CA21134 - Towards zer0 Pesticide AGRIculture : European Network for sustainability (T0P-AGRI-Network)

WG1. Setting the scene: identifying research gaps and needs Task 1.2 Analyze research gaps and needs based on literature review

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INTRODUCTION

In the current EU mainstream agriculture crop protection heavily relies on curative measures using chemical pesticides. The affordability and effectiveness of these pesticides have led to simplified cropping systems, short rotations, low crop diversity, landscape homogenization, habitat removal and regional monoculture specialization. Due to their long-lasting in the environment, accumulation in living organisms and potential adverse effects on human health, there is a pressing need for a paradigm shift towards preventive crop protection, prioritizing prophylaxis over the existing curative approach since pesticides are persistent organic pollutants. Most of them stay long-time in the environment, also they lipophilic properties and tend to accumulate in living organisms. While EU Member States have implemented Integrated Pest Management (IPM) principles to reduce pesticide use, varying interpretations and inconsistent implementations have hindered achieving the desired reduction targets. Substitution actions have often focused on specific pests, and IPM programmes aiming for gradual reductions have not yielded significant decreases in pesticide use and impact.

In the ever-evolving landscape of agriculture, the imperative for sustainable practices have taken centre stage with an increasing emphasis on the pivotal role of zero pesticides. As global populations burgeon and environmental concerns intensify, the need for agricultural methods that safeguard both human health and ecological balance becomes paramount. This introduction highlights the significance of transitioning towards zero pesticides, referencing key areas such as ecological impact, human health implications and the broader quest for sustainable farming practices.

Environmental Imperative:

Persistent organic pollutants (POPs), such as pesticides, are lipophilic, persistent and bioaccumulative in human and biota (Bruce-Vanderpuije et al., 2019). A pressing concern in contemporary agriculture is the ecological impact of pesticide usage. Pesticides from agricultural areas can affect the soil, ground and surface water, air by the soil resuspension or by firing the crop residues, and crops. The detrimental effects on soil health, water systems, and non-targeted species have raised alarms about the sustainability of conventional pesticide-dependent farming methods (Carvalho, 2017). The urgency to address these environmental ecological concerns underscores the importance of transitioning towards zero pesticides. One of the main importance for the mitigation of pollution is the identification of the pesticides and their metabolites in the environmental samples from agricultural areas and investigation of their bioavailability to crops and bioaccessibility to humans who are directly exposed to the agricultural soil, waters, and who consume crops.

Human Health Considerations:

Pesticide residues in food and environment (agricultural soil, water and air) and their potential impact on human health have sparked widespread apprehension (Jurewicz & Hanke, 2018). Human exposure to these persistent organic compounds (such as pesticides) may have disruptive effects on endocrine, reproductive, cardiovascular, hepatic, urinary systems, additionally to carcinogenic risk, neurotoxicity, and genotoxicity (WHO, 2020). The quest for zero pesticides aligns with a growing awareness of the need to safeguard human health by minimizing the exposure to potentially harmful chemical residues commonly found in conventionally grown crops.

Sustainable Farming Paradigm:

Embracing a zero pesticides approach aligns with the broader paradigm shift towards sustainable farming practices. The acknowledgement that excessive reliance on synthetic pesticides is inherently at odds with long-term agricultural sustainability has spurred global initiatives advocating for reduced chemical inputs (Pretty et al., 2018). Zero pesticides emerge as a linchpin in this transformative journey.

Biodiversity Conservation:

Pesticides have been identified as significant contributors to the decline in biodiversity, adversely affecting pollinators, beneficial insects, and other key components of ecosystems (Goulson, 2013). Transitioning to zero pesticides is instrumental in preserving biodiversity and restoring ecological balance in agroecosystems.

The objective of the current literature review was to: systematically identify the obstacles and levers faced by end-users, strategies of actors, impacts of private initiatives and public policies aiming at reducing pesticide uses and developing pesticide free chains.

The literature review process was organized as follows:

The literature search was carried out in a systematic and rigorous manner (although there is insufficient time to carry out a full systematic review). It was considered the use of crop protection, sustainable agriculture, agroecology and chemical pesticides. This should be done in two agricultural sectors – small grains and viticulture; included obstacles and levers at the farm, regional and market levels.

First there were selected the research articles based on the research words (see Appendix 1) from Web of Sciences and Scopus data base. After that a first selection of the articles was done based on the title, resulting a databased of 1134 articles, which were distributed among the participants registered for WG1. In the end there were reviewed 193 articles.

SMALL GRAIN

1. TECHNOLOGICAL ASPECTS

1.1. BIOTECHNOLOGICAL

1.1.1 Microbiota, chemical ecology (manipulations of pest-insect odorscapes) and new concepts of plant immunity

Needs

The increasing demand for food, driven by rapid population growth, needs practical and implementable approaches for middle-class farmers in developing countries (Balaganesh *et al.*, 2020), exerting an enormous pressure for intensive cultivation. While increased crop production was aided by synthetic pesticides and fertilizers sustained the Green Revolution, the urge also underscores the development of alternative strategies. Acknowledging that increased crop production with synthetic pesticides has supported the Green Revolution but also led to problems, urgent attention is directed towards developing alternative strategies. Balancing the benefits and drawbacks of current practices is crucial for the future of sustainable agriculture (Kellogg and Seogchan, 2020). There is a need for a second green revolution where food security is achieved in a sustainable way. A new generation of crops that yield more with fewer inputs and are adapted to more variable environments is needed (George et al., 2014). Furthermore, it is necessary to conduct more comprehensive studies to investigate the microbial diversity and responses to human activities and climate change (Netshifhefhe et al., 2020). The use of microbial introduction is a mean of assuring biological disease control due to the lack of options in organic production systems (Mazzola and Shirini, 2017).

Even if the positive effect on the abundance and richness of natural enemies of crop pests is well known by enriching agroecosystems with non-crop vegetation, the goal of reducing pest populations below economic threshold levels it is frequently not achieved (Colazza et al., 2023). The consecutive monoculture problem, also known as replant disease, is a common disorder from modern agricultural practices (Hongmiao and Wenxiong, 2020). In this context, the time (number of years) one single crop is continuously grown in a field is critical since the longer the stronger are the changes in the microbiome (Alami et al., 2021). Studies underlined the need for the sustainable intensification of global agriculture by current and advanced studies about GM technologies. There is a need for improving landscape connectivity with habitat mosaics that are highly permeable for dispersing organisms across landscapes. Incentives and regulations for biodiversity-friendly measures should come with a new focus on cropland diversification (i.e., small fields, high edge density), which is more important than organic farming for supporting biodiversity on farmland.

It is important to breed crops with higher performance under sustainable conditions involving interactions with beneficial soil microbes and optimising the usage of agrochemicals (Shtark et al., 2012), in order to deliver microbe-improved plants for agriculture (Compant et al., 2019). This can be achieved only by understanding the significance of microbiome beneficial for the plant in terms of ecology and function; studying the relationship among hosts, beneficial microbiomes and their ecological traits (Ali et al., 2023). Also there is a need to understand the change induced by the cover crops on the microbial community composition and quantity (Tosi et al., 2022). Furthermore, the studies should analyze the soil microbial community structure and biodiversity by using metagenomics and NGS to define which management practices are most adequate to benefit soil microorganisms. These are mostly focusing on increasing soil biodiversity and benefit microorganisms that contribute to increase the soil fertility, decrease the incidence of soil-borne diseases and promote crop growth and production (Morugán-Coronado et al., 2022). The control of pathogenic microorganisms in continuous cropping soil is the most direct improvement method for soil microorganisms (Chen et al., 2022). Studies should focus on understanding how different agricultural practices affect arbuscular mycorrhiza fungi (AMF) (Higo et al., 2020). It remains unclear whether and to what extent, AMF inocula increase P and mineral micronutrient uptake and concentrations in crop plants (Liu et al. 2022). Few studies have investigated the dynamics of the microbiota during postharvest disease development (Buchholz et al., 2018)

Researchers are actively exploring innovative methods to safeguard seeds for sowing while enhancing germination and growth rates without resorting to harmful chemicals. This is crucial for sustainable agriculture (Zahoranová et al., 2018). Additionally, there is a recognized need to breed legume crops with improved performance under sustainable conditions, involving beneficial interactions with soil microbes and optimizing agrochemical usage (Shtark et al., 2012). There is need for appropriate experimental designs to address the problem of assessing responses to mixtures of semiochemicals in chemical ecology (Lapointe et al., 2017). Researches should focus on "chemical ecology technology to analyze the interaction and mechanisms among plant-soil-microorganisms mediated by root, which exudates under continuous monoculture regimes" (Hongmiao and Wenxiong, 2020). Still there is a lack of knowledge about the role of flavonoids in plant-insect interaction, and about the influence on the resistance at the biochemical and molecular levels (Mouden et al., 2017). Pheromones (chemical ecological tools) can be used as a recording technique for scarab beetles, thereby proving a valuable technique for monitoring elusive saproxylic beetles (Harvey et al., 2018). Furthermore, it is important to analyze the "behavioural patterns in insects to unravel the underlying mechanism responsible for the proclaimed insecticidal activity" (Mouden et al., 2017). The influences of odorant receptors (ORs) and odorant-binding proteins (OBPs) was analyzed in their functional roles in pest behaviors, but still, there is a lack of research on comparative analysis of their role (Venthur et al., 2018).

Volatile pheromones and other semiochemicals represent tools that can be used before pest or pathogen development and for insect pests, often before contact with the host plant (Pickett et al., 2014). Volatiles can induce resistance to insect pests. Targeted alterations in the volatile metabolism of a few plants could provide community-level protection in the field (Subrahmaniam et al., 2018; Ninkovic et al., 2021). Importance of a "vaccination" done by mirids (zoophytophagous predators) in the activation of plant defences oin the plants were they feed on and communication of these plants to the ones that are in the vicinity; the plants that reacted are less susceptible to some pests and more attractive- to some natural enemies (Pérez Hedo et al., 2022). Exploitation of such volatiles may be particularly effective if they are combined with other CBC techniques that improve natural enemy fitness once they have been attracted to the crop or as an integral part of 'push-pull' strategies (Jonsson et al., 2008). There is need for an implementation design that enables a uniform distribution of the attracted natural enemies within the semiochemical-treated field (Ayelo et al., 2021), where are previous studies focusing on the effect of the semiochemicals, which neglected the aspects related to the distribution of natural enemies within the target field. This is nevertheless a key factor concerning to the herbivorous insect pest control (Ayelo et al., 2021). Bioremediation processes based on integrated bacterial consortia and manipulated by quorum sensing may represent the paradigm shift needed to achieve herbicide mineralization in a more efficient and sustainable manner than currently occurs to be analyzed (Pileggi et al., 2020).

Given the impact of viruses on the ecology and evolution of their host communities, determining how soil viruses influence microbiome dynamics is crucial to build a holistic understanding of rhizosphere functions (Muscatt et al., 2022). There are no examples of cultivars resistant to *Rhopalosiphum padi, R. maidis, Sitobion avenae or Metopolophium dirhodum* in wheat (screening is difficult and, when found, resistance levels are low) and there are few examples of cultivars resistant to barley yellow dwarf virus (BYDV). In order to obtain wheat cultivars resistant to aphids and BYDV, evaluation, phenotyping and identification of DNA markers, virus epidemiology must be promoted to detect adequate levels of resistance and to be able to incorporate multiple resistance genes into productive wheat cultivars (Aradottir and Crespo-Herrera, 2021).

There is a permanent need for developing advanced biotechnological applications, so in this study there is a focus on actinomycetes and their pharmacologically, clinically, and agriculturally relevant bioactive compounds (Farda et al., 2022). The encapsulation of microorganisms to use as biopesticides or fertilizers would improve efficacy and decrease environmental impact (Riseh et al, 2023).

Crop diversification offers several benefits, including a reduced reliance on chemical fertilization, leading to decreased pollution and eutrophication. It also contributes to the enhancement of soil health and fertility. There is a pressing need for the swift and effective testing, adoption, and scaling of sustainable agricultural processes, such as crop diversification, to promote environmentally friendly and efficient practices (Weituschat et al., 2023).

Conclusion: *these studies emphasize the importance of optimizing pest control strategies, understanding soil biodiversity, monitoring elusive beetles, managing soil contaminants, and promoting sustainable agricultural practices through innovative techniques and advanced biotechnological applications. The identified needs include addressing distribution challenges in pest control, filling knowledge gaps in soil biodiversity, and developing effective strategies for sustainable agriculture and environmental conservation.*

Barriers

First, various groups of BSM should be considered as an undivided functioning complex that has existed millions of years before. Novel technologies for cost-effective production and application of multicomponent inoculants based on BSM urgently need to be developed. Second, it is necessary to consider the plant genetic system, which controls interactions with the different BSM, as an undivided group of plant genes that functions in unison. Third, crop plants in a complex plant-BSM system should control effectiveness, select proper beneficial microsymbionts and be bred with improved effectiveness for interactions with all types of BSM. Positive changes in plant biomass production and quality of the production due to plant-BSM symbiosis should be used as the main parameters for evaluation of plant effectiveness in interactions with BSM (Shtark et al., 2012).

