA, Wako in Osaka, Japan, and Ultra Scientific in North Kingstown, RI, USA.

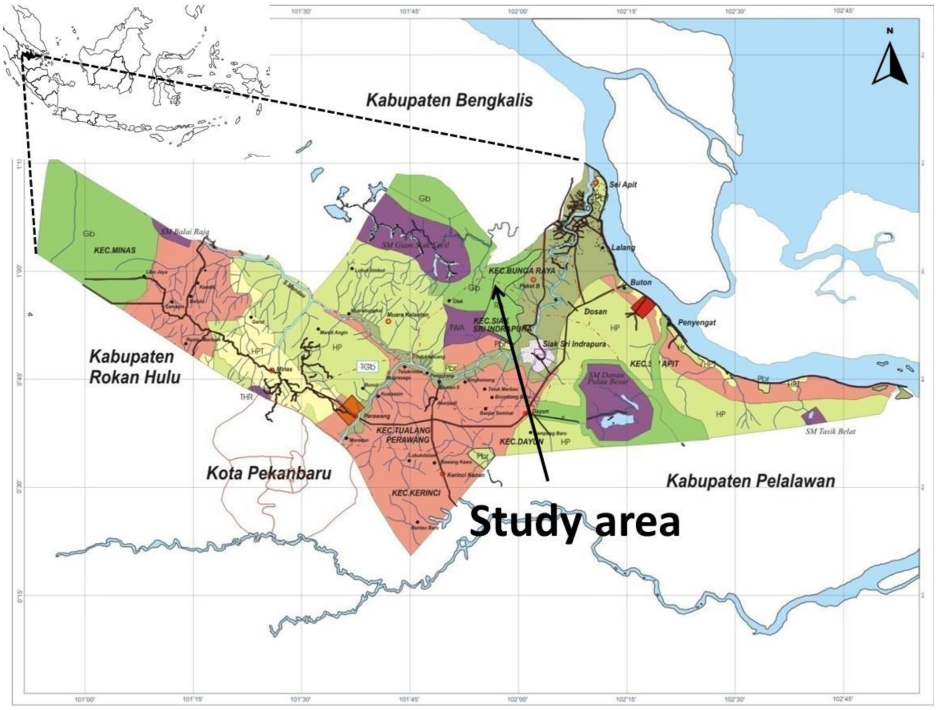


**Figure 2**. Location of study area

*Standard solutions*

Pesticide stock solutions were individually prepared at concentrations of 100 mg L$^{-1}$ in acetonitrile (ACN). Subsequently, a composite standard mixture comprising 506 pesticides was created at a concentration of 10 mg L$^{-1}$ by combining aliquots of individual stock solutions. Mixed standard working solutions with equal concentrations were serially diluted using ACN to construct calibration curves. All the solutions were stored at 4 °C.

*Sample extraction*

The QuEChERS method involves an extraction phase utilizing acetonitrile (ACN) and partitioning with $MgSO_4$ at room temperature. The extraction is subjected to cleanup using dispersive solid-phase extraction (dSPE) materials, namely primary secondary amine (PSA), octadecyl modified silica (C18), and graphite carbon black (GCB), as outlined by Malhat et al. (2023). In the process, 5 grams of frozen homogenized ground rice were accurately weighed and placed into a 50 mL polypropylene centrifuge tube. Subsequently, 10 mL of ACN was added to the tube, and the samples were subjected to vortexing for 2 minutes with the assistance of a ceramic homogenizer. Additional components, including 1 g of sodium chloride and 4 g of anhydrous magnesium sulfate, were incorporated into the mixture. The sample underwent hand-shaking for an additional 30 seconds. Following a centrifugation step at 5000 rpm for 5 minutes, 0.2 mL of the upper ACN layer was 5x diluted using ACN and subjected to vortexing for 30 seconds. Lastly, the contents of the tubes were filtered through a 0.22 μm nylon syringe filter to prepare them for subsequent LC–MS/MS analysis.

