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Review

Biological Control and Biofertilization of Oil Palm (*Elaeis Guineensis* Jacq.): Towards Sustainable Production

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Abstract
This review put insight into information about biological products used for oil palm production worldwide, particularly in Colombia. Biological products are drawing the next wave of sustainable agriculture in general and palm oil production in particular. The Colombian palm sector is committed to environmentally responsible farming and is a pioneer within America in oil palm certification under roundtable on sustainable palm oil standards. As the global demand for organic food and the awareness of environmental care increases, so does the market for biological products. Biological products help protect oil palm crops against pests and diseases, enhancing plants' growth, health, yield, and profitability. Numerous biological control agents (BCAs) and biofertilizer supplies have been approved and are part of the supply chain for oil palm production. This review offers a comprehensive list of BCAs and biofertilizer supplies commercially available for palm oil production. Thus, it helps cater to the needs of oil palm farmers, agriculturists, and everyone committed to working towards more sustainable oil palm production worldwide.

Keywords: biological control agents, biofertilizers, oil palm, *Elaeis guineensis*, sustainable agriculture

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1 INTRODUCTION

Agriculture is one of the economic pillars in many developing countries[1,2]. Agriculture is becoming increasingly dependent on chemical pesticides and fertilizers to fulfil the expanding food needs of a growing world population[2]. However, they can negatively affect the environment and human and animal health if misused or used excessively[3]. There are significant initiatives to stake out more sustainable agriculture; the most important one is innovations to meet the food needs of a growing world population, the increasing awareness of environmental protection, and the willingness of consumers worldwide to have access to healthier foods. Biological products offer a way to address these issues and are indeed drawing the next wave of sustainable agricultural productivity.

The term "biological products" or simply "biologicals" generally describes everything from natural compounds to micro and macro-organisms that help protect crops from pests and diseases while enhancing plants' growth, health, crop yield, and profitability. Biological products consist of beneficial microorganisms, macroorganisms, microbially- and plant-derived compounds, semiochemicals, and microbially- and plants-derived extracts[4,5]. They are typically categorized according to agricultural use as biological control agents (BCAs), biostimulants and biofertilizers[5].

Oil palm (*Elaeis guineensis* Jacq.) is the world's most important and productive vegetable oil crop. Its production is around 75 million tonnes annually, and the global production area is approximately 20 million hectares (ha) [6]. It has seen a growing demand and a significant increase in global production in the last 30 years, to which the oil palm industry responded by expanding the planted area. However, the expansion has been associated with deforestation, biodiversity loss, ecosystem services, and contributions to greenhouse gas emissions[7-10]. In addition, the use of chemical pesticides and fertilizers -of which around 80% are run-off into land and water ecosystems, discharges of mill effluent, wastewater and empty fruit bunch disposal, gasoline use in weed cutters, and glyphosate use for weed control are some other negative impacts associated with oil palm cultivation[3,11-13]. Several efforts are underway to respond to the calls for more responsible and sustainable oil palm production, including the use of biological products.

This review aims to bring up an updated view of biocontrol agents and biofertilizers as a sustainable practice for oil palm production worldwide, particularly in Colombia. Likewise, it aims to gather practical information on commercially available biological supplies to help cater to the needs of Colombians palm oil farmers and agriculturists, the agricultural and plant biology communities in general, and everyone committed to working towards more sustainable agriculture worldwide.

2 PALM OIL

2.1 Policies and Efforts Underway toward Sustainable Production Worldwide

Four countries-Indonesia, Malaysia, Thailand, and Colombia, constitutes 90% of oil palm world production[14] (Table 1). Few tropical plants have become as necessary as palm oil, which is now the main provider of edible oils, fats, and a variety of essential supplies, leading to the use of biomass and oleo-chemistry and the creation of alternative energy sources for biofuel-based diesel machinery and engines. On average, one hectare planted with oil palm produces six and ten times more oil than other oilseeds per year[15].

However, concerns and calls for more responsible and sustainable oil palm production are arising. As a result, various organizations, standards and policies have been developed, such as the International Federation of Organic Agriculture Movements (IFOAM) and the global Roundtable on sustainable palm oil (RSPO), among others[13]. Likewise, several efforts are underway, such as improving smallholder inclusiveness, increasing crop yield to minimize land use, expanding plantations in areas with low carbon stock, avoiding deforestation of natural forests, using biodiesel as a substitute for fossil fuels, producing biochar at the time of replanting, and increasing the use of BCAs and biofertilizers[8,12,16-19].