It is well known that low-temperature plasma (LTP) can be easily generated using electrical discharges in gas at low pressure. However, such plasma sources require a vacuum chamber, pumping equipment and do not allow for an easy implementation in the in-line production (Zahoranová et al., 2018).

Generally limited spectrum of target pathogens for any given biocontrol agent and inadequate colonization of the host rhizosphere, which can delay the progress in the utilization of this resource in commercial field-based crop production systems. The barriers and limitations to use the biopesticide model of biological control have long been recognized and described including narrow product markets and higher costs related to chemical alternatives (Mazzola and Shiri, 2017).

Although odorant-binding proteins (OBPs) and odorant receptors (ORs) provide excellent opportunities to be considered as pest control targets and a tool to design pest control agents, the debates on their binding specificity represent an obstacle. A major barrier to use ORs for semiochemical discovery is the lack of 3D crystal structures (Venthur et al., 2018).

Insufficient understanding on how differing histories of agricultural management and climate conditions jointly impact soil microbiomes (Azarbad, 2022).

Lack of studies including a high number of microbial parameters together and different management practices to perform more robust meta-analysis and therefore better information for decision making (Morugán-Coronado et al., 2022).

Poor information concerning distribution, population dynamics, biogeochemical processes and metabolisms of cave actinomycetes (Farda et al., 2022).

There were notices: (i) the opposition to evidence-based recommendations for registration of GM for crops by political groups opposed to the use of them on the grounds of the precautionary principle, (ii) lack of public awareness of the scientific principles and benefits of the transgene technology particularly in less developed countries, (iii) lack of a legal framework to commercialize GM of crops and where this is approved (Pickett et al., 2019).

Conventional tillage systems, including chisel plowing, rotary tillage, and disc harrowing, can disrupt the AMF hyphal network, inhibit AMF development and decrease AMF abundance in soil (Higo et al., 2020). Although plant derived biopesticides are generally considered to present lower risks to consumers, some plant metabolites such as alkaloids (pyrrolizidines, tropane) as well as certain glucosinolates and saponins are known for their adverse and possibly even more toxic effects (Mouden et al., 2017).

As with many chemicals, the dosage often determines the degree of effect it produces. Depending on the insect species, rutin and quercetin at varying doses, elicited variable behavioral responses are provoked both negative as well as stimulating effects on herbivore feeding (Mouden et al., 2017). For example, methanol extracts *of Lonicera maackii*, dominant in the flavonoid luteolin, deterred feeding of the generalist herbivore *Spodoptera exigua*. However, when offered as individual compound in diet plugs, no anti-herbivory activity was observed. Instead, luteolin was marginally stimulating when feeding (Jonsson et al., 2008).

Terminal electron-accepting processes (TEAP) need to be considered along with direct effects on the microbial population when assessing contaminant fate. Those, which do not degrade regardeless of TEAP require further study to ensure that public health is not compromised if treated wastewater is used for irrigation (Fang et al., 2020).

Suitable formulations are needed to ensure long-term viability of microbes during storage and the provision of sufficient viable cells/spores for field-grown plants (Compant et al., 2019).

Impact of triple transgenic insect-resistant and glyphosate-tolerant soybeans on the composition and function of root-associated microbiomes in rhizosphere host niches throughout the soil–plant continuum which remains unknown (Yang et al., 2022).

Good cases examples

For interference with mixture recognition, the orange wheat blossom midge, *Sitodiplosus mosellana* employs a multi-compound mixture of wheat semiochemicals, including 6-methyl-5-hepten-2-one, which when increased several-fold from the natural ratio, interferes with attraction (Pickett et al., 2014).

The combination of MeSA as attractant and buckwheat *Fagopyrum esculentum Möench* (*Polygonaceae*) as reward plant boosted the abundance of *Scelonidae wasps* on broccoli plants on *Eulophidae wasps* on sweetcorn plants (Ayelo et al., 2021).

Azospirillum brasilense inoculation improved growth of maize and wheat under controlled conditions but showed no significant effect on plant growth in the field (Compant et al., 2019).

Whey protein is a good natural polymer and can be used as an intermediate agent to plant growth promoter rhizobacteria (PGPRs) decreasing fertilizers need. Furthermore, this compound is a rich source of amino acids that can activate plant defense systems (Rishen at al., 2023).

Conclusion: *these barriers underline the complexity and interconnectedness of various factors in agricultural and biological systems, emphasizing the need for interdisciplinary research and innovative solutions to address these challenges. Additionally, good case examples highlight successful interventions, demonstrating the potential for overcoming these barriers with strategic approaches.*

1.1.2 Ecological immunology - allows understanding and promoting immunity in natural environments

Needs

Promote ecological processes, molecular biology and synthetic biology to increase soil fertility, pollination, natural enemy populations, nutrient cycling (Ali et al. 2023, Bruce, 2010; Spiegal et al., 2018) and increase knowledge on agricultural management on soil microbial stability in face of global change stressors (Azarbad, 2022), represent actual needs for sustainable development.

Exploring the plant's own defense mechanism by manipulating the expression of their endogenous defense proteins or introducing an insect control gene derived from other plants (Sagar and Dhall, 2018; Steenbergen et al., 2018) or using zoophytopagous insects that activate plant defence pathways (Pérez Hedo et al., 2022).

Development of diverse crop rotation using selecting plants with different VOC emission blends, mixed pattern of crops, alone or combined with land-sharing practices such as wildflower strips (Birilli et al., 2019; Tscharntke et al., 2021).

Scientific and reasonable fertilization strategy to maintain the balance of soil nutrient elements, the living space of microorganisms (Chen et al., 2022) and development of biosynthetic pathways to plant secondary metabolites with exploitable insecticidal activity (Pickett et al., 2019).

To focus the research on the complex molecular interaction involved in *Phytophthora sp.* pathogenicity and corresponding Hevea tolerance (Krishnan et al., 2019), the teosintes in order to identify resistance traits (on maize)(Azarbad, 2022) and has techniques to imitate precisely the mode by which the alarm pheromone is produced naturally (Pickett et al., 2019) to control pests (e.g. aphids),.

Improving knowledge about the effects of crop rotations (Ma et al., 2022) and to understand plant–bacterial interactions that help in alleviating abiotic stress in different crop systems in the face of climate change (Phour and Sindhu, 2022). Further research aimed at understanding the primary transmission from carrot to potato and secondary transmission from potato to potato plants by *Bactericera nigricornis* under field conditions in Europe is needed (Antolínez et al., 2019).

Facilitate key input access for agroecological practices (e.g., amendments, cover crop seeds, resistant varieties and rootstocks) and breed cover crop cultivars (Ackroyd et al., 2019;Boulestreau et al., 2019).

Conclusion: *complex challenges in crop protection require a multifaceted and integrated approach. From preserving genetic diversity and studying plant-pest interactions in order to understand soil microbial dynamics and implementing innovative agricultural practices, a holistic strategy is necessary. The synergy of different scientific disciplines, combined with sustainable farming practices, holds the key to ensuring global food security in the face of evolving challenges.*

Barriers

In the realm of crop protection, the use of volatile organic compounds (VOCs) from plants or bacterial and fungal volatiles to plants can respond faces challenges. Studies on VOC efficacy often employs concentrations that exceed those achievable ones in open fields, and the high biodegradability of VOCs may mitigate their impact and reduce long-term non-targeted effects. Meteorological factors significantly influence VOC compounds, adding complexity to their application. Moreover, the prohibitive sale prices and unproductive initial investments associated with synthetic VOCs raise economic concerns, impeding their widespread adoption (Birilli et al., 2019). Furthermore, there are other limitations to the use of VOCs field applications such as the correct identification, the optimization of the concentration and of the blends, as well as the application to the field (Kanchiswamy et al., 2015).

Genetically modified (GM) crops designed to exploit pheromones encounter issues related to the physical release of these compounds from plant tissues rather than from specialized organs in animals. This poses a unique challenge in the effective utilization of pheromones in agricultural practices (Pickett et al., 2019).

Additionally, barriers exist in the form of information deficit and the lack of comprehensive assessments for ecosystem service evaluations. Social norms and the low acceptance of genetically engineered (GE) crops by society and food retailers further hinder the integration of genome-edited crops into agricultural value chains (Spiegal et al., 2018; Maaß et al., 2019).

Conclusion: *the effective implementation of innovative approaches such as VOCs and GM crops in agriculture is impeded by a range of challenges. From practical issues like concentration levels and biodegradability to economic concerns and social acceptance, addressing these barriers is crucial for the successful integration of advanced technologies into sustainable and productive agricultural systems. Overcoming these challenges require collaborative efforts across scientific, economic and social domains to ensure the responsible and effective application of cutting-edge crop protection strategies.*

Good cases example

Using a rotation of sweet potatoes, peanuts and wheat is beneficial for the nutrient content (Chen et al., 2022).

Reducing the content of autotoxins in the root zone using adsorbents to improve microbial community structure (Chen et al., 2022).

The use of endophyte fungi increases the plant content of all macronutrients and many micronutrients to synthesize compounds that reduce plant stress (Poveda et al., 2022).

1.1.3 Physiological or molecular basis of immune responses in the broader context of ecology and adaptation

Needs

There is a need to understand the interaction of hormonal signaling pathways and mitochondria, which plays a crucial role in both sensing and responding to changing growth conditions as well as in the defense of a plant for pathogens and other stresses (Berkowitz et al., 2016). It is important to understand "the eco-evolutionary mechanisms of fungicide resistance and use that knowledge to develop mitigating approaches" (Yang et al., 2021). Microarray studies of the wild relatives of crop plants after exposure to pest attack in order to identify the resistance of genes should be conducted to facilitate identification of natural plant defense mechanisms (Bruce, 2010). Crops are often less resistant than their wild relatives, arising the need of enhancing plant defence capabilities in crop plants "through the conventional breeding and development of plant defence activator agrochemicals, but there are much wider possibilities via GM techniques" (Pickett et al., 2014). New solutions could include novel resistant cultivars with multiple resistance genes, suitable epigenetic imprints and improved defence responses that are induced by attack, ensuring the development of new resistant crops (Bruce, 2010). as well the plant-pathogen interactions and proteomics can give important insights on fungi pathogenesis and host resistance (Liu et al., 2022).

Further studies are required to examine the role of microplastics' experimental concentration, particle sizes and exposure conditions during a combination of microplastics and their effect accumulated (Xu et al., 2023).

There exists massive potential for ecological solutions to the ever-present threats faced in food production (Stratton et al., 2022). Smart application strategies for pesticide use (e.g., Integrated Pest and Pollinator Management techniques) are needed regardless of organic or conventional agricultural systems (Tscharntke et al., 2021).

Proteins in the plant vessel and apoplastic fluids can be important as barriers against pathogen infection and also as part of basal defence, more studies are required (Rodríguez-Celma et al., 2016).

Multidisciplinary approaches such as proteomics, metabolomics, bioinformatics, and functional genomics could be used to unravel the mechanism of Ca2+/CaM mediated signal transduction networks in plants (Huda et al., 2013).

Conclusion: *Challenges in plant biology and agriculture require a comprehensive and interdisciplinary approach, encompassing genetic, ecological and physiological perspectives. By advancing the understanding of these complex interactions, it can be the pave way for sustainable and resilient agricultural practices in the face of evolving environmental conditions.*

Barriers

Use of resistant crop cultivars is another solution but when based on single genes it also suffers from the evolution of biotypes of pests that can overcome the resistance conferred by the gene (Bruce, 2010). For the following hormones - gibberellin (GA), cytokinin (CK) and brassinosteroids (BS) – at the moment there are only limited information on their impact on mitochondrial function or biogenesis (Berkowitz et al., 2016).

Screening trials of new crop cultivars conducted under pesticide treated conditions have meant that pest resistance has in many cases been precluded from consideration as a trait for breeding and opportunities to develop resistant cultivars may have been lost (Bruce, 2010).

Difficulties in comparing and identifying proteins from different plant species, especially those whose genomes are not sequenced (Rodríguez-Celma et al., 2016).

Cereals other than oats do not synthesize with saponins, possibly as a result of breeding. BIosynthesis of secondary metabolites is a multi-step process and several genes can be involved (making it more difficult to introduce them into crop cultivars) (Papadopoulou et al., 1999).

