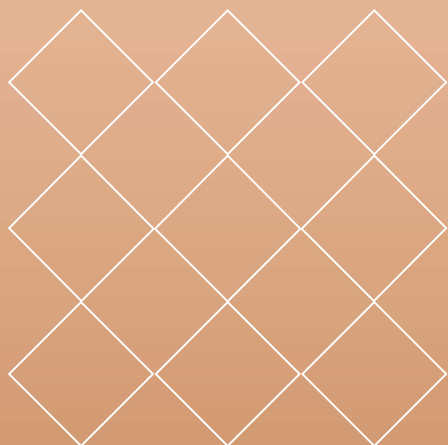




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The Impact of Inquiry-Based Science Education on the Development of Multidimensional Scientific Literacy

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Abstract Inquiry-based teaching supports the development of students' scientific literacy across multiple dimensions, including scientific knowledge, experimental skills, motivation, attitudes, the application of knowledge, and collaboration. In this study, third-grade primary school pupils participated in qualitative group interviews conducted before and after a series of inquiry-based learning activities focused on exploring natural phenomena, planning experiments, and applying knowledge in practical contexts. The qualitative analysis revealed improvements across all six investigated dimensions of scientific literacy. Students showed a deeper understanding of scientific concepts, enhanced experimental thinking, increased motivation, greater ability to apply scientific knowledge in everyday situations, and more active collaboration during discussions. The findings indicate that inquiry-based teaching can effectively promote the comprehensive development of scientific literacy and that its principles can be successfully implemented in higher grades, particularly within the *Human and Nature* curriculum, where pupils can build previously acquired inquiry skills to solve more complex scientific problems.

Keywords science education, inquiry-based learning, scientific literacy, experimental skills, knowledge application, collaboration

1. INTRODUCTION

In its contemporary understanding, scientific literacy extends beyond the mere acquisition and reproduction of factual knowledge. It encompasses the ability to think critically, construct and evaluate arguments, solve problems, and apply scientific knowledge in authentic real-life situations. Empirical research has shown that instruction based predominantly on the transmission and reproduction of information is insufficient for developing these competencies and often contributes to the persistence of students' misconceptions.

Current conceptions of the goals of science education go beyond the acquisition of isolated facts and concepts. Contemporary curriculum approaches emphasize the multidimensional nature of science education, whose primary aim is the development of students' scientific literacy (Bybee, 2013; Bellová, 2018; OECD, 2019; Osborne, 2014).

The multidimensional goal of science education encompasses the development of several interrelated domains: scientific knowledge, scientific skills, attitudes, and the ability to apply scientific knowledge in everyday contexts. Scientific literacy is defined as an individual's capacity to engage in discussions of scientific issues, explain natural phenomena using scientific knowledge, design and evaluate scientific investigations, and interpret data and evidence (OECD, 2016; OECD, 2019).

Within this framework, science education focuses on multiple dimensions of learning. The first is the knowledge dimension, which involves understanding fundamental scientific concepts, principles, and laws. The second is the process dimension, which concerns the development of scientific inquiry skills such as asking questions, formulating hypotheses, planning and conducting experiments, collecting and interpreting data, and drawing conclusions. The third is the attitudinal dimension, which includes fostering interest in science, curiosity, and positive attitudes toward understanding the natural world. An equally important component is the application and social dimension, reflected in the ability to use scientific knowledge for problem-solving and to engage in evidence-based discussions of scientific issues (Bybee, 2013; Hodson, 2014; Osborne, 2014).

Research in science education has consistently shown that the development of scientific literacy is more effective when students actively participate in the learning process through Inquiry-Based Science Education (IBSE). This approach enables students to investigate natural phenomena, formulate questions, test hypotheses, and interpret findings, thereby promoting a deeper understanding of scientific concepts (Oliver, McConney & Woods-McConney, 2021; Jegstad, 2023).

Recent studies further indicate that inquiry-based and problem-based instructional approaches make a substantial contribution to the development of scientific literacy, critical thinking, and problem-solving skills. Experimental and quantitative studies confirm that the implementation of inquiry-based strategies leads to improved conceptual understanding of scientific phenomena as well as increased student motivation to learn science (Eymur & Çetin, 2024; Faizin, Susantini & Raharjo, 2024).

The importance of inquiry-based learning is also supported by recent systematic reviews, which highlight its contribution to the

development of 21st-century competencies, including critical thinking, argumentation, collaboration, and the ability to interpret scientific evidence (Vo & Mooney Simmie, 2025; Nahar & Machado, 2025). Furthermore, research suggests that integrating digital tools and emerging technologies into inquiry-based learning can further enhance students' scientific literacy and the development of their scientific identity (Huang & Pei, 2024; Ramli & Borhan, 2024; Perdana, Yulianti & Bertiliya, 2025).

Taken together, these findings indicate that the multidimensional goal of science education is to develop learners who not only possess fundamental scientific knowledge but are also capable of critically evaluating and applying that knowledge in real-world situations and actively engaging in addressing issues related to nature, science, and technology.

2. RESEARCH OBJECTIVES AND HYPOTHESES

The aim of the study was to investigate the impact of implementing inquiry-based activities on the development of multidimensional scientific literacy among primary school pupils. Individual dimensions of scientific literacy – knowledge, scientific skills, attitudes, application of knowledge, and social collaboration - were examined through qualitative analysis of group interviews conducted before and after the educational intervention.

