Wastewater as a Resource for Pest Control: An Overview

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Pests have a negative impact on the economy and the environment. There is an increased urgency for adequate pest control because many pests show high adaptation and climate change has created favorable circumstances for pests. For pest control, synthetic chemicals are used that are lethal to non-target organisms and are toxic to pollinators and aquatic invertebrates. Chemical compounds in plants and derivatives from lignocellulosic materials act against pests. The wastewater from lignocellulosic biomass is a potential source of new compounds with bactericidal, fungicidal, and pesticidal effects that have demonstrated inhibitory activity against plant pathogens. Fungicidal, nematicidal, insecticidal, larvicidal, and bactericidal activities have been proven. Inorganic and organic compounds, such as phenols, aldehydes, esters, and furanics, are the main ones identified. Due to the antimicrobial activity of wastewater, applying it to the soil can modify the composition and structure of key microbial communities. Deep research about richness, biodiversity, functionality, and microbials is needed. This review provides a comprehensive overview of wastewater types that have been applied and possible sources to obtain potential compounds for pest control. Moreover, associated active compounds, recovery techniques, and environmental impacts are reviewed.

Keywords: Biological control; Metabolites sources; Liquid waste; Lignocellulosic biomass

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INTRODUCTION

Pests generate negative impacts because they decrease the quality and yield of crops (Savary *et al.* 2019). There is increased urgency because pests generate economic losses five times more than fires (Logan *et al.* 2003). Additionally, pathogens and pests are highly adaptable (Wingfield *et al.* 2015) and climate change can favor outbreaks and their extension (Rubin-Aguirre *et al.* 2015; Jactel *et al.* 2019). More so, the level of economic loss due to injuries caused by insects and pests is multifactorial, because they depend on the type of crop, temporal nature, and spatial location (Capinera 2020).

Plants contain chemical compounds that help fight disease and insects, for instance, phytohormones and secondary metabolites. The development of insecticides started from this discovery, and produced similar but more effective chemicals (Bednarek 2012; Erb *et al.* 2012; Matthews 2018). In contrast, lignocellulosic biomass is a copious and cheap source for pulp and paper, textile manufacturing, and agriculture in the forms of corn, wheat, rice, sorghum, barley, and sugarcane byproducts (Reddy and Yang 2005). Cellulose, hemicelluloses, and lignin are the main polymeric components (Sarip *et al.* 2016), the latter being the second most abundant biopolymer after cellulose (Demuner *et al.* 2019). In the lignocellulosic biomass pretreatment, the cellulose-hemicellulose-lignin structures are altered, facilitating the hydrolysis of cellulose and increasing the fermentable glucose concentration, whereby lignin derivatives are obtained (Kim 2018). Lignin contains several functional groups, such as phenolic hydroxyl, carboxylic, carbonyl, and methoxyl groups. Biological activities of phenolic hydroxyl and methoxyl groups (Espinoza-Acosta *et al.* 2016) were highlighted as antioxidant or antimicrobial activities (Alzagameem *et al.* 2019; Jinxiang *et al.* 2020). In addition, chemical compounds derived from the by-products from lignocellulosic materials provide protection for pests (Villaverde *et al.* 2016).

For pest control, methyl bromide gas was widely used as a broad-spectrum fumigant until 2005, when it was banned (Wedge *et al.* 2001). Neonicotinoid pesticides have become the most widely used class of insecticides in the world (Simon-Delso *et al.* 2014). However, they present significant environmental impacts (Saeed *et al.* 2019). For example, methyl bromide produces neurotoxicity and is a stratospheric ozone depleter (Wedge *et al.* 2001), the fipronil is toxic to pollinators and aquatic invertebrates (Sadaria *et al.* 2019), and most insecticides can be lethal to non-target organisms (Simon-Delso *et al.* 2014). In addition, pesticides are considered a powerful biological risk because they can persist in the environment for years (Sharma *et al.* 2020). Chemical fungicides are widely used because they are effective in sterilizing (Lin *et al.* 2020). However, they have also been reported to induce resistance in fungal plant pathogens (Swett *et al.* 2020). For the control of phytoparasitic nematodes, fumigants have been used that have the ability to eliminate not only target organisms but also affect the microbial population in the soil (Ntalli *et al.* 2020). This leads researchers to search for alternatives to control pests.