*Analytical conditions for HPLC-MS/MS*

Utilizing a Dionex Ultimate™ 3000 RS UHPLC+ focused system separation module Liquid Chromatograph (LC) system (Thermo Fisher Scientific, Austin, TX, USA) paired with the TSQ Altis triple quadrupole mass spectrometer (MS/MS), the LC–MS/MS analysis was conducted. Accucore RP-MS C18 column (100 × 2.1 mm, 2.5 μm film thickness; Thermo Scientific, Lithuania) was employed for chromatographic separation at 40 °C, with a 1 μL injection volume. The mobile phase, comprising water/acetonitrile (30/70, v/v) with 0.1% formic acid, ran for a total of 7 minutes. Pesticide detection utilized the multiple reaction monitoring (MRM) mode. Fine-tuning was conducted on the optimal MRM transitions, collision energies (CE), and radio frequencies (RF) of the S-lens. This adjustment utilized a standard solution of 0.5 mg/L in 50/50 (v/v) MeOH/$H_2O$ with 0.1% formic acid, maintaining a constant flow rate of 0.3 mL/min and an injection volume of 5 µL in infusion mode. The electrospray ionization functioned in the positive mode (ESI+), with a capillary ion spray voltage set at 3800 V and an ion source temperature maintained at 325 °C. The sheath and auxiliary gas pressures were regulated at 40 and 10 arb, respectively. Data acquisition and processing were executed using Trace Finder software (version 4.1). In optimizing the MRM transitions for individual compounds, the selection of the best quantifier, qualifier ion, and collision energies (eV) was based on the MRM analysis optimization obtained through injections at a concentration of 1 µg $ml^{-1}$.

### *Method validation*

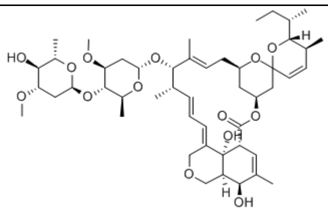
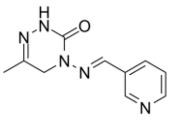
The method validation for pesticide residue analysis in rice was developed by the Central Agricultural Pesticide Laboratory (CAPL), Cairo, Egypt. CAPL serves as the analytical facility dedicated to assessing pesticide residues in this rice sample. The validation process ensures the reliability and accuracy of the analytical method employed for detecting and quantifying pesticide residues in rice samples. The limits of quantification (LOQs) varied for each pesticide, ranging from 0.005 mg/kg to 0.01 mg/kg.

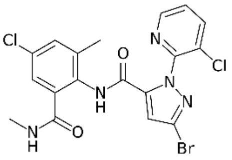
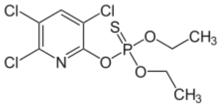
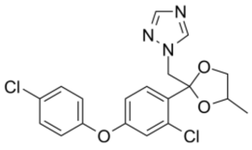
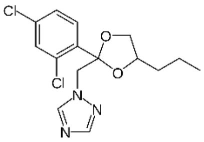
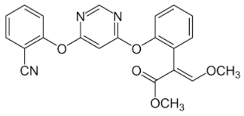
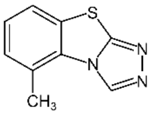
## RESULTS AND DISCUSSIONS

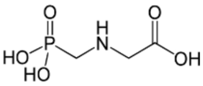
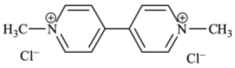
### *Pesticides used by farmers*

The agricultural landscape is marked by a diverse array of practices, and one crucial facet is the choice of pesticides adopted by farmers. In our study, a meticulous examination of the farming practices of the surveyed individuals revealed a striking divergence in the approach towards pest management. This section meticulously explores and discusses the nuances surrounding the pesticides used by farmers, drawing attention to the implications of these choices on pesticide residue profiles in the cultivated rice. The list of active pesticide ingredients utilized by two rice farmers in their paddocks can be observed in Table 1. In addition to weeds, which often impede the growth of rice plants, pest control predominantly involves the management of insect attacks and diseases through the application of pesticides. Several insects frequently posing threats to rice crops include *Nephotettix virescens*, *Scirpophaga innotata*, *Chilo suppressalis*, *Nymphula depunctalis*, *Sesamia inferens*, *Nilaparvata lugens*, *Leptocorisa acuta*, *Pareaucosmetus* sp, *Gryllotalpa* sp. Meanwhile, prevalent diseases affecting rice plants in the study area include blast, bacterial leaf blight, leaf smut, and stem rot.

**Table 1**. Active ingredients of pesticides utilized by two rice farmers: chemical structures and modes of action

| No | Pesticide type | Active ingredients | Chemical structure | Mode of action |
|---|---|---|---|---|
| 1. | Insecticide | Abamectin |  | Abamectin, derived from soil bacterium Streptomyces avermitilis, is an avermectin insecticide with potent acaricidal and insecticidal properties. It disrupts the nervous system of pests, offering effective control against mites and insects (Taha and Mohammed, 2021). |
| | | Pymetrozine |  | Pymetrozine, a systemic insecticide, interferes with insect feeding by inhibiting the feeding behavior of sap-sucking pests. Its selective mode of action against specific insects minimizes impact on beneficial organisms (Song et al, 2023). |