In this vein, RSPO and IFOAM certifications can make important contributions by engaging smallholders and even small-scale growers to adopt more sustainable, resilient, and responsible practices. For example, a case study was performed in Colombia to help smallholders to get their oil palm productions certified[13]. Interestingly, certified producers reported significantly lower agrochemical use, more on-farm conservation areas, reduced hunting, and better worker pay. The most notable difference between certified and non-certified groups was agrochemicals: 19% of certified producers used fertilizers, and 9% used pesticides, compared to 98% and 65% of non-certified producers[13,20]. This can be attributed to organic practices implemented on certified farms, representing a positive case study demonstrating that building and consolidating sustainable oil palm production is possible.

Global efforts toward sustainable agriculture are reflected in the continuous growth of the biological products market, estimated at USD 12.90 billion in 2022, and projected to reach USD 24.6 billion by 2027, growing at a compound annual growth rate (CAGR) of 13.7%[21].

2.2 Sustainable Production in Colombia

Colombia is the largest palm and palm kernel oil producer in America and the fourth largest globally[14]. Palm and palm kernel oils represent 94.1% of the Colombian national production of oils and fats in the local market and about 66% of the consumption of these products[15]. Palm oil is cultivated along 21 departments including 160 'Municipios', extending throughout 516.961 planted ha, generating 170.794 direct and indirect job positions[20,22].

The Colombian palm sector is committed to environmentally responsible farming, tending to a deforestation-free development, preserving biodiversity, and being in harmony with the natural riches of the palm-growing regions[15]. In this line, Colombia had 62.102 oil palm-certified hectares by May 31, 2019, according to RSPO[23]. This sustainable tendency -which has even been adopted by the oil palm industry in Latin America, contrasts with the trajectory followed by Southeast Asia producers. The most striking difference is in land-use changes during plantation expansion. This is commonly related to forest clearance

Table 1. The Top Five World Oil Palm Producers

Ranking	Country	Palm Oil Production	
		MT/y	%
1	Indonesia	46,500	59
2	Malaysia	19,800	25
3	Thailand	3,260	4
4	Colombia	1,838	2
5	Nigeria	1,400	2
	World	79,141	100

Notes: Data was updated on July 2022. References: MT/y, million tonnes/year. Source: Palm oil, USDA (2022).

in Malaysia and Indonesia, whereas plantations in Latin America are mostly established on previously cleared land, such as cattle pastures[13,24].

2.3 Main Pests and Diseases Affecting Oil Palm in Colombia

Oil palm, however, remains prone to a variety of pests and diseases, such as insects, bacteria, fungi, and vertebrates[25]. Some of the main threats affecting this crop in Colombia include lethal yellowing, red ring disease, beetle pests, root borer, bud rot, and sudden wilt, as reported by Cenipalma (Table 2)[26-28].

2.4 BCAs

BCAs encompass a diverse group of product technologies aiming to control plant pathogens and pests population via various modes of action. BCAs include microorganisms, like bacteria and fungi, which are known as microbial BCAs (MBCAs); beneficial macroorganisms, like predatory mites; biological compounds, like endotoxins, phytohormones, or plant- and microbially-derived elicitors, etc. It also includes microbially- and plant-derived extracts; biochemical compounds, like abscisic acid, 9,10-anthraquinone, ammonium bicarbonate, etc.; and semiochemicals, like pheromones[4,5,29-31]. BCAs offer multiple benefits for growers, consumers, and the entire food chain, compared to conventional agrochemicals (Table 3).

Many MBCAs and elicitors have been reported for their capacity to induce immune responses in a diverse range of plants and crops[30,32-43], including oil palm, which can respond faster and stronger to subsequent biotic and abiotic stresses[33,42-49]. Other MBCAs act via nutrient or space competition or other mechanisms modulating the growth conditions for the pathogen[30,31,50]. At the same time, antagonists act through hyper-parasitism and antibiosis, directly interfering with the pathogen[51-53].