The use of living biological organisms or their metabolites for pest control is called bio-pesticides (Butu *et al.* 2020). The demand is increasing to limit the use of chemical pesticides and to replace them with agents that have no or less negative effects on the environment (Di Ilio and Cristofaro 2020; Rashwan and Hammad 2020). Sharma *et al.* (2020) considered that biopesticides could facilitate increased crop production with or without minimal negative effects. Furthermore, biopesticides are biodegradable, less expensive, and possess less toxicity toward living organisms (Thakur *et al.* 2020).

There are different alternatives for pest control, such as genetically based resistance (Molinari 2011), integrated pest management (IPM) (Meissle *et al.* 2010), botanical pesticides (Lengai *et al.* 2020), larvicidal red-algae (Deepak *et al.* 2019), reductive soil disinfestation (RSD), anaerobic soil disinfestation (Huang *et al.* 2019), and microbial biopesticides (Thakur *et al.* 2020), among others. Biopesticide sources exist readily in nature (Thakur *et al.* 2020), and some have yet to be fully exploited and studied, for example, liquid waste.

Wastewater is a valuable source of biomolecules for different uses; by recovering these compounds, value is added, and at the same time the environmental impact in the treatment of these wastes is reduced (Larif *et al.* 2015; Ahmad *et al.* 2020). These wastes may possibly be considered one of the most abundant, cheap, and renewable resources on earth (Gonzalez-Coloma *et al.* 2013). It is time to change the paradigm and stop seeing them only as waste to treat them as by-products, revalue the "waste" and give them another type of value with sustainable management of these materials (Ordaz-Díaz *et al.* 2019).

Wastewater Types for Pest Control

The raw wastewaters used for pest control are cassava, olive mill, vinasses of wine, sugar beet, and sugarcane featuring fungicidal, nematicidal, insecticidal, larvicidal, and bactericidal activities (Table 1).

Cassava Wastewater

A feature of cassava wastewater is the presence of linamarin and lotaustralin compounds, cyanogenic glycosides that are lost in processing (Padmaja 1995). Near 5 to 7 L of wastewater are generated from a kilogram of fresh cassava root (Watthier *et al.* 2019). The cassava wastewater has been studied for more than 30 years for possible applications in pest management (Pinto-Zevallos *et al.* 2018), against insects, nematodes, and fungi (Table 1). The pest species that have been evaluated are *Coceus hesperidum* L., *Meloidogyne* spp., and *Oidium* sp., which are associated mainly with crops of fruit trees and tomato (Lebeda *et al.* 2015; Abdul-Rassoul 2016; Regmi and Desaeger 2020).

Olive Mill Wastewater

Olive mill wastewater contains phenolic compounds (Di Mauro *et al.* 2017). Due to the reducing power of these compounds, bacteria and plants are negatively impacted (Babić *et al.* 2019). The olive mill wastewater can be used against bacterial, fungal phytopathogens, and weed species (El-Abbassi *et al.* 2017). Pest mortality is attributed to phenolic compounds (Larif *et al.* 2013). Hence, polyphenolic fractions of the olive mill wastewater act as a strong natural chemosterilant (Di Ilio and Cristofaro 2020).

Euphyllura olivina and *Ceratitis capitata* Wiedemann, globally important pests, are Mediterranean parasitoids that affect olive and fruit crops, respectively (Alves *et al.* 2019; Hougardy *et al.* 2020). The olive mill wastewater has also shown insecticidal activity against both pests and larvicidal activity against *Euphyllura olivina*. Furthermore, *Aphis citricola*, an aphid related to apple orchards infestation (Kou *et al.* 2020), can be controlled using olive mill wastewater, due to larvicidal activity (Table 1).

Besides being effective against larvae and insects, the olive mill wastewater has also been shown to suppress fungi and bacteria activity (Table 1).

