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AUGMENTED REALITY BASED INDUSTRIAL DIGITALIZATION AND LOGISTICS

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ABSTRACT

The virtualization systems enable the examination of the system's virtual elements by manufacturers, thus allowing them to be analysed and designed where real-world changes are necessary. Unnecessary planning is reduced by virtual reality, which allows engineers to experiment with changes before the final solution is created. Realistic and risky simulations occurring in the manufacturing environment, such as chemical spills, hazardous machinery, and noisy surroundings, can be simulated through virtual reality training programs without exposing workers to actual danger. In the event of an inevitable occurrence, employees will have usable experience and are more likely to respond appropriately to the situation. The paper presents and describes some of the most important Logistics 4.0 technologies: Internet of Things, robotics and automation, augmented reality, 3D printing and automatic guided vehicles. The aim of this paper is to describe the concept of Logistics 4.0, define its significance, components and technologies using augmented reality.

Keywords: Industry 4.0, Augmented Reality, Head-Worn Displays, Logistics 4.0

1. INTRODUCTION

Technological development, automation, digitalization, networking, new forms of communication, etc. have led to the initiation of a new industrial revolution, also known as Industry 4.0. It is represented as a new form of organization and control of the value chain in the product lifecycle. By connecting and synergizing existing and new solutions and communication technologies, data collection, exchange, and analysis, production, process management, trade, etc., a new paradigm of human action, business, and living has been created. A concept has emerged that intensely alters manufacturing processes, but whose effects are also visible in other areas of human activity, primarily trade, healthcare, agriculture, logistics, etc. By applying Industry 4.0 solutions and technologies in the field of logistics, the concept of Logistics 4.0 has been developed with the aim of achieving greater efficiency of logistic systems and processes [1]. New technologies and solutions emerge daily, but the backbone of the development of the Logistics 4.0 concept consists of several key technologies, such as: Internet of Things (IoT), Autonomous Vehicles (AV), Artificial Intelligence (AI), Virtual Reality (VR), and Augmented Reality (AR), Big Data, Data Mining, Blockchain, Cloud Computing (CC), 3D Printing, etc. The aim of this paper was to define and describe in more detail the mentioned technologies as well as the possibilities of their application in logistic systems and processes through a review of relevant literature in this field. It can be concluded that logistics, as a multidisciplinary science, represents fertile ground for the acceptance and further development of existing modern technologies, but also an initiator and incubator of new technologies that could easily extend beyond the scope of logistics and become part of the family of Industry 4.0 solutions [2]. The aim of the concept is to achieve a complete manufacturing system based on both virtual elements and physical implementation, taking into account the advantages of customized mass production. The system should be capable of manufacturing various products – assembling them solely based on software modifications that can be previewed and monitored virtually before production. The diversity of manufactured products is determined by the components available in the inventory and the workstations/tools incorporated into the manufacturing process [3]. Despite the advanced capabilities of AR hardware, limitations such as field of view restrictions and battery life constraints may impact user

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experience and system usability. Technical challenges, including compatibility issues and data interoperability concerns, may arise during the integration of AR technology with existing industrial systems and workflows.

2. MATERIALS AND METHODS

Augmented reality technology can be utilized, with a focus on the Apple Vision Pro or similar AR headsets, renowned for their advanced optics, high-definition displays, and spatial sound capabilities, enabling users to experience immersive AR environments [4]. Custom AR applications can be developed using Unity 3D, a versatile game development platform recognized for its compatibility with AR technologies, facilitating the creation of real-time visualizations of digitalized industrial processes and logistics workflows as depicted on fig. 1.

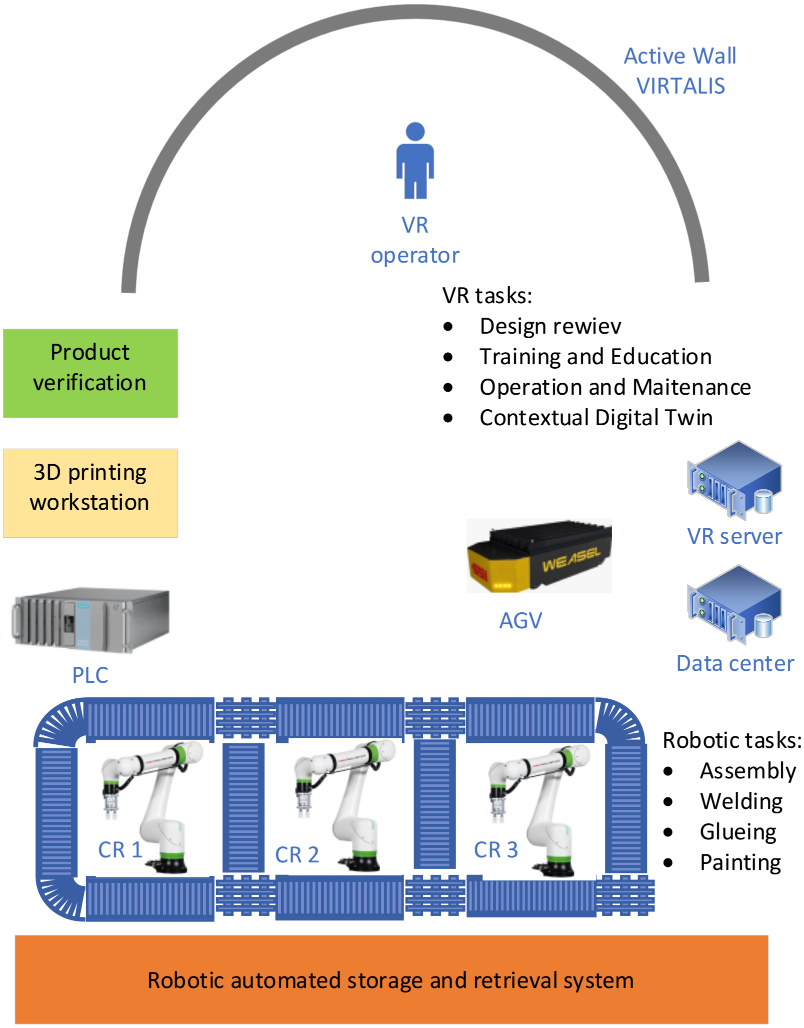

Figure 1. Holistic approach of the AR based industrial digitalization

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Industrial processes can be meticulously mapped through a combination of techniques, including on-site observations, process flow analysis, and expert consultations. This information was then digitized into 3D models using CAD software such as AutoCAD and SolidWorks. Logistics Workflow Digitization (LWD) or similar procedures can be followed for the digitization of logistics workflows, encompassing material handling procedures, inventory management systems, and transportation routes within industrial facilities.
This section outlines the materials and methods employed in the implementation of an augmented reality-based industrial digitalization and logistics system [5]. Through meticulous data acquisition, software development, integration of AR technology, user training, testing, and statistical analysis, the efficacy and usability of the system were evaluated, laying the groundwork for future research and industrial applications.

3. DISCUSSION

A series of testing phases were conducted to evaluate the effectiveness of the augmented reality-based digitalization and logistics system. User feedback, task completion times, and error rates were recorded and analyzed to assess the system's usability and performance. In this paper, an augmented reality (AR) based approach was employed to advance industrial digitalization and optimize logistics processes. The discussion herein synthesizes the findings and implications of the research, highlighting its contributions to the field of industrial automation and logistics management [6]. The integration of AR technology into industrial digitalization endeavors offers numerous advantages. The dynamic nature of industrial environments poses additional challenges for AR-based digitalization and logistics initiatives. Variability in lighting conditions, environmental factors, and equipment configurations may affect the performance and accuracy of AR systems, requiring continuous monitoring and adaptation to ensure optimal functionality as depicted on fig 2.

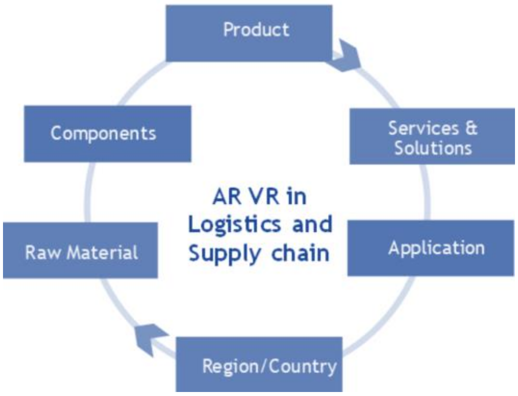

Figure 2. AR VR in Logistics and Supply Chain Market Overview

Firstly, AR facilitates the visualization of digitalized industrial processes and logistics workflows in real-time, enhancing operational transparency and decision-making capabilities. By overlaying virtual information onto the physical environment, AR enables workers to intuitively interact with digitalized models, leading to improved situational awareness and task performance. The utilization of AR headsets, such as the Apple Vison pro, provides users with immersive experiences, enhancing engagement and user satisfaction. The advanced optics and high-definition displays of AR headsets ensure the accurate rendering of virtual objects within the user's field of view, thereby augmenting their perception of the surrounding environment. Figure 3. presents an overview of the technological solutions in Logistics 4.0. Additionally, spatial sound capabilities further immerse users in the augmented reality experience,

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enhancing their ability to comprehend and respond to auditory cues within industrial settings [7]. The digitalization of industrial processes and logistics workflows through AR technology offers scalability and flexibility.

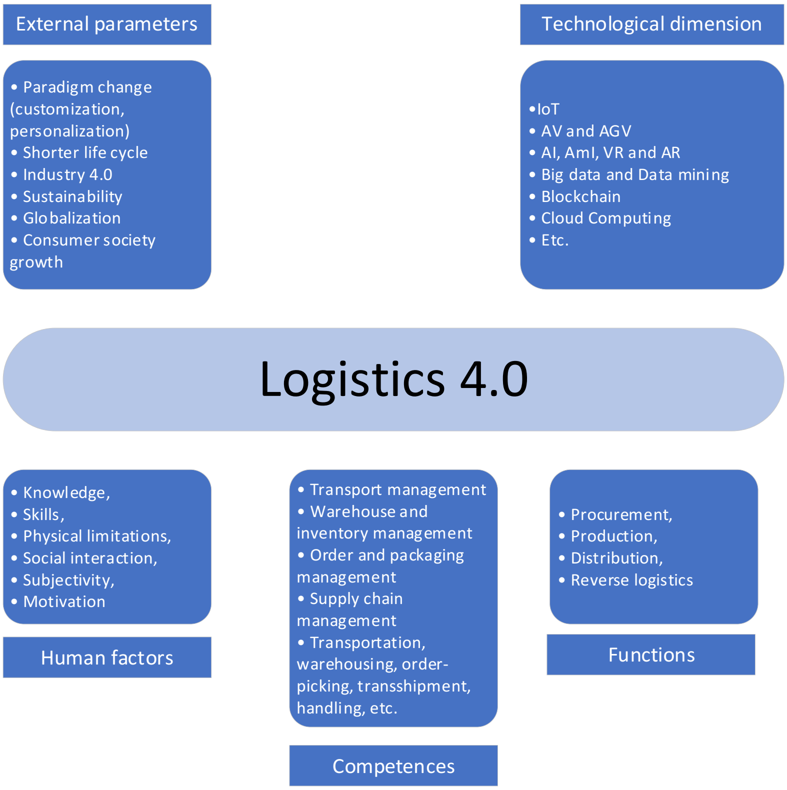

Figure 3. Overview of the technological solutions in Logistics 4.0

By digitizing complex industrial systems into 3D models, organizations can simulate various scenarios and optimize operations without disrupting physical infrastructure. Furthermore, real-time data synchronization ensures that AR visualizations accurately reflect the current state of industrial operations, enabling dynamic decision-making and adaptive responses to changing environmental conditions [8]. The findings of this study underscore the significance of user training and testing in the successful implementation of AR-based industrial digitalization and logistics solutions. Effective user training sessions are essential for familiarizing industrial personnel with AR headsets and custom AR applications, ensuring optimal usage and minimizing user errors. Additionally, rigorous testing and evaluation of the AR system's usability and performance provide valuable insights for iterative improvements and refinement. The statistical analysis of performance metrics, including task completion times, error rates, and user satisfaction scores, yields actionable insights into the effectiveness of the AR-based digitalization and logistics system [9]. Descriptive statistics, correlation analyses, and inferential tests enable researchers to identify trends, correlations, and significant differences, guiding future research directions and practical applications. Ethical considerations play a pivotal role in the deployment of AR technology in industrial settings. Prior informed consent from participants, data privacy, and confidentiality safeguards, as well as measures to ensure the security of sensitive data, are paramount. Adherence to ethical principles and guidelines ensures

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the ethical conduct of research and fosters trust and confidence among stakeholders [10]. The augmentation of industrial digitalization and logistics processes through AR technology holds immense potential for enhancing operational efficiency, productivity, and safety. By leveraging AR-based solutions, organizations can unlock new opportunities for innovation and competitiveness in an increasingly digitized and interconnected world. Future research efforts should focus on addressing challenges such as hardware limitations, integration complexities, and scalability issues, paving the way for widespread adoption and deployment of AR technology in industrial contexts.

5. RESULTS

In this section, the outcomes of the augmented reality (AR) based industrial digitalization and logistics study are presented, elucidating the findings derived from the implementation and evaluation of the AR system within industrial settings. The integration of AR technology into industrial digitalization initiatives yielded tangible improvements in operational efficiency and logistics management. Through the utilization of AR headsets, industrial personnel were able to visualize digitalized industrial processes and logistics workflows in real-time, enhancing their situational awareness and decision-making capabilities [11]. The digitalization of industrial processes facilitated by AR technology enabled organizations to simulate various scenarios and optimize operations without disrupting physical infrastructure. By digitizing complex industrial systems into 3D models, organizations gained insights into potential bottlenecks, inefficiencies, and optimization opportunities within their operations. Real-time data synchronization played a crucial role in ensuring that AR visualizations accurately reflected the current state of industrial operations. By interfacing AR applications with backend databases and enterprise resource planning (ERP) systems, organizations were able to access and display up-to-date information relevant to their operational context. User training sessions were instrumental in familiarizing industrial personnel with AR headsets and custom AR applications [12]. Participants reported high levels of satisfaction with the AR system's usability and intuitiveness, highlighting the effectiveness of the training program in facilitating smooth adoption and usage of AR technology within industrial settings. Testing and evaluation of the AR system's performance revealed significant improvements in task completion times and error rates compared to traditional methods. Users demonstrated enhanced efficiency and accuracy in executing tasks related to industrial processes and logistics workflows, validating the efficacy of the AR-based digitalization solution. Statistical analysis of performance metrics corroborated the qualitative findings, providing quantitative evidence of the benefits conferred by AR technology in industrial settings. Descriptive statistics, correlation analyses, and inferential tests revealed statistically significant improvements in productivity and task performance attributable to the AR system. The interoperability and compatibility of AR systems with existing industrial infrastructure and software applications are critical considerations. Ensuring seamless integration between AR platforms and enterprise resource planning (ERP) systems, manufacturing execution systems (MES), and other operational tools is essential for maximizing the effectiveness of AR-based solutions as depicted on fig 4.

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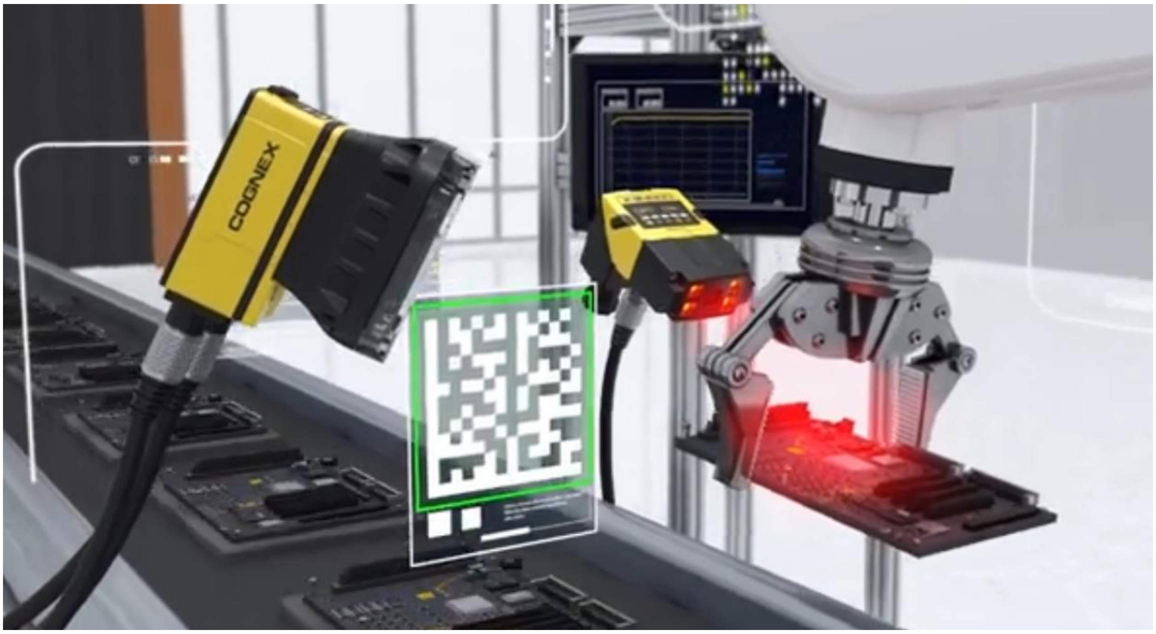

Figure 4. Machine vision and augmented reality in Logistics 4.0

Furthermore, user feedback and satisfaction surveys yielded valuable insights into areas for improvement and refinement of the AR system. Participants expressed a desire for enhanced functionality, such as augmented reality overlays providing contextual information and guidance during task execution. Ethical considerations were carefully addressed throughout the study, ensuring the ethical conduct of research and the protection of participant rights [13]. Prior informed consent was obtained from all participants involved in user testing sessions, and measures were implemented to safeguard data privacy and confidentiality. In summary, the results of this study demonstrate the efficacy of augmented reality-based industrial digitalization and logistics solutions in enhancing operational efficiency, productivity, and user satisfaction. By leveraging AR technology, organizations can unlock new opportunities for innovation and competitiveness in an increasingly digitized and interconnected industrial landscape. Future research efforts should focus on addressing challenges such as hardware limitations, integration complexities, and scalability issues to further advance the adoption and deployment of AR technology in industrial contexts. Looking ahead, several challenges and research directions emerge that warrant further investigation in the realm of augmented reality-based industrial digitalization and logistics.