In oil palm, the fungus *Metarhizium anisopliae* efficiently controls adults of *Haplaxius crudus*, the main vector of the lethal wilt disease[54-57] (Table 2). Using pheromones is one of the best tools to combat the weevils *Rhynchophorus palmarum, Dynamis borassi*, *Metamasius hemipterus*, and *Limnobaris calandriformis,* the vectors causing the red ring in palms[58]. The beetle pest, caused by the rhinoceros beetle *Strategus aloeus*[59,60]*,* is mainly controlled by conventional pesticides and old palm removal in renewal lots; some attempts to use entomopathogenic nematodes were also performed[61]. Some attempts were performed using Trichoderma isolate for the bud rot disease caused by the bacterium *Phytophthora palmivora*[62,63]. However, the best current option is an integrated crop management system that includes cultivar selection, proper drainage, good fertilization, regular monitoring, infected tissue removal, and destruction of infected tissue or plants (Table 2).

2.5 Biofertilizers

Biofertilizers encompass a diverse group of product technologies aiming to improve plant nutrient-use efficiency, enhance plant growth and health, and enrich the soil-especially the rhizosphere, in all kinds of micro- and macro-nutrients. They include bacterial bioinoculants, like plant growth promoting bacteria (PGPB); fungal bioinoculants, like arbuscular mycorrhiza fungi (AMF); biochemical materials, like organic acids, fulvic acids, amino acids, and humic acids; extracts or amendments, like seaweeds, organic matters, chitosan, laminarins, alginates, etc. Biofertilizers also include others, like protein hydrolysates, peptides, beneficial elements (Si, Na, Co, Ca, etc.), and inorganic salts, among many others[5]. This review will refer to "biofertilizers" as biological products with biostimulant and biofertilizer features. Biofertilizers offer multiple benefits for growers, consumers, and the entire food chain, compared to conventional fertilizers (Table 4).

PGPB encompasses a wide range of bacteria with diverse mechanisms of action that enhance the bioavailability of nutrients, which benefits plant nutrition and soil quality. They were reported to enhance growth, and nutrient uptake in oil palm, as well as improve soil quality and help to maintain or improve the beneficial microorganisms in the soil while reducing the use of chemical fertilizers[12,64-71]. Numerous pre-nursery, nurseries, greenhouse, and even field studies have been performed. For instance, the application of a biofertilizer

Table 2. Main Diseases and Pests Affecting Palm Oil in Colombia

Disease	Category	Causal Agent	Symptomatology	Comments	Biological Control	Ref.
Lethal yellowing	Insect (nymph and adult)	*Haplaxius crudus* (vector) *Candidatus palma* (causal agent, phytoplasma)	Leaves are affected without following a defined order; necrosis begins at the edges and advances from the tip towards the base. Shedding of fruits in immature clusters. Necrosis of bunch crown.	It is one of Colombia's most serious palm oil illnesses, causing millions of economic losses.	*Metarhizium anisopliae*[29-32]	[27,28,32-35]
Red ring	Insects (larvae and adults)	*Rhynchophorus palmarum* (vector) *Bursaphelenchus cocophilus* (causal agent, nematode)	Progressive chlorosis (yellowing) starts on the lower leaves and advances toward the youngest, which can be shortened. Orange and oily-looking spots on petioles and rachis. Orange stains of the meristem. Brown spots and stipes' ring. Closed or crowded bud. Loss of brightness of fruits. Rot bunches.	It is one of the main pests in palm oil plantations in Colombia, causing economic losses. Other weevils reported as vectors of red ring disease in Colombia are *Dynamis borassi*, *Metamasius hemipterus*, and *Limnobaris calandriformis*[36].	Pheromones[37]	[27,28,38]
Beetle pest	Insect (Larvae and adult)	*Strategus aloeus*	Overturning and death of the palm. Damage caused by these insects may serve as gateways for disease-causing microorganisms such as stem rot.	The adult male pierces the bulb of young palms (less than 2 years old), where it feeds and releases a pheromone to attract the female, who lays eggs and initiates reproduction.	Entomopathogenic nematodes[39]	[27,28]
Root borer	Insect (Larvae and adult)	*Sagalassa valida*	Palms have poor anchoring and overturn.	The larvae cause damage as a borer of the root system of a young or adult palm. Adults oviposit in leaf litter or soil debris from which larvae emerge and penetrate roots.	n.f.	[27,28]
Bud rot	Bacterial	*Phytophthora palmivora*	Mild chlorosis in the beam of the leaves. Generalized chlorosis on leaves 2 to 5, as the disease progresses; watery lesions with a foul odor.	It attacks palms at any age aggressively and spreads quickly. A single sick palm without treatment can affect neighbouring palms and even an entire plantation in a short time.	*Trichoderma*[40,41]	[65-70]
Sudden Wilt	Protozoa	*Phytomonas staheli*	Loss of fruits' brightness. Progressive drying of the leaves, yellowing (chlorosis), and reddish-brown discolouration of leaves.	It is a lethal disease present in the four palm regions of Colombia. It mainly affects young palms from the beginning of their productive stage[47].	n.f.	[33,48-51]