Table 1. Wastewater Type Used for Pest Control

Pest	Activity	Wastewater Type	Reference
Phytophthora parasitica, *Fusarium oxysporum* f. sp. *melonis* race, *F. oxysporum* f. sp. *radicis-cucumerinum*, *Pythium aphanidermatum*, and *Sclerotinia sclerotiorum*	Fungicidal	Sugar beet, sugarcane, and wine vinasse	Santos *et al.* 2008
Meloidogyne incognita	Nematicidal	Sugar beet vinasse	Núñez-Zofío *et al.* 2013
Sphenophorus levis	Insecticidal	Sugarcane vinasse	Martins *et al.* 2020
Stomoxys calcitrans			Jelvez Serra *et al.* 2017
Oregmopyga peruviana	Insecticidal	Wine vinasse	Dadther-Huaman *et al.* 2020
Coccus hesperidum L.	Insecticidal	Cassava	Ponte *et al.* 1988
Meloidogyne spp.	Nematicidal		Ponte and Franco 1983
Oidium sp.	Fungicidal		Santos and Ponte 1993
Euphyllura olivina	Insecticidal	Olive mill	Debo *et al.* 2011
Ceratitis capitata Wiedemann			Di Ilio and Cristofaro 2020
Euphyllura olivina and *Aphis citricola*	Larvicidal		Larif *et al.* 2013
Botrytis cinerea	Fungicidal		Yangui *et al.* 2010
Rhizoctonia solani and *Fusarium oxysporum*			Mohamed *et al.* 2015
Fusarium sambucinum, *Verticillium dahliae*, and *Alternaria solani*			Yangui *et al.* 2009
Pseudomonas syringae and *Xanthomonas campestris*	Bactericidal		Yangui *et al.* 2010

The fungicidal activity of olive mill wastewater has been tested against *Botrytis cinérea*, *Rhizoctonia solani*, *Fusarium oxysporum*, *Fusarium sambucinum*, *Verticillium dahlia*, and *Alternaria solani* (Table 1). These fungi affect various crops and the economic losses they generate are considerable. For example, *Botrytis cinérea*, a necrotrophic pathogen, produces severe crop losses worldwide in a wide variety of plant species (Hahn *et al.* 2014). *Rhizoctonia solani* is a root pathogen that affects cereal crops (Paulitz and Schroeder 2005). *Fusarium oxysporum* is a soil and seed-borne disease and is one of the main pathogens of dry rot (Tiwari *et al.* 2020). *Fusarium sambucinum* (root rot disease) and *Fusarium oxysporum* cause potato infection (Yangui *et al.* 2009; Piłsyk *et al.* 2015; Tiwari *et al.* 2020). *Verticillium dahliae* is a vascular pathogen that causes wilt and death of 400 cultivated and non-cultivated plant species including the tomato plants. *Alternaria solani* affects different parts of the plant from root rot to even cause tomato and potato rot (Yangui *et al.* 2009; EFSA Panel on Plant Health PLH 2014).

Pseudomonas syringae is an extracellular bacteria and is considered one of the main bacterial pathogens of plants (Mansfield *et al.* 2012; Xin *et al.* 2018). *Xanthomonas campestris* is a bacteria able to cause black rot infection in cruciferous plants (Papaianni *et al.* 2020). Due to the bactericidal activity of olive mill wastewater, both phytopathogenic bacteria are inhibited by this liquid waste (Table 1).

Vinasses

The vinasse, a liquid residue from alcoholic fermentation, contains various compounds such as alcohols, aldehydes, phenols, and acids (Couallier *et al.* 2006; Freitas *et al.* 2018; Fuess *et al.* 2018). In some cases, these compounds are undesirable. For example, in anaerobic wastewater treatment, phenolic compounds should be removed, because they participate as inhibitors (Borja *et al.* 1993; Ao *et al.* 2020). However, some of the compounds have a positive environmental and economic value.