- Enhanced AR Hardware: Continued advancements in AR hardware, such as improved display technologies, enhanced tracking capabilities, and ergonomic design, are essential for enhancing user experience and expanding the scope of AR applications in industrial settings.

- Integration with Emerging Technologies: Exploring synergies between AR technology and emerging technologies such as artificial intelligence (AI), Internet of Things (IoT), and cloud computing can unlock new opportunities for optimizing industrial processes and enabling real-time decision-making.

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- Human Factors and Ergonomics: Investigating the impact of AR interfaces on user cognition, workload, and fatigue is crucial for designing ergonomic and user-friendly AR systems that enhance rather than detract from worker productivity and safety.

- Data Security and Privacy: Addressing concerns regarding data security, privacy, and ownership in AR-enabled environments is paramount to foster trust and confidence among industrial stakeholders and ensure compliance with regulatory requirements.

- Scalability and Sustainability: Developing scalable and sustainable AR solutions that can accommodate the diverse needs and requirements of different industries, organizational sizes, and operational contexts is essential for driving widespread adoption and long-term success.

While augmented reality holds immense promise for revolutionizing industrial digitalization and logistics, addressing the aforementioned challenges and pursuing further research avenues is crucial to unlock its full potential and realize the vision of Industry 4.0 in industrial settings.

4. CONCLUSIONS

Future research efforts will focus on enhancing the functionality and usability of the augmented reality-based digitalization and logistics system, potentially involving the development of advanced AR applications and integration with emerging technologies such as artificial intelligence (AI) and Internet of Things (IoT). Efforts will also be directed towards promoting the adoption of AR technology in industrial settings through collaborations between academia and industry, as well as knowledge dissemination initiatives and technology transfer programs. With the spread of the effects of the new industrial revolution, the clarity of the need for the adoption and application of new technologies in various fields is evidenced. As logistics is one of the fields greatly influenced by Industry 4.0, the implications and possibilities of applying Logistics 4.0 technologies in real circumstances are explored in this paper through a review of relevant literature in the field. It can be concluded that the end of this revolution is not in sight and that with new scientific breakthroughs in almost all areas, all areas of human activity will continue to be changed. Logistics, as one of these areas, is not only represented as a fertile ground for the ideas of Industry 4.0 but also is acted upon as a driver of many changes aimed at further development of existing technologies, as well as the development of new technologies and opportunities in industry and logistics. This area of research is highly dynamic, with new technologies and solutions being discovered every day, or new possibilities for applying existing ones being found. Accordingly, this paper represents a cross-section of the current situation, and its main shortcoming is considered to be the inability to comprehensively consider all technologies and solutions and their potential application in the field of logistics. However, the paper is regarded as a solid foundation for further research into the application of the described technologies in specific organizations, regions, areas of logistics, and logistics systems, as well as for analyzing the mutual influence of technologies, making decisions on the priority of technology depending on expected effects, and for the development of new technologies.

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THE RELATIONSHIP BETWEEN SUPPLEMENTATION AND SPORT

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ABSTRACT

Nowadays, the fitness industry has become a growing industry alongside the nutritional supplements industry within the food industry. Small and large companies are fighting for consumers. They offer products tailored to different training goals, whether sold online or offline. Companies are developing their marketing strategies by observing consumer preferences and habits. But do we need supplementation? Are the products on the market safe? What do we even mean by a food supplement? Is it a good idea to buy supplements that are in line with the latest trends? In this study we will show whether or not supplementation is really necessary for athletes and what determines whether it is.

Keywords: food supplement, sport nutrition, food marketing, consumer preferences, fitness industry

1. INTRODUCTION

These days, more and more people are turning to gyms, which often commonly involves taking supplements. Do recreational, hobby and elite athletes need to take supplements? Are there cases where a varied diet is sufficient? Which nutrients should be included in the diet of athletes and for what purpose? The present study is devoted to answering these questions, among others.

The market for nutritional supplements has clearly grown in recent decades. Week after week, new products are being launched by supplement manufacturers. Each new period has its new 'miracle pills', creating a trend among dietary supplements. Consumers have more and more to look out for. From the nutritional content, to the different brands and formulations, there are many factors that influence why we should or should not choose a product. What we can say is that in this growing market, it is worth treating new products with caution, and if possible, finding out what they are good for. It is also worth considering whether it is really necessary to use a food supplement. If in doubt, it is worth seeking professional help from a doctor or dietician to avoid getting lost in the plethora of supplements.

As well as the source of the supplements you buy, it is also important to make sure that you buy foods and supplements from sustainable sources where possible. The issue of sustainable sports nutrition needs further research, but professionals should take care when preparing diets to ensure that the most sustainable and varied foods are put on the table of the individual athlete.

2. MATERIALS AND METHODS

This paper is based on further research in the literature. In order to keep our research as up-to-date as possible, we have tried to draw on the literature of recent years for the present research. We have used databases that list scientific works such as ResearchGate, Scopus, Google Scholar, among others.

This study is a complementary exploration of the literature review of our qualitative and quantitative research on sports nutrition supplements. As the literature review and market situation require a broadening of this research area, we will continue to conduct further research on this topic.

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3. LITERATURE REVIEW

3.1. The market of food supplements

A focus group survey of 25,000 people in 1998 [1] showed that nearly 41% of the people in the study were taking some type of vitamin and other supplements. 46.2% of women consumed such products, compared with 35.3% of men. Typically, the majority of consumers are middle-aged or older women, who typically suffer from arthritis, obesity, high blood pressure, high cholesterol and cancer. And the younger population uses supplements to boost their bodies and immune systems in times of fatigue, exhaustion and stress. The future of the industry is bright, but consumers need to be helped to know exactly what they need, in what quantities, and which products they can use as a preventative measure to prevent illness. Health professionals have a large and important role to play in this. They need to be informed and to know what supplements their patients are taking and why. Professionals also have a very important role to play in this, as they need to be able to assess the biological and psychological value of dietary supplements and what their use means for patients [1].

The more informed consumers involved in sport may notice that more and more companies are entering the market for sports supplements and that manufacturers are trying to come up with newer and newer products. Their marketing tools are reaching a wider and wider range of consumers. In addition to offline and online presence, influencer marketing has become part of today's marketing strategy. Many interesting questions can be asked on the subject. For example, what is the basis on which consumers choose nutritional supplements? How can manufacturers convince consumers to choose their products? Is supplementation important to individuals or is it just a marketing ploy? In addition to the interesting questions, this area requires a great deal of attention as it is a growing industry, and the importance and research aspects of the topic are justified.

Many people may ask whether it is necessary to take supplements or whether it is sufficient to get the nutrients we need from food. Close's 2022 study illustrates the point that it is not always enough to get the nutrients we need from food, as there are cases where it may be necessary to supplement with food. When we talk about food, we mean whole foods and beverages that are not fortified with various minerals, vitamins and other substances contained in food supplements. To avoid doping, experts recommend that nutrients should be taken primarily in the form of food, but it is also accepted that there are substances that should be taken in the form of supplements to improve health and performance. Close et al. have made a total of 6 claims that such supplementation may be necessary. The first of these is that there are substances that may be difficult to get into the body in the required amounts or would result in excessive energy intake. There are also foods that the athletic individual may not like, and foods rich in nutrients that may be needed to a greater extent. The nutritional content and ergogenic benefits of individual foods also vary greatly. Some nutrients are needed in concentrated amounts to promote immune tolerance and/or to make up for deficiencies. Some foods are difficult to consume immediately before, during or after exercise. It is also worth mentioning that in places where food hygiene and contamination may be a problem, tested supplements can help [2].

3.2. Consumer preferences

When looking at consumer preferences, it is worth considering why they choose a particular product when making a purchase. Stimuli and advertising through various online and offline platforms can influence their purchasing decisions. In addition, the experiences of people you know and your own experiences may also play a role in your decision to buy a particular product.

Among other things, we cannot ignore the appearance and packaging of products, because often, in many cases, this is the reason why consumers buy a product. A study from 2023 confirms this, as it plays a major role in profit making. On the one hand, a positive image can be created in the minds of consumers when they see packaging that appeals to them. On the other hand, if designers use eye-catching, attractive designs, they can influence the number of purchases. It is also important that the manufacturer chooses the right packaging

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units, as different needs may arise depending on habits and income. The choice of the packaging material itself is also an important issue, as care must be taken for both the product and the environment, as the protection of both is very important. In addition, the label should also be clear about all the information that the consumer needs to know. Here, of course, we must not forget the legislation and regulations in force. The country of origin can also be an important factor, so it should also be clearly indicated. Indications of the quality of the product should also be included on the packaging, in order to stimulate demand for other products from the manufacturer. [3]

Of course, it is not only the packaging that is important in terms of influencing consumer decisions, but also how this and other factors can influence the marketing strategy of different companies. Because if we can understand consumer behaviour and how it is distorted by consumers, we can provide a great basis for different companies to develop their marketing strategies. Because if they examine the factors that influence their decisions, manufacturers can respond as necessary. [4]

Consumer choices have been studied in the field of nutritional supplements. The results of a survey of 273 respondents in Hungary show that nearly 60% of respondents consume dietary supplements regularly or intermittently. Nearly 21% consume these products on a daily basis and nearly 39% on a dietary basis. The 2023 survey shows that women and those with a higher education are the main users of dietary supplements. However, it is important to ensure that this group of conscious consumers does not overdose on various minerals and vitamins, as they feel very knowledgeable on the subject. As a result of the quantitative research, the researchers were able to develop 3 distinct groups using cluster analysis. The members of the "supportive" and "traditionally minded" groups have a positive opinion on supplementation. The same cannot be said for the third cluster, the "opposing" cluster. It can be said that foods that are part of a healthy diet can be seen as a competitor in the market for dietary supplements [5].

3.3. Sustainability and supplementation

Nowadays, it's really important to look at the different aspects of sustainability and the protection of our environment. Of course, the need for this also extends to sports nutrition and supplementation. Consumers who consider sustainability to be an important aspect can also take this into account when choosing the products they want to buy. However, the 2020 study by Meyer et al. does not take a positive view of this issue, as sustainability is very low in sports nutrition recommendations. This is seen as a real research gap by the authors of the article, as there is very little mention of plant-based, whole-food nutrition in the various studies. So more research is needed on the effects of a sustainable diet on the health and performance of athletes. In addition, reducing food waste and the use of packaging materials is another area for further research. [6]

It can be said that depending on the training goal, athletes need to consume 1.2-2.0 g of protein per kg body weight [7][8]. A 2015 study also suggests that further research is needed on plant-derived proteins, but the results of a 3-month study showed that there was no difference in the results of athletes who had muscle gain and strength gains in a study with whey and pea protein groups [9].

It is also worth considering what diets should be followed by sporting individuals. We can point to the flexitarian diet as a win-win strategy for both the individual athlete and the environment. It can meet protein needs and provide adequate protein quality. Furthermore, sustainability guidelines can be met. It is also worth mentioning that in this diet, the athlete can decide whether or not to increase plant-based meals based on his or her own principles [10]

3.4. Consumers and supplementation

It is understandable that the nutritional needs of recreational athletes differ from those of individuals who participate in recreational sports and lead sedentary lifestyles. It is worth investigating these consumption patterns, as this would provide an indication of whether athletes are using certain supplements in accordance with their dietary requirements. It is also worth emphasising and making consumers aware that these products

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can be harmful and may not produce the right results if they are not consumed as prescribed. Monitoring these habits can help health professionals to reduce risks and maximise health. Of course, body image can also be a factor influencing the consumption of these products. It would be worthwhile to educate consumers on the appropriate use of supplements to dispel various misconceptions [11].

In 2019, Peter Peeling et al. conducted a comprehensive study of athletic athletes using dietary supplements to achieve and enhance optimal performance. The study addresses the fact that athletes are exposed to a wide variety of nutritional products due to the broad market promising different effects, but there is little evidence on their safety. It also discusses the costs of using dietary supplements, the risk that the expected performance may not be achieved, and the risks of using banned substances, which may result in a ban from sport. The authors thus conclude that sports foods and supplements should be used by athletes with strong evidence that they are safe, legal to use, effective to use and should be carefully tested by the athlete before use in preparation for competition [12].

4. RESULTS AND DISCUSSION

There is a huge range of nutritional supplements on the market for consumers to buy. However, it can be said that not all sports require supplementation. The concept of "food first" should be followed. This means that a varied and balanced diet is the first thing to follow, and that it is only when a high level of physical activity is being performed, or when the athlete needs to eat within a calorie limit and needs to take the necessary nutrients in the form of supplements, that supplements are appropriate.

Of course, the higher the level of sport that someone is involved in, the greater the chance that they will need some form of supplementation. Think of the various martial arts and powerlifters who need to be in a certain weight class. In addition, the strict diet of bodybuilders should not be forgotten. It is also important to take into account the food preferences of the individual athlete, as it would not be pleasant to prescribe a diet that includes foods that are not to his liking.

It is also worth mentioning that many people either overuse supplements or use them inappropriately. Certain periods have their own trends and fashions in dietary supplements. It's always worth treating any new product with caution and buying only from a safe source.

5. CONCLUSIONS

Overall, regardless of the level of sport or activity, it is worth trying to eat a more varied and colourful diet to get the necessary nutrients and minerals into your body in the most natural way possible. Of course, the more sport you do, the higher your physical activity level, the more you need to consume these substances. In cases where the athlete is no longer able to meet their nutrient needs through normal nutrition, it is advisable to opt for supplements. This is because we need to take into account the individual needs of the athlete, including his or her food preferences, his or her food intolerances and food intolerances. In many cases, an increase in one macronutrient may involve an increase in another macronutrient. Consider, for example, if you want to increase your protein intake for an athlete's training goals, and you want to supplement it with, say, oilseeds. However, in addition to being low in carbohydrates and high in protein, these foods are also relatively high in fat. Thus, the caloric needs of an athletic individual would be greatly exceeded. This is a good example of why supplementation is necessary.

We should not overlook the fact that the topic of sustainable supplementation is less researched and that these factors are not really addressed in dietary recommendations. It would be worthwhile to continue to address this in our current consumer society, as the ever-increasing supply could distort or even amplify this effect, and it would be worthwhile to provide consumers with the right education in good time.

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MODELLING HYSTERESIS WITH MEMRISTORS

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ABSTRACT

In the realm of electronics, the foundational passive components—resistors, inductors, and capacitors—are well-established. However, in 1971, Leon Chua introduced a theoretical fourth element, the memristor, identified by its distinctive characteristic of memristance and its manifestation in a pinched hysteresis loop. This intriguing property suggests potential applications beyond conventional electronics, particularly in modelling hysteresis phenomena across various domains. This paper delves into the exploration of memristance as a mathematical framework for simulating hysteresis in electrical and mechanical systems. We commence by elucidating the theoretical underpinnings of memristance and its hysteresis behaviour, followed by a comprehensive overview of existing hysteresis models. Subsequently, we propose a novel approach that leverages the memristor model to offer enhanced insights and predictive capabilities for hysteresis in these systems. Through analytical examination and simulation studies, we demonstrate the versatility and applicability of the memristor model, underscoring its potential as a universal tool for hysteresis modelling. This research not only broadens the understanding of memristive properties but also opens new avenues for cross-disciplinary applications, ranging from electronic circuit design to mechanical system analysis.