Conclusion: *related to pest management and crop resilience, it is evident that a multifaceted approach is necessary. While the use of resistant crop cultivars is a viable solution, careful consideration must be given to the potential evolution of pest biotypes. Furthermore, understanding the impact of hormones on mitochondrial function, exploring diverse defense pathways, and overcoming challenges in protein identification are essential for informed and effective agricultural practices. The cited examples highlight the success of resistant cultivar breeding, the benefits of symbiotic relationships with AMF, and the potential for targeted genetic modifications to enhance plant defenses. Overall, a combination of traditional breeding method, molecular insights, and sustainable agricultural practices is crucial for addressing the complex challenges faced in plant biology and agriculture.*

Good examples

- Breeding of resistant cultivars has been important for the management of some insect pests, for example the orange wheat blossom midge: *Sitodiplosis mosellana*.
- The addition of AMF resulted in signifcant upregulation of defense genes in opposing pathways. That maize grown with AMF may require less fertilizer. We found that the defense benefits AMF to provide plants which does not depend on fertilizer and may allow low-input systems to be protected and be highly productive (Stratton et al., 2022).
- In cereals such as maize -wheat and rye- there is the hydroxamic (benzoxazinoid) pathway. The benzoxazinoid biosynthetic pathway and the related genetics have been fully elucidated for maize and wheat. After the first committed step of the pathway that creates indole, a series of cytochromes P450 in the Cyp71C series take this through to DIBOA and DIMBOA, latter via the glucoside. Localized feeding by aphids, e.g. the barley yellow dwarf virus vector *Rhopalosiphum padi* (bird cherry-oat aphid), on wheat, causes the glucoside stored in vacuoles to be hydrolysed to DIMBOA via the upregulation of the glucosidase. By knocking out the gene for the first committed step in maize, aphid susceptibility can be raised significantly (Pickett et al., 2014).
- RNAi can be used to silent the gene *Abhydrolase-3 of Sclerotinia sclerotiorum* (Host Induced Gene Silencing – HIGS) on *Brassica napus* protecting the crop (Wytinck et al., 2022)

1.1.4 Pest-repulsive and/or auxiliaries-attractive companion plants, stimulation of plant defenses and plant nutrition

Needs

Modern agriculture faces challenges such as soil fertility loss, climate fluctuations, increased pathogen and pest attacks. The need for sustainable and environmentally safe agricultural production emphasizes eco-friendly approaches like biofertilizers, biopesticides and crop residue return (Gopalakrishnan et al., 2015). Strengthening research on microbial inoculants, particularly plant growth promoters (PGP) is crucial for their effective use in modern agriculture. Comprehensive knowledge of screening strategies and intense selection of the best rhizobacterial strains are needed for field-level success and sustainability (Gopalakrishnan et al., 2015). Plant growth-promoting rhizobacteria (PGPR), mycorrhizal fungi and archaeal microbes can be used as biofertilizers. Understanding the ecological behavior of strains collected from different sources is essential for effective field application (Odelade and Babalola, 2019; Compant et al., 2019). It is crucial to better understand the effect of multi-species PGPR formulations in order to maximize the benefits on plant growth and defence against pathogens, as synergies (or even additive effects) among PGPR species/strains are not always observed; antagonism has already been observed (Liu et al., 2022). With regard to P fertilizers, whose efficiency is very low in alkaline soils, promising results have been obtained on wheat with the coating of di-ammonium phosphate with a polymer enriched with phytohormones (Yasmeen et al., 2021).

Genetic breeding for tolerance should focus on comparing seed production rather than indirect measures like leaf damage or mite population dynamics. Understanding plant tolerance mechanisms in different crop-mite interactions is essential (Sperotto et al., 2018). There is limited information on the effects of barrier, mating disruption and masstrapping methods on the nutritional quality of crops (Rempelos et al, 2021). Genetic modification of crops has the potential to speed the development of crops with novel resistance (Bruce, 2010).

So far over 1700 plant volatile compounds have been identified from different plant families which belong both to angio- and gymnosperms, while more than 15 different tritrophic systems revealed induction of broad spectra of plant volatile compounds in response to herbivory attack. In this context the need for knowledge arises as the transfer to the economic environment (Tamiru and Khan, 2017).

Understanding chemical interactions between plants, herbivores and natural enemies is crucial for designing kairomone-based biological control measures. The role of volatiles in plant defense signaling pathways needs to be explored further (Ayelo et al., 2021).

Restoring herbivore-induced plant volatiles (HIPVs) in crops via synthetic lures can enhance biocontrol. However, more studies are needed to determine the effectiveness of this strategy, considering landscape variation and field size (Tooker et al., 2020).

The use of modern techniques like micro- and nano-encapsulation for simulating the natural release of volatile organic compounds (VOCs) is suggested. Understanding the perception mechanisms of VOCs within plant tissues and evaluating their application in open fields are areas which require further research (Birilli et al., 2019).

For biological pests control in annual cropping systems to be successful, natural enemy response to low pest densities may be important during the initial pest colonization of the crop (Mercer et al., 2020).

Widespread insecticides used in organic farming, such as natural pyrethrin and azadirachtin have associated challenges. There is a need to explore alternatives to persistent substances like copper sulfate and minimize environmental impacts (Tscharntke et al., 2021). The lack of indicators for soil compaction and the need for methods to evaluate legacy phosphorus (P) amounts are present and their distribution, availability to crops are highlighted issues (Kaufmann et al., 2010; Rowe et al., 2016).

Global water scarcity stems from various factors, including a growing population, socioeconomic dynamics, political influences, poverty, inequality, climate change impacts and unequal water distribution. Approximately 25% of the global population lacks access to the necessary water resources for sustaining agriculture. Addressing this issue requires the urgent development of affordable and environmentally friendly innovative techniques to sustain agriculture without compromising plant health and yield (de Lange et al., 2014).

Additional research is necessary to enhance our comprehension of both symbiotic and non-symbiotic microorganism associations with soybean. The examination of genes governing these interactions is imperative (Panago et al., 2020).

Variation in bacterial diversity within nodules is contingent upon the soybean cultivar and water status. It prompts the inquiry: can heightened diversity in nodules confer advantages for plant resilience across diverse environmental conditions? (Sharaf et al., 2019).

There is a dearth of understanding regarding how nutrients impact seed production in hybrid carrots (Moore et al., 2021).

According to Roriz et al. (2020), conventional agronomic strategies, plant breeding, and genetic engineering fall short in achieving the objective of augmenting the nutritional values of food.

Conclusion: *the current challenges in agriculture demand a holistic and forward-thinking approach that integrates diverse strategies. From eco-friendly practices like biofertilizers and biopesticides to the exploration of genetic modification and the restoration of herbivore-induced plant volatiles, researchers highlight the need for innovative solutions. Understanding intricate plant-microbe interactions, optimizing cultivation methods, and addressing soil-related concerns emerge as crucial elements in sustainable agriculture. The call for interdisciplinary research, coupled with an emphasis on genetic diversity and ecological alternatives underscores the collective effort required to develop resilient and environmentally responsible agricultural systems capable of meeting the growing demands for food production while mitigating the impact of environmental stressors.*

Barriers

The plant-herbivore community still has difficulties to use the appropriate fitness analysis in combination with recent methodological advances to increase our understanding of plant defense traits (Sperotto et al., 2018). In multi-herbivore systems the location of target herbivore-infested plants by natural enemies may be disrupted by the co-infestation of non-target herbivores (Ayelo et al., 2021). Natural enemy species show different attraction responses to volatiles of infested plants depending on the specificity and density of infesting herbivores (Ayelo et al., 2021).

An inherent problem of many secondary metabolites is their low aqueous solubility, which might hamper commercial formulation. Consequently, organic solvents are often used in large quantities (Mouden et al., 2017). Pathogenic bacteria resistance is associated with environmental microbial resistance and antibiotic resistance genes (Shi et al., 2019).

Integrated approach for collecting data regarding indicators for soil compaction is present. When data for such indicators were collected they showed agreement in showing the state of the soil and provided data for proper agricultural use of the soil (Kaufmann et al., 2010).

Technical limits of VOCs application; High costs of VOCs production and application in agricultural practice. (Birilli et al., 2019). Essential oils (EOs) can reduce or substitute chemical pesticide to control postharvest diseases and pests on stored products including grains but the strong aroma of EOs can limit their use as they can affect the food organoleptic properties and odor (Bolouri et al., 2022) besides the fact that the toxicology and the dose optimization of doses have to be addressed.

Conclusion: *the challenges span from methodological limitations in fitness analysis to the diminishing impact of plant growth promoters in real-world field conditions. The complexities of herbivore preferences, coupled with the inefficiency of combined production and application approaches, underscore the need for nuanced solutions. Laboratory success in repelling aphids with transformed plant volatiles doesn't always translate to field effectiveness, emphasizing the importance of context in implementation. Additionally, issues like low solubility of secondary metabolites, disruptions in natural enemy location strategies, and the impact of domestication on plant traits add layers of complexity to the pursuit of sustainable agriculture. Addressing these challenges requires innovative methodologies, increased research in field conditions and a comprehensive understanding of soil health. As we grapple with these barriers, there's a clear call for collaborative efforts, adaptive strategies, and a commitment to advancing agricultural practices for a sustainable and resilient future.*

Good cases examples

- "Emission of isoprenoids, the most abundant group of VOCs is stimulated by abiotic stresses and improves plant resistance either by direct quenching of reactive oxygen species (ROS); VOCs such as methyl salicylate (MeSA) and monoterpenes (i.e., camphene and pinene) have been found to actively participate in the mechanisms leading to systemic acquired resistance (SAR); citral, carvacrol, and trans-2-hexenal were effective in hampering in vitro growth and germination of *Monilinia laxa*, the agent of brown rot of stone fruit"(Birilli et al., 2019).
- The use of companion crops has demonstrated the value of semiochemical-based crop protection via plants. The most dramatic demonstration of its value has been achieved in sub-Saharan Africa without competition from the pest control technologies of high-input agriculture, which are not adopted by the majority of farmers in this region (Pickett et al., 2014).
- Our recent study on a wide range of maize germplasm revealed that some maize genotypes emit HIPVs attractive to egg and larval parasitic wasps at the egg-laying stage of insect attack. This represents a sophisticated defence response which provides time consuming and effective biological control at an early stage, before

much damage is caused by the hatching larvae. Some plant species constitutively release volatile semiochemicals that repel insect pests and attract natural enemies of the herbivore (Tamiru and Khan, 2017).

- Transgenic maize plants with overexpression of the maize TPS10 gene produced (E)-β-farnesene, (E)-α-bergamotene and other volatile defence signals which attracted the natural enemies of maize herbivores, *Cotesia marginiventris* (Tamiru and Khan, 2017).
- The potential of this strategy by restoring the emission of a specific below-ground volatile signal, (E)-β-caryophyllene, to the maize line that normally does not produce the signal in response to pests' damage on the root. (E)-β-caryophyllene is released by some maize lines in response to feeding damage by larvae of western corn rootworm, *Diabrotica virgifera virgifera*. The semiochemical signal attracts the entomopathogenic nematodes *Heterorhabditis megidis*, which parasitizes and kills the pest larvae within a few days (Tamiru and Khan, 2017).
- Maize line that normally does not emit (E)-β-caryophyllene was transformed with a (E)-β-caryophyllene synthase gene from oregano (Origanum vulgare), resulting in constitutive emissions of the signal. In corn rootworm-infested field plots where entomopathogenic nematodes were released, the (E)-β-caryophyllene-emitting plants suffered significantly less root damage. Moreover, there was significantly lower survival of the pest (60% fewer emergence of adult beetles) on the transformed plants than on to untransformed, non-emitting lines (Tamiru and Khan, 2017).
- For example, (E)-4,8-dimethyl-1,3,7- non-atriene (DMNT), an elm plant (*Ulmus minor Mill* [Ulmaceae]) OIPV induced by *Xanthogaleruca luteola* (Müller) (*Coleoptera: Chrysomelidae*) attracted the parasitoid *Oomyzus gallerucae* (Fonscolombe) (Hymenoptera: Eulophidae) in the field (Ayelo et al., 2021).
- Application of hydrocarbons, e.g., tricosane identified in extracts of Heliothis zea (Boddie) (Lepidoptera: Noctuidae) moth scales, increased the efficiency of host location by the parasitoids Trichogramma achaeae Nagaraja and Nagarkatti (Hymenoptera: Trichogrammatidae) also Microplitis croceipes (Cresson) (Hymenoptera: Braconidae), thereby increasing the parasitisation rate in the field (Ayelo et al., 2021).
- Isopentyl-butanoate—the aggregation pheromone of *Clavigralla tomentosicollis Stål* (Hemiptera: Coreidae)— strongly attracts Gryon sp. (Hymenoptera: Scelionidae), the parasitoid of Clavigralla species (Ayelo et al., 2021).
- Soil amendments can also mediate indirect interactions between plants and natural enemies. Although fertilizers affect herbivores by altering nutrient availability in plants, less is known about their effects on the third trophic level. For example, fertilization increased parasitism of tephritid flies in creeping thistle. Similarly, nitrogen fertilization increased aphid populations and the number of hoverfly pupae in wheat fields (Tooker et al., 2020).
- Buckwheat (Fagopyrum esculentum Moench) is an annual flower that can be attractive and beneficial for a wide array of predators and parasitoids (Mercer et al., 2020).

- Combining floral plantings with methyl salicylate lures improved the effectiveness of either method alone in beans, brassicas and vineyards with lepidopteran pests (Mercer et al., 2020).

1.2. NEW CROPPING SYSTEMS

Needs

The agricultural landscape is poised for transformation through innovative practices and research. The adoption of alternative cover crops and seeding methods is recognized as an imperative for providing immediate economic benefits to growers while extending the establishment period of cover crops (Mohammed et al., 2020). Increase knowledge on the stability of soil microbiomes taking in account the tradeoff between resistance and recovery of microbial characters in agricultural systems is needed (Azarbad, 2022). Develop cropping systems combining major commercial crop productions and agroecological soil health technology with sufficient income (Boulestreau et al., 2019) is also still needed. New crops that have increasing nutritional values using growth-promoting bacteria (Roriz et al., 2020).