Raw vinasse has proven useful in other fields of research. Phanapavudhikul (1999) observed an eradication of insects by adding the sugarcane vinasse to the soil, associating it with oxygen depletion. The first reports of vinasse use to control phytopathogenic fungi date back to 2008. It was reported that wine vinasse showed 100% efficacy in suppressing the growth of phytopathogenic fungi (Santos *et al.* 2008). Afterward, the sugar beet vinasse was tested for the control of nematodes in pepper crops, as an alternative to the disinfection of soil-borne pathogens (Núñez-Zofío *et al.* 2013). Furthermore, the vinasse compounds can be used as chemical attractants (Martins *et al.* 2020). Recently, in the treatment of mycoremediation, Fernandes *et al.* (2020) reported a decrease in the growth rate of fungi using a wine vinasse concentration higher than 60%.

The vinasses have been shown to be effective against fungi, insects, and nematodes. The fungicidal activity have been tested against *Phytophthora parasitica*, *Fusarium oxysporum* f. sp. *melonis* race, *F. oxysporum* f. sp. *radicis-cucumerinum*, *Pythium aphanidermatum, and Sclerotinia sclerotiorum* (Table 1). The *Phytophthora* genus is one of the most devastating pathogens to a wide range of crop plants (El-Sayed and Ali 2020). *Phytophthora parasitica* is a soilborne pathogen (Meng *et al.* 2014). This oomycete mainly affects tobacco (Hou *et al.* 2012), tomato crops (Vigo *et al.* 2000), and the citrus industry (Boava *et al.* 2011). *Fusarium oxysporum* f. sp. *melonis* race is one of the most important diseases causing tremendous losses in melon fruit (Almasi 2019). *F. oxysporum* f. sp. *radicis-cucumerinum* is a vascular wilt fungus and is associated with cucumber crops (Markakis *et al.* 2016). *Pythium aphanidermatum* is the most devastating pathogen that affects turmeric and *Sclerotinia sclerotiorum* is capable of attacking more than 400 crop species (Boland and Hall 1994; Chand *et al.* 2016).

Moreover, the insecticidal activity was evaluated using sugarcane and wine vinasse against *Sphenophorus levis*, *Stomoxys calcitrans*, and *Oregmopyga peruviana* (Table 1). *Sphenophorus levis* affects the sugarcane crops, *Stomoxys calcitrans* is a stable fly that acts as a mechanical vector for the lumpy skin disease virus on cattle, and *Oregmopyga peruviana* is a vine pest (Casteliani *et al.* 2020; Dadther-Huaman *et al.* 2020; Paslaru *et al.* 2020).

Meloidogyne incognita, a root-knot nematode damaging vegetable crops (Collange *et al.* 2011), also has been tested using sugar beet vinasse for pest control (Table 1).

Due to this potential, vinasse can be studied as a source of biocide for the prevention and control of various pests.

Active Compounds

Esters, acids, aldehydes, ketones, aromatics, alkanes, alcohols, nitrosamides, and terpenoids, are acting in a synergistic inhibitory manner of fungi and bacteria (Saxena and Strobel 2020). Table 2 shows the compounds present in wastewater, a diverse source (vinasses, olive mill, and cassava) that is of great interest for the control pests. Phenols, organic acids, aldehydes, esters, furanic, and inorganic compounds are the main ones.