Keywords: memristor, hysteresis, modelling

1. INTRODUCTION

The field of electronics has long relied on three fundamental passive components: resistors, inductors, and capacitors. These elements are essential to the design and functioning of electronic circuits, providing predictable and reliable behaviours. However, the discovery and theoretical introduction of the memristor by Leon Chua in 1971 marked a significant milestone, proposing a fourth fundamental component [1], [2] that could revolutionize our understanding and application of electronic systems. In 2008 the memristor had been developed by HP labs. The device was made up of a film of TiO_2 and a film of TiO_{2-x}, where oxygen vacancies act as mobile +2 dopants sandwiched between 2 platinum electrodes creating a metal-oxide-metal cross point device. The device exhibited the characteristics described by Leon Chua, a pinched hysteresis loop that was frequency dependent and the resistance of the device was changed by the direction of the current [3]. Since the 2008 discovery memristive systems have been used to describe neural networks [4], [5], [6], [7].
The term "memristor" combines "memory" and "resistor," reflecting the component's ability to change resistance depending on the applied current direction. Without an applied current, the resistance remains unchanged, meaning the memristor remembers its resistance state. The resistance of a memristor can vary between maximum (R_{ON}) and minimum (R_{OFF}) values, and this change is not necessarily linear. Several studies have discussed the equations describing the memristors behaviour [8], [9], [10], [11], [12], [13], [14], [15]. The memristor can be described as charge controlled or flux controlled as described in equations 1-4.

$$\varphi = \hat{\varphi}(q) \tag{1}$$

$$q = \hat{q}(\varphi) \tag{2}$$

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$$U(t) = \frac{d\varphi(t)}{dt} = \frac{d\hat{\varphi}(q)}{dq}\frac{dq}{dt} = R(q)I(t) \tag{3}$$

$$I(t) = \frac{dq(t)}{dt} = \frac{d\hat{q}(\varphi)}{d\varphi}\frac{d\varphi}{dt} = M(\varphi)I(t) \tag{4}$$

Where $\hat{\varphi}(q)$ and $\hat{q}(\varphi)$ are continuous and piecewise differentiable functions with bounded slopes [16]. In this study, we propose a novel modelling approach that explores the mechanical analogue of the memristor, demonstrating its hysteresis behaviour through simulation. Our method bridges electrical and mechanical domains, providing a framework to enhance the understanding and predictive capabilities of hysteresis phenomena mechanical systems.

2. MATERIALS AND METHODS

The equations for modelling electronic components can be derived from the base quantities, these are charge q with units [C] and magnetic-flux φ with units of [Wb]. Taking the derivative with respect to time we get dφ/dt with units of [V] noted as U and dq/dt with units of [A] noted as I. From the derived units building up the equations of the base elements of resistance R, inductance L, capacitance C and memductance M follows a simple pattern. Resistance has a unit of [Ω] and is calculated by U/I ([V/A]) which is [(Wb/s)/(C/s)] and this simplifies to [Wb/C]. The equations for the voltage and current of a resistor can be seen in equations 5 and 6. Inductance has a unit of [H] and is calculated by ((Ut)/I) ([Vs/A]) which is [(Wbs/s)/(C/s)] and this simplifies to [Wbs/C]. The equations for the voltage and current of a inductor can be seen in equations 7 and 8. The equation to calculate the energy stored in an inductor can be seen in equation 9. Capacitance has a unit of [F] and is calculated by ((It)/U) ([As/V]) which is [(Cs/s)/(Wb/s)] and this simplifies to [Cs/Wb]. The equations for the voltage and current of a capacitor can be seen in equations 10 and 11. The equation to calculate the energy stored in an capacitor can be seen in equation 12. Memductance has a unit of [S] and is calculated by I/U ([A/V]) which is [(C/s)/(Wb/s)] and this simplifies to [C/Wb]. The equations for the voltage and current of a memristor can be seen in equations 13 and 14.

$$U_R(t) = RI_R(t) = R\frac{dq(t)}{dt} \tag{5}$$

$$I_R(t) = \frac{1}{R}U_R(t) = \frac{1}{R}\frac{d\varphi(t)}{dt} \tag{6}$$

$$U_L(t) = L\frac{dI_L(t)}{dt} = L\frac{d^2q(t)}{dt^2} \tag{7}$$

$$I_L(t) = \frac{1}{L}\int U_L(t)dt = \frac{1}{L}\varphi(t) \tag{8}$$

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$$E_L(t) = \frac{1}{2} L I_L^2(t) \tag{9}$$

$$U_C(t) = \frac{1}{C} \int I_C(t) dt = \frac{1}{C} q(t) \tag{10}$$

$$I_C(t) = C \frac{dU_C(t)}{dt} = C \frac{d^2 \varphi(t)}{dt^2} \tag{11}$$

$$E_C(t) = \frac{1}{2} C U_C^2(t) \tag{12}$$

$$U_M(t) = \frac{1}{M} I_M(t) = \frac{1}{M} \frac{dq(t)}{dt} \tag{13}$$

$$I_M(t) = M U_M(t) = M \frac{d\varphi(t)}{dt} \tag{14}$$

Electrical and mechanical systems often share analogous behaviour, this enables the use of similar mathematical models across both fields. The equations for modelling mechanical components can be derived from the base quantities, these are displacement s with units [m] and momentum p with units of [I]. Taking the derivative with respect to time we get dp/dt with units of [N] noted as F and ds/dt with units of [m/s] noted as v. From the derived units building up the equations of the base elements of mechanical resistance b (dampening), mechanical inductance m (mass), mechanical capacitance k (elasticity) and mechanical memductance M follows a similar pattern to the electrical components. Mechanical resistance is calculated by F/v ([N/m/s]) which is [(I/s)/(m/s)] and this simplifies to [I/m]. The equations for the force and speed of a mechanical resistor can be seen in equations 15 and 16. Mechanical inductance has a unit of [kg] and is calculated by ((Ft)/v) ([Ns/m/s]) which is [(Is/s)/(m/s)] and this simplifies to [Is/m]. The equations for the force and speed of a mechanical inductor can be seen in equations 17 and 18. The equation to calculate the energy stored in a mechanical inductor can be seen in equation 19. Mechanical capacitance has a unit of [m/N] and is calculated by ((vt)/F) ([(m/s)s/N]) which is [(ms/s)/(I/s)] and this simplifies to [ms/I]. The equations for the force and speed of a mechanical capacitor can be seen in equations 20 and 21. The equation to calculate the energy stored in a mechanical capacitor can be seen in equation 22. Mechanical memductance has a unit of [I/m] and is calculated by v/F ([(m/s)/N]) which is [(m/s)/(I/s)] and this simplifies to [I/m]. The equations for the force and speed of a mechanical memristor can be seen in equations 23 and 24.

$$F_b(t) = b v_b(t) = b \frac{ds(t)}{dt} \tag{15}$$

$$v_b(t) = \frac{1}{b} F_b(t) = \frac{1}{b} \frac{dp(t)}{dt} \tag{16}$$

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$$F_m(t) = m\frac{dv_m(t)}{dt} = m\frac{d^2s(t)}{dt^2} \tag{17}$$

$$v_m(t) = \frac{1}{m}\int F_m(t)dt = \frac{1}{m}p(t) \tag{18}$$

$$E_m(t) = \frac{1}{2}mI_m^2(t) \tag{19}$$

$$F_k(t) = \frac{1}{k}\int v_k(t)dt = \frac{1}{k}s(t) \tag{20}$$

$$v_k(t) = k\frac{dF_k(t)}{dt} = k\frac{d^2p(t)}{dt^2} \tag{21}$$

$$E_k(t) = \frac{1}{2}kF_k^2(t) \tag{22}$$

$$F_M(t) = \frac{1}{M}v_M(t) = \frac{1}{M}\frac{ds(t)}{dt} \tag{23}$$

$$v_M(t) = MF_M(t) = M\frac{dp(t)}{dt} \tag{24}$$

The analogies can be seen between charge and displacement, magnetic-flux and momentum, voltage and force, current and speed, electrical resistance and mechanical resistance or dampening, electrical inductance and mechanical inductance or mass, electrical capacity and mechanical capacity or elasticity. Therefore it is reasonable to postulate that a mechanical memristor could also exist and that its behaviour would be similar to that of an electric memristor. Namely that the dampening would be dependent on the displacement and bound between a minimum and maximum value and the hysteresis affect would be inversely proportional to frequency. An example of a mechanical memristor can be seen in Figure 1.

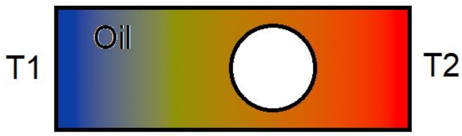

Figure 1. An example of a mechanical memristor

The example depicts a cylinder filled with oil. Two temperature potentials T1 and T2 are applied to the two ends where T1 < T2 producing a temperature gradient in the oil that influences the viscosity of the oil

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through the cylinder. Because of the temperature gradient in the oil the ball moving within the cylinder experiences different damping coefficients depending on its position within the cylinder.

3. RESULTS AND DISCUSSION

Since the equations are analogous for the mechanical and electrical cases, it is possible to model the behaviour of mechanical systems using the Simscape electrical elements by substituting current for speed and voltage for force. Figure 2 depicts a system modelled in Simulink where two memristors are in series and driven by a current source. The current source outputs 0.05 A for 1s and -0.05 A for 1s. By interpreting this in a mechanical sense we get a source of speed that moves the system at 0.05 m/s for 1s and at -0.05 m/s for 1s moving the system 0.05 m before returning to the starting position.

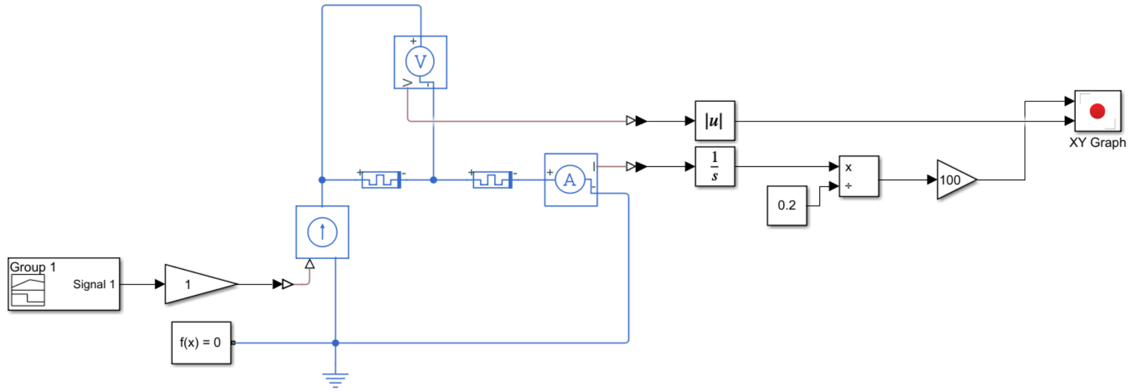

Figure 2. Simulink model to demonstrate hysteresis modelling

The first memristor is configured with R_{ON} = 0.0000001 Ω and R_{OFF} = 40000 Ω and the total charge required to change from R_{ON} to R_{OFF} is 0.04 C while the second memristor is configured with R_{OFF} = 0.0000001 Ω and R_{ON} = 40000 Ω. The integrator after the current meter calculates the charge applied to the system this translates to displacement. In this model it is assumed to be a system with a maximum charge of 0.2 C, dividing by 0.2 and multiplying by 100 gives a percentage value. Figure 3 depicts the results of a 2s simulation.

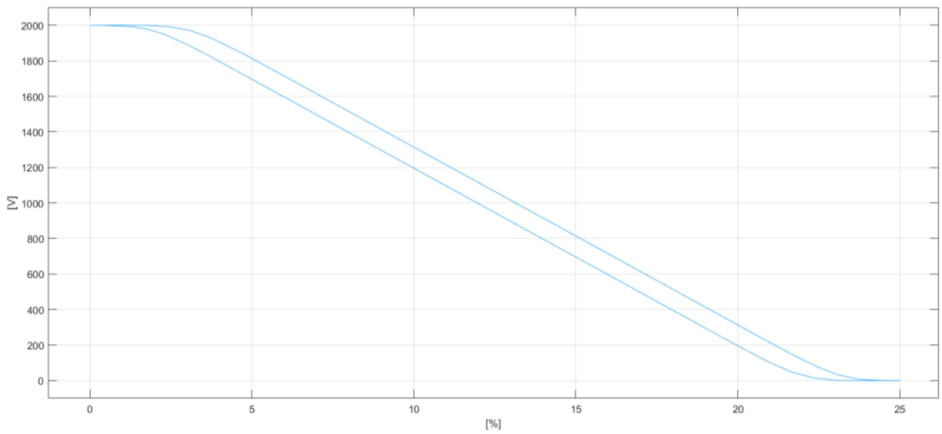

Figure 3. Results of hysteresis modelling

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Interpreting the figure as a mechanical system that has a total length of 0.2 m and can contract a maximum of 25% it is visible that maximum force is exerted at 0% contraction and minimum force is exerted at 25% contraction. Depending on the direction of motion the exerted force varies for a set contraction. The simulation results depicted in Figure 3 clearly exhibit a hysteresis loop of memristive systems. The mechanical interpretation suggests that maximum force occurs at zero contraction, decreasing as contraction increases. This behaviour confirms that damping in the mechanical analogue is non-linear and dependent on position. These findings highlight the potential of using memristor models to predict mechanical hysteresis phenomena, broadening their applicability across disciplines.

4. CONCLUSIONS

In this study, we proposed a novel modelling approach to simulate hysteresis phenomena using memristor analogues. By drawing analogies between electrical and mechanical systems, we demonstrated the viability of a mechanical memristor through simulations. These findings lay the groundwork for future research into memristors with use in mechanical systems, including in energy dissipation and dynamic system modelling. Using the current memristor model in simscape limits the model to a linear relation between R_{ON} and R_{OFF}. By modifying the model it is possible to achieve a wider array of possible curves. This is possible since the flux and charge based memristor equations only need to be continuous and piecewise differentiable. This flexibility is crucial for adapting the model to various real-world scenarios, enhancing its applicability and predictive accuracy.

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EXAMINATION OF XANTHAN PRODUCTION ON BIODIESEL INDUSTRY EFFLUENT-BASED MEDIUM IN LAB-SCALE BIOREACTOR

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ABSTRACT

Xanthan is microbial polysaccharide with outstanding rheological properties, non-toxic nature, biodegradability, and biocompatibility. This biopolymer is widely used in food, biomedical, pharmaceutical, petrochemical, chemical and textile industry. Industrial xanthan production is generally conducted by aerobic submerged cultivation of *Xanthomonas campestris* strains on the media with glucose or sucrose under optimal conditions. Results from previous research indicate that xanthan can be successfully produced on media containing crude glycerol from biodiesel industry by different *Xanthomonas* species. The aim of this study was to examine the course of xanthan biosynthesis by the reference strain *X. campestris* ATCC 13951 in lab-scale bioreactor on medium containing crude glycerol generated in domestic biodiesel factory. The bioprocess was monitored by the analysis of cultivation medium samples taken in predetermined time intervals, and its success was estimated based on the xanthan concentration in the medium, separated biopolymer average molecular weight and degree of nutrients conversion. At the end of bioprocess, cultivation medium contained 12.34 g/L of xanthan with the average molecular weight of $3.04 \cdot 10^5$ g/mol. Within this study, the achieved degree of glycerol, total nitrogen and total phosphorous conversion were 75.91%, 53.27% and 38.96%, respectively.

Keywords: xanthan, lab-scale bioreactor, biodiesel industry effluent, crude glycerol

1. INTRODUCTION

Xanthan is known as one of the most widely examined polysaccharides of microbial origin [1]. This bacterial-derived biopolymer is extensively used in food, cosmetics, pharmaceutical, paper, textile and other industries owing to its exceptional rheological properties, non-toxic nature, biodegradability, and biocompatibility [2, 3]. Besides the industry, xanthan is also widely used in medicine, biomedical engineering, agriculture, and wastewater treatment. Market demand for xanthan has been increasing progressively, with an annual rate of 5–10%. The estimated production of xanthan is believed to be 30000 tons per year and since 2005, China has become one of the largest xanthan producers [4].
The selection of the producing strains, cultivation medium composition, and bioprocess parameters highly affect the success of xanthan production [5]. Although various *Xanthomonas* species, such as *X. malvacearum*, *X. phaseoli*, *X. axonopodis* and *X. euvesicatoria*, are able to biosynthesise xanthan, *X. campestris* is most commonly used producing strain in industry [6, 7]. Commercial production of xanthan is generally conducted as aerobic submerged batch cultivation of the reference strain *X. campestris* ATCC 13951 on appropriately formulated media under optimal conditions [8]. Cultivation medium for xanthan production has a clearly defined composition, in favour of providing the necessary macronutrients, of which the most important are carbon and nitrogen [9]. Generally used carbon sources in the media for xanthan production are glucose and sucrose [10], while yeast extract, casein hydrolysates, peptone, soy flour, ammonium and nitrate salts are mostly used as nitrogen sources [11]. Based on the literature data, the highest xanthan yield is achieved when yeast extract is used as a nitrogen source in cultivation medium [12]. Taking into account that the cost of substrate is crucial factor for commercial xanthan production and the rising prices of the aforementioned nutrients, it is of great importance to find more economical carbon and nitrogen source in order to reduce the overall production costs [13]. Since carbon source is the major

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component of xanthan production medium, there is a need to first explore suitable alternative for this nutrient. Waste streams and by-products from different industries are heterogeneous in their composition and that is why they have a great potential as alternative substrate for microbial production of various products, including xanthan. According to the results from previous studies xanthan can be successfully obtained on media containing carbon sources from kitchen and agro-industrial waste and by-products [14-16]. However, usage of aforementioned alternative substrates in xanthan production is limited due to their intensive utilization for therapeutic application and production of other high value-added products [17-19] and thus there is a need for exploitation of other alternative substrates of lower market value.