The main research aim was further elaborated into a set of specific objectives that enabled its systematic achievement:

1. **Knowledge Dimension:** To determine whether the implementation of inquiry-based activities contributes to a deeper understanding of fundamental scientific concepts and phenomena, as reflected in more accurate and scientifically sound responses provided by pupils during the interviews.
2. **Process/Skills Dimension:** To examine the extent to which pupils, after participating in inquiry-based activities, can formulate research questions, propose simple hypotheses, plan and conduct experiments, and interpret the data obtained.
3. **Motivational–Attitudinal Dimension:** To investigate whether inquiry-based instruction influences pupils' attitudes toward science education, particularly their motivation, curiosity, and willingness to engage actively in learning activities.
4. **Application Dimension:** To explore pupils' ability to apply scientific knowledge when explaining simple real-life situations, as demonstrated through concrete examples and evidence-based reasoning during the interviews.
5. **Social Dimension:** To examine the extent to which the implementation of inquiry-based activities promotes collaboration, discussion, and evidence-based argumentation among pupils, as reflected in their responses during group interviews.
6. **Assessment of Overall Scientific Literacy Development:** To determine whether inquiry-based instruction contributes to the development of pupils' scientific literacy in its multidimensional conception through a comparison of qualitative data obtained from interviews conducted before and after the intervention.

Based on these objectives, the following research hypotheses were formulated:

H1 (Knowledge Dimension): The implementation of inquiry-based activities in primary science education will contribute to a deeper understanding of fundamental scientific concepts and phenomena, which will be reflected in pupils' interview responses through more accurate and scientifically sound explanations.

H2 (Process Dimension – Scientific Skills): Following participation in inquiry-based activities, pupils will demonstrate a higher level of scientific inquiry skills, particularly in asking questions, formulating simple hypotheses, planning and interpreting experiments, as evidenced by their verbal responses during the interviews.

H3 (Attitudinal Dimension): The implementation of inquiry-based instruction in science education will lead to positive changes in pupils' motivation and attitudes toward learning science, particularly regarding their interest, curiosity, and willingness to engage in learning activities, as reflected in their verbal and reflective interview responses.

H4 (Application Dimension): After participating in inquiry-based activities, pupils will be able to apply scientific knowledge when explaining simple everyday situations, as demonstrated in the interviews through the use of concrete examples and evidence-based reasoning.

H5 (Social Dimension): The implementation of inquiry-based activities will enhance pupils' ability to discuss, collaborate, and construct evidence-based arguments, as reflected in their responses during the group interviews.

H6 (Overall Multidimensional Effect): Inquiry-based instruction contributes to the development of pupils' scientific literacy in its multidimensional conception (knowledge, skills, attitudes, and application of knowledge), which will be identifiable through qualitative analysis of the interview data collected before and after the intervention.

Table 1. Alignment of Scientific Literacy Dimensions, Research Hypotheses, and Interview Questions (Scientific Inquiry Competencies)

Dimension	Hypothesis	Competency Area Assessed
Knowledge Dimension	H1 – Understanding of scientific concepts and phenomena	Level of knowledge; accuracy and scientific correctness of explanations
Process/Skills Dimension	H2 – Development of scientific inquiry skills	Observation, hypothesis formulation, experimentation
Attitudinal (Motivational) Dimension	H3 – Motivation and attitudes toward science	Interest, curiosity, willingness to engage
Application Dimension	H4 – Application of knowledge in everyday life	Practical application of knowledge, evidence-based reasoning
Social Dimension	H5 – Collaboration and argumentation	Communication, teamwork, discussion
Multidimensional Dimension	H6 – Development of scientific literacy	Integrated development across all dimensions

3. RESEARCH METHODOLOGY

The study was conducted with a sample of 30 third-grade primary school pupils. The aim was to examine the effectiveness of Inquiry-Based Science Education (IBSE) in fostering the development of

multidimensional scientific literacy. Participation was voluntary, and informed parental consent was obtained prior to the study.

The first stage of the research involved a pre-intervention group interview conducted prior to the implementation of inquiry-based lessons. Subsequently, the educational intervention was carried out through a series of inquiry-based learning activities in which pupils actively participated. Following the completion of the instructional sequence, the same interview protocol was administered again (post-intervention interview) in order to identify changes across the previously defined dimensions of scientific literacy.

The interviews were conducted in the classroom, audio-recorded, and subsequently transcribed verbatim. Data analysis was carried out using qualitative content analysis. Pupils' responses were categorized according to the individual dimensions of scientific literacy and compared across the pre-intervention and post-intervention phases.

This procedure enabled the identification of changes in pupils' scientific knowledge, inquiry skills, attitudes, ability to apply scientific knowledge, and social collaboration, thereby allowing the effectiveness of inquiry-based instruction to be evaluated.

The interview protocol consisted of 12 questions, which were organized according to the dimensions of scientific literacy and aligned with research hypotheses H1–H6.

4. IMPLEMENTATION OF INQUIRY-BASED ACTIVITIES

As part of the research, five inquiry-based science lessons were implemented with the pupils. These lessons included a variety of activities designed to foster the development of multidimensional scientific literacy:

1. **The World of Insects and Plants** – pupils investigated plants and insects in the school environment, conducting observations and recording data.
2. **Water and Its Properties** – pupils explored the water cycle, evaporation, condensation, and solubility through inquiry-based investigations.
3. **Magnetic and Electrical Interactions** – pupils experimented with magnets and simple electrical circuits, exploring basic physical phenomena.
4. **Colours and Light** – pupils observed the dispersion of white light using a prism, mixed colours, and investigated shadow phenomena.
5. **Soil and Plants** – pupils compared plant growth in different soil types and moisture conditions, recorded observations, and drew conclusions based on the collected evidence.

These activities enabled pupils to observe and explain natural phenomena, plan and conduct experiments, collaborate with peers, construct evidence-based arguments, and apply scientific knowledge in practical contexts. In this way, the effectiveness of Inquiry-Based Science Education (IBSE) in promoting multidimensional scientific literacy was examined.