Table 2. Compounds Identified in Wastewater Samples of Interest in Pest Control

Wastewater Type	Classification	Compounds	Content	Reference
Wine Vinasses	Phenol	Gallic acid	10.83 g /L	Díaz *et al.* 2012
		Hydroxytyrosol	ND	
		Total phenols	18.9 g/L	
Baijiu Vinasse		Ferulic acids	1.674 mg/K	Wang *et al.* 2019
Sugar Beet Vinasse		Ferulic acid	< 5 mg/L	Bostyn *et al.* 2009
Tequila Vinasse		Eugenol	0.9 mg/L	Félix *et al.* 2018
		2,4-di-tert-butylphenol	90 mg/L	
		4-(2-hydroxyethyl) phenol	ND	
Mezcal Vinasses		Gallic acid	478 to 542 mg/L	Robles-González *et al.* 2012
Olive Mill Wastewater		Gallic acid	ND	Puoci *et al.* 2012
		Oleuropein	14.32	Di Mauro *et al.* 2017
		Hydroxytyrosol	267.17 to 821.86 mg/L	
Tequila Vinasse	Aldehydes	Benzaldehyde	ND	Félix *et al.* 2018
	Esters	Ethyl butanoate, ethyl lactate, and ethyl palmitate	ND	
	Alkanes	Dodecane, tetradecane, and eicosane	ND	
	Furanic compounds	Furfural	50 mg/L	
		5-methyl furfural	ND	
	Pyrans	4H-pyran-4-one,2,3-dihydro-3,5-dihydroxy-6-methyl and pyrrolo[1,2-a] pyrazine-1,4-dione, hexahydro-3-(2-methylpropyl)	ND	
Sugarcane Vinasse	Organic acids	Lactic acid	$1.2X10^{-1}$ mol/L	Sedenho *et al.* 2017
Cassava Wastewater	Triazine	Cyanuric acid	ND	Pinto-Zevallos *et al.* 2018
		Free cyanide	257.20 mg/L	Neves *et al.* 2014
Sugarcane Vinasse	-	Melanoidins	16600 g/L	Kaushik et al. 2018

ND=no data

Pest mortality has been attributed to the presence of phenolic compounds (Larif *et al*. 2013), due to being part of the protection system of plants against pests (Patzke and Schieber 2018). Lignin or lignin-rich biomass are a source of phenols, which can be obtained through the hydrothermal process (Peng *et al*. 2019). Therefore processes that contain lignin and are subjected to high temperatures will contain phenolic compounds in their wastewater, thanks to thermal hydrolysis. The wastewater contains phenols, such as hydroxytyrosol, gallic acid, ferulic acid, eugenol, oleuropein, 2,4-di-tert-butylphenol, and 4-(2-hydroxyethyl) phenol, which can be used or recovered for pest control (Table 2). For instance, hydroxytyrosol metabolite, a phytochemical polyphenol with antioxidant properties, has exhibited antimicrobial activity (Bisignano *et al.* 1999), insecticidal activity (Debo *et al.* 2011), disinfectant activity on seeds (Yangui *et al.* 2009), and fungicide activity (Yangui *et al.* 2010; Khan and Murphy 2020). The main sources of hydroxytyrosol are olive and wine (Rebollo-Romero *et al.* 2020). However, it is also reported in wine vinasse and olive mill wastewater (Table 2). Gallic acid, a secondary polyphenolic metabolite, is considered one of the most powerful antioxidants and has been reported in most plants (Erukainure *et al.* 2018; Martínez *et al.* 2018). From an environmental point of view, gallic acid present in agro-industrial wastewaters must be removed, due to its toxicity (Víctor-Ortega and Airado-Rodríguez 2018), because it can affect the microbial communities in wastewater discharge points. However, it can be used for the management of bacteria pathogen pests, as Borges *et al.* (2013) reported bactericidal activity. This phenolic compound is available in olive mill wastewater, wine, and mezcal vinasses, as an alternate source (Table 2). Ferulic acid is a phenolic compound extremely abundant and found widely in nature (Rosazza *et al.* 1995), showing fungicidal and bactericidal activities (Borges *et al.* 2013; Patzke and Schieber 2018). Based on Table 2, this compound has been reported in baijiu and sugar-beet vinasses. The eugenol (4-allyl-2-methoxyphenol) found in tequila vinasse (Table 2); it is an acaricidal agent, having fungicidal and bactericidal activities (Abd El-Baky and Hashem 2016; Shang *et al.* 2020). Oleuropein shows bactericidal and fungicidal activities, mainly contained in olives (Bisignano *et al.* 1999), and, as shown in Table 2, was also in the wastewater. Additionally, 2, 4-di-tert-butylphenol demonstrated fungicidal and acaricidal activity (Dharni *et al.* 2014; Chen and Dai 2015; Varsha *et al.* 2015), and 4-(2-hydroxyethyl) phenol showed nematicidal activity (Yang *et al.* 2012).

Therefore, phenolic compounds are considered a natural alternative to conventional plant protection agents (Patzke and Schieber 2018). Additionally, the recovery of phenols and the obtaining of added value products is attractive from industrial and environmental points of view (Víctor-Ortega and Airado-Rodríguez 2018).