Several research studies have confirmed that crude glycerol can be successfully used in biotechnological production of xanthan [5, 20]. According to the literature, some *Xanthomonas* isolates are able to metabolize glycerol in higher degree than glucose [7]. Considering that research attributed to the xanthan biosynthesis on glycerol-based media is still in initial stages and there is a need for improvement, and thereupon, it is necessary to monitor the course of the cultivation of the selected strain on a crude glycerol-based medium in order to observe the critical points of the bioprocess and define the next steps in the research.

The aim of this study is to examine xanthan biosynthesis by cultivation of the reference strain *X. campestris* ATCC 13951 in a lab-scale bioreactor on medium containing crude glycerol from biodiesel production in domestic factory. The bioprocess was monitored by the analysis of cultivation medium samples taken in predetermined time intervals, in terms of rheological behaviour, biomass concentration, as well as content of essential nutrients for biotechnological production of xanthan. Bioprocess efficiency was estimated based on the quantity and quality of separated xanthan and conversion rate of the most important nutrients at the end of biosynthesis.

2. MATERIALS AND METHODS

2.1 Producing microorganism and inoculum preparation

The reference strain *X. campestris* ATCC 13951 was used as the producing microorganism in this research. The applied strain was stored at 4ºC on agar slant (Yeast Maltose Agar, HiMedia, India) and subcultured every four weeks within the Microbial Culture Collection of the Faculty of Technology Novi Sad, Serbia. Commercial liquid medium (Yeast Maltose Broth, HiMedia, India) was used for its incubation during inoculum preparation. Prepared media were sterilized by autoclaving (121°C, 2.1 bar, 20 min).

Within this study, inoculum was prepared in two steps: Inoculum I and Inoculum II. Producing microorganism was subcultured on agar slant and incubated at 25°C for 48 h. Inoculum I preparation procedure was included suspending of producing microorganism cells in commercial liquid medium. The prepared suspension was then incubated in aerobic conditions at 25°C and 150 rpm (laboratory shaker KS 4000i control, Ika® Werke, Germany) for 48h. Inoculum II preparation was performed by adding 10% (v/v) of Inoculum I in commercial liquid medium followed by incubation in identical conditions as for inoculum I preparation.

2.2 Xanthan production

Biotechnological production of xanthan was conducted on medium containing crude glycerol from biodiesel production in factory located in the Republic of Serbia. Glycerol content in crude glycerol was around 50% (w/v) and its content in cultivation medium was adjusted to around 17.00 g/L, based on the results from the previous study [21, 22]. The cultivation medium also contained yeast extract (3.0 g/L), $(NH_4)_2SO_4$ (1.5 g/L), K_2HPO_4 (3.0 g/L) and $MgSO_4 \cdot 7H_2O$ (0.3 g/L). The pH value of production medium was adjusted to 7.0±0.2 and then sterilized by autoclaving (121°C, 2.1 bar, 20 min).

The xanthan production was carried out in 3 L lab-scale bioreactor (Biostat® A plus, Sartorius AG, Germany) with 2 L of crude glycerol-based cultivation medium. Inoculation was performed by adding 10%

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(v/v) of inoculum prepared as previously described. The xanthan biosynthesis was carried out under aerobic conditions for 168 h. In the first 48 h, the biosynthesis was performed at temperature of 25°C, air flow rate of 1 vvm and agitation rate of 200 rpm, and afterwards, temperature and air flow rate were increased to 30°C and 2 vvm, respectively, while agitation rate was corrected as needed and according to the dissolved oxygen concentration which was maintained at values higher than 30% during the biosynthesis.

At the end of biosynthesis, xanthan was separated from the supernatant of cultivation medium (10,000 rpm, 10 min, ultracentrifuge Hettich Rotina 380 R,Germany) by precipitation with cold 96% (v/v) ethanol in the presence of potassium chloride. Ethanol was gradually added to the supernatant at constant stirring until the alcohol content in mixture was 60% (v/v). A saturated solution of potassium chloride was added when half of the necessary ethanol amount was poured into the supernatant in a quantity obtain a final content of 1% (v/v). After precipitation, the mixture was kept on 4°C, for 24 h and then centrifuged (4,000 rpm, 15 min). The precipitate was dried to a constant mass at 60°C and this data was used to calculate the xanthan concentration in medium.

2.3 Analysis of cultivation media

The biomass concentration was expressed as viable cell count per millilitre of cultivation medium and is determined by counting of colony forming units (CFU). The samples of cultivation medium, taken under aseptic conditions, were serially diluted in sterile saline solution and plated on agar plates (Yeast Maltose Agar, HiMedia, India) which were incubated at 25°C for 48 h. Living bacterial cell on the plate was grown into a colony, and the viable cell count in the cultivation medium was then calculated by multiplying the final number of colonies by the dilution factor.

The samples of cell-free cultivation media taken in previously defined time intervals, obtained by centrifugation at 10,000 rpm for 15 min (Rotina 380 R, Hettich Lab Technology, Germany), were analysed for glycerol, total nitrogen and total phosphorus contents.

Glycerol content was determined by high performance liquid chromatography (HPLC). The samples were filtered through a 0.45 µm nylon membrane (Agilent Technologies Inc, Germany) and then analysed. The HPLC instrument (Thermo Scientific Dionex UltiMate 3000 series) was equipped with a HPG-3200SD/RS pump, WPS-3000(T)SL autosampler (10 µL injection loop), Zorbax NH2 column (250 mm × 4.6 mm, 5 µm) and RefractoMax520 detector. 70% (v/v) acetonitrile was used as eluent with a flow rate of 1 mL/min and elution time of 10 min at a column temperature of 30°C. The contents of total nitrogen and phosphorus were determined using volumetric method proposed by Kjeldahl [23] and spectrophotometric method [24], respectively.

The nutrient content results were used to calculate degree of crude glycerol, total nitrogen and total phosphorus conversion (K, %) using Equation (1):

$$K_Y = \frac{(Y_0 - Y)}{Y_0} \cdot 100 \tag{1}$$

where Y_0 is initial nutrient content (g/L), while Y is residual nutrient content (g/L).

The results for glycerol content after inoculation and xanthan concentration in medium were used to calculate the degree of initial glycerol conversion into xanthan ($K_{P/S}$, %) using Equation (2):

$$K_{P/S} = \frac{P}{S_0} \cdot 100 \tag{2}$$

where S_0 is the initial glycerol content (g/L) and P is the xanthan concentration in medium at the end of bioprocess (g/L).

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The initial and residual glycerol content results as well as xanthan concentration in medium were used to calculate the degree of metabolized glycerol conversion into xanthan ($K_{P/\Delta S}$, %) using Equation (3):

$$K_{P/\Delta S}=\frac{P}{S_0 - S}\cdot 100 \tag{3}$$

where S_0 is the initial glycerol content (g/L), S is the residual glycerol content (g/L), and P is the xanthan concentration in medium at the end of bioprocess (g/L).
The rheological behaviour of cultivation medium samples taken in previously defined time intervals were evaluated using rotational viscometer (REOTEST 2 VEB MLV Prufgerate-Verk, Mendingen, SitzFreitel) with double gap coaxial cylinder sensor system, spindle N. Based on deflection of measuring instrument (α, Skt), shear stress (τ, Pa) was calculated under defined values of shear rates (D, 1/s) using the Equation (4):

$$\tau = 0.1 \cdot z \cdot \alpha \tag{4}$$

where z is the constant with the value 3.08 $dyn/cm^2 \cdot Skt$.
The pseudoplastic behaviour of the cultivation medium was confirmed by fitting the experimental data to the Ostwald-de-Waele model using the power regression. The values of the consistency factor (K, $Pa \cdot s^n$), flow behaviour index (n) and determination coefficient (R^2) were determined by Excel software 2013 and used for calculation of medium apparent viscosity (η_a, mPa·s) from Equation (5):

$$\eta_a = K \cdot D^{n-1} \tag{5}$$

where D is shear rate with the value of $100 s^{-1}$.

2.4 Analysis of xanthan

The average molecular weight of the separated xanthan was estimated based on the intrinsic viscosity of its 1% (w/v) solution in 0.1 M sodium chloride using the Mark-Houwink type equation [25].

3. RESULTS AND DISCUSSION

In accordance with the defined aim of this research, xanthan was produced by reference strain *X. campestris* ATCC 13951 on medium prepared with crude glycerol generated in domestic biodiesel facility. The bioprocess course in applied experimental conditions was monitored by the analysis of cultivation medium samples, taken in previously defined time intervals, in terms of rheological behaviour, biomass concentration, as well as content of essential nutrients for biotechnological production of xanthan. The obtained results are graphically represented in Fig. 1. The bioprocess success was assessed based on the xanthan concentration in medium, separated biopolymer average molecular weight, and degree of conversion of total glycerol, initial glycerol and metabolized glycerol into xanthan, nitrogen and phosphorus and results of these analyses are summarized in Tab. 1.
Xanthan production was conducted under controlled conditions, and pH, temperature and dissolved oxygen concentration of cultivation media were measured and regulated by adding acid or base and by adjustment of mixing speed and aeration intensity, respectively. During xanthan production, the pH of cultivation medium decreases from neutral to values close to 5 due to the production of organic acids and xanthan which contains acid groups [9]. Considering the fact that the optimum pH for the bacterial growth range is between 6 and 7.5 and the optimum pH range for the xanthan production is between 7 and 8 [26], this parameter was regulated during the bioprocess, i.e. it was maintained above 6.0 by adding 5.0 M KOH.

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The dissolved oxygen concentration was maintained at values greater than 30% of saturation during the entire bioprocess by regulating the aeration intensity and mixing speed as recommended in literature [27].

3.1 Monitoring of the xanthan production

Cell concentration in the medium at the beginning of cultivation was $4.40 \cdot 10^8$ CFU/mL. Based on the graphically presented results in Fig. 1, it can be seen that during the first 48 h of cultivation the producing microorganism multiplied intensively and the cell concentration in the medium increased to $1.02 \cdot 10^{10}$ CFU/mL. This denotes that exponential growth phase of producing microorganism occurred since the beginning of bioprocess and lasted until 48 h. Between 48 h and 72 h, a slower increase of biomass concentration was achieved, getting to a maximum value of $1.16 \cdot 10^{10}$ CFU/mL in 72 h. There was no significant change in the biomass concentration after 72 h, and hence it can be believed that the stationary phase of producing microorganism growth has occurred. After 168 h of biosynthesis, the biomass concentration was $1.14 \cdot 10^{10}$ CFU/mL. The behaviour of applied producing strain is in agreement with the behaviour of another *Xanthomonas* strain which was cultivated in similar conditions, indicating that achieved biomass concentration is appropriate for successful xanthan production on crude glycerol-based medium [22].

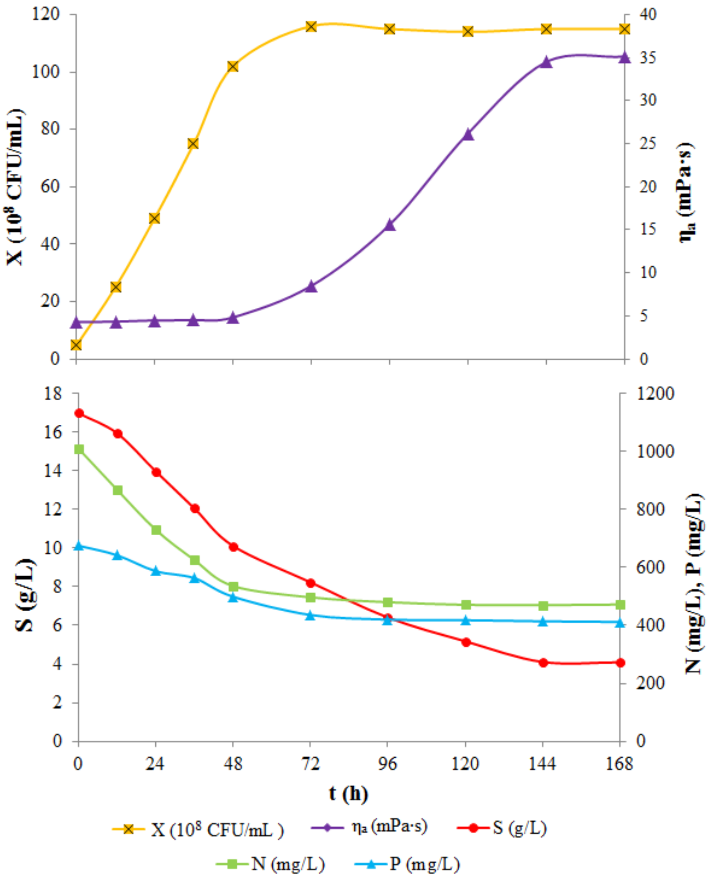

Figure 1. The course of xanthan production in 3 L lab-scale bioreactor on crude glycerol-based medium in terms of biomass concentration (X), medium apparent viscosity (η_a), glycerol content (S), total (N) content, and total phosphorus content (P)

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The xanthan production under the experimental conditions was evaluated according to the rheological behaviour of the crude glycerol-based medium during the cultivation of the applied producing strain. Rheological measurements of cultivation medium were performed and the obtained values were fitted with a power law equation of Ostwald-de Waele model in order to define the values of the flow behaviour index and the consistency factor, on the basis of which the apparent viscosity of cultivation medium was calculated. Accordingly, the change in the apparent viscosity of cultivation medium during the xanthan production by the reference strain *X. campestris* ATCC 13951 in lab-scale bioreactor on medium containing crude glycerol is also represented in Fig. 1. As it can be seen from graphically presented results, the value of apparent viscosity of the medium during biosynthesis did not change significantly up to 48 h. Initial value of apparent viscosity of the medium was 4.23 mPa·s and in 48 h the value of this parameter was 4.79 mPa·s. After 48 h of cultivation a serious increase in the apparent viscosity of the cultivation medium was noticed up to 144 h, when its value amounted 34.78 mPa·s. Based on the results shown in Fig. 1 it can be noticed that the value of the apparent viscosity of the cultivation medium increased with lower intensity after 144 h of cultivation, and at the end of biosynthesis, the value of this parameter was 35.12 mPa·s. Moreover, the rheological measurement showed that all samples have pseudoplastic properties, a known characteristic of xanthan solutions [9]. This finding is supported by the values of flow behavior index which decreased from 0.5834 to 0.4767 indicating that during the cultivation in applied experimental conditions pseudoplastic behavior of crude glycerol-based medium became more pronounced. The Ostwald-de-Waele model showed a good agreement with the experimental data, since the regression coefficients were higher than 0.92 for all tested samples.
Considering that the concentration of carbon source in cultivation media affects the xanthan yield, cultivation medium samples were analysed in terms of glycerol content. The results shown in Fig. 1 indicate that the glycerol content in cultivation medium decreased during the xanthan production in applied experimental conditions. According to the results presented in Fig. 1, it can be noticed that during the first 48 h of cultivation there was an intense decrease in the glycerol content from initial 16.98 g/L to a value of 10.11 g/L. After 48 h, the glycerol content continued to decrease with a lower intensity until 144 h. In 144 h the content of this nutrient was 4.11 g/L. After 144 h of cultivation, there was no significant change in the glycerol content in the medium and its value in 168 h was 4.09 g/L. The obtained results indicate that if there is no carbon source consumption, xanthan biosynthesis does not occur in the stationary phase of producing microorganism growth [11] and the bioprocess can be shorten for 24 h. The obtained results demonstrate that intensive metabolic activity of reference strain *X. campestris* ATCC 13951 appeared in the first 48 h of cultivation in 3 L lab-scale bioreactor, confirming that the used producing strain has the ability to metabolize crude glycerol from biodiesel industry in applied experimental conditions. This finding is in agreement with the results from previous studies when performing the bioprocess by the different producing strains [22, 28].
Nitrogen source also represent an essential nutrient in xanthan production media [9]. The obtained results given in Fig. 1 show that initial content of total nitrogen in medium decreased intensively from the very beginning of the cultivation. Therefore, the total nitrogen content was reduced from the initial 1010 mg/L to 536 mg/L in the first 48 h. As it can be seen in the Fig. 1, the period of intensive consumption of nitrogen components is in accordance with the exponential growth phase of the producing microorganism. After 48 h of cultivation there was no significant change in the total nitrogen content, which is a result of the onset of the stationary growth phase of the microorganism. At the end of bioprocess, the residual concentration of overall nitrogen components was 472 mg/L.
According to the literature, phosphorous have a great effect on the bacterial growth and the production of xanthan [9], and therefore, cultivation medium samples were also analysed in terms of phosphorous content. The results shown in Fig. 1 indicate that an intensive consumption of phosphorus is evident. Considering all previously discussed results, it can be noted that the change in the total phosphorus content is similar to the change in the content of total nitrogen during the xanthan production on crude glycerol-based medium. The initial phosphorus content of 675.10 mg/L decreased intensively in the first 48 h, to the

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value of 499.20 mg/L. The change in the total phosphorus content in cultivation medium was insignificant after 48 h and at the end of cultivation phosphorus content was 412.02 mg/L.
Taking into account the results for the change in the content of the most important nutrients in crude glycerol-based medium during this bioprocess, it can be concluded that the metabolic activity of used producing strain in applied experimental conditions was easily carried out, i.e. that the biomass concentration has increased, and that all conditions for the successful xanthan biosynthesis were provided. Additionally, the discussed changes in the value of apparent viscosity of the medium during the cultivation of used producing strain are a reliable confirmation that xanthan was produced in the applied experimental conditions.