Notes: This list was prepared based on the main pests and diseases reported by Cenipalma (https://www.cenipalma.org/sanidad), an institution that promotes the sustainable development of palm oil agribusiness in Colombia. References: n.f., not found any reference.

made up of a consortium of bacteria and fungi, including *Proteobacteria*, *Bacillus*, *Providencia*, *Phyllobacterium* and *Sphingobacterium* bacteria, *Trichoderma*, *Antrodia*, *Pichia*, *Pycnoporus*, and *Phanerochaete* fungi, led to the

Table 3. Benefits of Biological Control Agents (BCAs) over Conventional Agrochemicals

BCAs	Agrochemicals
Reduce the risk of exceeding residue limits as they are biological products.	High risk of exceeding residue limits upon misuse, with negative consequences for humans and the natural flora and fauna.
Precise effects mainly affect the pathogen/pest or closely related organisms; they are less harmful to beneficial insects, helping promote natural crop protectors.	Broad spectrum effect, affecting not only the pathogen/pest but also the surrounding flora and fauna.
New modes of action help reduce the risk of resistance among pests and diseases; they induce plant immune defenses, produce antibiotic compounds, attract target organisms by pheromones, etc.; minimum risks of the evolution of target organisms to evade the control.	Traditional modes of action (direct kill or inactivation) generally affect a vital process of the target organism, which can evolve to resist the active molecule of agrochemicals.
Higher consumer satisfaction through the promotion of more sustainable and transparent production systems.	Increasing awareness of environmental protection and willingness of consumers to have access to healthier foods.
Dual or triple beneficial effects enhance plant health, growth, and yields.	They do not induce any plant growth *per se.*
Wide compatibility with other biological and chemical crop protection products.	Lower compatibility with BCAs or even chemical insecticides and pesticides.
Approved for use in organic systems.	Only approved for conventional agriculture.
Enhance integrated pest management (IPM), reducing the use of chemical pesticides/insecticides/fungicides/bactericides while crop yields remain high.	Strongly dependent on the use of chemical pesticides/insecticides/fungicides/bactericides, while crop yields remain high.
Less than one year to be approved by EPA.	More than three years to be approved by EPA.

Notes: BCAs, biological control agents; EPA, the US Environmental Protection Agency.

Table 4. Benefits of Biofertilizers over Chemical Fertilizers

Biofertilizers	Agrochemicals
Enhance bioavailability and absorption of nutrients and water present in the soil.	External rapid source of nutrients, around 80% runs off, contaminating land and water bodies.
Increase yields, crop quality, and shelf-life, leading to increased profitability.	Similar to biofertilizers.
Promote the early vigor of plants and vigorous growth of roots and shoots.	Similar to biofertilizers.
Stimulate nutrient mineralization by organic material decomposition, improving rhizosphere conditions, and enhancing native microbiota growth.	Do not stimulate nutrient mineralization, which can negatively affect roots if applied in excess.
Facilitate the establishment of seedlings after transplant to the field.	Similar effect as biofertilizers.
Improve soil aggregation, helping to reduce erosion.	Do not improve soil aggregation.
Induce plant innate immune defenses, improving crop health and tolerance to biotic and abiotic stresses.	Do not induce plant innate immune defenses.
Less harmful to beneficial insects, protecting native flora and fauna.	Negative impact on the surrounding flora, fauna, and human health when misused.
Approved for use in organic systems.	Only approved for conventional agriculture.

increase of vegetative measurements and nutrients uptake in palm oil seedlings when combined with a reduced dose of conventional fertilizer[65]. Similarly, palm oil seedlings grown with endophyte nitrogen fixing-PGPB bacteria were significantly taller and bigger in girth size. They presented a higher dry weight of shoots and roots and chlorophyll content compared to control seedlings[72]. Previous studies reported that the application of biofertilizers (one constituted by a consortium of bacteria and the other by a consortium of bacteria, fungi, and yeast, integrated with a low rate of chemical fertilizer) led to better palm oil growth, a balanced and sufficient nutrient availability, and help to maintain the survivability of beneficial microorganisms in the soil under greenhouse conditions[64]. Furthermore, Veeramachaneni and Ramachandrudu (2020)[73] demonstrated that bioinoculants, namely *Azotobacter chroococcum*, *Azospirillum brasilense*, *Bacillus megaterium*, *Frateuria aurantia,* and *Glomus aggregatum,* enhanced palm oil seedling growth through increased microbial population and enzyme activity in the rhizosphere, allowing to reduce up to 25% the recommended dose of chemical fertilizers.