In terms of innovation a comprehensive approach is outlined, addressing diverse settings. This includes farm and field research on longer rotations in conventional farming, public subsidies supporting diversification crops, and collaborative organization of farmers to reduce power imbalances and facilitate negotiation (Morel et al., 2020). Additionally, initiatives outside the traditional framework involve research on organic minor crops, intercropping, and innovation in post-harvest management, processing technologies to adapt to the needs of small-scale actors (Morel et al., 2020).

Challenges persist in identifying agronomically useful and economically viable break crops for organic ley/arable rotations, urging the need for continued research in this domain (Rempelos et al., 2021). Sustainable crop protection strategies, including the use of companion plants to produce signals or semiochemicals for appropriate repellency or attraction are emphasized for a new era of environmentally friendly practices (Pickett et al., 2019). Habitat manipulations such as push-pull strategies, are recognized for their potential to enhance pest management and yields, particularly in less intensive agricultural systems (Bruce, 2010). For a rotation to produce the best results, the microbiome shaped by one crop should also be favorable to the following crop. In this context, the time (number of years) one single crop is continuously grown in a field is critical, since the longer the stronger are the changes in the microbiome (Alami et al., 2021). Changing the current cropping system with poor crop diversity and absence of rotation (Chen et al., 2022).

In heterogeneous landscapes, efforts should be made to forestall landscape simplification to prevent degradation of potential pest-control services (among other benefits for the broader system), whereas in more homogeneous landscapes pests control would likely benefit from meaningful increases in abundance and/or quality of noncrop habitats (Tooker et al., 2020).

Furthermore, the reasonable addition of microelement fertilizers for the soil is recognized as a strategy to alleviate nutrient deficiencies caused by preferential absorption of crops, maintaining stable soil properties and enhance plant health, immune resistance (Chen et al., 2022). Exploiting imaging and sensors for decision-making in agriculture is suggested as a promising avenue to enhance precision farming practices (Filgueiras et al., 2020).

"Crop diversification is one of the main strategy of agroecological transition. Increased crop diversity: There is a need for new cropping systems that promote diversity in agricultural landscapes.

Farmers need access to information about new crops that are suitable for their region. It is important to evaluate the yield potential of new crops in order to determine their viability as a crop. New crops must be compatible with existing crop rotations in order to be successfully integrated into the farming system. The economic benefits of introducing new crops must be evaluated in order to determine their profitability. There is a need for new methods that characterize cropping systems at the regional level to evaluate the potential for introducing new crops" (Marraccini et al., 2020).

Exploring the opportunities to diversify cropping systems by increasing the variety of crops to enhance soil health and nutrient cycling represents a need. Consider adopting alternative wetting and drying (AWD), water management practices to minimize greenhouse gas emissions and conserve water. Enhance market access, land ownership and farm infrastructure to facilitate crop rotations and encourage the cultivation of alternative crops. Strengthen communication and collaboration among growers, researchers, and stakeholders to facilitate the exchange of knowledge and best practices related to crop rotations (Rosenberg et al., 2022).

The continuous use of agricultural soils can build pathogen pressure but can also develop disease-suppressive soils containing microorganisms mediating disease suppression e.g *Pseudomonas, Streptomyces, Bacillus, Paenibacillus, Enterobacter, Pantoe, B urkholderia and Paraburkholderi*a (Compant et al., 2019).

Conclusion: *the agricultural landscape is at a pivotal juncture, demanding a paradigm shift towards innovative practices and research-driven solutions. The identified needs for alternative cover crops, seeding practices and establishment methods underscore the necessity of immediate economic incentives for growers, while promoting long-term sustainability. Diversifying crops and embracing longer rotations through collaborative efforts and public support emerge as vital strategies. The focus on understanding soil microbiome stability, integrating sustainable crop protection measures and incorporating diverse companion plants signals a commitment to environmentally conscious agriculture. Moreover, the call for a departure from conventional cropping systems towards more dynamic, diverse and disease-suppressive approaches reflect a forward-looking perspective. The emphasis on precision farming, spatial planning and the adoption of advanced technologies showcases a commitment to optimize resource use and decision-making. This comprehensive approach envisions a resilient and environmentally friendly future for agriculture, rooted in scientific advancements and farmer-centric practices.*

Barriers

Continuous cropping leads to significant reshaping of the soil and root microbiome compositions, also diversity in a crop specific manner. This is a challenge in a context of crop rotations since the microbiome selected by one crop is very likely different and possibly not as favorable to support the productivity of the next crop (Alami et al., 2021; (Han et al., 2022).

There is still a lack of information and training about how to select suitable crops for rotation or intercropping (Chen et al., 2022).

The highest number of barriers are related to the production level such as developing knowledge and management tools to integrate new crops in historically simplified and short term profit-oriented production systems. Barriers are also related to changes required in cognitive, regulatory and administrative frames to facilitate spatial innovations at new scales (crop strips on the farm, territorial collaboration between farmers) (Morel et al., 2020).

Companion planting is difficult for industrialized agriculture (Pickett et al., 2019).

No-till practices in vegetable production present barriers due to high weed competition and low soil nitrogen availability, leading to lower plant growth, nitrogen uptake and yield components in cropping systems (Gallandt, 2014).

Lack of attractive short-term economic returns to growers and limited time for cover-crop establishment following maize and soybean harvest are major reasons for slow adoption (Mohammed et al., 2020).

High spatial resolution images have smaller dimensions, covering smaller portion of the Earth's surface and resulting in a lower temporal resolution. High temporal resolution images tend to cover larger portions of the surface on Earth, resulting in a poor spatial resolution (Filgueiras et al., 2020). No extensive evaluation of different cover crops species with varying sowing date has been made for maize production in the Mediterranean conditions (Perdigão et al., 2021).

The lack of local references regarding new crops. This can make it difficult to know where and how a new crop can be introduced into existing crop rotations and whether it would be profitable or not. The mainstream methods for assessing land suitability are also limited because they mainly focus on assessing soil and climate suitability, but may not be considered important factors such as crop rotation and economic viability (Marraccini et al., 2020).

Several challenges hinder the implementation of crop rotations such as issues with heavy clay soils and poor drainage, a lack of contracts and markets for alternative crops, financial barriers related to land ownership and farm infrastructure, limited experience and knowledge of different viable crops, and concerns about potential yield losses and economic risks (Rosenberg et al., 2020).

Conclusion: *the multifaceted challenges in modern agriculture, ranging from the reshaping of soil microbiomes in continuous cropping to barriers hindering the adoption of sustainable practices like no-till and diversified cropping systems underscore the need for a holistic approach to address environmental, economic and agronomic concerns. Overcoming these obstacles requires concerted efforts in research, education and policy implementation. Farmer training programmes should be developed to enhance knowledge about suitable crop rotations, intercropping and cover crop practices. Additionally, promoting sustainable technologies such as no-till demands a shift in perception and addresses concerns about chemical reliance. Embracing alternative and diverse cropping systems neeeds collaborative efforts among stakeholders, including farmers, researchers and policymakers. Moreover, recognizing the distinct challenges within different innovation settings such as longer rotations in conventional farming and alternative value chains in thiss, emphasizes the importance of tailored solutions for each context. Overall, achieving sustainable and diversified agriculture requires a comprehensive strategy that integrates scientific* *advancements, educational initiatives, and supportive policies to propel the agricultural sector towards a resilient and environmentally friendly future.*

Good cases examples

- Low-input approach has been used with much success in maize and sorghum in eastern Africa against the two main pest problems, stem or stalk borers, and the African witchweed, *Striga* sp. (Bruce, 2010).
- Planting flowering strips in winter wheat fields reduced cereal leaf beetle damage by 61%, irrespective of landscape complexity (Tooker et al., 2020).
- Forests are a key resource of biological diversity with their structural complexity providing ideal habitats for a particularly rich array of wildlife. Within forests, decaying wood is a key indicator for biodiversity and the species which are dealing with the conservation value of the forest, and it is an important substrate for a wide variety of insect species (Harvey et al., 2018).
- Perhaps worryingly, more than half of the species are classified as data-deficient, i.e. there is insufficient knowledge to assess their risks of extinction. Furthermore, despite their role in the ecosystem as decomposers and nutrient recyclers, few countries have any systematic monitoring schemes for saproxylic beetles and, with the exception of the stag beetle*, Lucanus cervus L.* (Coleoptera: Lucanidae), there are no European initiatives to coordinate successful monitoring regimes to improve this situation (Harvey et al., 2018).
- Take-all disease (*Gaeumannomyces graminis*) of wheat is supressed by endophytes belonging to *Serratia* and *Enterobacter* (Compant et al., 2019).
- The approaches for reduced tillage and no-till developed in organic farming can also serve in order to reduce herbicide use while continuing soil conservation measures (Zikeli and Gruber, 2017).

1.3. PRECISION FARMING AND/OR IMPROVED DECISION-MAKING TOOLS

Needs

In the realm of modern agriculture the importance of monitoring systems for pests is emphasized with a focus on better-targeted control and tracking changes in the distribution of noxious organisms associated with climate change (Bruce, 2010). Acknowledging the evolving landscape, European farmers are urged to manage information effectively both on and off their farms, needing an integrated information system for informed decision-making during the crop cycle (Blackmore et al., 2010). Assessing crop performance beyond phenological development requires a combination of methods urging a comprehensive approach (Liu et al. 2022). In the context of precision agriculture the need for complex investigations to understand how crops respond to spatially variable nitrogen is highlighted, emphasizing the positive impact on grain yield and quality (Romaneckas et al., 2015). Moreover, there is a need in technological advancement to tackle the issue of environmental variability, decreasing productivity and the rising cost (Rahim et al., 2022). There is need for improvement of agro-equipment and digital services for agro-ecological transition, but also for developing specialized farm machinery and new practices. Farmers should be encouraged to use farm machinery and digital technologies as part of the agroecology transition. The users should be in the design of agro-equipment, creating financial incentives for innovative equipment purchase and also train end-users (Maurel and Huyghe, 2017).

Precision farming needs management rules to apply spatially differentiated treatments in agricultural fields such as: digital soil mapping and digital elevation models (Kühn et al., 2009); measuring crop growth during an actual growing season and using a crop growth model together are essential for timing and sizing the amount of additional fertilizer (Hakojärvi et al., 2014). There is also a need for development of a system using IoT which measures the mineral contents of the soil along with other parameters such soil moisture, humidity, temperature, pH etc. for suggesting the crop to be planted (Patil et al., 2019). Adopting new decision-making tools assure the ability to operate weed management systems without causing damage to the crop; to control unit for guiding partial rotations in a forward-backward balancing system; to use the sensor for detecting plants in advance to trigger the rotation of the tool or machine and to have knowledge of the appropriate formulas and calculations for setting the correct angular velocity and transmission ratio in the plant-skipping system (Assirelli and Liberati, 2022). The dosage of additional fertilizer application can be based on the difference between simulated and measured biomasses (Hakojärvi et al., 2014).

Crop protection will need to be even more effective so that the carbon footprint associated with seasonal inputs such as nitrogen fertilizers and the energy expended on delivery, soil preparation is at least directed at food production and not consumed by pests, diseases or weeds (Pickett et al., 2014). Using high-resolution spatial imagining is still far from being accessible for decision support and requires a high level of expertise in order to be useful this should be more user-friendly (Filgueiras et al., 2020). The development of a detection system using gas sensors, image classification and a neural network based on IoT aims to provide an effective and automated method for identifying Fall Armyworm infestation on maize plants. Such a system would enable farmers and agricultural stakeholders to detect infestations early, take appropriate control measures promptly, and potentially reduce the extent of damage caused by the pest [705].

Adopting automated irrigation system could lead to solution to control the site specific irrigation, save water and improve water productivity [697]. However, site-specific irrigation management can potentially improve the overall water management in comparison to irrigated areas of hundreds of hectares [708].

There is a need for a long-term effective solution for farmers to monitor water pH and electric conductivity (EC) [698]. Besides this there is a need to explore and evaluate the effectiveness of digital technologies in optimizing organic production [699].

Conclusion: *in the ever-evolving landscape of agriculture, the imperative for technological innovation is paramount to address multifaceted challenges. From precision farming and integrated information systems to automated irrigation and advanced sensing technologies, the agricultural sector calls for a holistic approach. Embracing computational power, deep learning and spatial modeling, researchers underscore the need for sophisticated tools that go beyond traditional methodologies. The emphasis on site-specific approaches coupled with the integration of IoT and digital services points towards a future where sustainable and efficient agricultural practices are driven by advanced technologies. As the industry grapples with issues ranging from pest control and soil health to crop monitoring and environmental variability, a unified commitment to technological advancement emerges as the key to achieving a resilient, productive and environmentally friendly agricultural future.*

Barriers

Technological advancements represent a barrier for producing the maximum amount of food. The major focus should be on using and collaborating with emerging technology in agriculture to boost outputs [716]. Extensive experience in Precision Farming research should be integrated into a farmer-based prototype system (Blackmore et al., 2010). On one hand there is also a lack of collaboration between farm machinery designers and on the other hand designers of new cultivation and breeding systems (Maurel and Huyghe, 2017), besides the lack of technical knowledge and expertise to properly set up and operate the new technologies (Assirelli and Liberati, 2022).