| No | Pesticide type | Active ingredients | Chemical structure | Mode of action |
|---|---|---|---|---|
|  |  | Chlorantraniliprole |  | Chlorantraniliprole, belonging to the diamide class, acts as an insecticide with translaminar activity. It targets the insect's muscles, affecting feeding behavior and ultimately leading to pest control (Shah and Shad, 2020). |
|  |  | Chlorpyrifos |  | Chlorpyrifos is a broad-spectrum insecticide capable of lethally affecting insects upon contact. Its mode of action involves disrupting the normal functioning of the nervous system by inhibiting the breakdown of the neurotransmitter acetylcholine. (ACh) (Wolejko et al., 2022). |
| 2 | Fungicide | Difenoconazole |  | Difenoconazole, a widely used triazole fungicide, has gained popularity for its effectiveness against various fungal pathogens. Its systemic nature allows for translocation within the plant, providing robust protection against diseases such as powdery mildew and leaf spots (Wang et al., 2019). |
|  |  | Propiconazole |  | Propiconazole, belonging to the triazole class, is renowned for its systemic action against fungal pathogens. It inhibits ergosterol biosynthesis, a crucial component in fungal cell membranes, making it effective against diseases like rusts and leaf spots (Chaulagain et al., 2019). |
|  |  | Azoxystrobin |  | Azoxystrobin operates by impeding fungal respiration through the disruption of the electron transport chain, thereby hindering ATP synthesis. This occurs as azoxystrobin binds to the Qo site of Complex III within the mitochondria (Gikas et al., 2022). |
|  |  | Tricyclazole |  | Tricyclazole, a fungicide, is particularly effective against rice blast disease. It inhibits melanin synthesis in fungi, disrupting the development of the pathogen. Its application aids in |

| No | Pesticide type | Active ingredients | Chemical structure | Mode of action |
|---|---|---|---|---|
| | | | | maintaining healthy rice crops (Heidrich et al., 2021) |
| 3 | Herbicide | Glyphosate |  | Glyphosate can rapidly enter and translocate to actively growing parts of the plant, inhibiting the activity of the enzyme known as 5-enol-pyruvyl-shikimate-3-phosphate synthase (EPSPS). By inhibiting this enzyme, the biosynthesis process of amino acids is disrupted. Plants treated with glyphosate typically succumb within 1-3 weeks. (Geddes et al., 2022) |
| | | Paraquat |  | Paraquat, a contact herbicide, exerts its effect through rapid desiccation of plant tissues upon contact. Its quick action and non-selective nature make it a common choice for weed control, but concerns over toxicity have led to restricted use in some regions (Stuart et al., 2023). |

Our analysis hinges on the meticulous examination of pesticides chosen by farmers. While only two rice samples were collected from fields treated with excessive pesticide use, it is important to note that over 150 other farmers in the study area continue to employ pesticides, with a significant majority using them excessively. Conversely, an equally noteworthy group of two farmers intentionally refrained from conventional pesticide usage. These environmentally conscious individuals opted for a pesticide-free approach, relying on the application of botanical pesticides. The decision by two farmers to forego conventional pesticides in favor of botanical alternatives is a noteworthy deviation from mainstream practices. This approach aligns with the growing global emphasis on sustainable and eco-friendly agricultural practices. Utilizing plant-derived pesticides, these farmers not only contribute to reduced environmental impact but also underscore the importance of cultivating crops in harmony with nature (Souto et al., 2021; Gahukar and Das, 2020).

**Table 2**. Harvest Yields per Hectare for Farmers with Different Pesticide Practices

| Farmer | Pesticide usage | Productions (tons/ha) |
|---|---|---|
| A | No pesticide used | 2.42 |
| B | No pesticide used | 2.55 |
| C | Excessive pesticide use | 6.14 |
| D | Excessive pesticide use | 7.01 |

Intricately woven into the fabric of pesticide-free farming is the reliance on natural agents for pest control. This method often involves the use of plant extracts known for their pesticidal properties, a practice rooted in traditional agricultural wisdom. As reported by Souto et al. (2021), botanical pesticides have gained recognition for their efficacy in pest management while minimizing adverse environmental effects. The deliberate choice of these farmers to explore alternatives beyond synthetic pesticides reflects a conscientious effort towards a more sustainable agricultural paradigm. Conversely, the adoption of conventional pesticides by the remaining two farmers raises pertinent questions about the dynamics driving such choices. Conventional pesticides, though effective in pest eradication, have been associated with environmental pollution and concerns about residual effects on food products. The work of Vryzas et al. (2020) underscores the potential risks associated with synthetic pesticide residues in crops, prompting a re-evaluation of conventional practices.

The farmers' preference for synthetic pesticides may be influenced by various factors, including the immediate efficacy of pest control, potential loss of yields, economic considerations, or a lack of awareness about alternative methods. Chèze et al.'s (2020) study suggests that farmers often opt for conventional pesticides due to their perceived reliability and rapid impact on pest populations. This contributes to the prevalent use of pesticides, with farmers believing it enhances production. Table 2 illustrates the harvest yields per hectare for each farmer, revealing a stark contrast between those not using pesticides (2.4-2.55 tons) and those using excessive pesticides (6.1-7 tons per hectare). However, it is crucial to acknowledge the long-term repercussions of such practices, encompassing both environmental sustainability and potential consequences for consumer health. The study emphasizes the need to evaluate the trade-offs associated with immediate gains in production against the broader impacts on ecosystems and public well-being.