Tequila vinasse compounds such as aldehydes, esters, alkanes, furanic compounds, and pyrans can be used for pest control. The benzaldehyde identified in tequila vinasse (Table 2) could be applicable for developing novel insecticides for agricultural use due to having been tested as agents effectively inhibiting fungi, insects, and microbials (Kim *et al.* 2011; Ullah *et al.* 2015). This compound is present in *Agave* alcoholic beverages such as bacanora, mezcal from *A. angustifolia*, mezcal from *A. durangensis*, mezcal from *A. potatorum*, mezcal from *A. salmiana*, raicilla, sisal, sotol, tequila, and pulque (De León Rodríguez *et al.* 2008). Therefore it is also found in the vinasse of each process. The ethyl butanoate, an ester, was identified in male rectal glands during periods of sexual activity in the banana fruit fly (*Bactrocera musae* Tryon). Therefore, ethyl butanoate could be used to control this pest as a possible biological role of these compounds in the mating system (Noushini *et al.* 2020). The ethyl lactate can be generated from biomass raw materials through fermentation (Pereira *et al.* 2011). As shown in Table 2, it is also present in liquid distillation wastes of tequila. A mix of ethyl lactate and acetic acid exhibits an antifungal effect (Sleven *et al.* 2016). Ethyl palmitate was identified as a component of the pheromone from the brood of bees, and this volatile compound attracts the small hive beetle, a pest of honeybees. This finding can be useful for trap development and management (Dekebo and Jung 2020). Other compounds present in the tequila vinasse, such as dodecane, tetradecane, and eicosane (Table 1), are the female sex pheromone compounds of *Paranthrene diaphana* Dalla Torre and Strand (Lep. Sesiidae), a destructive pest of willow trees (Minaeimoghadam *et al.* 2017). Therefore, the vinasse could be used to attract and control this pest. Moreover, furanic compounds with antifungal activity, such as furfural and 5-methyl furfural, can help decrease the commercial antifungal agrochemical dose against *Alternaria mali* (Jung *et al.* 2007). Additionally, 4H-pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl (Table 2) is part of a mixture that shows insecticidal, larvicidal, and pupicidal effects (Ravindran *et al.* 2020), and pyrrolo[1,2-a] pyrazine-1,4-dione, hexahydro-3-(2-methylpropyl) (Table 2) has an antifungal function (Kannabiran 2016).

Lactic acid identified in sugarcane vinasse (Table 2) showed antifungal activity against *Aspergillus*, *Penicillium*, and *Fusarium genera* (Lind *et al.* 2005). L-Lactic acid has used as a pesticide and can be obtained through a fermentation process (Liu *et al.* 2013). The cyanide that is present in cassava wastewater (Table 2) acts as a natural plant defense against pests (Pinto-Zevallos *et al.* 2018). This is the case for the cyanogenic glycosides in wastewater that comes from the soaking stage in the manufacture of flour from cassava (Alitubeera *et al.* 2019).

Melanoidins are the end products of the Maillard reaction between carbohydrates and amino compounds (Cämmerer and Kroh (1995). They are found in vinasses (Table 2), and have antimicrobial activity (Kaushik *et al.* 2018).

It can be seen in Table 2 that the composition of wastewater is diverse. Koul and Walia (2009) mentioned that this can be an advantage because the possibility of pests developing resistance is reduced.

Techniques for Target Compounds Recovery

The direct application of raw wastewater has been the most used for the evaluation of the power against pests. However, it is possible to recover the target compounds.

For the compound's recovery in rich phenolic wastewater, magnetic extraction, ultrasound-assisted extraction, solvent extraction, adsorption, or combined processes, such as hydrolysis-purification and extraction-adsorption, are used (Table 3). However, sometimes the suspended matter needs to be removed by flocculation, as a preliminary stage (Azzam and Hazaimeh 2021).