5. COMPARATIVE ANALYSIS OF RESULTS BEFORE AND AFTER THE EDUCATIONAL INTERVENTION

The collected data were analysed using **thematic analysis**, specifically the procedure of **open coding**, which enabled the

systematic identification of meaningful patterns in pupils' responses before and after the implementation of the inquiry-based activities. The analysis was conducted in several successive stages. First, the group interviews were transcribed verbatim, creating a reliable corpus for qualitative analysis. Subsequently, **meaning units** were identified within the transcripts. These consisted of segments of text containing information relevant to the investigated dimensions of scientific literacy.

In the next phase, **open coding** was applied, whereby individual meaning units were assigned codes that captured their content and significance. This process was inductive in nature, with codes emerging directly from the data rather than being derived from a predetermined coding framework. Subsequently, conceptually related codes were grouped into broader thematic categories representing the principal dimensions and aspects of the phenomenon under investigation (Table 2).

The resulting categories enabled a systematic interpretation of the data and facilitated the identification of changes in pupils' responses between the pre-intervention and post-intervention phases of the study. The results of the analysis were processed separately for each phase and organized into comprehensive analytical tables. Owing to their extent, these tables are not included in the present paper.

The processed data were subsequently synthesized in **Table 2**, which presents the qualitative differences observed between the pre-intervention and post-intervention phases. This procedure made it possible to identify developments within the individual dimensions of scientific literacy resulting from the implementation of Inquiry-Based Science Education (IBSE).

Table 2. Comparison of Categories Emerging from Pupils' Responses Before and After the Implementation of Inquiry-Based Activities

Category	Before the Activities – Characteristics of Pupils' Responses	After the Activities – Characteristics of Pupils' Responses
Understanding of Scientific Experimentation	An experiment is generally seen as a way to find things out or test an idea.	Pupils describe an experiment as a planned test to verify assumptions.
Purpose of Experimentation	Pupils mainly provide general reasons, such as learning something new or finding an answer to a question.	Responses are more precise; experimentation is described as a means of testing ideas and understanding how things work.
Knowledge of Natural Phenomena	Pupils mention basic examples derived from classroom instruction.	More specific knowledge acquired through the activities is evident in their responses.
Ways of Obtaining Information about Nature	Responses include reading books or general observation of nature.	Pupils more frequently mention planning investigations, observing changes, and testing their own ideas.
Experimental Thinking	Pupils only partially describe procedures for testing ideas.	More systematic reasoning includes comparing conditions,

Category	Before the Activities – Characteristics of Pupils' Responses	After the Activities – Characteristics of Pupils' Responses
		controlling variables, and monitoring results.
Understanding of the Concept of Observation	Observation is often understood as “paying attention to the teacher.”	Pupils describe observation as monitoring changes during an investigation and noticing differences.
Understanding of the Concept of Hypothesis	Most pupils are unfamiliar with the term or unable to explain it.	Pupils describe a hypothesis as a prediction that must be tested.
Collaboration During Investigations	Pupils mainly mention difficulties related to cooperation (e.g., problems reaching agreement).	Positive aspects of collaboration emerge, such as task distribution and listening to one another.
Reflection on Experimental Results	Pupils provide general reasons, such as sharing information or describing what they have learned.	Pupils recognize the importance of discussing results and different observations.
Motivation for Inquiry	Most pupils report enjoying investigations, mainly because they learn something new.	Motivation is stronger and linked to direct experience with investigations.

6. VERIFICATION OF THE RESEARCH HYPOTHESES AND DISCUSSION

The qualitative comparison was followed by a quantification of the findings, which resulted in the construction of a summary graph (Figure 1). The graph was based on the identified categories and codes, with the occurrence of relevant pupil responses being recorded for each category in both the pre-intervention and post-intervention interviews. These occurrences were subsequently expressed as frequencies, enabling the representation of the prevalence of individual phenomena across both phases of the study.

Figure 1 thus provides a synthetic overview of changes across the individual dimensions of scientific literacy. Comparing the frequencies observed before and after the intervention makes it possible to identify increases or decreases in the occurrence of the investigated indicators. The graph therefore serves as a basis for testing the proposed hypotheses, as it illustrates the extent of development in pupils' scientific knowledge, inquiry skills, attitudes, ability to apply scientific knowledge, and social competencies.

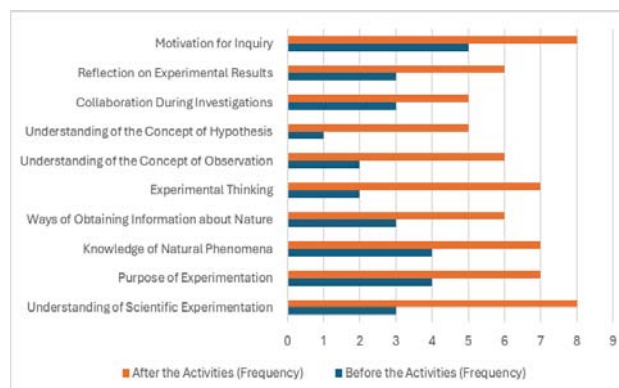


Figure 1. Comparison of the Frequencies of Categories Emerging from Pupils' Responses in the Pre-Intervention and Post-Intervention Interviews.

Based on the data presented in Figure 1, the proposed hypotheses can be evaluated as follows:

H1: Knowledge Dimension

The most substantial increases were observed in the categories **Understanding of Scientific Experimentation** (+5) and **Experimental Thinking** (+5), indicating a significant deepening of pupils' understanding of the principles of scientific inquiry. Considerable improvement was also evident in the categories **Understanding of the Concept of Observation** (+4) and **Understanding of the Concept of Hypothesis** (+4), suggesting a better grasp of fundamental scientific concepts.