3.2 Efficiency of xanthan production

With the purpose of observing performance of xanthan production on crude glycerol-based medium, selected indicators of bioprocess success were determined and the obtained results are given in Tab. 1.

Table 1. Indicators of the success of xanthan production by reference strain X. campestris ATCC 13951 in 3 L lab-scale bioreactor on crude glycerol-based medium

Indicator	P (g/l)	$K_{P/S}$ (%)	$K_{P/\Delta S}$ (%)	K_S (%)	K_N (%)	K_P (%)	M_w (10^5 g/mol)
Value	12.34	72.67	95.73	75.91	53.26	38.96	3.04

P - xanthan concentration in medium; $K_{P/S}$ - degree of initial glycerol conversion into xanthan; $K_{P/\Delta S}$ - degree of metabolized glycerol conversion into xanthan; K_S - degree of glycerol conversion; K_N - degree of total nitrogen conversion; K_P - degree of total phosphorus conversion; M_w - average molecular weight of xanthan.

At the end of the cultivation, xanthan concentration in the medium was 12.34 g/L (Tab. 1). This value is higher comparing to the values obtained in previous researches, when xanthan was produced by *Xanthomonas* strains, isolated from pepper leaves and crucifers, on crude glycerol-based medium in smaller volumes (300 mL Erlenmeyer flasks and 2.0 L Woulff bottles) and in the similar lab-scale bioreactor (3.0 L) where xanthan concentration in media varied from around 5.00 g/L to 11.00 g/L [22, 28, 29]. Xanthan concentration obtained in this study is also higher in comparison with the results obtained when reference strain *X. campestris* ATCC 13951 was cultivated on medium containing crude glycerol (15.00 g/L). In this research, xanthan concentration in media varied from 6.77 g/L to 7.22 g/L [30]. Considering the aforementioned results and results obtained in research where xanthan content of 5.59 g/L was achieved during the *X. campestris mangiferaeindicae* 2103 cultivation on crude glycerol-based medium (20 g/L) in a 4.5 L bioreactor [20], it is clear that xanthan biosynthesis conducted within this research was very successful if the concentration of produced biopolymer is considered as an indicator. Findings from this study also indicate that producing strain, medium composition, process parameters, as well as the geometry of the vessel in which the bioprocess is carried out has a great effect on xanthan biosynthesis.
In addition to xanthan production, the conversion of important nutrients presents a very important indicator of the bioprocess success. Previously discussed results from Fig. 1 indicate that the glycerol, total nitrogen and total phosphorus content in the medium decreased during the xanthan biosynthesis in applied experimental conditions. At the end of bioprocess, degree of glycerol conversion was very high, amounting 75.91%. Initial and metabolized glycerol conversions into xanthan were also high, amounting 72.67% and 95.73%, respectively (Tab. 1). Conversion of glycerol achieved in this study is higher comparing to the value of the degree of glycerol conversion of 63.14% obtained in previous study when the same strain was cultivated on crude glycerol-based medium but in smaller volume and less intensive bioprocess conditions [28]. The value of the degree of glycerol conversion achieved in present study is also higher comparing to the value of this parameter of 62.82%, achieved when xanthan was produced by *Xanthomonas* PL 3 strain in crude glycerol-based medium (glycerol content of 20 g/L) in a 3 L lab-scale bioreactor [22]. The values of metabolized glycerol conversion into xanthan and initial glycerol conversion into xanthan in

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aforementioned research conducted by the authors was far lower comparing to the value achieved in the present study. In industrial conditions, the degree of carbon sources conversion into xanthan ranges from 50-85% [31], so it can be concluded that in this research, very high efficiency of bioprocess has been achieved.

As mentioned earlier, nitrogen and phosphorus sources are also essential nutrients in cultivation media for xanthan production. Based on the data presented in Tab. 1 total nitrogen conversion achieved within this study was 53.26%, and this value is greater comparing to the value of 33.07% achieved in previous study when the cultivation of the same producing strain on crude glycerol-based medium was performed in 2.0 L Woulff bottle [29] for 168 h with inoculum prepared for 72 h and value of 41.51 achieved when xanthan production was conducted by *Xanthomonas* PL 3 strain on medium containing crude glycerol [22]. The value of total phosphorus conversion of 38.96% obtained in the present research is higher comparing to the result obtained in aforementioned research when degree of total phosphorus conversion during the cultivation of the *Xanthomonas* PL 3 strain on crude glycerol-based medium was 24.80% [22]. This finding indicates that among other parameters, the success of xanthan production is highly influenced by the selection of producing strain, as reported previously [5, 7].

The quality of xanthan is also an important indicator of xanthan production efficiency and it can be estimated based on several parameters, such as the viscosity of its solutions, composition, molecular weight, etc. [32]. In the present study, the average molecular weight of separated xanthan was used as biopolymer quality indicator. From the results given in Tab. 1 it can be seen that average molecular weight of xanthan produced on medium containing crude glycerol from biodiesel production is $3.04 \cdot 10^5$ g/moL. This indicates that the findings from this study are in accordance with the results obtained in previous study where xanthan biosynthesis was performed on crude glycerol-based medium by different *Xanthomonas* strains, isolated from crucifers and pepper leaves. Average molecular weight of separated biopolymers in this research was in the range from $5 \cdot 10^4$ g/moL to $3.0 \cdot 10^5$ g/moL [22]. The obtained results also indicate that xanthan produced within present study is of greater quality, if the average molecular weight of separated xanthan was used as biopolymer quality indicator, than xanthan produced by *Xanthomonas* PL 3 strain in similar conditions [22].

Taking all the results from Fig. 1 and Tab. 1 into consideration, it can be concluded that xanthan production by cultivation of reference strain *X. campestris* ATCC 13951 in 3 L lab-scale bioreactor on medium containing crude glycerol from biodiesel production was successful. Biotechnological production of xanthan on crude glycerol-based medium represents a promising solution for sustainable valorisation of this effluent demonstrating a promising potential for purpose of minimizing the negative impact of crude glycerol from biodiesel production on the environment.

4. CONCLUSIONS

The obtained results have confirmed that crude glycerol generated by the domestic biodiesel industry can be used as a sole carbon source in cultivation medium for a successful xanthan production by reference strain *X. campestris* ATCC 13951. Besides the good quality and quantity of the produced biopolymer, acceptable conversion of essential nutrients was also achieved within this research. The results of this study have a great importance from an ecological point of view, considering the fact that the biotechnological production of xanthan on a cultivation medium containing crude glycerol from the biodiesel industry represents a promising solution for the sustainable valorization of this effluent.

Moreover, the results obtained in this study represent valuable information that can be used in future investigations related to the optimization of the bioprocess in terms of increasing the xanthan yield and quality, the bioprocess scale-up, as well as the estimation of possible applications of this biopolymer.

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THE RISKS OF AI IN AGRICULTURE

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ABSTRACT

Integration of artificial intelligence (AI) into agriculture has the potential to revolutionise agriculture, but it also presents challenges and risks that must be carefully managed. AI can improve planning, streamline work processes, and improve decision making in crop cultivation and animal husbandry, ultimately leading to higher returns for farmers. However, lack of training and high implementation costs can make it difficult for some farmers to adopt AI, creating a competitive disadvantage and concentrating agricultural resources. Additionally, AI may contribute to unemployment among those with lower skill levels and poses cybersecurity risks that need continuous monitoring. Legal concerns also arise with respect to data ownership and usage rights, with questions about who can access and utilise collected data. Farmers often have to rely on AI systems as "black boxes", with limited understanding of how they work. If these systems fail and cause damage, accountability becomes an important issue. It is crucial to assess the drawbacks and risks of AI implementation in agriculture and educate farmers about these risks to prevent significant damage. Managing these risks effectively and ensuring data accuracy and security are essential in the global adoption of AI in agriculture.

Keywords: artificial intelligence, agriculture, dangers, risks

1. INTRODUCTION

The notion that robots will replace human labour in crop harvesting is now a reality rather than a mere fiction. Artificial intelligence (AI), also known as machine intelligence (MI), has emerged as a novel technology that not only simplifies daily life, but also enhances productivity and profitability in various systems. The importance of AI is evident from the projected value of the global AI market, which is expected to reach a staggering 1,581 billion US dollars by 2030 [1]. AI has already permeated the entire economy, making its presence felt in industries, finance, education, trade, and increasingly in the agricultural sector.

Agriculture and farming, which are among the oldest and most crucial fields of human activity, have immense social importance, even though their contribution to the gross domestic product may have diminished over time. Throughout history, mankind has used various technologies to cultivate crops, grow plants, and use animals. However, with the growing population and the shrinkage of arable land, it has become imperative to make farming more efficient and innovative. Consequently, efforts are being made to improve productivity and yield in cultivated areas [2].

Improvement is crucial not only to ensure food supply but also to address the significant ecological footprint and harmful side effects associated with food production, which contribute to climate change [3]. Agriculture and related industries face numerous intricate and challenging issues that require a fresh perspective and innovative – sometimes revolutionary – solutions. Increasing efficiency to the maximum, acquiring and analysing high-quality data, and mobilising previously untapped or underutilised resources have emerged as crucial concerns, thereby fostering more sustainable practices. Within this framework, a significant hurdle lies in the form of global warming, escalating water scarcity, erratic weather patterns and occurrences, the dearth of essential resources vital for agriculture, migration, waning interest or attrition of the societal strata engaged in agriculture to alternative sectors, financial constraints, inequitable distribution of wealth and income, and unfavourable working conditions. In addition, there is the pressing issue of the growing demand for food, which is accompanied by the imposition of increasingly stringent food safety and quality

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regulations, the evolution of consumer preferences driving these changes, and the need to minimise the use of harmful pesticides [4] [5].
The widespread adoption of digital technologies in agriculture is based primarily on various technological solutions such as sensor technology for data collection, actuators for intervention, microcomputers for onboard control, (mobile) telecommunication systems for data transmission, and databases for remote or cloud-based services and server technologies [6]. These technological advances can be further enhanced through the integration of AI.
AI offers numerous opportunities to transform agricultural work processes, but it also comes with risks and dangers that must be carefully considered [1]. To determine the appropriate use of AI in agriculture and to address the associated risks and downsides, it is essential to draw information from existing AI applications. Moreover, the Collingridge dilemma, which suggests that the full impact of technology cannot be predicted until it is widely adopted, emphasises the challenges of subsequent control and changes once technology is fully integrated into daily practices [7].

2. MATERIALS AND METHODS

The prevalence of AI is evident in the extensive collection of over 1.4 million articles on Google Scholar (https://scholar.google.com/) in the past 5 years that pertain to this field. Surprisingly, only a mere 36,000 articles touch on the potential risks associated with this emerging technology. In comparison, the number of articles concerning agriculture in relation to AI is considerably lower, with approximately 30,000 articles available, of which around 18.6 thousand acknowledge the risks associated with its application in this domain.
Scite – Citation Statement Search (https://scite.ai/search) found 256,339 articles related to AI between 2019 and 2024, of which 68,222 mentioned some kind of risk involved in the use of AI. 13,048 of the published articles mentioned AI and agriculture in relation to each other, of which 4,284 also mentioned risks.
Consequently, it becomes apparent that while numerous studies explore the possibilities and advantages of artificial intelligence, insufficient emphasis is placed on the potential risks.
After briefly examining the concept of AI, its main types and the advantages that arise from its implementation in the field of agriculture, our research strives to synthesise pertinent sources that can provide a more comprehensive understanding of the dangers and challenges posed by AI.

3. RESULTS AND DISCUSSION

3.1. The interpretation of AI and the advantages in agriculture

According to the European Parliament, AI is poised to become the predominant technology of the future, allowing machines to exhibit human-like behaviour through capabilities such as environmental sensing, learning, problem solving, planning, reasoning, and creativity [8].
Numerous interpretations of AI can be found in the academic literature, making it difficult to pinpoint the most precise definition that satisfies all requirements. Marvin Lee Minsky was a prominent figure in the field of AI, known for his groundbreaking research. He defined AI as the discipline focused on developing machines capable of performing tasks that typically require human intelligence [9].
AI systems, while not equivalent to human intelligence, can mimic certain aspects of it [1]. These systems can analyse their surroundings, exhibit intelligent behaviour, and perform specific tasks autonomously. AI can manifest itself through software applications or physical entities such as robots and drones. Machine learning plays a crucial role in AI, enabling systems to create algorithms for tasks such as recognition and classification based on training data [10]. AI has the ability to identify and understand complex scenarios through rapid processing, merging, and analysis of large and diverse data sets [3]. It is not mandatory that all data and the objective for data computation are predetermined and familiar to AI; the system must also have the capability to operate with unfamiliar data. It must have the ability to autonomously determine which data

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to use for a specific purpose [11] [12]. According to ref. [11] and [13], AI, which includes both software and/or hardware components, is capable of self-improvement, thus improving its own performance. By continuously processing incoming data and information from various sources, AI undertakes tasks that were previously exclusive to human capabilities. The most advanced AI solutions have the ability to generate novel combinations of previously acquired knowledge elements. Data collection and processing in business organisations serve primarily to facilitate management decisions. With the integration of AI, systems can generate decision proposals for decision makers, which could lead to automation of execution and elimination of human intervention in certain cases [3]. As per ref. [14], the primary objective of AI applications already in use is to improve the efficiency of digital analysis and automation solutions within business organisations. These applications typically involve quantitative changes aimed at optimising resource management and reducing costs [11].

There are three main types of AI that can be distinguished [15] [16]:

- The first type is Artificial Narrow Intelligence (ANI), which is controlled by complex algorithms and neural networks. ANI systems can learn from experience, detect patterns, and make predictions. However, they are still far from possessing the full range of human intelligence. Examples of ANI include image and facial recognition systems, self-driving vehicles, and virtual assistants.
- The second type is Artificial General Intelligence (AGI), which encompasses the capabilities of ANI and goes beyond them. AGI systems can extrapolate acquired knowledge to tasks and situations that are not closely related to the data and algorithms they have processed. To achieve AGI, significant computing power is required, currently only available in supercomputers. While AGI systems are still under development, examples can be found in super- or quantum computers, as well as generative models like ChatGPT.
- The third type is Artificial Superintelligence (ASI), which represents the highest level of AI sophistication. ASI systems possess complete self-awareness and are capable of understanding and imitating human behaviour. They combine human-like characteristics with superhuman processing and analytical capabilities. Although the creation of ASI systems in the near future is unlikely, it is important to prepare for a world where AI can surpass and potentially render humans obsolete in various ways. This preparation should involve ethical, legal, and other means. The point at which AI surpasses human mental capabilities, known as the technical or AI singularity, is a significant milestone in the rapid development of AI.