As PGPB-based biofertilizers, organic amendments and fertilizers can also improve oil palm growth, health, and

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Table 5. Biological Control Agents (BCAs) and Biofertilizers for the Sustainable Production of Palm Oil

No	Category (sub-category)	Product	Company	Origin	Composition		Target		Benefits
					Organic/ biological compounds	Microorganisms	Pest/ disease	Plant/ soil	
1	Biofertilizer and BCA (fungicide, bactericide and nematicide)	Botrycid	Natural Control	Colombia	n.c.	*Burkholderia vietnamensis* (1×10^8CFU/cc)	Yes	Yes	Promotes plant growth; N fixation; vigorous growth of roots and shoots; bioavailability of nutrients; increases overall plant performance. Inhibits the growth and development of phytopathogenic fungi, bacteria, and nematodes.
2	Biofertilizer and BCA (fungicide, nematicide and insecticide)	Micorrizagro	Natural Control	Colombia	0.50% P, 0.20% K, 7.2% Mg, 8% Si, Mieses and Saccharides.	AMF (*Glomus* spp., *Entrophospora* spp., *Scutellospora* spp., *Acaulospora* spp.; minimum of 230sp/g)	Yes	Yes	Improves nutrients and water bioavailability and absorption; improves soil aggregation, decreasing erosion; more vigorous growth of roots and shoots; increases overall plant performance. Plants better support drought stress and root pathogens (nematodes, insects, and parasitic fungi). Allows to replace up to 25% of conventional fertilizer.
3	Biofertilizer and BCA (biofungicide and bactericide)	BIOGRIM	Perkins	Colombia	n.c.	PGPB (*Azospirillum brasiliense; Azotobacter chrococcum; concentration n.s.*)	Yes	Yes	Promotes growth of stronger plants; enhances N fixation; improves plant nutrition; activates the formation of roots; favors nutrients and water uptake; helps plants establishment; promotes plants tolerance to difficult initial conditions; enhances crop yields by 6% to 96%. Inhibits the growth and development of bacteria and fungi pathogens (*Fusarium* sp., *Colletotrichum* sp., *Pythium* sp., *Aspergillus* sp., *Helminthosporium* sp., and *Peronospora arborescens*).
4	Biofertilizer and BCA (fungicide and bactericide)	*Pseudomona fluorescens*	Perkins	Colombia	n.c.	*Pseudomona fluorescens* (concentration n.s.)	Yes	Yes	Promotes plant growth; enhances nutrient solubilization (especially of fixed P) and absorption. Induces plants' immune responses; controls fungal and bacterial diseases.
5	Biofertilizer and BCA (fungicide and bactericide)	PROMOBIOL	Perkins	Colombia	n.c.	PGPM consortia (*Trichoderma sp., P. fluorescens, Azotobacter, Azospirillum, B. subtilis;* 1×10^8 UFC/g each one)	Yes	Yes	Improves nutrients and water bioavailability and absorption (including fixed P); promotes plant growth; N fixation; improves crop yield and reduces the number of conventional fertilizers; improves soil aggregation, decreasing erosion. Controls soil bacteria and fungi pathogens (*Rhizoctonia* sp., *Fusarium* sp, *Botrytis* sp, *Alternaria* sp, *Sclerotium* sp, *Pythium*).