The dichotomy in pesticide choices among farmers sets the stage for an insightful examination of pesticide residue profiles in the cultivated rice. Pesticide residue, the lingering presence of pesticides on agricultural products, has far-reaching implications for both human health and the environment. The residue profiles in rice samples from fields utilizing synthetic pesticides are expected to differ significantly from those cultivated using botanical alternatives. The study by Silva et al. (2019) underscores the importance of considering pesticide residue profiles as an outcome of farming practices. Synthetic pesticides, characterized by their chemical persistence, may leave traces in crops long after application. In contrast, botanical pesticides may offer a more transient presence, influenced by factors such as degradation rates and application methods. The implications of these residue profiles extend to consumer health considerations. The work of Kubiak-Hardiman et al. (2023) emphasizes the need for comprehensive assessments of pesticide residues in food products, particularly staple crops like rice. Consumers are increasingly cognizant of the potential health risks associated with pesticide residues, making it imperative for agricultural practices to align with evolving societal expectations.

### *Pesticides residues in rice samples*

Our investigation into pesticide residues in rice samples yielded compelling findings, shedding light on the impact of agricultural practices on the purity of this staple food. Rice sourced from fields cultivated in adherence to Good Agricultural Practices (GAP) exhibited a notable absence of over 500 pesticide types, as shown in Table 3, indicating a commendable commitment to sustainable and responsible farming practices (Schoneveld et al., 2019). In stark contrast, rice harvested from fields where pesticides were either excessively applied or deviated from GAP guidelines presented a concerning scenario.

The analysis identified the presence of seven pesticides—propiconazole, chlorpyrifos, bifenthrin, azoxystrobin, tebuconazole, tricyclazole, and difenoconazole. Of particular concern, two pesticides, tricyclazole and propiconazole, surpassed the globally established residue threshold by a factor of two, signifying potential health and environmental risks associated with their elevated levels (Shukla et al., 2021). From Table 3, it can also be observed that although abamectin is extensively used by farmers in the cultivation process (refer to Table 1), it was not detected in the pesticide residue analysis data in the rice samples. This is presumed to be attributed to the photodegradable nature of abamectin, particularly when exposed to sunlight and relatively high temperatures (Feng et al., 2021; Feng et al., 2020). Moreover, the research site is situated in a tropical region characterized by intense sunlight and elevated temperatures. This aligns with previous studies, indicating that the dissipation rate of pesticides is faster at relatively higher temperatures compared to lower temperatures (Purnama et al., 2014).

**Table 3**. Detected active ingredients of pesticide residues and maximum residue limits (MRLs) in rice Samples (mg/kg)

| No. Sample | Number of detected | Detected active ingredients of pesticide residues in rice samples (mg/kg) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Propiconazole | | Chlorpyrifos | | Azoxystrobin | | Tebuconazole | | Tricyclazole | | Difenoconazole | | Bifenthrin | |
| | | Found | MRLs | Found | MRLs | Found | MRLs | Found | MRLs | Found | MRLs | Found | MRLs | Found | MRLs |
| S1 | - | ND | 0.01 (EU) | ND | 0.01 (EU) & 0.5 (WHO) | ND | 5 (EU &WHO) | ND | 1.5 (EU & WHO) | ND | 0.01 (EU) | ND | 0.07 (WHO) | ND | 0.05 (EU) |
| S2 | - | ND | 0.01 (EU) | ND | 0.01 (EU) & 0.5 (WHO) | ND | 5 (EU &WHO) | ND | 1.5 (EU & WHO) | ND | 0.01 (EU) | ND | 0.07 (WHO) | ND | 0.05 (EU) |
| S3 | 3 | 0.002 | 0.01 (EU) | 0.002 | 0.01 (EU) & 0.5 (WHO) | ND | 5 (EU &WHO) | ND | 1.5 (EU & WHO) | 0.001 | 0.01 (EU) | ND | 0.07 (WHO) | ND | 0.05 (EU) |
| S4 | 7 | 0.02 | 0.01 (EU) | 0.007 | 0.01 (EU) & 0.5 (WHO) | 0.007 | 5 (EU &WHO) | 0.004 | 1.5 (EU & WHO) | 0.021 | 0.01 (EU) | 0.003 | 0.07 (WHO) | 0.003 | 0.05 (EU) |

Note: S1-S4 represents rice samples from Farmers A-D respectively, and 'ND' indicates that the pesticide residues were not detected

Further scrutiny of the seven identified pesticides revealed a surprising revelation. Bifenthrin and tebuconazole, two of the detected pesticides, were not among the types commonly utilized by farmers in the preceding one years. This discrepancy raises questions about the origin and application of these specific pesticides, pointing towards potential contamination or the use of unauthorized substances in rice cultivation. Moreover, our investigation uncovered the presence of pesticide residues in rice samples even when farmers had not utilized these specific pesticides. This phenomenon is attributed to the accumulation of pesticides in the peat soil, the predominant soil type in the region. The peat soil's capacity to retain and accumulate pesticides allows for their uptake by rice plants, leading to the unexpected presence of residues in rice grains (Fan et al., 2020).