Precision farming aims to manage production inputs over many small management zones rather than on large zones [708] with high investment and maintenance costs (Maurel and Huyghe, 2017; Assirelli and Liberati, 2022). Precision farming depends on: field topography, soil properties and nutrients, crop canopy volume, water content and availability, tillage practice, crop rotation and other factors (Romaneckas et al., 2015).

However, there are many techniques for obtaining maps of the spatial distribution of soil properties for precision farming that are primarily related to geostatistical methods, the classical methods of geostatistics is not based on the factors affecting the distribution of soil properties over the field (Sahabiev et al., 2021). VRA maps involves data about intra-field variability description of soil parameters that should be supplemented with the techniques of geostatistical and hybrid modeling (Sahabiev et al., 2021).

The complex data processing and statistical analyses might restrict the applicability of such a technique to more scientific areas unless image processing and data analyses are embedded in easy-to-use tools for farmers (Liu et al. 2022). Both digital technologies reflected the yields well but the information on the field soil cover allowed better explanation of the reasons for lower yields (Astrauskas and Staugaitis, 2022).

Conclusion: *the integration of emerging technologies, particularly in precision farming is pivotal for boosting output and fostering sustainable practices. However, challenges lie in the lack of collaboration between farm machinery designers and cultivation system innovators, coupled with a deficiency in technical expertise for the seamless operation of new technologies. Precision farming with its focus on managing inputs across small zones faces obstacles such as high costs and dependency on various field factors. While geostatistical methods offer spatial distribution maps for precision farming, they fall short in accounting for the nuanced factors influencing soil properties. Overcoming these challenges require user-friendly decision support tools and collaboration across domains, ensuring that the potential of digital technologies is harnessed effectively for informed, efficient and sustainable agricultural practices.*

1.4. MECHANICAL TOOLS

Needs

Time optimization in order to increase productivity represents a critical need for these innovative seed-sowing machines, which are expected that they would assure accuracy during the sow seeds, ensuring optimal crop growth and yield on one hand, and labor cost reduction on the other hand (Kathiravan and Balashanmugam, 2019). Weed control represents one of the most problematic issues for both conventional and organic systems; it is necessary to continue the research to identify appropriate high-residue cover crop choices and integrated weed management practice to use in vegetable cropping systems (Price and Norsworthy, 2013)

Also, there were identified needs for development of more cost-efficient insect release systems using aircraft, gyrocopters or drones; development of more efficient genetic sexing systems (Vreysen et al., 2021), and to facilitate access to specific equipment (Boulestreau et al., 2019).

Micro-credit financing through cooperative and nationalized banks to help farmers to buy critical inputs, establish irrigation facilities and obtain small-scale farm mechanization to combat climate change effects (Reddy et al., 2022).

Barriers

A slow adaptation of conservation practices (Price and Norsworthy, 2013), poor organization of the farmers on territory and lack of equipment were noticed (Boulestreau et al., 2019). Also, , andthe producers reported lacking the equipment or having insufficient on-farm storage as obstacles (Aune et al., 2017).

1.5. ORGANIC FARMING

Needs

Crops diversification practices depend on the development of more inclusive markets, local value chains and the recognized benefits by the society (Rodriguez et al., 2021). In this context collaboration among stakeholders could increase the investment capacity and improve access to new markets (Rodriguez et al., 2021). In order to increase the volume of edible products, farmer incentives have to be improved so that they not only motivate to farm organically but also to produce and develop products that are sold to consumers (Winter et al., 2021). There is a need of for the existence of demonstrations farms and processing plants in order to educate the farmers. Beside this, it is of the major importance the existence of the specific course, industry meetings, and conferences available for farmers to attend and improve their knowledge to which the famers to attend (Mazurek-Kusiak et al., 2021).

Identifying organic transitional practices that mitigate or exacerbate damage from soilborne diseases and pests would facilitate risk assessment of pest resurgence following conversion from conventional to organic production (Chellemi et al., 2013). There is limited knowledge regarding the impact of soil amendments and biological control on the nutritional composition of crop plats (Rempelos et al., 2021). Organic fertilizers have influence on the complex organic compounds (Compant et al., 2019), while integrated pest management leads to the build-up of different soil and plant microbiota. Integrated Weed Management must be developed and promoted because comprising cultural, mechanical and biological practices are warranted for managing weeds in an environmentally friendly way in organic farms (Gallandt, 2014), and need to be incorporated into organic zero tillage research efforts (Carr et al., 2013). Further studies are needed to qualify the legacy effects of soil fertility beyond individual crop rotation cycles (Pullens et al., 2021). There is also a need for the investment in research to overcomes technical difficulties related to seed multiplication under organic conditions (Padel et al., 2021).

Famers need (free) advice to adapt their farm to the existing legislation (Mazurek-Kusiak et al., 2021), while agronomists need methodologies to assess the sustainability of cropping systems (Colomb et al., 2013). This advice is especially important in the transition period (Polonio-Punzano et al., 2021). Research efforts are required to develop location-specific bio-herbicides to use in organic farms (Gallandt, 2014), improving plant immunity for diseases can be beneficial in organic cropping, because Si can enhance resistance of crops to fungal diseases (Pozza et al., 2015); incorporate a microbial-based approach into organic farming for compensation of the lower yield under global warming (Azarbad, 2022), development of products that are sold to consumers (Łuczka et al., 2021).

The potential of integrated weed management strategies, combining cultural, biological and mechanical controls are emphasized for incorporation into research efforts focused on organic zero tillage. The performance of market crops in organic zero tillage systems has shown variability due to issues such as weed management, nutrient cycling and other unresolved challenges. While studies comparing organic conservation tillage and inversion tillage systems have demonstrated soil quality benefits, there is a lack of research on zero tillage treatments. Further research is necessary to identify agronomic strategies that optimize market crop performance, achieve acceptable levels of weed suppression, and assess soil quality benefits following the adoption of organic zero tillage. Additionally, economic comparisons between organic zero tillage and other conservation tillage systems, including those utilizing cover crops and conventional tillage are crucial as agronomical questions related to these systems are addressed (Carr et al., 2013).

Conclusion: *the success of crop diversification practices are contingent on the simultaneous development of inclusive markets, local value chains and societal recognition of the associated benefits. Collaboration among stakeholders is crucial for enhancing investment capacity and expanding market access, encouraging a transition towards more sustainable cropping systems. To boost the volume of edible products, improving farmer incentives is essential, motivating not only organic farming but also the production and development of products for consumers. The establishment of demonstration farms, processing plants, and educational initiatives are vital for farmers' education. Identifying organic transitional practices, addressing gaps in knowledge regarding soil amendments and biological control, also promoting environmentally friendly practices such as Integrated Weed Management is essential for successful organic farming. Further research on the legacy effects soil fertility, investment in overcoming technical challenges related to seed multiplication under organic conditions, and the development of location-specific bio-herbicides are crucial for the continued advancement of sustainable agriculture. Additionally, providing farmers with advice to adapt to legislation, equipping agronomists with sustainability assessment methodologies, exploring innovative approaches such as microbial-based strategies and product development contributes to a comprehensive and resilient agricultural framework.*

Barriers

Barriers to organic agriculture could be identified in terms of education, technology and market. It was noticed a limited access to knowledge, technology and markets for minor crops, and concerns about the consistency of policies (Rodriguez et al., 2021; Boulestreau et al., 2019). However organic agriculture is seen as the solution, it mostly lacks technologies for intensive food production (Pickett et al., 2014). In general farmers are reluctant to switch to organic systems due to the risk of pests resurgence following the required transitional period (Chellemi et al., 2013) and bio pesticides based on microorganism are more expensive than the synthetic ones (Gallandt, 2014), and the farmers have limited capacity to produce botanical extracts (Riar et al., 2017).

Furthermore, natural fertilizers and pesticides should be carefully used and analyzed due to content of heavy metals and pharmaceutics and hormones present in animal manures, and the toxicity of essential oils to nontarget organisms, lack of reproductibility activity (complex mixture of compounds dependent of several factors), and possible carcinogenic and/or mutagenic activity should be addressed (Gallandt, 2014; Ackroyd et al., 2019 ; Belouri et al., 2022; Häfner et al., 2023). Furthermore, analyses of the composts for pharmaceuticals and hormones are costly and of limited availability (Ackroyd et al., 2019) and continuous application of manure with urine can produce NaCl accumulation in the soil requiring mitigation measures (Häfner et al., 2023). Reduced capacity to produce varieties of seeds resistant to diseases and pests represents as well a barrier for organic agriculture (Padel et al., 2021). A barrier for the investment could be the lack of "information about availability and price for organic seed" (Padel et al., 2021), also the high economic pressure reinforced risk aversion regarding alternative practices that required extra investments (Boulestreau et al., 2019).

Breeding for organic agriculture is a relatively new and evolving discipline, characterized by numerous questions and fewer definitive answers. A key inquiry in organic breeding revolves around determining the optimal selection environment. Currently, two types of breeding programmes are employed for developing varieties suitable for organic farming. Organic farming, despite utilizing tillage for weed suppression has been recognized for promoting soil quality. The adoption of zero tillage and other conservation practices are identified as enhancing soil quality in systems reliant on synthetic agri-chemicals for crop nutrition and weed control. Efforts to eliminate tillage entirely in organic cultivation face challenges, and while vegetative mulch from killed cover crops in organic zero tillage can suppress annual weeds, substantial amounts are required for effective early-season weed control. However, established perennial weeds are not effectively controlled by cover crop mulch. Understanding the impact of cover crops on nutrient cycling, weed, disease, and insect pest management in organic zero tillage and other conservation tillage systems is limited despite its critical importance for successful adoption by organic farmers [841, Carr et al., 2013).

Measures to prevent contamination for adjoining non-organic areas have to be implemented: aquatic plants in ponds to reduce water contamination and buffer zones with natural or artificial barriers to reduce drifting of sprayed pesticides are needed (Rizal et al., 2022).

Conclusion: *barriers of the widespread adoption of organic agriculture are multifaceted, encompassing challenges in education, technology and market access. The limited availability of knowledge, technology, and markets for minor crops coupled with concerns about policy consistency impedes the organic sector's growth. While organic agriculture is viewed as a potential solution, the lack of technologies for intensive food production poses a significant obstacle. Farmer reluctance transition to organic systems is driven by concerns about the risk of pests resurgence during the required transitional period, and the higher cost of biopesticides based on microorganisms compared to synthetic alternatives further hinders adoption. Careful consideration is necessary when using natural fertilizers and pesticides due to the potential issues such as the presence of heavy metals in animal manures and the toxicity of essential oils to non-targeted organisms along with potential carcinogenic or mutagenic activity. Additionally, the reduced capacity to produce disease- and pest-resistant seed varieties poses a substantial barrier for the organic agriculture. The lack of information about the availability and pricing of organic seeds coupled with economic pressures and risk aversion toward alternative practices requiring extra investments further complicates the landscape for potential investors. Addressing these barrier needs a comprehensive approach that encompasses education, technology development and supportive market conditions to promote the sustainable growth of organic agriculture.*

Good cases examples

The safety methods for weed control in clean agriculture encompass various approaches. Mechanical weeding techniques include soil solarization, mulching, hot water and steam treatment, stubble burning and the use of natural herbicides. Cultural control methods involve the selection of competitive plant varieties and the application of the stale seedbed technique. Additionally, new and nontraditional methods such as the use of

Fresnel lenses, biological weed control, and flame weeding are explored as alternatives for safe and effective weed management in agriculture. (Gallandt, 2014)

Marble and wood ashes are good sources of K for organic farming. Marble for K fertilization on maize crops gave excellent results (Santos, 2020).

2. SOCIAL-MARKET

2.1 EDUCATION

Needs

It is critical to understand farmers' perceptions of climate change, the precision with which they perceive climate change and the efficacy of agricultural adaptation to climate change (Reddy et al., 2022). Famers should be aware about the impact of sustainable practices, especially of those, which are related to rational use of inputs and to the use of organic fertilisers. It is also important the possibility of obtaining yields that meet the farms' sustainability requirements (Timpanaro et al., 2022).

Regarding the education of the farmers, more training courses about precision farming should be done especially for those who are less familiar with the subject (Reichardt et al., 2009). Education courses should cover the topics related to crop diversification, root viral communities and the use of the minor crops, both for farmers and extension agents (Meynard et al., 2018; Muscatt et al., 2022). More experiments should be carried out in different agricultural ambients with different crops to study the effect mound building termite on soil properties under different soil conditions, slope class and land use (Tilahun et al., 2021). Crop rotation influence on the composition and activity of bulk soil, rhizosphere soil (Muscatt et al., 2022) and the negative effects of continuous cropping including the buildup of root rot diseases, which decrease in soil health, quality and nutrients depletion from the field, deterioration of soil physicochemical characteristics, soil enzymatic activities, accumulation of autotoxic chemicals (Alami et al., 2021), representing important subject for farmers' education. . Information on the application of biopesticides has to be addressed in farmers' training courses (Polonio-Punzano et al., 2021).