The category **Knowledge of Natural Phenomena** increased by +3, indicating that pupils' explanations became more accurate and conceptually sophisticated. A similar increase was observed in the category **Ways of Obtaining Information about Nature** (+3), further supporting the development of scientific reasoning.

Overall, the most pronounced changes occurred in categories related to conceptual understanding and scientific thinking, providing direct evidence in support of **Hypothesis H1**. Following the intervention, pupils' responses were more accurate, scientifically sound, and conceptually deeper. Therefore, **H1 can be considered confirmed**.

H2: Process Dimension – Scientific Inquiry Skills

The evaluation of H2 focused on categories associated with the development of scientific inquiry skills, particularly hypothesis formulation, experiment planning, and interpretation of results.

The largest increase was observed in **Experimental Thinking** (experiment planning) (+5; from 2 to 7), indicating a better understanding of experimental design and a more systematic approach to problem-solving. **Understanding of the Concept of Hypothesis** increased by +4 (from 1 to 5), while **Understanding of the Concept of Observation** increased by +4 (from 2 to 6), suggesting that pupils acquired essential scientific inquiry concepts. The category **Understanding of Scientific Experimentation** increased by +5 (from 3 to 8), demonstrating a more comprehensive understanding of the experimental process and its purpose. Furthermore, the increase in **Reflection on Experimental Results** (+3; from 3 to 6) indicates an enhanced ability to draw conclusions and communicate them verbally.

The overall improvement across all relevant categories indicates a substantial development of pupils' scientific inquiry skills, as reflected in their verbal responses during the interviews. Therefore, **Hypothesis H2 can be considered confirmed**.

H3: Attitudinal Dimension

The evaluation of H3 focused on categories reflecting the affective and value-related aspects of learning.

Following the implementation of the inquiry-based activities, an increase was observed in the category **Purpose of Experimentation** (+3; from 4 to 7), indicating a deeper appreciation of the value of scientific investigation. Similarly, **Reflection on Experimental Results** increased by +3 (from 3 to 6), suggesting a greater willingness among pupils to think about and articulate their own learning experiences. The increase in **Ways of Obtaining Information about Nature** (+3; from 3 to 6) indicates a broader understanding of how knowledge about the natural world can be acquired.

Although the category **Motivation for Inquiry** increased by +3 (from 5 to 8), the key finding is that positive changes were also evident in broader attitudinal indicators, including pupils' appreciation of experimentation and their engagement in the learning process.

These findings confirm that Inquiry-Based Science Education (IBSE) contributed to positive changes in pupils' motivation and attitudes toward science learning. Therefore, **Hypothesis H3 can be considered confirmed**.

H4: Application Dimension

The evaluation of H4 focused on categories reflecting pupils' ability to apply scientific knowledge in real-life contexts and to construct evidence-based explanations.

Following the implementation of the inquiry-based activities, pupils demonstrated an increased ability to:

- **Apply knowledge of natural phenomena** by providing examples from everyday life, indicating a stronger connection between scientific knowledge and practical contexts.
- **Reflect on experimental results and interpret observations.** The increase in the category **Reflection on Experimental Results** (+3; from 3 to 6) suggests an improved ability to draw conclusions and transfer them beyond the immediate experimental setting.
- **Construct evidence-based arguments.** Pupils increasingly referred to observed data and experimental results when explaining phenomena, clearly indicating the development of scientific reasoning and argumentation.

Improvement was also evident in pupils' ability to connect scientific concepts and phenomena with practical situations, as reflected in the category **Ways of Obtaining Information about Nature**.

These findings confirm that Inquiry-Based Science Education (IBSE) supported the development of pupils' application skills. Pupils not only demonstrated an understanding of scientific concepts and phenomena but were also able to apply this knowledge in practical contexts. Therefore, **Hypothesis H4 can be considered confirmed**.

H5: Social Dimension

The evaluation of H5 focused on the social dimension of scientific literacy, namely collaboration, discussion, and evidence-based reasoning.

Following the implementation of the inquiry-based activities, improvements were observed in pupils' abilities to:

- **Collaborate during investigations.** The frequency of relevant responses increased from 4 to 6 (+2), indicating

more active coordination of tasks and greater participation in group work.

- **Construct evidence-based arguments.** The increase in the category **Reflection on Experimental Results** from 3 to 6 (+3) demonstrates more frequent use of observations and experimental evidence to justify conclusions.
- **Engage in discussion and share ideas.** The increase from 3 to 6 (+3) in categories related to reflection and sharing results suggests more active communication, responsiveness to classmates' opinions, and constructive argumentation.

Additional observations confirmed that pupils more frequently asked their peers for opinions, proposed alternative explanations, and discussed experimental outcomes. These behaviours reflect active participation and the collaborative construction of knowledge. These findings indicate that Inquiry-Based Science Education (IBSE) supported the development of pupils' social competencies. Therefore, **Hypothesis H5 can be considered confirmed**.

H6: Overall Multidimensional Effect

In conclusion, **Hypothesis H6 was confirmed**, as positive changes were observed across all investigated dimensions of scientific literacy. The findings indicate an overall improvement in pupils' scientific literacy, encompassing scientific knowledge, inquiry skills, attitudes, application of knowledge, and social competencies.

Taken together, the results suggest that Inquiry-Based Science Education (IBSE) is an effective pedagogical approach for fostering the multidimensional development of scientific literacy in primary school pupils.

7. CONCLUSION

The overall findings of the study indicate that the implementation of Inquiry-Based Science Education (IBSE) in primary science education significantly contributes to the development of pupils' scientific literacy in its multidimensional conception, encompassing scientific knowledge, inquiry skills, attitudes, and the ability to apply knowledge. This conclusion is consistent with previous international research demonstrating that inquiry-based and active-learning approaches enhance learning outcomes, student motivation, and understanding of scientific concepts (Li & Ding, 2023; Strat, Henriksen, & Jegstad, 2023).