6	Biofertilizer and BCA (nematicide and insecticide)	Micosplag WP	Orius Biotech	Colombia	n.c.	*Paecilomyces lilacinus* (1×10^8sp/g) *Metarhizium anisopliae* (1×10^6sp/g) *Beauveria bassiana* (1×10^6sp/g)	Yes	No	Protects roots from damage by nematodes, plague, and pests (*Meloidogyne* sp., *Helicotylenchus* spp., *Pratylenchus* spp., *Sagalasa valida*, *Loxotoma elegans*, *Stenoma cecropia*, *Euprosterna* sp., *Sibine* sp., *Opsiphanes* sp., *Dirphia* sp., *Brassolis* sp., *Lephtopharsa* sp.).
7	Biofertilizer and BCA (biofungicide and nematicide)	Concentrated Micorrhiza Powder	Peptech Biosciences	India	Seaweed extract, hydrolyzed protein, humic acids, and chelated nutrients.	AMF (3500IP/g; species n.s.)	Yes	Yes	Promotes seedlings, cutting, transplanting, and direct sown crops. Increases root volume by 50-150%; facilitates macro and micronutrient absorption. Induces plants' resistance to drought, soil-borne fungal pathogens, and nematodes.
8	Biofertilizer and BCA (biofungicide)	Fitotripen	Natural Control	Colombia	Cereals, sucrose, and organic carbon.	*Trichoderma* (*T. harzianum, T. koningi y T. viridae;* 1×10^8sp/g);	Yes	Yes	Biomineralizes organic and inorganic nutrients, especially Ca. Inhibits soil and foliage phytopathogenic fungi (*Fusarium* spp., *Phytophthora* spp., *Rhizoctonia* spp., *Pythium* spp., *Sclerotinia* spp., *Rhizopus* spp.); activates plant's immune responses.
9	Biofertilizer and BCA (biofungicide)	Agroint-T	Agrobrokers	Colombia	n.c.	*Trichoderma harzianum* 4% (1×10^9sp/g)	Yes	No	Promotes plant growth; synthesizes substances that activate the production of hormones and root growth; facilitates nutrient absorption. Protects crops against root diseases caused by phytopathogenic fungi. Induces immune resistance and releases compounds that limit phytopathogen development.
10	Biofertilizer and BCA (biofungicide)	MYCOFERT	Perkins	Colombia	n.c.	AMF consortium (*Glomus* sp. *Entrosphospora* sp. *Acaulospora* sp., *Gigaspora* sp., *Scutellospora* sp.; 5sp/g)	No	Yes	Improves macro and micronutrient absorption, increases root and overall plant development, increases crop yield and uniformity, improves soil aggregates, increases resistance to transplanting, and reduces the amounts of conventional fertilizers. Improves resistance to attack by root pathogens, increases tolerance to environmental stress, improves plants' resistance to nutrient imbalance.
11	Biofertilizer and BCA (biofungicide)	BioFungo WP	Orius Biotech	Colombia	n.c.	*T. harzianum* OBTh55 (concentration n.s.)	Yes	Yes	Induces root formation; conditions soil; biostimulates plant growth. Blocks diseases in the soil, roots, and residues of the previous harvest; reduce the number of damaged roots, seed death, and sick plants in the next crop due to diseases; enhances plant sanity and reduces the number of fungicides applications. Recommended for organic agriculture.

12	Biofertilizer and BCA (biofungicide)	Agroint-T	Agrobrokers	Colombia	n.c.	*Trichoderma harzianum* 4% (1×10^9sp/g)	Yes	No	Promotes plant growth; synthesis of substances that activate the production of hormones and root growth; facilitates nutrient absorption. Protects crops against root diseases caused by phytopathogenic fungi, induces immune resistance, and releases compounds that limit phytopathogens development.
13	Biofertilizer and BCA (soil pathogens)	Mycorrizz®	Suppra	Colombia	n.c.	AMF (consortia of 20 species; 35,000 – 45,000sp/kg soil)	Yes	Yes	Increases tolerance to adverse soils; improves soil aggregation, decreasing erosion; stimulates greater root mass; improves absorption of nutrients and water; plants recover faster from hydric stress; more vigorous growth. Increases resistance to pathogens, especially those in the soil that attack roots. Allows to replace up to 25% of conventional fertilizer.
14	Biofertilizer and BCA (soil pathogens)	Bacthon SC	Orius Biotech	Colombia	Additives 80%	PGPB (*Azospirillum brasilense* 5%, *Azotobacter chroococcum* 5%, *Lactobacillus acidophillus* 5%, *Saccharomyces cerevisiae* 5%, 10,000CFU/ml each one)	Yes	Yes	Detoxifies agricultural soil and roots; breaks down toxins, alcohols, ammonia, and agrochemicals. Improves macro and micronutrients and water bioavailability and absorption; improves soil fertility, structure, porosity, and permeability; activates root formation; promotes plants growth and health; helps plants' initial establishment and enhances tolerance to adverse conditions. Contributes to eliminating phytopathogens' hosts and pest insects present in the soil.
15	Biofertilizer and BCA (soil pathogens and *Phytophthora palmivora*)	Báliente	Natural Control	Colombia	Cereals, sucrose and organic carbon.	*B. amiloliqu-efaciens* species (concen-tration n.s.)	Yes	Yes	It fixes nutrients; improves plant nutrition. Activates plant immune responses. Produces antibiotic compounds (bacillustatin and bacteriocin) with fungicide and bactericide capacity towards a broad spectrum of plant pathogens, including *Phytophthora palmivora*, the bacterium causing bud rot.
16	Biofertilizer and BCA (plant pathogens)	Galileo	Natural Control	Colombia	0.60% N, 1%P, 0,20% K, 10% Mg, 10% Si and oxidizable organic carbon.	AMF (100,000sp/g; species n.s.).	Yes	Yes	Solubilizes nutrients; increases nutrients and water bioavailability and absorption; promotes robust and branched roots; increases crop yield and profitability. Promotes resistance against plant pathogens.