Studies pointed out that famers training on seed production and pest management is necessary to support the transition to 100% organic seed use (Winter et al., 2021), while methods and enforcement of farmers' education on safe usage of agrochemicals represents as well an important topic (Laary, 2012).

In order to farmers adopt the proper technologies the information and dissemination process should be improved, on one had (Reichardt et al., 2009; Riar et al., 2017) and reforms at policy-making levels should be done, in all agricultural nations across the globe (Arora et al., 2022), on the other hand. The need of a redesign of policies and particularly the agri-environmental payments scheme should be considered as well (Nave et al., 2013). Implementation of new technologies implies knowledge about how to develop farming in the long run and has a recognized business plan with a scheme for investments and how to achieve identified short-term goals (Väre et al., 2021). The need for collaboration between research institutions, universities, and agricultural training centers to develop interdisciplinary training programmes was pointed out (Meynard et al., 2018). The barriers to adopt the conservation agriculture must be overcome by politicians, public administrators, farmers, researchers, extension agents and university professors. With adequate policies to promote Conservation Agriculture/No-till it is possible to obtain what is called the triple bottom line - economic, social and environmental sustainability - while at the same time improving soil health and increasing production (Derpsch et al., 2010). To enssure a proper communication channel extension, outreach materials should be written at a basic level (Brock et al., 2021). Organize combined training and discussion clubs where the farmers are able to learn from each other and professional daily farm advisors as well as inspire each other (Riar et al., 2017; Väre et al., 2021).

Conclusion: *addressing climate change challenges in agriculture requires a comprehensive approach. Understanding farmers' perceptions, promoting sustainable practices, and providing targeted education, especially on precision farming and organic methods are crucial. Policy reforms, improved information dissemination, and collaboration among stakeholders are essential for adopting proper technologies. Overcoming barriers to conservation agriculture demands collective efforts, and effective communication channels, basic-level materials, and discussion clubs can facilitate knowledge exchange. With coordinated efforts and supportive policies, achieving economic, social and environmental sustainability in agriculture is possible.*

Barriers

Barriers to education on this topic could include limited funding for research and education programmes, a lack of qualified educators and researchers in the field, a lack of access to advanced technologies and equipment needed for research, limited public awareness, interest in the importance of ecological immunology. Additionally, the interdisciplinary nature of this topic may pose challenges for traditional educational programmes that are often structured around more specific fields of study, such as biology or ecology (Xue et al., 2017).

Although the use of semio-chemicals has evolved as a novel tool for environmentally friendly pest control, farmers who are the end-users continue to primarily rely on the use of chemical insecticides for crop protection (Ayelo et al., 2021). Farmers generally only pay attention to the application of fertilizers which are rich in macroelements such as nitrogen, phosphorus and potassium fertilizer, ignoring the trace elements and organic fertilizer (Chen et al., 2022).

Lack of knowledge and awareness among farmers and other stakeholders about the risks and impacts of herbicide resistance. Resistance to change and reluctance to adopt new practices or technologies (Schroeder et al., 2018).

There is little information in the literature regarding the changes in yield from branches and stem caused by row spacing (narrow row, twin-row, crossed rows and traditional row spacing) and by seeding rate-row spacing interaction considering soybean cultivars with compact plant architecture and indeterminate growth type (Ferreira et al., 2018). Even if there are cases in which farmers are aware of the adverse effects of overuse of natural resources, they continue to do it. Developing and adopting climate-resilient practices is a significant challenge as the agriculture systems are operated mainly by small producers and most of them are not well educated or their resource is not high with an even lower adaptive capacity (Reddy et al., 2022).

Conclusion: *the challenges in modern agriculture, ranging from herbicide resistance to educational gaps highlight the complex and evolving nature of the industry. Issues such as limited knowledge on crop successions, row spacing impacts and resource overuse underscores the need for continuous research and education. Barriers in ecological immunology education, concerns about food safety and GMOs emphasize the importance of addressing funding limitations and improving communication. The slow transition from chemical to environmentally friendly pest control methods and the focus on macroelement-rich fertilizers point the ongoing challenges in adopting sustainable practices. Moving* *forward, collaborative efforts and a commitment to innovation are crucial for addressing these multifaceted challenges in agriculture.*

2.2 ADVICE

Needs

The advice for addressing education barriers could include incorporating interactive and experiential learning approaches, providing access to resources such as online databases and scientific literature, also partnering with industry and government agencies to provide practical applications and career opportunities. These efforts can help to increase interest and engagement in the field of ecological immunology and promote the development of skilled professionals who can contribute to the advancement of sustainable agriculture and environmental management (Xue et al., 2017).

More work is needed to bring a community-wide, interdisciplinary approach to understanding the complexity of managing weeds within the context of the whole farm operation and for communicating the need to address herbicide resistance. Recommendations for managing herbicide resistance, including the use of diversified crop rotations, cultural practices and non-chemical control methods. Sustainable and environmentally friendly agriculture practices (Schroeder et al., 2018).

Growers may not apply regular pest monitoring to aid decision-making for or against the use of pesticides. However, it needs to be noted that the observed recommendations may reflect only a segment of all pest management practices as growers may be visiting the plant clinics when an unfamiliar problem emerges rather than for the most common, regularly encountered pest problems. Governmental agricultural extension services can help changing agricultural practices towards more sustainable farming and may subsequently improve food safety. This suggests that at least countries where agriculture contributes significantly to the gross domestic product, investment in large networks of frontline governmental agricultural extension services may be more warranted than reducing or phasing out such services (Toepfer et al., 2020; Glithero et al., 2013). There is need for a better understanding of the effects of pesticide reduction strategies (Birch et al., 2011) and better implementation of measures and legislation for pesticide reduction (Gosme et al., 2010). In this case there is a need for strengthening extension service and seed delivery systems (Mugumaarhahama et al., 2021), also training and consulting on management when developing organic farms and farming (Väre et al., 2021).

Further research regarding siRNA and ARG transport in soil and transfer to microbial communities and further HGT to other microbes in a case-by-case manner is needed to protect microbial diversity and their associated ecosystem services (Un Jan Contreras and Gardner, 2022). Improving general knowledge about eDNA, plant elicitors, plant immune system, plant priming, DAMPs and PAMP (Carbajal-Valenzuela et al., 2022).

Conservation tillage and soil health research, outreach efforts should be adapted to farmers who rely on horse-drawn implements (Brock et al., 2021). Advisers need tractable tools and decision maintaining systems to support farmers in designing optimal crop rotation, or at least to adopt best practices under continuous cropping. Mainstreaming soil health diagnostics would allow the effective deployment of such strategies since optimization is based on prior knowledge of the status of the soil microbiome (Alami et al., 2021). There is a need to improve the availability of technical advice and support for farmers interested in diversifying their crops and to develop mechanisms to share information and best practices among farmers, extension agents and other stakeholders (Meynard et al., 2018).

Conclusion: *overcoming education barriers in ecological immunology involves interactive learning, resource access and industry-government partnerships. To address herbicide resistance, a holistic, interdisciplinary approach emphasizing sustainable practices is crucial. Regular pest monitoring, supported by government extension services can enhance sustainable farming and food safety. Research gaps in soil health, siRNA, and knowledge improvement in various agricultural aspects must be addressed. Advisers need tools for optimal crop rotation, and improved technical advice is vital for crop diversification. Collaborative efforts can drive sustainable agriculture and environmental management*

Barriers

There are several challenges, gaps in addressing climate change and its impact on farmers. Limited general knowledge about climate change effects, insufficient availability of improved plant varieties and protection methods, and low income contribute to the challenges. Additional obstacles include insufficient land quality and profit, inadequate plant protection programmes, a focus on single solution strategies, and limited understanding of the consequences of pesticide reduction. The slow pace of transformation processes and a lack of robust prediction models further hinder progress. Redundancy and descriptive nature in studies about soil microbiome and the absence of large-scale observations are also noted challenges. Collaboration gaps between research centers and industries dedicated to organic manure and biological pesticides production persist. To address these issues, research and education efforts should focus on managing various change situations on farms (Saifan et al., 2021; Abid et al., 2015; Meynard et al., 2018; Mugumaarhahama et al., 2021; Glithero et al., 2013; Gc et al., 2022; Qiu and Hu, 2020; , Birch et al., 2013; Gosme et al., 2010; Filgueiras et al., 2020; Higo et al., 2020, 764, Väre et al., 2021).

Conclusion: *addressing climate change challenges in agriculture involves overcoming obstacles such as limited farmer knowledge, insufficient access to improved practices and financial constraints. Additional issues include land quality, plant protection programmes and the slow pace of transformation. Challenges in understanding pesticide reduction consequences, soil microbiome studies and collaboration gaps also need attention. To tackle these, a focus on adaptive management strategies for diverse farm situations is crucial.*

2.3 CONSUMER BEHAVIOUR

Needs

There is a call for increased education on consumer habits with a specific emphasis on the promotion of zero pesticide production and organic production. General education and research on controlling bacterial plant pathogens are also highlighted. To encourage sustainability, local sourcing, and crop diversification, recommendations include developing marketing and communication strategies as well as shifting towards a "place-based" sourcing approach (Clarke et al., 2013; Meynard et al., 2018; Qion et al., 2020; Polonio-Punzano et al., 2022 Weituschat et al., 2023).

Barriers

Among barriers could be the lack of data about the cost/benefits of a commercial solution (using commercially acquired satellite imaging data) (Filgueiras et al., 2020), while wholesalers and retailers have many restrictive demands that are assumed to reflect consumers' request to farmers (Boulestreau et al., 2019). The higher prices of the products from more sustainable producing systems is a barrier to a larger consumer demand (as well as the lack of confidence on certification) (Murshed and Uddin, 2020).

2.4 VALUE CHAIN

Needs

Recommendations for enhancing various agricultural aspects include:

Financial Support and Subsidies:

Advocacy for greater financial support from regional or national governments to grow the sustainable rice production (SRP) market. Introduction of targeted subsidies as incentives for growers to address the lack of local supply chains. Encouragement for research funding that facilitates closer collaboration between universities and industry, translating positive research findings into supportive policy measures (Lindegaard et al., 2016).

Market Perspective and Collaboration:

Recognition of the potential role of price premiums in helping farmers cover additional costs associated with organic seeds (Winter et al., 2021).

Strengthening collaboration along the food chain to enhance fairness, increase farmers' profits and develop organic production in Finland (Väre et al., 2021).

Economic Research and Knowledge Gaps:

Consideration of the integrated nature of many organic corn farming systems in economic research.

Advocacy for renewed efforts to collect and publish data to address knowledge gaps in the economic performance of diversified noncereal cropping systems (Brock et al., 2021;, Sánchez et al., 2022).

Value Chain and Coordination:

Acknowledgment that shorter value chains enhance the adoption of resistant varieties. Emphasis on improved coordination and communication between stakeholders in value chains to ensure fair distribution of added value and promote crop diversification. Need for value chain formation, including new organizational forms at the value chain level such as contractual arrangements, professional associations or partnerships, to internalize funding mechanisms for scaling (Finger et al., 2023;, Moghaddam et al., 2014; Sánchez et al., 2022; Spiegal et al., 2018; Bolou-Bi et al., 2023; Meynard et al., 2018; Weituschat et al., 2023).

Conclusion: *fostering sustainable agricultural practices and market viability needs collaborative efforts and financial support from governments. Initiatives such as targeted subsidies, price premiums for organic seeds, and strengthened value chain coordination can enhance the economic performance of diversified farming systems. Addressing knowledge gaps through research, advocating fair distribution in value chains, and creating value chain formations are crucial steps toward ensuring long-term viability, scalability and resilience in agriculture.*

Barriers

There were encountered barriers related to logistical constraints to harvest, commercialization of the products (Meynard et al., 2018; Mouden et al., 2017), this enchanting the idea that the famers are not in full control regarding the crop diversification process and value chain formation (Weituschat et al., 2023), which is being noticed by a

lack of market support (Sánchez et al., 2022). There is also need for professional help in terms of business model, processing and marketing (Väre et al., 2021).
Very few studies have included cost benefit assessments of CBC up-to-date (Jonsson et al., 2008).

Farmers and extension service agents criticized input suppliers for giving little information on the available inputs for agroecological practices (Boulestreau et al., 2019). There was a notice on a low constancy and dialogues between farmers and marketing companies making initiative both in changing their commercial and farming practices (Boulestreau et al., 2019).

Conclusion: *the advancement of agroecological practices and crop diversification faces multifaceted challenges, including limited information from input suppliers, communication gaps between farmers and marketing entities and a lack of awareness among value chain actors. Logistical constraints, coordination difficulties and the need for market support further complicates the spread of diversified systems. The phasing out of derogations for non-organic seeds introduces potential farm-level gross margin losses. Overcoming these hurdles requires addressing solubility issues, conducting comprehensive cost-benefit assessments, and providing professional support for farmers in business models, product processing, and marketing. Overall, a holistic approach involving collaboration, enhanced communication, and supportive policies is essential to foster sustainable agricultural practices and successful crop diversification.*

2.5 Quality Signs

Needs

- Special attention should be paid to support farm successions and especially new entrants without farm background. (Väre et al., 2021).