Empirical evidence further suggests that the inclusion of inquiry-based activities substantially improves pupils' attitudes toward science subjects, their emotional engagement, and their willingness to participate actively in the learning process (Ganajová, Orosová, Sotáková, & Letošníková, 2025).

Systematic reviews and meta-analyses have also shown that contextualized inquiry tasks, discussion of scientific explanations, and students' independent justification of their responses are crucial for the development of critical thinking and scientific inquiry skills. These approaches enable learners to move beyond the simple acquisition of facts toward deeper, more active, and reflective reasoning in the context of authentic problems (Furtak, Seidel, Iverson, & Briggs, 2012; Crawford, 2014).

The results of the present study revealed improvements across all investigated dimensions, ranging from verbally expressed scientific knowledge and the planning and interpretation of experiments to the application of knowledge in everyday situations and the development of positive attitudes toward science. These changes do not represent isolated or incidental occurrences; rather, they are consistent with the existing body of research on the effectiveness of

inquiry-based approaches in science education. The findings therefore confirm the potential of Inquiry-Based Science Education to foster comprehensive scientific literacy and greater student engagement in science learning. The educational approach presented in this study may be progressively implemented in higher grades within the curriculum area **Human and Nature**. At this stage of schooling, pupils already possess basic experience with inquiry-based activities, enabling them to engage more actively in solving complex tasks and to participate in scientific investigations at more advanced levels of inquiry.

Nevertheless, it should be acknowledged that the findings support the proposed hypotheses only within the context of a single class and a relatively small sample of pupils. Consequently, the generalizability of the results to other schools or larger populations remains limited. Future research should therefore include multiple classes, larger samples, and diverse school contexts to strengthen the validity and generalizability of the findings. We also propose several directions for future research that could deepen the understanding of these effects and enable broader generalization of the findings:

Investigation of interdisciplinary relationships – The aim would be to examine whether an inquiry-based approach to science education also enhances critical thinking, mathematical skills, and language literacy. This would help determine the extent to which the multidimensional goals of science education foster broader student competencies.

Comparative research on different types of inquiry-based activities – The objective would be to compare the effectiveness of various forms of inquiry-based learning activities, such as individual tasks, group work, and digital simulations. The research would employ experimental and quasi-experimental designs, classroom observations, assessment of student outcomes, and qualitative interviews. The expected contribution would be the identification of those types of activities that most effectively promote skill development, positive attitudes toward learning, and the ability to apply acquired knowledge.

Examination of the social dimension and teamwork – The aim would be to investigate in greater detail how students' collaboration, discussion, and argumentation influence the learning process and the development of scientific literacy. The research would utilize recordings of group discussions, sociometric analyses of interactions, and qualitative interviews. The expected contribution would be a better understanding of the social dimension of inquiry-based learning and its effects on motivation and sustainable learning.

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Komunikácia satirickej platformy Zomri v prostredí sociálnych médií

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Abstrakt Rastúci význam sociálnych médií prispel k vzniku nových digitálnych aktérov, ktorí sa popri tradičných médiách podieľajú na interpretácii spoločenského a politického diania. Medzi takéto subjekty patrí aj slovenská satirická platforma Zomri, ktorá prostredníctvom internetových memov, humoru a satiry reflektuje aktuálne udalosti a vstupuje do verejnej diskusie. Cieľom vedeckej štúdie je identifikovať charakteristické znaky komunikácie platformy Zomri na sociálnych sieťach so zameraním na tematické zameranie publikovaného obsahu a komunikačné stratégie využívané pri interpretácii spoločenských a politických tém. Výskum využíva kvalitatívnu obsahovú analýzu doplnenú o diskurzívnu analýzu a hermeneutickú interpretáciu príspevkov publikovaných na oficiálnych profiloch platformy na sociálnych sieťach Facebook a Instagram. Výsledky ukazujú, že komunikácia platformy je charakteristická tematickou hybridizáciou, dominantným zastúpením domácich spoločenských a politických tém, využívaním memetickej vizuálnej komunikácie, neformálneho jazykového štýlu a participatívneho modelu tvorby obsahu. Satira pritom neplní iba zábavnú funkciu, ale predstavuje interpretačný mechanizmus, prostredníctvom ktorého platforma rámcuje aktuálne udalosti a spoluutvára verejnú diskusiu. Štúdia rozširuje poznatky o fungovaní digitálnej satirickej komunikácie a poukazuje na význam satirických platforiem ako špecifických mediálnych aktérov podieľajúcich sa na interpretácii spoločenského diania.

Kľúčová slova sociálne médiá, digitálne médiá, satira, internetové memy, politická komunikácia, kvalitatívna obsahová analýza, Zomri

1. ÚVOD A TEORETICKÉ VÝCHODISKÁ

Súčasný mediálny ekosystém je charakteristický rastúcim významom online médií a sociálnych sietí, ktoré popri tradičných médiách predstavujú jeden z hlavných zdrojov informácií a verejnej komunikácie. Digitálne platformy umožnili vznik nových mediálnych aktérov, ktorí sa od tradičných spravodajských médií odlišujú nielen spôsobom tvorby a distribúcie obsahu, ale aj formou komunikácie s publikom. Medzi takéto subjekty patrí aj slovenská satirická platforma Zomri, ktorá prostredníctvom sociálnych sietí dlhodobo reflektuje spoločenské a politické dianie a predstavuje špecifický fenomén slovenského mediálneho prostredia.

Médiá plnia v spoločnosti viacero funkcií, predovšetkým informačnú, korelačnú, mobilizačnú, persuzívnu a zábavnú (Ježek

& Jiráček, 2014). V digitálnom prostredí sa ich význam ďalej rozširuje, keďže sociálne médiá vytvárajú priestor nielen na šírenie informácií, ale aj na interakciu používateľov, budovanie komunít a verejnú diskusiu. Zároveň významne ovplyvňujú spôsob, akým jednotlivci prijímajú, interpretujú a ďalej zdieľajú mediálny obsah.