As previously explained, the samples in this study originated from the peatland rice fields of farmers, characterized by a relatively high content of organic matter. It is suspected that interactions occur between the organic components present in the soil and the five active pesticide ingredients, leading to their prolonged accumulation in the soil compared to other pesticides. Previous studies have found that soil organic matter and soil organic carbon (SOC) influence the absorption of tebuconazole, clothianidin, chlorpyrifos, penconazole, and bifenthrin into the soil (Li et al., 2019; Mulligan et al., 2015; Mukherjee et al., 2010; Badawi et al., 2016; Gondar et al., 2013, Alvarez et al., 2013). Based on research conducted by Fan et al. (2020), Han et al. (2017), and Ge et al. (2017), soils contaminated with pesticide residues are highly likely to be taken up by plants, leading to contamination even when farmers do not spray the pesticides. Therefore, future studies are needed to conduct monitoring of pesticide residues in agricultural environments, especially in peatland areas.

These findings emphasize the crucial importance of adhering to Good Agricultural Practices (GAP) principles in rice cultivation to ensure the safety and quality of this essential food source. The elevated levels of certain pesticides in non-compliant practices highlight the need for stringent monitoring, regulatory measures, and farmer education to mitigate the potential risks associated with pesticide residues in rice. This is because not only consumers who consume rice with pesticide levels exceeding the maximum threshold are in danger, but also farmers who engage in spraying, potentially increasing the number of farmer deaths due to cancer caused by the accumulation of pesticide residues in their bodies. Certainly, the adverse effects resulting from the excessive use of pesticides beyond recommended doses are unacceptable in achieving Sustainable Development Goals (SDGs). Additionally, addressing the issue of pesticide accumulation in peat soil is imperative for sustainable and contaminant-free rice production.

## CONCLUSION

The meticulous analysis of pesticide residues in rice samples from different cultivation practices has revealed significant variations in the residue profiles. Rice cultivated in accordance with GAP exhibited the absence of over 500 types of pesticides, underscoring the effectiveness of sustainable farming methods in minimizing pesticide residues. Conversely, rice from fields employing excessive or non-GAP-compliant pesticide use showed the presence of seven pesticides, including propiconazole, chlorpyrifos, bifenthrin, azoxystrobin, tebuconazole, tricyclazole, and difenoconazole. Notably, two of these pesticides, bifenthrin and tebuconazole, were not among those commonly used by farmers in recent years. This study not only contributes valuable insights into the pesticide residue profiles in rice but also underscores the significance of adopting sustainable agricultural practices to ensure food safety and environmental sustainability. The findings advocate for the promotion of GAP to minimize the use of harmful pesticides, protect public health, and foster a resilient and eco-friendly agricultural landscape. Future research should further explore alternative pest management strategies and their implications for sustainable agriculture, especially in rice field areas on peatland.

## ACKNOWLEDGEMENTS

The completion of this research was made possible through the support and funding provided by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia under the Fundamental Research Grant, with contract number 186/E5/PG.02.00.PL/2023.

## REFERENCES

Ali, S., Ullah, M. I., Sajjad, A., Shakeel, Q., & Hussain, A. (2021). Environmental and health effects of pesticide residues. *Sustainable Agriculture Reviews 48: Pesticide Occurrence, Analysis and Remediation Vol. 2 Analysis*, 311-336. https://doi.org/10.1007/978-3-030-54719-6_8

Álvarez, M., Du Mortier, C., & Fernández Cirelli, A. (2013). Behavior of insecticide chlorpyrifos on soils and sediments with different organic matter content from Provincia de Buenos Aires, República Argentina. *Water, Air, & Soil Pollution*, *224*, 1-6. https://doi.org/10.1007/s11270-013-1453-0

Andina, L. (2015). Analisis Residu Endosulfan, Endrin, Dieldrin, Aldrin, P, P-Ddt, dan Heptaklor Pada Beras Varietas Siam Unus di Kalimantan Selatan. *Jurnal Pharmascience*, *2*(2), 103-108. https://ppjp.ulm.ac.id/journal/index.php/pharmascience/article/view/5828