Some of the solvent extraction process steps are acidification or condensing, delipidation extraction, and purification used for phenol recovery in olive mill wastewater (Deng *et al.* 2017; Çelik *et al.* 2020). The acidification with acetic acid allows hydroxytyrosol enrichment (Debo *et al.* 2011), and ultrasound-assisted extraction could increase the yield of phenolic compounds (Deng *et al.* 2017). In the ultrasound-assisted extraction, less solvent is required (Albero *et al*. 2015), which makes it a more environmentally friendly technique. To remove lipids, a fraction delipidation step is employed, and hexane is the most used (Rubio-Senent *et al.* 2017). Ethyl acetate is the solvent more commonly used for the recovery of high added-value compounds from wastewaters (Table 3). This solvent was the most efficient for the recovery of phenolic monomers from olive mill wastewater (Allouche *et al.* 2004), and the system was able to reach a total recovery of polyphenols (Bostyn *et al.* 2009). After extraction, the resins are used in the purification step to increase the amount and purity of phenolic compounds (Çelik *et al.* 2020).

Despite adsorbents or chemicals used in conventional treatment (absorption and extraction) are cheaper than advanced treatments, both show high efficiencies (Villegas *et al.* 2016). It is even possible to reduce costs further with the use of low-cost adsorption media (Daragon *et al.* 2014).

Table 3. Processes Used for the Recovery of Phenol in Wastewater

Wastewater Type	Compounds	Solvent	pH	Process	Reference
Olive Mill Wastewater	Hydroxytyrosol	Ethyl acetate	2	Solvent extraction	Allouche *et al.* 2004
		-	3	Hydrolysis (acetic acid) and purification (resin)	Debo *et al.* 2011
	Polyphenols	Ethyl acetate	-	60 °C	Larif *et al.* 2015
				Solvent extraction	Azzam and Hazaimeh 2021
Tequila Vinasse	Phenolic compounds			Adsorption resins	Sanchez *et al.* 2019
Sugar Beet Vinasse	Phenolic acids	Ethyl acetate	4	Solvent extraction	Bostyn *et al.* 2009
Olive Oil Wastewater	Gallic acid	Ethanol		Solvent extraction and adsorption (molecularly imprinted polymers)	Puoci *et al.* 2012
Aqueous Solutions	Gallic acid	Ethyl acetate	-	Solvent extraction	Daneshfar *et al.* 2008
	Phenolic compounds	-	-	Magnetic extraction	Deng *et al.* 2011
Urban wastewater	Phenolic compounds	-	-	Ultrasound-assisted	Kotowska *et al.* 2014

Table 4 shows that certain wastewater types can have high lignin content, such as wheat straw and kraft pulping effluent. In fact, the dark color in cassava wastewater is due to the presence of lignin breakdown products and lignin phenols (Zhang *et al.* 2017). Lignin can be used as a raw material in the production of aromatic monomers (Gu *et al.* 2020). Currently, catalytic hydrothermal depolymerization has been used to obtain phenolic monomers from lignin (Roy *et al.* 2020), with the yield increasing 49% and 83% when using mannitol and sucrose addition (Gu *et al.* 2020).

Table 4. Lignocellulosic Biomass in Wastewater

Wastewater Type	Polymer	Content	Reference
Olive mill	Lignin	25.5 *	Uğurlu and Kula 2007
Wheat straw	Lignin	310 to 660 *	Wang 2020
Aspen kraft pulp	Lignin	230 to 770 *	
Sorghum and rice vinasse	Lignin	14.95 **	Cao *et al.* 2019

*mg/L, **% Dry matter

Environmental Impacts

For pest control, the use of compounds in wastewater should be discussed relative to potential environmental impacts. This source is a new field of research and the possible negative or positive effects have not been studied in depth.

As previously discussed, the positive effect of wastewater use on pests has been shown. However, when the wastewater is in contact with parts of the plants, with the soil, or is infiltrated into underground water, the effects are unclear. Possible environmental negative and positive impacts of the use of wastewater for pest control are shown in Table 5.