Význam sociálnych médií spočíva aj v ich schopnosti formovať verejnú mienku. Prostredníctvom algoritmov, personalizácie obsahu a odporúčacích systémov dochádza k selekcii informácií, ktoré sa zobrazujú jednotlivým používateľom. Výsledkom môže byť vznik tzv. názorových bublín, v ktorých sú používatelia vystavovaní predovšetkým obsahom podporujúcim ich existujúce postoje (Van Bavel et al., 2021; Srba et al., 2023). K šíreniu názorov zároveň prispieva vysoká miera virality sociálnych médií, ktorá umožňuje rýchle rozšírenie obsahu prostredníctvom zdieľania a ďalších interakcií používateľov. Tento mechanizmus možno vnímať aj ako prejav širšej technologickej interferencie do spôsobu, akým jednotlivci – najmä mladšie generácie – prijímajú a interpretujú informácie o spoločenskom diania, keďže satirický a memetický obsah čoraz častejšie supluje alebo priamo nahrádza tradičné informačné a vzdelávacie zdroje.

Osobitné postavenie v online komunikácii majú internetové memy. Vďaka jednoduchému vizuálnemu spracovaniu, stručnosti a humoru predstavujú efektívny spôsob komentovania aktuálneho spoločenského a politického diania. Hoci sú často vnímané predovšetkým ako forma zábavy, mnohé z nich plnia aj informačnú a interpretačnú funkciu a môžu významne ovplyvňovať spôsob, akým používatelia vnímajú jednotlivé udalosti. V spojení so satirou vytvárajú špecifický komunikačný nástroj, prostredníctvom ktorého dochádza ku kritike spoločenských javov, verejných osobností či politických rozhodnutí.

Práve na tomto princípe je postavená aj platforma Zomri, ktorá patrí medzi najvýraznejšie satirické projekty slovenského online prostredia. Od svojho vzniku v roku 2016 si vybudovala rozsiahlu komunitu používateľov na Facebooku a Instagrame a prostredníctvom kombinácie memov, satiry, ironie a komentovania aktuálnych udalostí sa stala významným aktérom digitálnej komunikácie. Napriek tomu, že jej primárnym cieľom nie je spravodajská činnosť, jej obsah pravidelne reaguje na spoločenské a politické udalosti, čím vstupuje do verejnej diskusie a ovplyvňuje spôsob ich interpretácie. Popularita platformy zároveň poukazuje na meniace sa postavenie nových digitálnych aktérov v súčasnom mediálnom ekosystéme a otvára otázky ich vplyvu na formovanie verejnej mienky.

Vzhľadom na svoj charakter predstavuje Zomri špecifický komunikačný fenomén, ktorého postavenie v slovenskom mediálnom prostredí nie je jednoznačné. Na jednej strane nejde o spravodajské médium v tradičnom ponímaní, keďže jeho obsah je založený na satire, irónii a subjektívnej interpretácii spoločenského diania. Na druhej strane však platforma pravidelne reflektuje aktuálne udalosti, vytvára priestor na verejnú diskusiu a prostredníctvom vysokej miery interakcie so svojimi používateľmi ovplyvňuje spôsob, akým sú vybrané spoločenské a politické témy interpretované. Práve kombinácia satiry, vizuálnej komunikácie a aktívneho zapojenia komunity odlišuje Zomri od väčšiny tradičných médií aj iných digitálnych platforiem.

Význam platformy potvrdzuje aj jej rozsiahla komunita na sociálnych sieťach a skutočnosť, že jej obsah pravidelne rezonuje aj v tradičných médiách. Hoci administrátori sami deklarujú, že cieľom stránky nie je poskytovať objektívne spravodajstvo, ale satiricky komentovať spoločenské dianie, jej príspevky sa často stávajú súčasťou širšej verejnej diskusie. Platforma tak predstavuje príklad nového typu mediálneho aktéra, ktorý síce neplní všetky charakteristiky tradičných médií, no prostredníctvom svojho dosahu a komunikačných stratégií vstupuje do procesu formovania verejnej mienky.

Rastúci význam satirických platforiem v digitálnom prostredí zároveň otvára otázky týkajúce sa ich komunikačných stratégií, tematického zamerania a postavenia v súčasnom mediálnom ekosystéme. Napriek popularite platformy Zomri sa tejto problematike na Slovensku venuje len obmedzený počet odborných prác. Z tohto dôvodu sa predkladaná štúdia zameriava na analýzu komunikačných stratégií platformy Zomri, jej tematického zamerania a spôsobov, akými prostredníctvom satiry a memetickej komunikácie reflektuje spoločenské a politické udalosti. Takto koncipovaný výskum môže prispieť k lepšiemu pochopeniu úlohy nových digitálnych aktérov v súčasnom mediálnom prostredí.

2. CIEĽ A METODIKA

Cieľom predkladanej štúdie je identifikovať charakteristické znaky komunikácie satirickej platformy Zomri na sociálnych sieťach s dôrazom na tematické zameranie publikovaného obsahu a komunikačné stratégie využívané pri reflektovaní spoločenského a politického diania. Štúdia zároveň poukazuje na špecifiká komunikácie platformy v kontexte súčasného digitálneho mediálneho prostredia.

Na dosiahnutie stanoveného cieľa boli formulované nasledujúce výskumné otázky:

VO1: Aké charakteristiky vykazuje obsah publikovaný platformou Zomri na sociálnych sieťach?

VO2: Aké komunikačné stratégie využíva platforma Zomri pri sprostredkovaní spoločenských a politických tém?