Ardiwinata, A. N., & Nursyamsi, D. (2012). Residu pestisida di sentra produksi padi di Jawa Tengah. *Jurnal Pangan*, *21*(1), 39-58. https://jurnalpangan.com/index.php/pangan/article/view/103/90

Badawi, N., Rosenbom, A. E., Jensen, A. M., & Sørensen, S. R. (2016). Degradation and sorption of the fungicide tebuconazole in soils from golf greens. *Environmental Pollution*, *219*, 368-378. https://doi.org/10.1016/j.envpol.2016.10.045

Chaulagain, B., Dufault, N., Raid, R. N., & Rott, P. (2019). Sensitivity of two sugarcane rust fungi to fungicides in urediniospore germination and detached leaf bioassays. *Crop Protection*, *117*, 86-93. https://doi.org/10.1016/j.cropro.2018.11.014

Chèze, B., David, M., & Martinet, V. (2020). Understanding farmers' reluctance to reduce pesticide use: A choice experiment. *Ecological Economics*, *167*, 106349. https://doi.org/10.1016/j.ecolecon.2019.06.004

Damalas CA, Eleftherohorinos IG. (2011). Pesticide exposure, safety issues, and risk assessment indicators. *Int J Environ Res Public Health*, *8*(5): 1402-1419. https://doi.org.10.3390/ijerph8051402.

FAO (2019). The Impact of Pesticide Residues on Human Health: A Global Challenge. FAO Reports.

Fan, T., Chen, X., Xu, Z., Liu, L., Shen, D., Dong, S., & Zhang, Q. (2020). Uptake and translocation of triflumezopyrim in rice plants. *Journal of Agricultural and Food Chemistry*, *68*(27), 7086-7092. https://doi.org/10.1021/acs.jafc.9b07868

Feng, J., Yang, J., Shen, Y., Deng, W., Chen, W., Ma, Y., Chen, Z., & Dong, S. (2021). Mesoporous silica nanoparticles prepared via a one-pot method for controlled release of abamectin: Properties and applications. *Microporous and Mesoporous Materials*, *311*, 110688. https://doi.org/10.1016/j.micromeso.2020.110688

Feng, J., Chen, W., Shen, Y., Chen, Q., Yang, J., Zhang, M., Yang, W., & Yuan, S. (2020). Fabrication of abamectin-loaded mesoporous silica nanoparticles by emulsion-solvent evaporation to improve photolysis stability and extend insecticidal activity. *Nanotechnology*, *31*(34), 345705. https://doi.org/10.1088/1361-6528/ab91f0

Gahukar, R. T., & Das, R. K. (2020). Plant-derived nanopesticides for agricultural pest control: challenges and prospects. *Nanotechnology for Environmental Engineering*, *5*, 1-9. https://doi.org/10.1007/s41204-020-0066-2

Ge, J., Cui, K., Yan, H., Li, Y., Chai, Y., Liu, X., Cheng, J., & Yu, X. (2017). Uptake and translocation of imidacloprid, thiamethoxam and difenoconazole in rice plants. *Environmental Pollution*, *226*, 479-485. https://doi.org/10.1016/j.envpol.2017.04.043

Geddes, C. M., Owen, M. L., Ostendorf, T. E., Leeson, J. Y., Sharpe, S. M., Shirriff, S. W., & Beckie, H. J. (2022). Herbicide diagnostics reveal multiple patterns of synthetic auxin resistance in kochia (Bassia scoparia). *Weed Technology*, *36*(1), 28-37. https://doi.org/10.1017/wet.2021.69

Gikas, G. D., Parlakidis, P., Mavropoulos, T., & Vryzas, Z. (2022). Particularities of fungicides and factors affecting their fate and removal efficacy: A review. *Sustainability*, *14*(7), 4056. https://doi.org/10.3390/su14074056

Gondar, D., López, R., Antelo, J., Fiol, S., & Arce, F. (2013). Effect of organic matter and pH on the adsorption of metalaxyl and penconazole by soils. *Journal of Hazardous Materials*, *260*, 627-633. https://doi.org/10.1016/j.jhazmat.2013.06.018

Hamid, Y., Tang, L., Wang, X., Hussain, B., Yaseen, M., Aziz, M. Z., & Yang, X. (2018). Immobilization of cadmium and lead in contaminated paddy field using inorganic and organic additives. *Scientific reports*, *8*(1), 17839. https://doi.org/10.1038/s41598-018-35881-8

Han, Y., Mo, R., Yuan, X., Zhong, D., Tang, F., Ye, C., & Liu, Y. (2017). Pesticide residues in nut-planted soils of China and their relationship between nut/soil. *Chemosphere*, *180*, 42-47. https://doi.org/10.1016/j.chemosphere.2017.03.138