Positive Impacts

The positive impact, in general, is that wastewaters rich in nutrients are considered as an alternative fertilizer, bringing enhanced crop growth, water-holding capacity improvement, and microbial communities in wastewater coadjutant to phenolic degradation in soil (Table 5). Moreover, better soil basal respiration has been reported in cassava wastewater (Table 5), and the increase in CO_2 produced in soil respiration is associated with the improvement biological activity of organisms (Phillips and Nickerson 2015). The treated olive mill wastewater germination index increases and water-holding capacity with raw wastewater is improved and does not contain high heavy metal levels (Table 5).

Table 5. Environmental Impacts of Wastewater Used as Pest Control

Wastewater Type	Environmental Impact		Reference
	Positive	Negative	
Cassava	Increased nutrients	Initial toxic effect on soil fungal	dos Santos Moura *et al.* 2018
	Total organic carbon increase		
	Microbial biomass increase		
	Better soil basal respiration		
	Soil fertility improvement	Soil hydrophobicity	Abegunrin *et al.* 2016
	Enhanced crop growth		
	Crop yield increase		Cabral *et al.* 2010
Olive Mill	Germination index increase		Mekki *et al.* 2013
	Water-holding capacity Improvement		
	Low heavy metal loads	Seeds germination	Sassi *et al.* 2006
	Increased nutrients and organic matter	Soil infiltration rates decrease	Zema *et al.* 2019
		Soil infiltration rates decrease	Albalasmeh *et al.* 2019
	Microbial communities in olive mill wastewater coadjutant to phenolic degradation in soil		El Hassani *et al.* 2020
Sugar Beet Vinasse		Vegetation cover decreasing	Tejada *et al.* 2009
Sugarcane Vinasse		Methane emissions	Do Carmo *et al.* 2012
	Organic carbon increase		Soobadar and Ng Kee Kwong 2012
	Crop yield increase		

Negative Impacts

The raw and concentrated wastewater show negative impacts, for instance, concentrated olive mill wastewater blocked seed germination, and an initial toxic effect on soil fungal activity were identified (Table 5). Sassi *et al.* (2006) reported a dilution of 1/16 to guarantee full germination. High salt content in vinasse can cause vegetation cover decrease and changes in the structure and porosity of the soil (Tejada *et al.* 2009). When wastewaters are added to the soil, the organic matter accumulation in the soil affects penetration resistance and water repellency (Albalasmeh *et al.* 2019). A pre-treatment is recommended before applying it to the soil (Abegunrin *et al.* 2016). To avoid soil hydrophobicity and methane emissions (Table 5), a flocculation process can help.

Wastewater reviewed in this paper contained compounds with antimicrobial activity (Table 2). Therefore, care must be taken when applying it to the soil, as it can modify the composition and structure of key microbial communities. Hence, more research addressed toward microbial communities' impacts on the soil is needed, with a focus on richness, biodiversity, functionality, and microbial adaptability.

To avoid most of the negative environmental impacts associated with raw and concentrated wastewater for pest control, compound recovery processes with fungicidal, acaricidal, nematicidal, bactericidal, and insecticidal activities can be exploited. However, it is necessary to assess the economic and environmental benefits of both options, with more in-depth research.

Otherwise, there is another wastewater type with compounds that can inhibit pests; for example, pulp and paper mill effluent, which is a chlorophenol source (Cheng *et al.* 2015). Chlorophenols used as herbicides or fungicides on crops were banned, due to human carcinogenic risk (Owuor 2003; Badanthadka and Mehendale 2014). Therefore, pulp and paper mill effluent is not susceptible to use as a source for control pests.

Humans and animals as part of the environment can also be affected by the use of compounds that help control pests and plant diseases. Lin *et al.* (2020) mention that the use of chemical fungicides in fruits or vegetables could modify the composition of the intestinal microbiota. Therefore, a more complete study is required on the application of wastewater in pest control, either as a direct application or compounds recovery of interest, considering the present economic-environmental impact.

CONCLUSIONS

1. Wastewater is a potential and alternative source of compounds with bactericidal, fungicidal, and pesticidal effects that have demonstrated inhibitory activity.
2. The phenolic compounds are mainly responsible for pest mortality using wastewater.
3. Because wastewater is a variable chemical composition, its use can be dangerous for the environment. Therefore, the isolation of target compound is recommended.

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