Na zodpovedanie výskumných otázok bola využitá kvalitatívna obsahová analýza, doplnená o diskurzívnu analýzu a hermeneutickú metódu, ktorá umožnila interpretovať významové roviny skúmaného obsahu v širšom spoločenskom, kultúrnom a mediálnom kontexte (Hendl, 2005). Kombinácia zvolených metodologických prístupov umožnila komplexne analyzovať charakter komunikácie platformy, identifikovať jej dominantné komunikačné charakteristiky a objasniť významové súvislosti satirického diskurzu.

Výskumný súbor tvorili zámerne vybrané príspevky publikované na oficiálnych profiloch platformy Zomri na sociálnych sieťach Facebook a Instagram v prvom kvartáli roka 2026. Zámerný výber bol uplatnený s cieľom zabezpečiť tematickú aj formátovú

rozmanitosť analyzovaného materiálu naprieč všetkými stanovenými analytickými kategóriami, nešlo teda o vyčerpávajúcu analýzu všetkých príspevkov publikovaných v danom období. Analýza sa zameriavala na textovú aj vizuálnu zložku príspevkov, pričom predmetom skúmania boli predovšetkým ich tematické zameranie, formát publikovaného obsahu, vizuálne spracovanie, štýl komunikácie a využívané komunikačné stratégie. Pri interpretácii výsledkov bol zohľadnený aj komunikačný kontext jednotlivých príspevkov a ich význam vo vzťahu k aktuálnemu spoločenskému a politickému daniu.

Získané údaje boli spracované prostredníctvom vopred definovaných analytických kategórií, ktoré vychádzali z cieľa výskumu a zvoleného teoretického rámca.

Tabuľka 1: Analytické kategórie použité pri kvalitatívnej obsahovej analýze

Oblasť analýzy	Analyzované kategórie
Tematické zameranie obsahu	politika, spoločnosť, šport, zahraničné udalosti, kultúra a ďalšie spoločensky relevantné témy
Charakter obsahu	autorský obsah, používateľský obsah, prevzatý obsah
Formát príspevkov	meme, fotografia, story, video
Vizuálne charakteristiky	fotografie, screenshoty, grafické prvky, text vo vizuáli
Jazykové prostriedky	irónia, humor, hyperbola, metafora, slang, vulgarizmy, expresívne výrazy
Komunikačné stratégie	satira, participácia používateľov, dialogickosť, aktuálnosť, kontextualizácia

Zdroj: vlastné spracovanie, 2026

3. VÝSLEDKY A ICH INTERPRETÁCIA VZHLADOM K VÝSKUMNÝM OTÁZKAM

Výsledky kvalitatívnej obsahovej analýzy umožnili identifikovať charakteristické znaky komunikácie platformy Zomri z hľadiska tematického zamerania publikovaného obsahu, spôsobu jeho tvorby a využívaných komunikačných stratégií. Zistenia poukazujú na to, že jednotlivé analytické kategórie nevystupujú izolovane, ale vytvárajú vzájomne prepojený komunikačný model založený na kombinácii satiry, vizuálnej komunikácie, participácie používateľov a aktuálnosti reflektovaných tém. Z tohto dôvodu sú výsledky prezentované vo vzájomných súvislostiach, ktoré umožňujú komplexnejšie pochopiť spôsob fungovania platformy v prostredí sociálnych médií.

3.1 Charakter publikovaného obsahu a jeho tematické zameranie

Analýza publikovaného obsahu ukázala, že komunikácia platformy Zomri je charakteristická výraznou tematickou rozmanitosťou a vysokou mierou aktuálnosti. Publikované príspevky systematicky reflektovali spoločenské udalosti rezonujúce vo verejnom priestore, pričom platforma reagovala najmä na témy s vysokým spoločenským, politickým alebo mediálnym významom. Charakteristickým znakom analyzovaného súboru bola schopnosť prepájať viacero tematických rovín do jedného komunikačného celku. Jednotlivé príspevky preto len výnimočne reflektovali izolovanú udalosť. Naopak, prostredníctvom satiry prepájali politické, spoločenské, kultúrne, športové či medzinárodné udalosti a vytvárali širší interpretačný rámec, ktorý používateľom umožňoval

vnímať jednotlivé témy vo vzájomných súvislostiach. Výsledky naznačujú, že tematická hybridizácia predstavuje jeden z charakteristických prvkov komunikácie platformy a zároveň významne prispieva k jej satirickému potenciálu.

Z hľadiska tematického zamerania dominovali predovšetkým príspevky reflektujúce domácu politiku a aktuálne spoločenské dianie. Pozornosť platformy bola sústredená najmä na verejné vystúpenia politických predstaviteľov, rozhodnutia vládnej koalície a udalosti s výrazným spoločenským dosahom. Politické témy však neboli komunikované izolovane ani spravodajským spôsobom. Platforma ich pravidelne prepájala s ďalšími spoločenskými javmi, čím vznikali nové významové súvislosti založené na satirickej interpretácii reality. Takýto spôsob spracovania obsahu naznačuje, že Zomri nevystupuje ako producent primárnych informácií, ale ako subjekt, ktorý prostredníctvom humoru a irónie poskytuje vlastný interpretačný pohľad na aktuálne spoločenské udalosti.

Významné zastúpenie mali aj príspevky reagujúce na udalosti presahujúce politickú sféru. V analyzovanom období platforma intenzívne reflektovala športové podujatia, predovšetkým Zimné olympijské hry 2026, ako aj medzinárodné udalosti, ktoré boli následne interpretované vo vzťahu k domácej spoločenskej a politickej situácii. Podobný prístup bol identifikovaný napríklad aj pri témach súvisiacich s vojnovým konfliktom na Ukrajine či poškodením ropovodu Družba. Tieto udalosti neboli prezentované ako samostatné informačné celky, ale stávali sa súčasťou širšieho satirického komentára reflektujúceho spoločenskú náladu a verejnú diskusiu. Analýza tak ukazuje, že platforma systematicky pracuje s princípom kontextualizácie, prostredníctvom ktorého prepája zdanlivo nesúvisiace udalosti a vytvára nové interpretačné významy.