3. REGULATION

3.1 CERTIFICATION

Needs

Since many new varieties are developed each year it is essential to have an up-to-date, easily accessible database to provide farmers/buyers with the educational requisite and training information associated with the new varieties. It is critical to ensure that farmers comprehend all the necessary processes and adhere to the established standards and systems. Providing support for the farmers to connect them to reliable financial transaction networks will contribute to their success. Farmers need to fully understand and trust the certification process and label information to make the right choice for their successful production. A clearly designated organization with adequate central authority to oversee the whole process is critical for success. The farming policy in individual countries is critical. The associated legal framework needs to have clearly defined and encompassing rules, regulations and systems. Clauses for new cultivar registration with IP protection for developers will encourage more innovation towards scaling up production and adapting to changing environmental conditions. Collaborations between reputable private and public sectors is favorable for leveraging strength on both sides, particularly in terms of the offerings in modern technology. A transparent seed certification and labeling system managed by a trusted authority will boost farmers' confidence in using the seeds (Chen et al., 2022).

A legal basis is needed to increase consumers' credibility and reliability on organic products (Esteves et al., 2021).

In order to achieve a 10 to 20% reduction in pesticide use the required policies should relate mainly to extension and training services, the role of institutions responsible for advising farmers being a central importance. Achieving higher reductions in the use of pesticides presupposes setting up other economic incentives or regulatory instruments. Pesticide taxation is probably the most efficient way to achieve reduction in pesticide use, but the level of taxes should be high enough for this kind of mechanism to be effective. In these cases compensation should also be considered. Other economic incentives can be applied particularly on the remuneration of environmental services through voluntary contracts subsidisinglow-input practices. Also the present appraisal of the AgriEnvironmental measures from the second pillar of the CAP shows that more research is needed to combine acceptability and measure efficacy (Jacquet et al., 2011). International Plant Nutrition Institute promoted Si to the category of 'beneficial substance' and Si compounds are now also classified as biostimulants in EU regulations and used as fertilizers (Singh et al., 2020).

There is a lack of evidence on efficacy of combinations from the available IPM technologies and absence of rigorous analysis of their economic performance compared to the current practice. There should be done more to evaluate such combinations of non-chemical control measures together with approved pesticides to assess the efficacy of integrated systems against the target pests as well as calculating the associated economic outcomes. There is a need to harmonise the many environmental schemes with the promotion of IPM. Farmers will require technical support and training on how to design appropriate IPM systems as one component of an IFM plan. The challenge will be to do this without further pressure on the profitability of farming enterprises and avoiding substantial increases in food prices (Hillocks, 2012). The need to replace these harmful solvents by safer, non-toxic, inexpensive and easily available ones has significantly increased over the past decades, partially in response to the stringent environmental regulations (Mouden et al., 2017).

The digitized services for economic monitoring and forecasting as well as different easy-to-use tools for administrative work (such as applying for subsidies and permits) can help to meet the requirements on economic competence and administrative knowledge (Väre et al., 2021).

Long-term policy initiative should be developed (Lindegaard et al., 2016) to offer guidance for future developed pathways for legume-based food and feed-systems (Ferreira et al., 2021). There is a need for support from the government not only for motivating professional and product oriented organic farmers through policy measure, but also for solving the problems and challenges that farmers are facing (Väre et al., 2021).

Conclusion: *the success of agriculture hinges on crucial factors: an accessible database for new crop varieties, farmers' understanding of standards, support in financial transactions and transparent seed certification. Legal frameworks and intellectual property protection are essential for innovation. Establishing a legal basis enhances consumer trust in organic products. To reduce pesticide use policies should focus on training, taxation and economic incentives. Harmonizing environmental schemes with integrated pest management is vital. Replacing harmful solvents aligns with environmental regulations. Digitized services and tools aid economic competence. Long-term policy initiatives, government support, and collaborative efforts are pivotal for sustainable agriculture and legume-based systems.*

Barriers

Barriers are related to the taxation of the producers' income (Jacquet et al., 2011), seed certification and labeling (Chen et al., 2022), lack of knowledge regarding the implementation of the organic management plan (Esteves et al., 2021), problems of waste and energy consumption reduction during the production process (Poponi et al., 2019), lack of clear definition of hazard criteria, categories of pesticides which could be excluded on the basis of the inclusion of 'hazard' criteria at EU level (Hillocks, 2012), regulatory barriers - acceptance of GMO (if classical breeding is not used) (Botha, 213)

Regulatory framework for PGPR (Plant growth-promoting rhizobacteria) products (quality regulation, risk information), including also GM PGPR. Many countries do not have specific regulations for PGPR (Phour and Sindhu, 2022).

Conclusion: *barriers in sustainable agriculture encompasses challenges related to income taxation, seed certification and labeling. Additional hurdles include a lack of knowledge in implementing organic management plans, issues of waste and energy consumption reduction, and regulatory challenges such as clear definition of hazard criteria, also acceptance of genetically modified organisms. There is also a lack of specific regulations for plant growth-promoting rhizobacteria products, including genetically modified variants in many countries.*

3.2 Others

Needs

Policy incentives such as financial support from government-sponsored cost-share programmes, and the development of a self-seeding cover crop system with efficient technologies for seeds dispersal potential strategies to reduce the implementation costs of cover crops are needed (van Eerd et al., 2023). To implement the appropriate policy measures is crucial to have context specific understanding of the available scenarios (Riar et al., 2017).

Need the implementation of regional ration-based production restriction policies and control arable land pollution through regional food production and consumption accounting (Liu and Xie, 2018).

Development of standards and certification systems to ensure the quality and traceability of minor crops in value chains (Meynard et al., 2018).

Policy interventions such as institutional support, credit facility, and subsidy mechanism to support good adaptation strategies would boost climate-resilient agriculture (Reddy et al., 2022).

Conclusion: *addressing challenges in agriculture requires policy interventions. Financial support, self-seeding cover crop systems, and efficient seed dispersal technologies can reduce implementation costs of cover crops. Implementing regional ration-based production restriction policies is essential to control arable land pollution. The development of standards and certification systems ensures the quality and traceability of minor crops in value chains. Additionally, policy measures like institutional support, credit facilities and subsidies are crucial to boost climate-resilient agriculture.*

Barriers

Barrier for cover crop: Extra cost (such as cover crop seeding and termination) associated with cover crop inclusion into the production system poses an issue to growers. Cover crop planting may require additional equipment that adds an extra cost (Van Eerd et al., 2023).

The implementation of the high-tax scheme (chemical fertilizer) pushes some farmers with lower marginal revenues out of the arable land cultivation industry and into aquaculture or non-agricultural industries (Liu and Xie, 2018).

II. VITICULTURE

4 TECHNOLOGICAL

4.1. BIOTECHNOLOGICAL

4.1.1 Microbiota, chemical ecology (manipulations of pest-insect odorscapes) and new concepts of plant immunity

Needs

- Not applied, research associated with human health and clinical studies of phytoalexins metabolism in the human body (Leifer and Barberio, 2016)
- It was shown that the two cell lines differ with respect to the elicitor response of microtubules and actin filaments, and that this distinctive response is correlated with differential microtubule stability and a differential response of defence genes. Furthermore, defence genes can be partially triggered by pharmacological manipulation of microtubules in the absence of elicitor, providing the first evidence for a role of the cytoskeleton as a positive regulator of elicitor-triggered gene expression (Qiao et al., 2010).
- As revealed, plant defences were stimulated by the induction of a set of proteins belonging to the pathogenesis-related 10 class, suggesting that they could play an essential role in cell defence mechanisms against flumioxazin (Castro et al., 2005).
- To get the knowlegde about how can vineyard soil microbiome be altered by different management practices such as the use of biostimulants (AMF inoculation vs. non-inoculated) and/or irrigation management (fully irrigated vs. half irrigated) (Torres et al., 2021).

Barriers

- Herbicide could act systemically in grapevine tissues, probably via root uptake. Finally, some of these proteins could serve as putative biochemical markers to monitor the presence of the herbicide in grapevine tissues, as well as to evaluate the impact of fmx in some other non-target species of the vineyard ecosystem (Castro et al., 2005).
- Lack of the current knowledge about the topic (Torres et al., 2021).

4.1.2 Ecological immunology - allows understanding and promoting immunity in natural environments

Needs

- Results indicated that one of the final grapevine cell responses to the DIMEB-elicited signal consists in the modulation of phenolic metabolism, especially stilbene and monolignol biosynthesis (Zamboni et al., 2009).
- Not applied, research associated with human health and clinical studies of phytoalexins metabolism in the human body (Leifer and Barberio, 2016).

Barriers

- The results cannot immediately be translated to grapevine crop plants and they will need further verification in the vineyard. The identification strategy was not trivial and required the use of de novo sequencing techniques to identify some of the protein functions by homology in phylogenetically close organisms that are already sequenced (Castro et al., 2005).

4.1.3 Physiological or molecular basis of immune responses in the broader context of ecology and adaptation

Needs

- Heptakis(2,6-di-O-methyl)-β-cyclodextrin (DIMEB) was reported to be the most effective resveratrol elicitor in different *Vitis vinifera* cultivars. The ability of the modified β-cyclodextrins to act as elicitors probably resides in their chemical similarity to the alkyl-derivatized pectic oligosaccharides released from the cell walls during fungal infection. Along with stilbene accumulation, these experiments highlighted a more general response involving peroxidase activity as well as inhibition of *Botrytis cinerea* growth. DIMEB, a resveratrol inducer, seems to mimic a defence elicitor, which enhances the physical barriers of the cell, stops cell division and induces phytoalexin synthesis (Zamboni et al., 2009).
- Using resveratrol synthase and stilbene synthase as examples, it could be shown that pharmacological manipulation of microtubules could induce gene expression in the absence of elicitor. These findings are discussed with respect of a role for microtubules as positive regulators of defence-induced gene expression (Qiao et al., 2010).
- In the grapevine berry, most stilbenic compounds were synthesized in the berry skin and seeds. Trans-resveratrol is one of the important stilbenic phytoalexins in grapevine. As berries undergo the ripening process, they become vulnerable to attacks from various pathogens. The gradual build-up of stilbenic compounds, such as trans-resveratrol, in the skin of the berries is likely attributed to the heightened activity of STS genes throughout the developmental stages. Another explanation is that increase of STS transcript abundance and trans-resveratrol content partly is a result of more exposure for the berry to various types of pathogens and pests (Dai et al., 2012).

Barriers

- Lack of plant defence-related metabolism (Zamboni et al., 2009).
- Future work should try to elucidate, on one hand in the case of molecular interaction between microtubules and ion channels, and on the other, in the case of molecular interaction between type III effectors and the cytoskeleton. To dissect the chain of events, it will be necessary not only to follow cytoskeletal responses in vivo using appropriate fluorescent marker lines (to capture also the subtle and rapid changes of microtubules), but also to administer the elicitor to specific locations of the cell to investigate the spatial patterns of cellular responses (Qiao et al., 2010).
- In this study, authors selected eight STS genes, STS8, STS27/31, STS16/22, STS13/17/23 and applied quantitative polymerase chain reaction (qPCR) to characterize their transcriptional expression profiles in leaf tissues upon infection by the powdery mildew fungus (PM), *Erysiphe necator* (Schw.) Burr (Dai et al., 2012).

4.2. NEW CROPPING SYSTEMS

Needs

- Having in mind the problems with the lack of water and irrigation, it is necessary to maximize the effects of possible irrigation for the biological systems (Torres et al., 2021).

Barriers

- Lack of water in irrigation systems (Torres et al., 2021).

Good cases examples

- Vineries have started experimenting with new grape varieties and growing techniques, such as vertical training systems and precision viticulture to increase the quality and yield of their crops while reducing the use of pesticides and herbicides (Rauhut Kompaniets, 2022).

4.3. MECHANICAL TOOLS

Needs

- Mechanical weed control is one of the practices used in organic viticulture. There is no further discussion of mechanical tools beyond this (Graça et al., 2017).

4.4. ORGANING FARMING

Needs

- Reduction of environmental impacts and improve sustainability (Graça et al., 2017).
- Improved access to technical assistance and more diversified markets (Boncinelli et al., 2017).

Barriers

- Higher costs and lower yields (Graça et al., 2017).
- High production costs and difficulties in finding suitable land for organic production (Boncinelli et al., 2017).

4.5. OTHER TOPIC

Needs

- Intercropping and cover cropping to enhance soil fertility and reduce the use of synthetic fertilizers. Diversification in crop rotation systems to maintain soil quality and to prevent the build up of pests and diseases (Boncinelli et al., 2017).
- Appropriate methods to include land usage change and labour input in LCA (Villanueva-Rey et al., 2014).

Barriers

- Marketing, resistant varieties may taste different and do not have the same branding (Finger et al., 2023).