17	Biofertilizer and BCA (soil and seed pathogens)	Tricho Pep-V	Peptech Biosciences	India	n.c.	*Trichoderma viride* (1.5%)	Yes	Yes	Induces plants vigorous growth; decomposes organic matter; improves biomineralization and absorption of soil P; reclaims adverse soils; protects soil ecosystem. Protects against several soil-borne and seed-borne pathogens in nursery beds and the field; induces plant resistance to drought and diseases.
18	BCA (biofungicide and bionematicide)	Tricho Pep-H	Peptech Biosciences	India	n.c.	*Trichoderma harzianum* (2×10^6sp/g)	Yes	No	Controls numerous fungi (*Pythium* spp., *Rhizoctonia* spp., *Fusarium* spp., *Sclerotinia* spp. *Macrophomina*, *Cephalosporium* sp., *Sclerotium rolfsii*, *Phytophthora* sp., and *Meloidogyne* sp.) and root-knot nematodes.
19	BCA (bionematicide)	AsaSol TM	SoluNeem	USA	Azadira-chtin 6%	n.c.	Yes	No	Controls a broad spectrum of insects and pests. It is recommended for Palm oil and organic agriculture since it derives from the Neem plant.
20	BCA (bionematicide)	Agroin– PAE®	Agrobrokers	Colombia	n.c.	*Paecilomyces* sp. 1×10^9sp/g)	Yes	No	Controls nematodes eggs and females.
21	BCA (bioinsecticide)	Agroin–M® PW	Agrobrokers	Colombia	n.c.	*Metarhizium anisopliae* (1×10^9sp/g)	Yes	No	Controls insect pests mainly of the orders Coleoptera and Hemiptera.
22	BCA (bioinsecticide)	Agroin-B® PW	Agrobrokers	Colombia	n.c.	*Beauveria bassiana* (1×10^9sp/g)	Yes	No	Controls insect pests mainly of the orders Coleoptera and Lepidoptera.
23	BCA (bioinsecticide)	CRISOPA	Perkins	Colombia	n.c.	*Chrysoperla carnea* (13.000eggs/g product)	Yes	No	Predates pest insects such as aphids, thrips, mites, soft scales, mealybugs, eggs and larvae of Lepidoptera.
24	Semio-chemicals (pheromone)	Palmalure FG	n.s.	Colombia	S-Rhinco-pherol (2-metil-4hidroxi-5-heptenol)	n.c.	Yes	No	Combats *R. palmarum* species causing the red ring in Palm oil.
25	Semiochemicals (pheromone)	COMBOLURE	Chemtica International S.A.	USA	E-6-methylhept-2-en-4-ol, 199.45g/kg 2-methyl-4-heptanol, 39.89g/kg 4-methyl-5-nonanol, 159.56g/kg	n.c.	Yes	No	Combats the red palm weevils *R. palmarum*, *Dynamis borassi*, and *Metamasius hemipterus*, vectors of the red ring in Palm oil.
26	Biofertilizer	RhyzoPlex-®3-3-3	Novozymes	Denmark	3% N, 3% P, 3% K, 1% Ca, 0.6%Mg, 10% humic acids, 2.5% lignin, vitamins, seaweed extracts	PGPB and AMF (0.51% bacterial cultures of 6 *Bacillus* species + 5% consortium of 18 endo- and ecto-mycorrhiza species)	Yes	Yes	Improves nutrients and water bioavailability and absorption; vigorous growth of roots and shoots; improves plant performance. Healthier plants lead to better tolerance to biotic and abiotic stresses. Allows to replace up to 25% of conventional fertilizer.