Heidrich, D., Pagani, D. M., Koehler, A., Alves, K. D. O., & Scroferneker, M. L. (2021). Effect of melanin biosynthesis inhibition on the antifungal susceptibility of chromoblastomycosis agents. *Antimicrobial Agents and Chemotherapy*, *65*(8), 10-1128. https://doi.org/10.1128/AAC.00546-21

Jepson, P. C., Murray, K., Bach, O., Bonilla, A. M., Neumeister, L., 'Selection of Pesticides to Reduce Human and Environmental Health Risks: A Global Guideline and Minimum Pesticides List', Lancet Planet Health 4, 2020, pp. 56-63. https://doi.org/10.1016/S2542-5196(19)30266-9

Kılıç, O., Boz, İ., & Eryılmaz, G. A. (2020). Comparison of conventional and good agricultural practices farms: A socio-economic and technical perspective. *Journal of Cleaner Production*, *258*, 120666. https://doi.org/10.1016/j.jclepro.2020.120666

Kubiak-Hardiman, P., Haughey, S. A., Meneely, J., Miller, S., Banerjee, K., & Elliott, C. T. (2023). Identifying Gaps and Challenges in Global Pesticide Legislation that Impact the Protection of Consumer Health: Rice as a Case Study. *Exposure and Health*, *15*(3), 597-618. https://doi.org/10.1007/s12403-022-00508-x

Kumari, D., & John, S. (2019). Health risk assessment of pesticide residues in fruits and vegetables from farms and markets of Western Indian Himalayan region. *Chemosphere*, *224*, 162-167. https://doi.org/10.1016/j.chemosphere.2019.02.091

Li, W., Zhang, Y., Jia, H., Zhou, W., Li, B., & Huang, H. (2019). Residue analysis of tetraniliprole in rice and related environmental samples by HPLC/MS. *Microchemical Journal*, *150*, 104168. https://doi.org/10.1016/j.microc.2019.104168

Lushchak, V.I., Matviishyn, T.M., Husak, V.V., Storey, J.M., Storey, K.B. (2018). Pesticide toxicity: A mechanistic approach. *EXCLI Journal*, *17*, 1101-1136. https://doi.org/10.17179/excli2018-1710

Mahmood, A., & Gheewala, S. H. (2023). A comparative environmental analysis of conventional and organic rice farming in Thailand in a life cycle perspective using a stochastic modeling approach. *Environmental Research*, *235*, 116670. https://doi.org/10.1016/j.envres.2023.116670

Malhat, F., Anagnostopoulos, C., Bakery, M., Youssef, M., El-Sayed, W., Abdallah, A., Purnama, I., & El-Salam Shokr, S. A. (2023). Investigation of the dissipation behaviour and exposure of flonicamid and imidacloprid in open field green beans under dry climatic conditions. *International Journal of Environmental Analytical Chemistry*, 1-13. https://doi.org/10.1080/03067319.2023.2186227

Mukherjee, I., Singh, R., & Govil, J. N. (2010). Risk assessment of a synthetic pyrethroid, bifenthrin on pulses. *Bulletin of environmental contamination and toxicology*, *84*, 294-300. https://doi.org/10.1007/s00128-010-9940-0

Mulligan, R. A., Parikh, S. J., & Tjeerdema, R. S. (2015). Abiotic partitioning of clothianidin under simulated rice field conditions. *Pest management science*, *71*(10), 1419-1424. https://doi.org/10.1002/ps.3946

Nurjannah, N., Yulianty, R., Marzuki, A., Kasim, S., & Djide, N. J. N. (2020). Analisis Residu Pestisida Klorpirifos Pada Beras (Oryza Sativa) Yang Berasal Kecamatan Baebunta Kabupaten Luwu Utara. *Majalah Farmasi dan Farmakologi*, *23*(3), 109-111. https://doi.org/10.20956/mff.v23i3.9402

Prabawardani, S., Gunawan, G., & Purnomo, W. (2020). Aplikasi pestisida dan analisis residunya pada produksi beras petani di Kampung Sidomulyo Distrik Oransbari Kabupaten Manokwari Selatan. *Cassowary*, *3*(1), 11-21. https://doi.org/10.30862/casssowary.cs.v3.i1.34

Purnama, I., & Mutamima, A. (2023). Pestisida dalam Produk Pertanian: Dampak, Analisis, dan Strategi Pengelolaan, Soega Publishing.