For agricultural decision makers, the use of AI in a strategic way has the potential to improve productivity, minimise waste, and optimise costs. Various studies have highlighted several ways in which AI can benefit farmers [17] [18] [19] [20] [21]:

- Utilisation and analysis of diverse data types: A plethora of data types can be obtained from various devices such as photos, videos, light, IoT sensors, and other technologies that capture inputs.
- Real-time data tracking: Even a single plant can produce significant data on the impact of light, water, weather, and environmental changes on production, taste, disease susceptibility, and more. Over time, these data can offer valuable insight to improve efficiency, increase yield, determine pricing based on estimated crop yields, reduce waste, enhance nutritional value, and optimise the use of diminishing resources such as water, arable land, fertilisers and pesticides.
- Livestock health monitoring: AI can monitor vital signs, daily activity levels, and food intake of animals to ensure their well-being.
- Continuous machine learning with round-the-clock monitoring: Continuous data collection, including drone use, allows real-time information on crop growth and environmental conditions, allowing farmers to adapt to unexpected events.
- Deployment of Autonomous Systems: Intelligent self-driving vehicles, robots, and drones offer a solution to perform various agricultural tasks that are challenging to perform with human labour.
- Supply chain monitoring: Enhancing the traceability of supply chains to facilitate the delivery of fresher and safer produce to the market has become a crucial aspect of agricultural operations.

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3.2. Risks and dangers

Like any emerging technology, AI presents numerous questions and obstacles that need to be addressed. The pursuit of advantages inevitably brings about risks. It is crucial to analyse the potential unintended consequences of using AI in agricultural settings, as well as the impact of AI advancements in other sectors on agriculture. Additionally, according to ref. [22], failure to realise the potential benefits of the AI application poses a risk that must be taken seriously. Throughout the development of AI, all potential risks must be evaluated and assessed, and the possible drawbacks of implementation must be carefully examined [23] prior to the deployment of the AI system.

The creation of a machine that mimics human intelligence demands significant time and resources, resulting in high production costs. It requires cutting-edge hardware and software for operation, increasing additional expenses [16]. Stakeholders in agriculture, similar to other industries, face challenges related to AI use, such as substantial investment requirements, compatibility with existing technological frameworks, and the need for specialised skills and resources for operation [2].

It is crucial to ensure proper collection, storage, and processing of daily generated data necessary for the functionality of AI systems [24]. The variation in the quality of the data collected in agriculture [25] can pose challenges during processing. To facilitate data transmission, the establishment of a high-speed (wireless) computer network is imperative. Furthermore, achieving interoperability between systems from different software developers and clarifying the collected data may present obstacles [24] [26]. The effective use of these systems also requires user training (farmer) and the organisation of specialised workshops [27]. Lastly, the development of innovative business models is vital to the efficient adoption of new technologies [25] [26].

A. Legal Considerations

The rapid advancement of AI in agriculture has the potential to make existing regulatory frameworks obsolete, thereby posing challenges to the safe and responsible use of this technology. A significant barrier to the widespread adoption of data-driven agricultural technology is the lack of clarity surrounding the legal interpretation of data ownership and data security concerns [25] [28].

In the European Union, personal data are protected by stringent regulations, such as the General Data Protection Regulation (GDPR). Although certain agricultural data can be considered personal data, most of the data in this domain are not subject to the same level of regulatory oversight. In 2018, a contractual agreement known as the EU Code of Conduct on the sharing of agricultural data was established and approved by nine major European agricultural organisations [29]. According to this agreement, the data producer is deemed the rightful owner of the generated data, and any subsequent use of these data requires prior consent and adherence to the conditions outlined in the contract, often involving a fee. Although this agreement is voluntary in nature, the participation of influential organisations that have signed it provides some assurance about the transparency and responsible use of data produced by agricultural entities [10].

It is crucial that both agricultural practitioners and researchers have access to the data that have been collected. However, this can potentially clash with the concerns and rights of farmers, who often harbour apprehensions about their data being disclosed to the public [28]. Despite the presence of contracts that aim to regulate data security, there is still a sense of mistrust with respect to data management between farmers and companies [30].

The question arises as to who should be responsible for the damages caused by AI [2]. Should it be the owner/user, the manufacturer/distributor of the ‘device’, or the programmer? If the sole burden of damages falls on the user, it could potentially erode trust in AI-driven technologies, while excessively stringent regulations may hinder innovation [31].

AI has the potential to affect the right to privacy and data protection through various means, such as facial recognition technology, online tracking, and profiling [31]. The misuse of data poses a significant risk, which justifies the need for legal regulations. Although data ownership and security are often highlighted in legal discussions, it is essential to consider other areas that may also be influenced by AI, such as aviation safety regulations, self-driving vehicle regulations, and environmental protection issues [32]. Furthermore, ethical considerations should not be overlooked [33] along with the legal and regulatory frameworks.

B. Reliability Considerations

The current capabilities and future advancements of AI, including generative language models such as ChatGPT, present both opportunities and challenges, as well as potential dangers, for humanity and specifically for the field of agriculture. AI-powered chatbots are now widely accessible through various search engines, offering a convenient and efficient means of accessing relevant information, including agricultural topics. This accessibility saves valuable time and effort that would otherwise be spent on lengthy search and research processes. However, it is crucial to acknowledge that improper training or imprudent use of these chatbots can introduce risks to users. Despite their ability to provide seemingly plausible answers, even to experts, these systems are not immune to generating incorrect or non-sensical responses, as highlighted by ref. [34].

AI systems, particularly those employing machine learning, often function as enigmatic "black boxes" for users [35]. This opacity raises concerns about the lack of human understanding of the decision-making process and its potential for unpredictable behaviour under unexpected circumstances [22]. Consequently, the reliability of such systems and the appropriate circumstances for their use are in question [36]. For instance, when an AI system, known for its reliability, suggests a course of action that contradicts a farmer's own judgment, what should the farmer do? This dilemma prompts an examination of the parties responsible for the results generated by AI systems and the distribution of accountability [37] [38] [39] [40], as discussed in the section on legal considerations. Who bears responsibility in such cases? Is the farmer using the tool, the system designers, or the individuals who provided the training data? Furthermore, there is a risk that the party at fault may evade accountability or that no one will be held responsible at all. Until these issues are resolved, the potential benefits of AI in agriculture may not be realised, as farmers and agricultural producers hesitate to adopt and embrace AI technologies [22].

C. Digital (data) security considerations

The agricultural industry faces a significant challenge in effectively managing the vast amount of data it generates. Traditional tools and methods are no longer sufficient to meet the demands and complexities of the present time. Therefore, there is a need for new and more advanced technological solutions [30].

The advent of digitalisation in agriculture brings with it the potential vulnerability to cyberattacks. It is crucial to consider not only the familiar forms of attacks such as ransomware and denial of service in other sectors, but also the disruption of AI-controlled machinery. These machines include autonomous sprayers, self-driving tractors and harvesters, and robot swarms used for crop inspection, among others [23]. Furthermore, the deployment of AI itself can pose risks [41]. For example, attacks that deceive autonomous tractors into planting seeds too deep or causing damage to crops can have severe consequences on food security, the economy, and society as a whole [22]. To mitigate this risk, it is crucial to involve appropriate professionals, such as ethical hackers, during the development phase of AI systems. Their expertise can contribute to ensuring the security and integrity of these systems [42].

If AI becomes widely adopted and plays an important role in agriculture, there is a potential vulnerability to cyber attacks targeting the agricultural sectors of developed countries, especially during times of war or terrorist activity [43] [44]. This could lead to the exposure or misuse of sensitive agricultural data if adequate security measures are not in place. The risk of data leakage is a concern, which could have serious implications for farmers, farms, and food security due to the compromise of critical information related to crops, livestock, and supply chains [42] [45].

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In addition, AI systems have the ability to increase surveillance on agricultural workers using the data they generate to monitor and supervise individuals [46]. AI applications that interact physically with individuals or are integrated into the human body may pose security risks if not designed and implemented with adequate precautions, used incorrectly, or targeted by online attacks.

D. Algorithmic Bias Considerations

The effectiveness of machine learning systems is highly dependent on the quality of training data. When the data used for training are distorted, inaccurate results can be obtained, aligning with the GiGo (Garbage In, Garbage out) principle. Data distortion refers to data that deviates from the reality it is intended to represent. For instance, image recognition systems are trained using photographs captured under various lighting conditions and backgrounds. Consequently, AI algorithms learn to classify objects based on these diverse factors [47] [48]. There are two distinct types of bias in this case:

- First, the use of systems trained in different regions with varying environmental conditions [49] can pose numerous challenges for agricultural producers. Diskrepancies in environmental factors can lead to inaccurate predictions or recommendations, affecting the effectiveness of AI-based agricultural practices.
- Second, another issue arises from the fact that the data used to train AI systems predominantly originate from industrial management practices. This can be problematic as many regions still adhere to small-scale and indigenous farming traditions, where digital agriculture technologies are not prevalent. Consequently, AI systems may not be trained on data that represent these local farming practices, which can result in inadequate support or exclusion of local farms. As a result, society would lose valuable knowledge embedded in the traditions of local climate, flora, and fauna [22].

E. Economic vulnerability considerations

Ref. [50] suggests that the use of artificial intelligence systems that have the ability to have a significant impact on stock exchange rates can have extensive economic consequences that extend to agriculture, food raw materials and food prices. These consequences could cause a crisis and potentially disrupt the entire agricultural sector. It is important to note that the data used in these systems are not limited to agricultural properties or plants. The entire food supply chain is involved in producing and using these data, which affects the entire chain [51]. Furthermore, the reliance on artificial intelligence technology can lead to the loss of traditional knowledge and skills, as well as to a lack of diversity in agricultural practices. Overreliance on AI systems can leave farmers vulnerable to various disturbances, including system failures, data loss, or technical problems. This poses significant risks not only for farmers but also for the broader food economy [44].

Automating agricultural processes can also lead to a loss of autonomy for farmers, as they may depend on AI systems [22] or systems manufacturers [24] to make decisions. This change in decision-making powers may lead agricultural experts to hand over control to organisations that own the data.

F. Considerations Related to the Deepening of economic inequalities

Farmers using artificial intelligence systems can gain a competitive advantage over low-level technology system users [24]. Information gaps between the modern AI-based and other economies can distort market competition because the former have access to better and more in-depth information. The high cost of implementing artificial intelligence tools can make them unobtainable for economies with low capital intensity, exacerbate existing inequalities in the agricultural sector, and restrict access to advanced technologies that may be most useful. This situation could lead to a further concentration of capital and energy for larger agricultural enterprises [23] [52] [53].

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The development and ownership of AI technology is predominantly in the hands of large companies, which use their dominance to control the entire food supply chain and market. As small economies struggle to compete with industrial giants, the concentration of power and capital can deepen economic and social inequality [22] [25] [54] [55].

G. Considerations for Agri-Jobs

The appeal of AI lies in its ability to perform cognitive tasks traditionally performed by humans, which could lead to a reduction in the demand for human labour if machines prove to be more efficient in producing goods and delivering services. The probability of automation depends on whether they involve cognitive or manual tasks, as well as whether they follow a routine pattern or not [56] [57]. It is evident that AI will also bring about a transformation in the nature of work within the agricultural sector [22].
The potential impact of AI on the workforce, particularly in agriculture, is a topic of concern due to the risk of mass unemployment associated with its widespread adoption [7]. The use of AI-powered robots in agriculture poses a threat to jobs that involve manual labour and require lower qualifications. Moreover, the notion that AI could replace many intellectual tasks is a common concern [58]. Consequently, the implementation of AI in agriculture, similarly to other sectors, may jeopardise the employment of people engaged in both physical and cognitive work [57].
The proliferation of AI is expected to result in job displacement, while simultaneously generating new job opportunities that require higher skill levels and fostering the emergence of creative job roles [16]. The supervision of AI systems is expected to require fewer individuals, but those engaged in this work will require greater expertise [59].
Furthermore, it is expected that if only tasks beyond the capabilities of machines are performed, the expertise required for these remaining jobs will likely decrease compared to the present [59] [60]. In the realm of agriculture, the overall impact is projected to be negative. Although the implementation of AI will undoubtedly create new jobs, it is unlikely to generate as many jobs in agriculture as it eliminates [22].
Researchers speculate that in the future, the management of a farm will resemble the management of any other business, with teams consisting of humans and robots [22]. Education and training play a vital role in equipping individuals with the necessary skills for these domains [31].

H. Considerations on the Transformation of the relationship between the Country and the city

The potential impact of AI on rural areas goes beyond job losses. It can cause demographic changes and alter the social and political dynamics of rural and urban populations [61]. This can have an impact on the political and financial support received by farmers and the agricultural sector. If agriculture is perceived as a mere part of the information technology sector or if resources are concentrated in this sector, maintaining support is difficult and could lead to political dissatisfaction.
It should also be noted that a decrease in employment opportunities in agriculture can also lead to the emergence of new companies in rural areas, such as hospitality and tourism [62]. Reorganisation of agricultural jobs can gradually blur cultural differences between urban and rural areas [63] [64] [65] and lead to economic and political transformations [22].

I. Environmental Considerations

AI systems that prioritise resource-intensive management practices, despite their inefficiency, can initially enhance efficiency and increase crop yield. However, this improvement often comes at the expense of the environment. AI systems programmed solely to maximise short-term crop yield tend to overlook the long-term environmental consequences associated with their actions [42]. Such disregard for the environment can

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result in long-term negative effects, such as the excessive use of chemicals that disrupt the delicate balance of local flora and fauna. Ultimately, this disruption can cause damage to ecosystems and biodiversity [66].
Furthermore, the contribution to the proliferation of monoculture is another concern, as it is widely recognised to have detrimental effects on the environment [67]. The development and increased adoption of genetically modified crops may also make agriculture more susceptible to crop losses, as these modifications can inadvertently enhance vulnerability to plant diseases [22].
AI systems trained on data from a specific region may not consider the unique environmental factors and biodiversity of other regions, potentially leading to unintended consequences and exacerbating biodiversity loss. This highlights the importance of responsibly developing AI technologies and testing them in controlled environments to prevent negative impacts on the environment [8] [42]. Ensuring the sustainability of AI solutions in agriculture is essential for long-term economic and environmental viability, as well as the preservation of natural resources.

J. Alienation from the Natural World

AI systems have the ability to simplify and distort our perception of the world by transforming everything into data. This can lead to a loss of connection with the natural world, as highlighted by ref. [68] and [69]. The widespread use of AI in agriculture has the potential to alter our understanding and appreciation of the natural world, as it encourages us to view it through the lens of data. This change in perspective can undermine political support for environmental initiatives, as the value of the natural world may be overshadowed by its quantifiable aspects.
Furthermore, improper use of AI can negatively impact animal welfare. Articles [70] [71] [72] have highlighted their concern that, in certain agricultural contexts, the suffering of animals may be obscured by the collected data and the relationships formed from them.
It is important to recognise that if we treat nature solely as a data system to be analysed and manipulated, there can be detrimental consequences for both the environment and us. Our world cannot be fully described or understood solely by numerical data, and it is crucial to recognise that plants and animals are not mere machines [22].

4. CONCLUSIONS

Some analysts predict that in the near future, a market-economic environment may emerge that does not favour the widespread adoption of AI in agriculture. This can be attributed to several key factors, such as a significant decline in investor and user interest in new technology, increased development costs, and the need for stringent regulations [73].
As appears, AI now has enormous potential in various sectors, including agriculture, making it an attractive prospect for farmers and suppliers of AI systems. Its integration into agriculture has the potential to increase efficiency, productivity, and sustainability, ultimately leading to a more resilient and food-secure world.
However, along with these numerous opportunities and advantages, the introduction and implementation of this new technology also brings forth a multitude of risks and hazards, discussed in this article. In the agricultural industry, there are unprecedented challenges posed by AI for which only seemingly suitable solutions are currently being developed. For the squeezing solution many stakeholders are required to cooperate between experts of several disciplines, farmers, companies, governments, and international organisations.

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CONTRIBUTION TO THE PETROGRAPHIC STUDY OF THE GEOLOGICAL FORMATIONS OF THE MBANGA SECTOR AND ITS HEADWATERS IN THE TSHELA TERRITORY (CENTRAL KONGO, DRC)

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ABSTRACT

In order to fill the glaring gaps in the geological data for the Mbanga region and surrounding area, in the Province of Kongo-Central in DR Congo, geological investigations were carried out in the field over a three-week period. The results obtained, coupled with those from the laboratory, led to the identification of eight different lithofacies in the study area, namely: metaryolites, sericite schists and biotitose schists, all with grey to greenish grey facies. This work consists of a detailed petrographic study to identify the different facies of the West Congo Supergroup belonging to the Mayumbian Group and the Zadinian Group. The geology of the Mbanga sector and its surroundings is made up of metamorphic layers of volcanic and sedimentary origin. The various rock formations in our study area are grouped into two West Congo Supergroup groups; the metarhyolite formation belongs to the Tshela/Seke-Banza Group (Mayumbian) and the others belong to the Matadi Group (Zadinian).

Keywords: Lithofacies ; Analysed Polarised Light ; petrography; central Kongo; macroscopic; lithological.