5. SOCIAL-MARKET

5.1 EDUCATION

Needs

Consumer education on the benefits of sustainable products, such as organic cotton and wine is crucial for informed purchasing decisions and increased demand for sustainable options (Wang et al., 2022). Farmers' education and social learning plays a vital role in the successful adoption of sustainable practices (Graça et al., 2017). Training programmes are necessary for farmers to understand organic farming principles, acquire technical and managerial skills, and grasp marketing aspects to access markets and enhance income (Boncinelli et al., 2017). Education initiatives are needed to enhance the skills and knowledge of local wine producers, contributing to the improvement of the wine production sector (Rauhut Kompaniets, 2022). The soil microbiomes' significance in vineyards has gained attention, influencing bacterial and fungal communities in grapevine tissues and contributing to the regional characteristics of the wine. The concept of 'microbial terroir' adds to the traditional notion of 'terroir,' emphasizing the role of microbial inhabitants in shaping grape characteristics and quality (Torres et al, 2021).

Conclusion: *understanding among consumers regarding the benefits of sustainable products, such as organic cotton and wine, is pivotal for driving informed purchasing decisions and increasing demand. Farmers' education and social learning are essential components in the successful adoption of sustainable practices, emphasizing the need for training programmes to impart organic farming principles, technical skills, managerial expertise and marketing knowledge. Additionally, recognizing the significance of the soil microbiome in vineyards introduces the concept of 'microbial terroir, highlighting its role in shaping grape characteristics and contributing to the regional uniqueness of wine. Overall, education emerges as a key factor in promoting sustainability across various sectors from agriculture to viticulture.*

Barriers

- The lack of consumer awareness and knowledge about sustainable production methods, which hinders their ability to make informed purchasing decisions. Specifically, consumers may not understand the environmental and social benefits associated with organic cotton or sustainably produced wine, and may not be willing to pay a premium price for these products without such knowledge. (Wang et al., 2022)
- Access to training and education programmes is often limited and may require financial investments that can be challenging for some growers, especially small-scale ones. Therefore, financial constraints could be a potential barrier. (Graça et al., 2017).
- Lack of formal education and training programmes (Rauhut Kompaniets, 2022).

Conclusion: *efforts should focus on enhancing consumer awareness and knowledge about the environmental and social benefits of sustainable products, such as organic cotton and wine, to drive informed purchasing decisions. Additionally, overcoming barriers for growers, including limited access to training and education programmes and financial constraints is crucial for the successful adoption of sustainable practices. The development* *of formal education and training initiatives is essential to empower farmers with the necessary skills and knowledge, fostering a more sustainable and resilient agricultural landscape.*

5.2 ADVICE

Needs

- More community engagement and cooperation was highlighted as a crucial factor for sustainable vineyard management (Graça et al., 2017).
- Farmers should seek advice from agronomists and other experts on organic viticulture practices. (Boncinelli et al., 2017).

Barriers

- Providing advice on sustainable products, such as organic cotton and wine is the lack of clear and consistent labeling and certification systems that consumers can rely on. This leads to confusion and skepticism among consumers, making it difficult for them to make informed and sustainable choices. (Wang et al., 2022)
- Lack of communication and coordination among stakeholders and the lack of incentives for cooperation (Graça et al., 2017).
- Cost of consultation for seeking advice and the limited availability of experts in some areas, which may limit access for small-scale and less-resourced farmers. Lack of trust or skepticism among some farmers regarding the benefits and effectiveness of organic and environmentally friendly practices (Boncinelli et al., 2017).

5.3 CONSUMER BEHAVIOUR

Needs

Addressing the lack of consumer awareness about sustainable production methods is crucial for informed purchasing decisions. Efforts should focus on educating consumers about the environmental and social benefits associated with organic cotton and sustainably produced wine (Wang et al., 2022). While financial constraints may pose a barrier to accessing training and education programmes for growers, finding solutions to overcome these challenges is essential, especially for small-scale farmers (Graça et al., 2017). The absence of formal education and training programmes need to be addressed to enhance the skills and knowledge of local wine producers (Rauhut Kompaniets, 2022).

Furthermore, recognizing consumer concerns about pesticide use emphasizes the need for promoting zero pesticide production and incorporating relevant labeling to drive purchase decisions (Wang et al., 2022). To foster the transition to sustainable agriculture, ongoing education and outreach efforts are vital to increase awareness of the benefits for zero pesticide production and organic farming (Graça et al., 2017). The wine industry, particularly in the Chianti region, should explore consumer behavior and preferences related to organic and zero pesticide production, potentially leading to a premium quality for certified wines (Boncinelli et al., 2017; Valenzuela et al., 2022). Finally, valuing the lower environmental impact of hybrid farming systems, such as biodynamic-conventional wine, underscores the importance of considering ecological factors in food production (Villanueva-Rey et al., 2014).

Barriers

The value of zero pesticide production is hindered by a lack of awareness and understanding regarding the health and environmental impacts of conventional pesticides. It is essential to bridge this knowledge gap to demonstrate that organic products are not inherently superior solely based on labels. Their benefits encompass nutritional, climate, environmental and social aspects of agricultural products (Wang et al., 2022). Additionally, the limited awareness of the environmental and health advantages of organic farming, coupled with the higher cost of organic products compared to conventional ones, impacts consumer demand for zero pesticide production (Graça et al., 2017). The challenge extends to consumers' limited knowledge of organic and zero pesticide production methods, along with higher costs and limited availability of these products, particularly in markets where conventional alternatives are more accessible and affordable (Boncinelli et al., 2017). Furthermore, variations in willingness-to-pay for sustainably produced wine, with older individuals showing less inclination indicate the diverse factors influencing consumer preferences (Valenzuela et al., 2022). As efforts continue to enhance consumer education and make sustainable options more accessible the transition to zero pesticide production faces both informational and economic challenges.

Good cases example

- Targeted marketing and communication strategies to better inform consumers about the benefits of organic and zero pesticide products (Boncinelli et al., 2017).

5.4 VALUE CHAIN

Needs

- Ensuring sustainable production and consumption of specific products such as organic cotton and wine (Wang et al., 2022).
- Transparency and traceability throughout the value chain to promote sustainability (Graça et al., 2017).
- Improvement of cooperation and coordination among stakeholders in the supply chain to meet the growing demand for zero pesticide products and ensure a sustainable market for organic and environmentally friendly wines (Boncinelli et al., 2017).

Barriers

- Lack of transparency and traceability of sustainable production processes (Wang et al., 2022).
- Lack of trust and cooperation among stakeholders, inadequate communication and information-sharing, also limited access to finance and other resources (Boncinelli et al., 2017).

Good cases example

- Creation of networks and partnerships among value chain actors and the promotion of participatory decision-making processes that involve all stakeholders in the development and implementation of strategies to enhance the sustainability and profitability of the organic viticulture (Boncinelli et al., 2017).

5.5 Quality Signs

Needs

- Quality signs on specific sustainable products like cotton and wine are crucial for consumers to make informed decisions about their purchasing choices (Wang et al., 2022).
- Clear and more standardized quality signs or labels for organic products in order to increase consumer trust and facilitate market access for producers (Boncinelli et al., 2017).

Barriers

- Existing quality signs identified in the publication and the lack of knowledge and awareness among consumers about the different types, which can lead to confusion and mistrust. (Wang et al., 2022)

6. REGULATION

6.1 CERTIFICATION

Needs

- Products are sustainable and have undergone rigorous inspection and verification processes. (Wang et al., 2022)
- Regulation and certification can play a crucial role in promoting sustainable vineyard management practices. Certification schemes can help increase transparency and trust among consumers, which can incentivize vineyard managers to adopt sustainable practices (Graça et al., 2017).
- Regulation aspect of certification can drive the adoption of organic viticulture. Clear and strict regulation regarding certification is required to ensure the integrity of the organic production process and to guarantee the compliance with established standards to increase consumer confidence (Boncinelli et al., 2017).
- Certification of hybrid cropping systems like "biodynamic-conventional viticulture" (without synthetic pesticides) to support marketing of such wine products (Villanueva-Rey et al., 2014).

Barriers

- High cost of certification and lack of awareness among consumers (Wang et al., 2022).
- Complexity and cost associated with certification can discourage small-scale farmers from pursuing certification. Certification does not necessarily guarantee environmental or social sustainability (Graça et al., 2017).
- Certification procedures can be complex and bureaucratic, which can be a challenge for small-scale farmers. Costs associated with obtaining and maintaining certification (Boncinelli et al., 2017).

Good cases example

- Organic vineyard management practices had lower environmental impacts and higher biodiversity than conventional practices (Graça et al., 2017).

6.2 QUALITY SCHEMES

Needs

- Organic cotton and wine is to provide the assurance of the sustainability and environmental responsibility of the production process. (Wang et al., 2022)
- Clear and transparent rules for the certification of quality schemes in order to enhance the confidence of consumers in the products. Effective monitoring and control of the quality schemes to prevent fraudulent practices and ensure that the products meet the expected standards (Boncinelli et al., 2017).

Barriers

- Consumers may not be familiar with the specific labels or may not trust the credibility of the certification organizations. (Wang et al., 2022)
- High cost of certification, which may be prohibitive for small-scale producers. Complexity of the certification process, which may deter producers from participating in the quality scheme (Boncinelli et al., 2017).

Conclusion

In summary, addressing challenges in agriculture needs a multifaceted and interdisciplinary approach. Key areas of focus include optimizing pest control strategies, understanding soil biodiversity, and promoting sustainable practices through innovative techniques and advanced biotechnological applications. These efforts aim to ensure global food security amidst evolving challenges.

On the technological front precision farming, integrated information systems, automated irrigation, and advanced sensing technologies are highlighted as crucial components for sustainable and efficient agricultural practices. The integration of computational power, deep learning and spatial modeling along with a commitment to technological advancement emerges as a key strategy to tackle issues ranging from pest control to environmental variability.

Crop diversification practices require simultaneous development of inclusive markets, local value chains and societal recognition of associated benefits. Collaboration among stakeholders is essential to enhance investment capacity and expand market access, encouraging a transition towards more sustainable cropping systems. Moreover, overcoming education barriers, addressing climate change challenges and fostering sustainable agricultural practices demand comprehensive approaches, including policy reforms, improved information dissemination and collaboration among stakeholders.

Tackling climate change challenges in agriculture requires a collaborative approach emphasizing farmer education, sustainable practices and supportive policies. Overcoming barriers in ecological immunology and addressing herbicide resistance needs interdisciplinary efforts, regular pest monitoring and improved technical advice. Government support, initiatives like subsidies and premium prices for organic seeds, and strengthened value chain coordination are vital for fostering sustainable agricultural practices, ensuring economic viability and addressing knowledge gaps in the field.

In the regulatory domain, establishing an accessible database for new crop varieties, ensuring farmers' understanding of standards, and promoting transparency in seed certification are crucial. Legal frameworks and intellectual property protection play a vital role in fostering innovation, while policies to reduce pesticide use should encompass training, taxation and economic incentives. Harmonizing environmental schemes with integrated pest management and replacing harmful solvents align with environmental regulations, contributing to sustainable agriculture.

In conclusion, a unified commitment to innovative practices, interdisciplinary research and collaborative efforts is essential to navigate the complexities of agriculture, ensuring resilience, productivity and environmental responsibility.

These diverse challenges in agriculture underscore the intricate nature of the field, needing interdisciplinary research and innovative solutions. Successful interventions showcased in specific cases demonstrate the potential for overcoming these barriers strategically.

Addressing the hurdles to implement advanced technologies in agriculture such as VOCs and GM crops is crucial for their successful integration. From practical and economic concerns to social acceptance a comprehensive approach is needed. Collaborative efforts across scientific, economic and social domains are essential for responsible and effective applications.

The multifaceted challenges in crop protection and resilience demand a comprehensive strategy. Understanding plant-pest interactions, exploring defense pathways, and addressing protein identification challenges are crucial. The success stories of resistant cultivar breeding, symbiotic relationships, and genetic modifications highlight the importance of combination of traditional and molecular approaches.

Overcoming challenges in modern agriculture requires holistic approaches. Farmer education, promoting sustainable technologies, and tailored solutions for different contexts are crucial. Achieving sustainable and diversified agriculture needs a comprehensive strategy integrating scientific advancements, education and policies.

Integrating emerging technologies in precision farming is pivotal, but challenges like collaboration gaps and technical expertise must be addressed. User-friendly decision support tools and cross-domain collaboration are essential to harness digital technologies effectively for sustainable agriculture.

Barriers to organic agriculture span education, technology and market access. The lack of knowledge, technology, and markets along with concerns about policy consistency, impedes organic sector growth. Addressing these challenges requires a comprehensive approach covering education, technology development and supportive market conditions.

The challenges in modern agriculture from herbicide resistance to educational gaps, emphasize the need for continuous research and education. Addressing funding limitations, improving communication, and fostering innovation are crucial for overcoming these multifaceted challenges.

Addressing climate change challenges in agriculture involves overcoming obstacles like limited farmer knowledge, insufficient access to improved practices and financial constraints. Adaptive management strategies for diverse farm situations are crucial to tackle these challenges.

Advancing agroecological practices and crop diversification face challenges like limited information, communication gaps and lack of awareness. Overcoming these hurdles requires addressing solubility issues, conducting comprehensive assessments and providing professional support.

Barriers in sustainable agriculture include challenges related to income taxation, seed certification and labeling, as well as regulatory hurdles for genetically modified products. Specific regulations for plant growth-promoting products are lacking in many countries.

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