Purnama, I., Malhat, F., Jaikaew, P., Watanabe, H., Noegrohati, S., Rusdiarso, B., & Ahmed, M. T. (2014). Degradation profile of azoxystrobin in Andisol soil: laboratory incubation. *Toxicological & Environmental Chemistry*, *96*(8), 1141-1152. https://doi.org/10.1080/02772248.2015.1015297

Queirós, L., Vidal, T., Nogueira, A. J., Gonçalves, F. J., & Pereira, J. L. (2018). Ecotoxicological assessment of the herbicide Winner Top and its active substances—are the other formulants truly inert?. *Ecotoxicology*, *27*, 945-955. https://doi.org/10.1007/s10646-018-1939-z

Schoneveld, G. C., Van Der Haar, S., Ekowati, D., Andrianto, A., Komarudin, H., Okarda, B., Jelsma, I., & Pacheco, P. (2019). Certification, good agricultural practice and smallholder heterogeneity: Differentiated pathways for resolving compliance gaps in the Indonesian oil palm sector. *Global Environmental Change*, *57*, 101933. https://doi.org/10.1016/j.gloenvcha.2019.101933

Shah, R. M., & Shad, S. A. (2020). House fly resistance to chlorantraniliprole: cross resistance patterns, stability and associated fitness costs. *Pest management science*, *76*(5), 1866-1873. https://doi.org/10.1002/ps.5716

Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G.P.S., Handa, N., Kohli, S.K., Yadav, P., Bali, A.S., & Parihar, R.D. (2019). Worldwide Pesticide Usage and its Impacts on Ecosystem. *SN Applied Sciences, 1*(11), 1446. https://doi.org/10.1007/s42452-019-1485-1

Shukla, A. K., Singh, A., Banerjee, T., & Chaudhary, S. K. (2021). Impact of Agricultural Chemical Inputs on Human Health and Environment in India. *Agricultural Chemical Inputs*, 66. https://www.sac.org.bd/archives/publications/Agricultural%20Chemical%20Inputs.pdf

Silva, V., Mol, H. G., Zomer, P., Tienstra, M., Ritsema, C. J., & Geissen, V. (2019). Pesticide residues in European agricultural soils–A hidden reality unfolded. *Science of the Total Environment*, *653*, 1532-1545. https://doi.org/10.1016/j.scitotenv.2018.10.441

Song, X. Y., Peng, Y. X., Gao, Y., Zhang, Y. C., Ye, W. N., Lin, P. X., Gao, C. F., & Wu, S. F. (2023). Resistance Monitoring of Nilaparvata lugens to Pymetrozine Based on Reproductive Behavior. *Insects*, *14*(5), 428. https://doi.org/10.3390/insects14050428

Souto, A. L., Sylvestre, M., Tölke, E. D., Tavares, J. F., Barbosa-Filho, J. M., & Cebrián-Torrejón, G. (2021). Plant-derived pesticides as an alternative to pest management and sustainable agricultural production: Prospects, applications and challenges. *Molecules*, *26*(16), 4835. https://doi.org/10.3390/molecules26164835

Stuart, A. M., Merfield, C. N., Horgan, F. G., Willis, S., Watts, M. A., Ramírez-Muñoz, F., Jorge, S., U., Utyasheva, L., Eddleston, M., Davis, M. L., Neumeister, L., Sanou, M.R., & Williamson, S. (2023). Agriculture without paraquat is feasible without loss of productivity—lessons learned from phasing out a highly hazardous herbicide. *Environmental Science and Pollution Research*, *30*(7), 16984-17008. https://doi.org/10.1007/s11356-022-24951-0

Taha, B., & Mohammed, R. (2021). Morphological, Histological Changes and Acetyl Cholinesterase Activity in Chicken Embryos After Exposure to Abamectin Insecticide. *Journal of Life and Bio Sciences Research*, *2*(02), 64-69. https://doi.org/10.38094/jlbsr20248

Tudi, M., Daniel Ruan, H., Wang. L., Lyu J., Sadler, R., Connell, D., Chu, C, Phung DT. (2021). Agriculture Development, Pesticide Application and Its Impact on the Environment. *Int J Environ Res Public Health*, 18(3):1112. https://doi.org/10.3390/ijerph18031112.

Vryzas, Z., Ramwell, C., & Sans, C. (2020). Pesticide prioritization approaches and limitations in environmental monitoring studies: from Europe to Latin America and the Caribbean. *Environment International*, *143*, 105917. https://doi.org/10.1016/j.envint.2020.105917

Wang, S. Q., Jia, M. A., Wang, M., Wang, X. H., LI, Y. Q., & Jie, C. H. E. N. (2019). Combined application of Trichoderma harzianum SH2303 and difenoconazole-propiconazolein controlling Southern corn leaf blight disease caused by Cochliobolus heterostrophus in maize. *Journal of Integrative Agriculture*, *18*(9), 2063-2071. https://doi.org/10.1016/S2095-3119(19)62603-1

Wolejko E, Łozowicka B, Jabłońska-Trypuć A, Pietruszyńska M, Wydro U. (2022). Chlorpyrifos Occurrence and Toxicological Risk Assessment: A Review. *Int J Environ Res Public Health*, *19*(19):12209. https://doi.org.10.3390/ijerph191912209.