1. INTRODUCTION

In the Democratic Republic of Congo, studies and research in the field of geology remain of undeniable importance. The first information on the geological make-up of Central Kongo came from the major reconnaissance traverses carried out by [1], [2] [3]. On the basis of work carried out in our study area by [4];[5],[4], who define the Mayumbian as a volcano-plutonic sequence with sedimentary intercalations, and specify that its internal lithostratigraphy varies from one place to another and that stratigraphic correlations are also difficult; the same applies to the Zadinian, which shows a strong lateral variation in facies [4];[5].These assertions tend to demonstrate that,on the one hand, the studies carried out by the authors were significant contributions to our knowledge of the geology of Central Kongo, but were not totally exhaustive and, on the other hand, that detailed studies are necessary for greater precision.The new discoveries do not contradict the authors, but make a contribution to their work and to our knowledge of the geology of this region of the country.

2 STUDY AREA

2.1 Localization

The study area is located in the province of Central Kongo, specifically in the territory of Tshela. It is bordered to the north by the Republic of Congo, to the north-west by the enclave of Cabinda (Angola), with the Shiloango river forming the natural border, to the south by the territory of Lukala and to the east by the

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territory of Seke-Banza.It extends along the following geographical coordinates:4°58'30‘’and 5°03'30‘’south latitude and 12°59'42‘’ and 13°07'20‘’ east longitude (Fig.1).

2.2 Morphology

The relief of the study area is made up of gentle hills with peneplain side plateaux. The slopes of the Mayumbian range contrast with the low-lying western part, whose eastern edge features peaks of metamorphic and eruptive bedrock.

2.3 Geological and structural context

The geological formations in the target region virtually follow the morphology of the province, with the coastal plain occupied by Mesozoic and Cenozoic terranes of generally marine origin in horizontal and subhorizontal formations, while in the east, the plateaux are composed of sub-tabular Mesozoic and Cenozoic layers of generally continental origin found throughout the central basin of the Congo Basin.

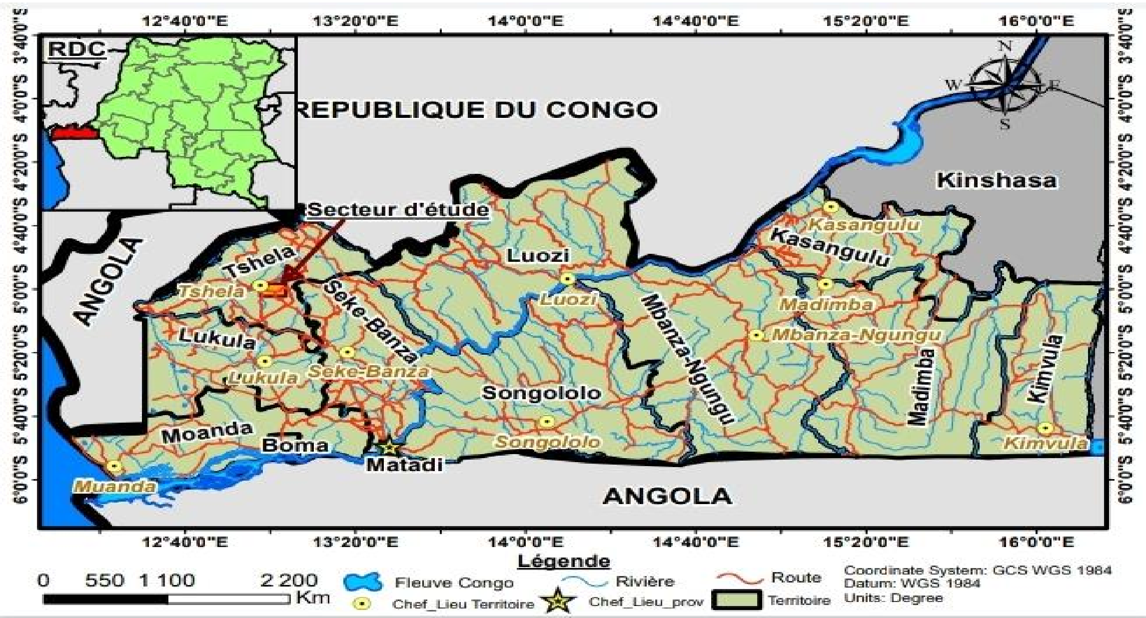

Figure 1: Location map of the study area in the Province of Central Kongo

3 METHOD, TECHNIQUE AND MATERIALS

Apart from the documentation phase, this work went through the following two major stages in any geological investigation:

3.1 Field stage

Over the course of a month's stay, an exhaustive geological survey was carried out in the area, to maximise the chances of encountering the outcrops in place, to orientate the structural elements, to sample and number the samples by giving them a number preceded by the initial WI, and to photograph the outcrops and structural elements. Finally, we photographed the outcrops and structural features, using basic geological equipment (including a hammer, compass with clinometer, GPS, notebook with pencils, camera, etc.) and a 1:50. 000 of the target region, we located outcrops, described and collected rock samples, took structural measurements (azimuth, direction and dip of planar and linear structural elements) and took photographs of certain interesting geological details observed in situ.

3.2 Laboratory stage

This stage includes:(1) the selection of representative samples with a view to the preparation, at the Geosciences Laboratory of the University of Kinshasa, of thin slides intended for the description of the rocks under a polarising microscope (Optika brand); the determination of the minerals was based on the criteria established by [6],[7]. (2) The production of geological sections to illustrate the spatial layout of the rocks, sampling and geological maps using software (Adobe Illustrator 2017, sas planet, ArcGIS (ArcMap), Office 2019. [6]. [17].

4. RESULTS AND DISCUSSION

4.1 Geological survey

The fieldwork led to the production of a map showing the location of the observation and sampling stations (with the initials WI) followed by a number according to the order of sampling, as shown in Figure 2.

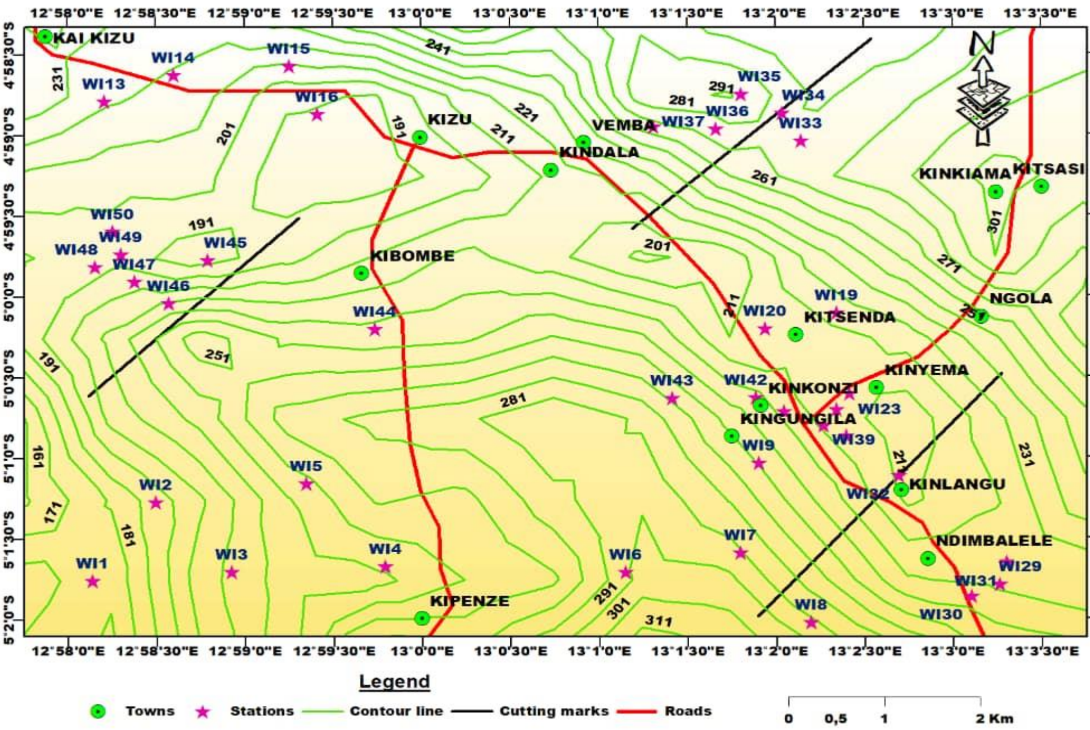

Figure 2. Location map of observation and sampling stations.

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Petrographic analysis

For our study area as a whole, we made 3 sections that cut across the area from north to south-east:

- ✓ Section 1: Kinkonzi village: Kitsenda village;
- ✓ Section 2: Kitsasi village: Kinyema village;
- ✓ Section 3: village Vemba: village Kibombe

From a lithological point of view, eight lithofacies have been defined in the study area, as follows:

4.2.1. Section of the Kinkonzi village in Kitsenda

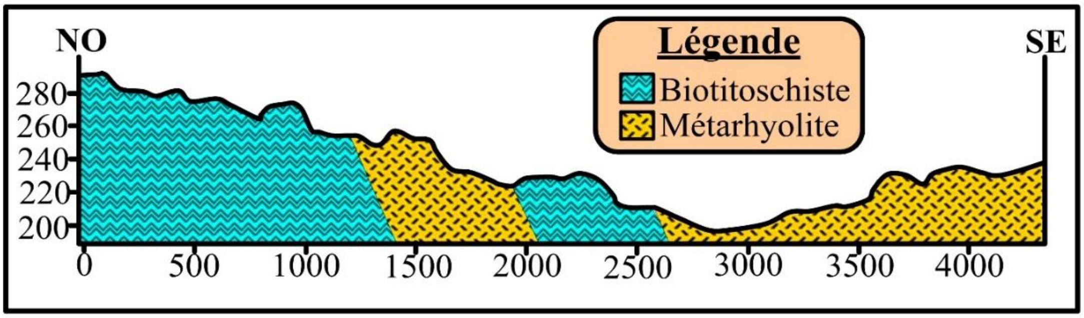
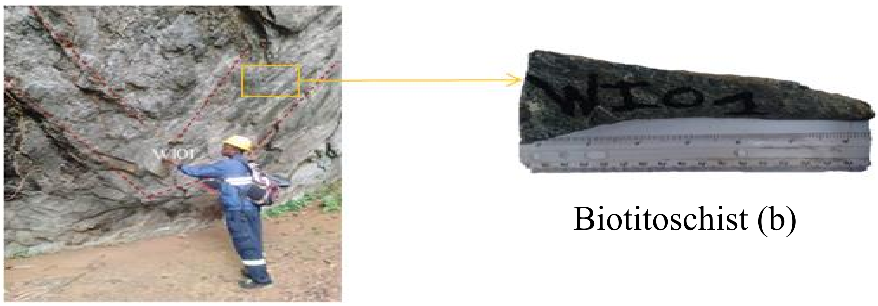


Figure 3. *Cross-section of the Kinkonzi village in Kitsenda*

4.2.2. Lithofacies of biotitoschist (Ech.WI 01)

Macroscopically, the rock has a greenish colour.. It is cut in plates; rich in micas sheets which are accompanied by quartz with a little feldspar. Coordinates: S 5° 13‘ 31’‘ and E 13°38'11’' Direction and dip: N 130°/56° SW (photo 1).



Biotitoschist (b)

Biotitoschist (a)

Figure 4. *Outcrop view of biotitoschist (a) sample WI 01 (b)*

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Microscopically, the rock has a lepidoblastic texture. This is highlighted by the intercalation of small sections of brownish biotite (LPA and LPNA) between small xenomorphic and subautomorphic crystals of white or grey (LPA) and colourless (LPNA) quartz. Alongside these schistosities, elongated quartz crystals can be seen (Figure5).

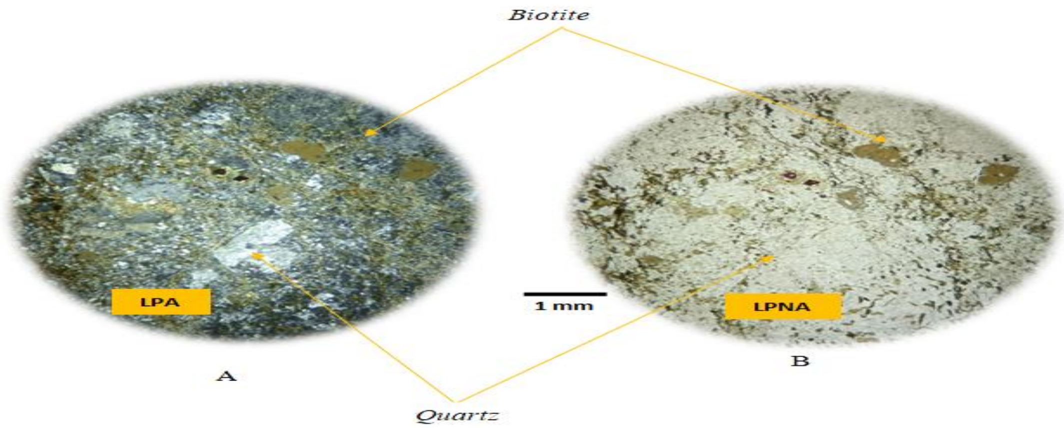

Figure 5. seen under a biotitoschist microscope (A: in LPA; B: in LPNA).

4.2.3. Lithofacies of metarhyolite (Ech. WI 02)

Macroscopically, the rock has a massive structure with frustrated layers of greenish to brownish colouring due to alteration, and a quartz vein 20cm wide: S 5°13'57‘’ and E 13°33'53‘’; direction and dip measurements: N 85°/80°NW (the fault plane) (Figure 6).

Metarhyolite (b)

Metarhyolite (a)

Figure 6. Outcrop view of Metarhyolite (a) sample WI 02 (b)

Microscopically, the rock has a porphyroblastic texture, highlighted by white or grey (LPA) and colourless (LPNA) quartz porphyroblasts embedded in a granular mass of porphyroblasts, and by medium and fine

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quartz crystals between the granules, which are interspersed with elongated greenish sericite crystals (LPA) (Figure7).

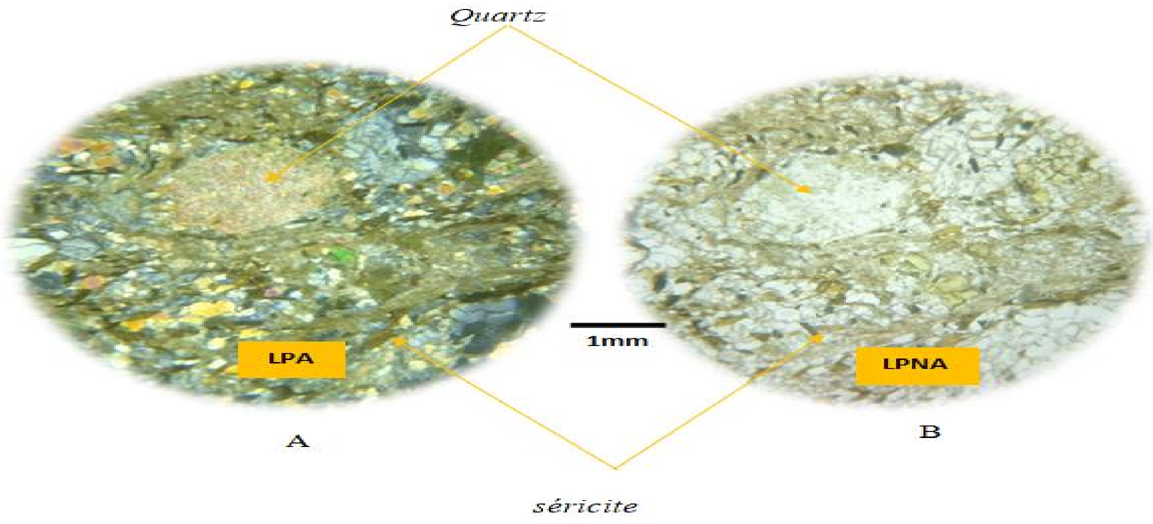

Figure 7. Microscopic view Metarhyolite lithofacies (A: in LPA; B:in LPNA).

4.2. Section of the village Kitsasi in Kinyema

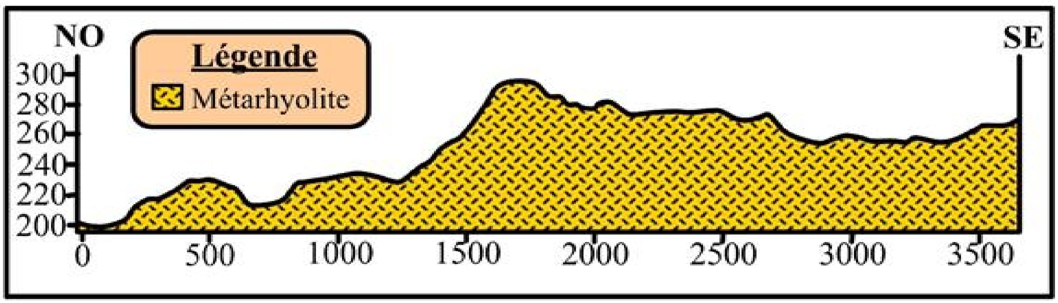

Figure 8. Cross-section of the Kitsasi village in kinyema

4.3.1.Lithofacies of biotitoschist (WI 03)

This is a zone of damage and crushing of the rock. The rock is greenish to blackish in colour. Geographical coordinates: S 5°14'20‘’and E 13°10'40‘’; direction and dip measurements: N146°/52°SW (schistosity plane) (Figure9).