27	Biofertilizer	Gedeon WP	Natural Control	Colombia	Phytases and Phosphomonoesterases (100mills. enzimes/g)	n.c.	No	Yes	Solubilizes and mineralizes organic and inorganic P, augmenting its bioavailability for better plant nutrition.
28	Biofertilizer	Cénturion	Natural Control	Colombia	A mix of organic acids, reducing potassium acids, and oxidizable organic carbon.	n.c.	No	Yes	Improves the rhizosphere's conditions; promotes mineralization of nutrients by organic matter decomposition; augments nutrients bioavailability and absorption; serves as an energy source for rhizobiota.
29	Biofertilizer	SOIL Activator®	Agrogama	Colombia	n.c.	PGPB (*B. subtilis*, 2.48×10^8CFU/g, *B. amiloliquefaciens* 5×10^6CFU/g, *P. monteilii*, 1×10^6CFU/g)	Yes	Yes	Improves nutrients and water bioavailability and absorption (including fixed P); promotes plant growth and health; improves crop yield and reduces the number of conventional fertilizers by 25% to 66%; augments crop yield by 36% when used as a stand-alone fertilizer.

Notes: This list was based on an exhaustive search of microbial-based biological supplies recommended specifically for Palm oil (*Elaeis guineensis*), as stated in the respective technical data sheets. It is not considered complete; any omissions or errors are regretted. Furthermore, indications of these supplies by the authors do not signify an endorsement of the companies. References: BCAs, biological control agents; n.s., not specified; n.c., it does not contain; PGPB, plant growth promoting bacteria; PGPM, plant growth promoting microorganisms; AMF, arbuscular mycorrhiza fungi; sp/g of product; sp/kg, spores/kilogram; N, nitrogen; P, phosphorous; K, potassium; Mg, magnesium; Ca, calcium; Si, silicon.

yield throughout the different stages of production. Some interesting approaches reported positive effects in raising oil palm seedlings and field-established plants in organic-based substrates like Klasmann, coconut husk, coconut husk: soil (1:1)[74], biochar, and compost oil palm empty fruit bunch (EFB)[67,75-80]. It is exciting how the exploitation of such organic wastes may promote better management of oil palm plantations.

3 BIOLOGICAL PRODUCTS APPROVED FOR THEIR USE IN PALM OIL IN COLOMBIA

Contributing to sustainable oil palm production, this review aims to gather practical information about the bioproducts effectively used in oil palm for their biocontrol, biostimulator, and biofertilization features. An exhaustive list was performed based on microbial-based biological supplies recommended specifically for oil palm (*Elaeis guineensis*), as stated in the respective technical data sheets (Table 5). For this purpose, numerous online vademecum available online were used, such as 'Portal TecnoAgrícola'[81], 'croper.com'[82], and the CABI BioProtection Portal[83]. The latter is a useful and free tool to discover natural, registered biocontrol, and biopesticides products that growers and advisors can use for organic agriculture or in integrated practices management worldwide.

4 CONCLUSION

Biological products are drawing the next wave of sustainable oil palm production worldwide. As the global demand for organic food and the awareness of environmental care increases, so does the market for biological products. This review brings out information about biological products in general, oil palm production worldwide, and Colombia in particular. It offers a comprehensive list of commercially available BCAs and biofertilizer supplies to help cater to comprehend the needs of palm oil farmers and agriculturists and everyone who is committed to working towards more sustainable oil palm production worldwide.

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Not applicable.

Conflicts of Interest

The authors declared no conflict of interest.

Author Contribution

Hael Conrad V wrote, edited, and proofread the manuscript. Juan PM critically reviewed the manuscript.

Abbreviation List

AMF, Arbuscular mycorrhiza fungi
BCAs, Biological control agents
Ha, Hectare
IFOAM, International federation of organic agriculture movements
MBCAs, Microbial biological control agents

PGPB, Plant growth promoting bacteria
PGPM, Plant growth promoting microorganisms
RSPO, Roundtable on sustainable palm oil

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