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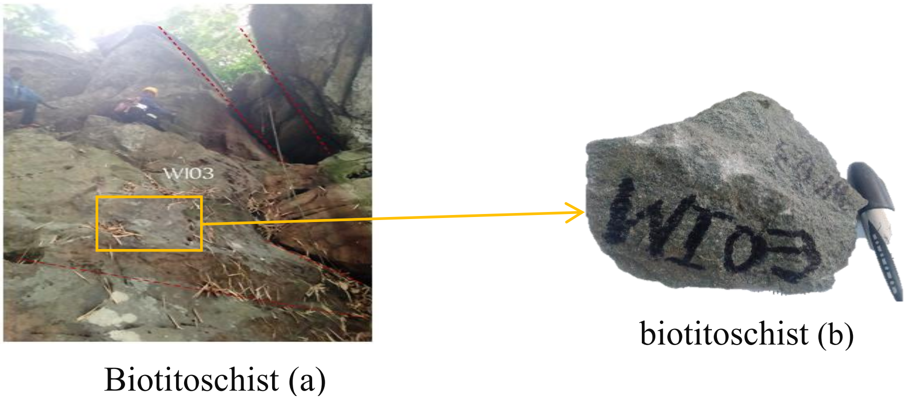

Figure 9. *Outcrop view of biotitoschist (a) sample WI 03 (b)*

Microscopically, the rock has a lepidoblastic texture. This is highlighted by the intercalation of small sections of brownish biotite (LPA and LPNA). Photo 10.

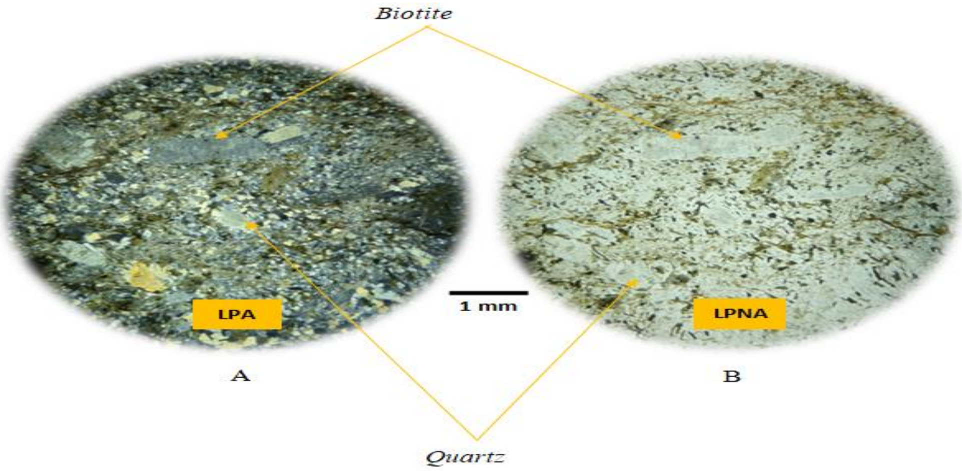

Figure 10 . *Microscopic view biotitoschist lithofacies (A: in LPA; B: in LPNA).*

4.2. Section of the Village Vemba to Village Kibombe

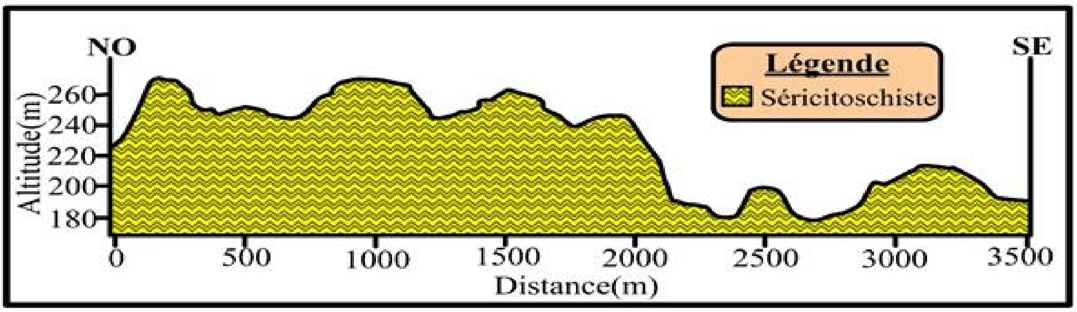

Figure 11. Cross-section of the Vemba village in kibombe

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4.4.1. Lithofacies of sericite schist (WI 27)

Macroscopically, the rock is relatively schistose, with a massive, fine-grained, greenish texture. It is characterised by abundant sericite, quartz crystals and feldspar. The geographical coordinates are S°4 50'32‘’ and E12°27'40‘’; direction and dip measurements: N120°/86°SW (Figure 12).

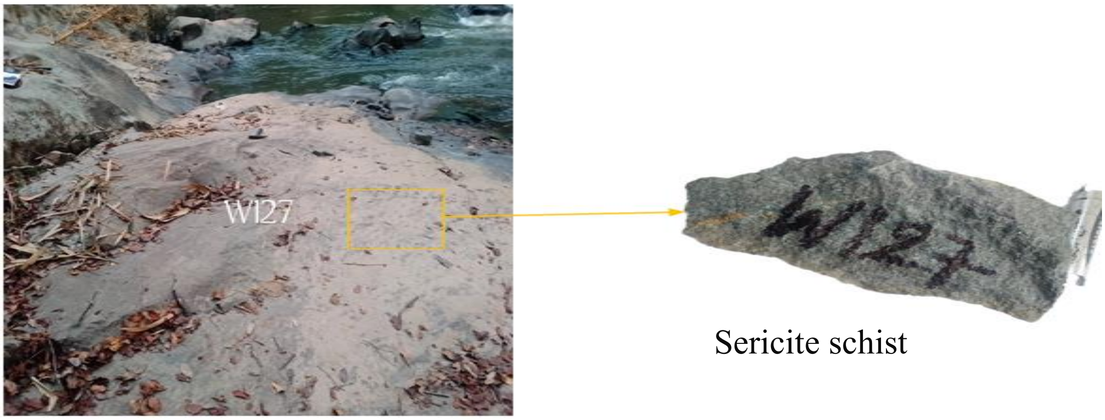

Figure 12.*Outcrop view of Sericite schist (a) sample WI 27(b)*

Microscopically, the rock is schistose, with alternating granoblastic and lepidoblastic levels. The granoblastic levels are made up of white or grey (LPA) and colourless (LPNA) quartz crystals. Between these crystals are elongated plagioclase and medium to coarse quartz. Some crystals are slightly cracked. The lepidoblastic levels consist of needles of brightly coloured sericite of refractive scale order (LPA) and yellowish to greenish (LPNA). Granules and streaks of opaque minerals can also be seen. The alignment of sericite gives the rock a schistosity. (Figure 13).

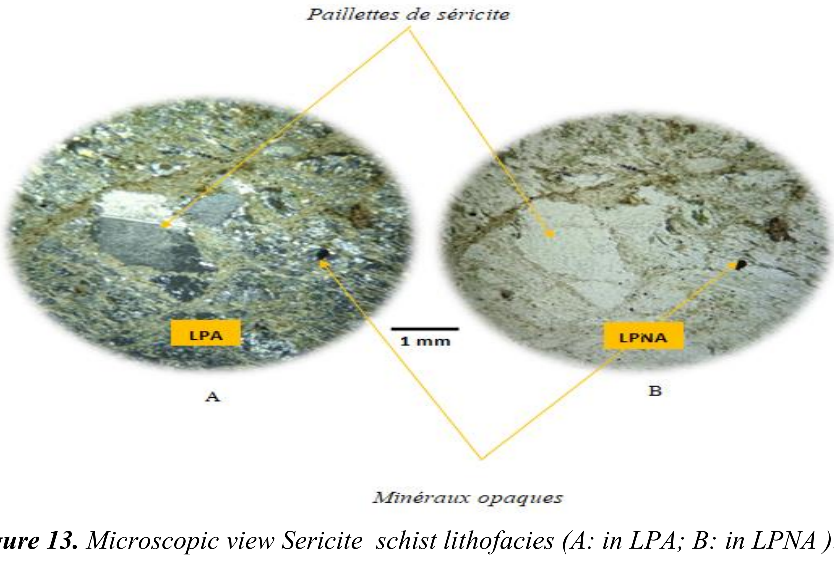

Figure 13. *Microscopic view Sericite schist lithofacies (A: in LPA; B: in LPNA).*

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5. RESULTS AND DISCUSSION

Macroscopic and microscopic observations of the rocks in our study area reveal that the zone is metamorphosed. These are metamorphic rocks resulting from regional metamorphism. They have the following characteristics

- ✓ Variation in colour from light brown to greenish;
- ✓ The presence of schistosity and laminations;
- ✓ Varied quartz morphology;
- ✓ The varied nature of micas and green hornblende;
- ✓ Varied crystal sizes;
- ✓ The presence of sericite.

5.1. Petrographic Context

- ✓ A variation in colour is observed. It consists of a greenish tinge that increases from west to east, and a light brownish colour. Different planes of schistosity can also be seen. The varied nature of micas, hornblende and hydrothermal minerals such as sericite [7].

❖ Colouring

The light colouring observed in the rocks in our study area is due to the presence of light-coloured minerals and also to the presence of silica dispersed in the metarhyolites. The greenish hue diminishes from west to east, where only the metarhyolites are observed.sericite is thought to have been produced by epizonal metamorphism, which means that the western part of our study area can be classified as a 'Greenschist-facies' or green schist metamorphic facies [8], [15].

❖ The morphology and size of quartz and feldspars

The morphology of quartz and feldspar in metarhyolites is a source of information about the cooling of magma of rhyolitic origin [9]. Subautomorphic and automorphic crystals indicate relatively slow cooling in the inner part of the rhyolitic massif, while xenomorphic crystals indicate much faster cooling in the upper part of the massif. In the metarhyolites, the crystals are equidimensiols, which means that we can be certain that this is a metamorphic quartzite [10],[16].The feldspar porphyroblasts with crystallisation tails, combined with other observations, are indicative of the shear zones highlighted in our study area.

❖ The presence of sericite

For metarhyolites that have undergone regional metamorphism and cataclasis.This mineralogical argument supports the existence of two generations of rhyolite, one with an age of 920±8 Ma and the other with an age of 912 ±7 Ma [4]. The green hornblende present in the rocks in our study area is characteristic of the relatively low-temperature range [11].The presence of sericite is thought to be due to sericitisation. Sericitisation results from the partial or total replacement of feldspars and biotite, and is one of the pervasive alterations present in the study area. It is generally very intense in felsites.Sericitisation is a good tracer of mineralised zones [12];[13].

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5.2. Mineral Paragenesis of Various Rocks in The Study Area

❖ Metarhyolite

Metarhyolite is characterised by the presence of high-temperature alkaline feldspars (sanidine) indicating rapid cooling of the source magma, and intermediate-temperature feldspars (orthoclase) with perthites indicating slow cooling, quartz, and also iron minerals (hematite, magnetite and pyrite) probably of hydrothermal origin [9].

❖ Biotitoschist

is characterised by the presence of biotite sheets interspersed between quartz crystals. This suggests that we are still in the greenschist facies, but the absence of chlorite suggests that we are moving towards a facies of relatively high grade.

❖ Sericite schist

is characterised by the presence of xenomorphic, subautomorphic and automorphic sericite crystals.

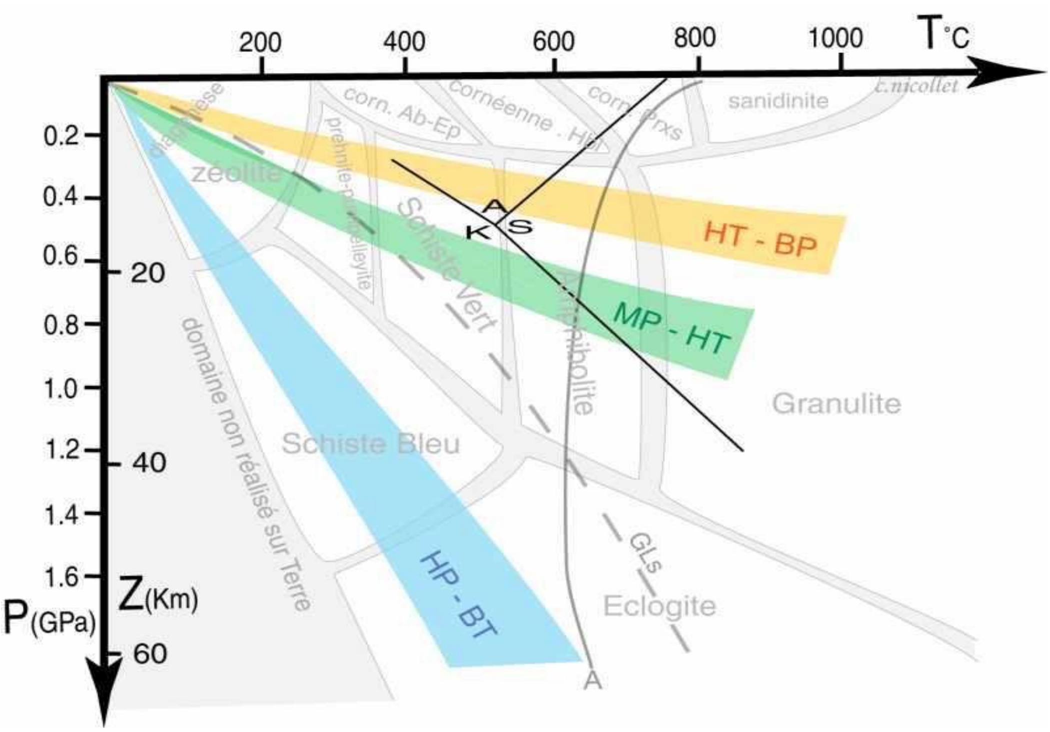

Figure 7. Metamorphic facies: the figure shows a selection of isograd reactions delineating the different metamorphic facies [10].The yellow zone shows the metamorphic facies in our study area.

These different parageneses show that, from west to east in our study area, we move from Epidote-amphibolite facies to greenschist facies, i.e. the degree of metamorphism decreases from west to east, as demonstrated by [4].Thus, we can group the different rock formations in our study area into two Groups of

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the West Congo Supergroup (Table 2). The metarhyolite formation belongs to the Tshela/Seke-Banza Group (Mayumbian) and the others to the Matadi Group (Zadinian).

Table 2: Distribution of formations in and around Tshela-Mbanga within the groups in West Congo.

	FORMATIONS	LIKELY GROUP	AGE
1	Metarhyolite	Mayumbien	Summit 912±7Ma and base 920±8 Ma
2	Sericitoschist	Zadinien	999±7 Ma (Tack et al., 2001)
4	Biotitoschiste		

5.3. On The Metamorphic Level

The formations in our study area have undergone cataclasis, as evidenced by the presence of cracked minerals, the presence of quartz veins and faults oriented preferentially NE-SW.Quartz veins and veins are present in most of the formations encountered (in varying thicknesses and lengths).The quartz vein at Mpangi-Ngabu is a senestial strike-slip fault with a displacement of 22cm.the cracked porphyroblasts of plagioclase in the metarhyolite and those showing recrystallisation tails are characteristic of shear zones. These structures are typical of fault rocks. The recrystallisation tails show that these minerals were present in the rock before deformation, i.e. they are a mineral phase known as 'antecinematic or antischistose' [10].The schistosity observed in the samples is formed by the simultaneous action of a localised dissolution process on discrete surfaces and a rigid rotation of the material linked to the folding of the microlithons [14].

6. CONCLUSION

Overall, the geology of the Mbanga sector and surrounding area is characterised by the presence of metamorphic layers of volcanic origin (metavolcanites: metarhyolites) and sedimentary origin (sericite and biotitose) of the Epidote-Amphibolite Facies and Greenschist-facies, from west to east. These rocks formed during the West Congo orogeny underwent cataclasis responsible for faulting and hydrothermal alteration (sericitisation). These rocks formed during the West Congo orogeny underwent the cataclasis responsible for fault rocks and hydrothermal alteration (sericitisation). The lepidoblastic structure is characteristic of rocks formed by lamellar crystals (micas, chlorite) in significant quantities and arranged parallel to one another. The porphyroblastic structure is similar in appearance to the porphyritic structure of igneous rocks. It consists of the presence of a few crystals, generally belonging to the same mineralogical species, of larger dimensions than the other crystals in the rock, which are of average size.

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