Analýza geografického pôvodu tém zároveň potvrdila jednoznačnú orientáciu platformy na slovenské publikum. Hoci sa v analyzovanom období objavovali aj zahraničné udalosti, ich výber bol podmienený predovšetkým ich významom pre slovenské spoločenské alebo politické prostredie. Zahraničné témy boli spravidla využívané ako prostriedok na interpretáciu domácich udalostí alebo na ich porovnanie s vývojom v zahraničí. Takýto prístup naznačuje, že platforma cielene vytvára obsah kultúrne aj spoločensky zrozumiteľný pre domácich používateľov, čím podporuje ich identifikáciu s publikovanými príspevkami a zároveň zvyšuje potenciál ich ďalšieho šírenia v online priestore.

Významným zistením je aj spôsob tvorby publikovaného obsahu. Analýza preukázala, že Zomri nefunguje výlučne ako producent vlastných príspevkov, ale využíva hybridný model tvorby obsahu založený na kombinácii autorskej produkcie, komunitných podnetov a materiálov prevzatých z tradičných médií alebo sociálnych sietí. Charakteristické pritom nebolo samotné preberanie existujúceho obsahu, ale jeho následná satirická reinterpretácia a zasadenie do nového komunikačného kontextu. Platforma tak vystupuje nielen ako autor, ale aj ako editor, kurátor a interpret digitálneho obsahu. Osobitné postavenie mali príspevky vytvárané samotnými sledovateľmi, predovšetkým tzv. „pozdravy z dovolení“, ktoré predstavovali pravidelne sa opakujúci formát komunikácie. Ich výrazné zastúpenie poukazuje na vysokú mieru participácie používateľov a zároveň naznačuje, že komunita zohráva aktívnu úlohu pri spoluvytváraní identity platformy. Konkrétnym príkladom je opakujúci sa formát, v ktorom sledovatelia zdieľajú fotografie nápisu 'ZOMRI' vytvoreného napríklad v piesku, snehu alebo na displeji telefónu na pozadí známych svetových lokalít. Tieto príspevky, publikované prevažne prostredníctvom miznúcich príbehov, dokladujú, že komunita sa nepodieľa iba na interpretácii publikovaného obsahu, ale priamo na spoluvytváraní vizuálnej identity platformy.

Z hľadiska formátu publikovaného obsahu jednoznačne dominovali obrázkové príspevky využívajúce princíp internetových memov. Ich prevaha potvrdzuje, že komunikácia platformy je postavená na stručnom, vizuálne orientovanom obsahu umožňujúcom rýchlu orientáciu používateľov v komunikovanej téme. Meme formát pritom nepredstavuje iba atraktívny spôsob prezentácie obsahu, ale plní aj významnú interpretačnú funkciu. Prostredníctvom kombinácie obrazu, krátkeho textu a kultúrne zdieľaných významov umožňuje efektívne sprostredkovať satirickú pointu a podporuje vysoký potenciál ďalšieho zdieľania obsahu. Ostatné formáty, predovšetkým príbehy (stories) a audiovizuálny obsah, boli využívané skôr doplnkovo, najmä na podporu interakcie s publikom alebo sprostredkovanie používateľského obsahu. Výsledky preto naznačujú, že výber komunikačných formátov je podriadený predovšetkým rýchlosti komunikácie, jednoduchosti interpretácie a potenciálu virálneho šírenia.

Tematické charakteristiky publikovaného obsahu zároveň úzko súvisia so spôsobom jeho spracovania. Preto bola ďalšia pozornosť venovaná analýze komunikačných charakteristík platformy, ktoré významne ovplyvňujú interpretáciu jednotlivých tém.

3.2 Charakter komunikácie platformy Zomri

Analýza komunikačných charakteristík platformy Zomri ukázala, že jej komunikácia je postavená na konzistentnom prepájaní vizuálnych, jazykových a satirických prvkov, ktoré spoločne vytvárajú ľahko identifikovateľný komunikačný štýl. Jednotlivé zložky komunikácie pritom nepôsobia izolovane, ale navzájom sa dopĺňajú a vytvárajú ucelený interpretačný rámec. Výsledný význam príspevkov preto nevzniká prostredníctvom jednej dominantnej zložky, ale kombináciou obrazu, textu, spoločenského kontextu a satirickej pointy. Práve táto synergia predstavuje jeden z hlavných faktorov odlišujúcich komunikáciu platformy od tradičných spravodajských médií aj od bežnej komunikácie na sociálnych sieťach.

Nadväzujúc na dominanciu meme formátu identifikovanú vyššie, analýza sa ďalej zamerala na spôsob jeho vizuálneho spracovania. Platforma pritom cielene uprednostňuje minimalistické grafické riešenia, ktoré neodvádzajú pozornosť od samotného významu komunikovaného obsahu. Vizuálne prvky preto neplnia primárne estetickú funkciu, ale predstavujú nositeľov významu podporujúcich satirickú interpretáciu aktuálnych udalostí. Charakteristické bolo využívanie autentických fotografií, screenshotov príspevkov, komentárov alebo mediálnych výstupov, ktoré boli často ponechané v pôvodnej podobe. Takéto spracovanie zvyšovalo dôveryhodnosť komunikácie a zároveň vytváralo dojem bezprostrednej reakcie na aktuálne spoločenské dianie. Príkladom je séria príspevkov reagujúcich na kontroverznú cenu veľkoplošnej LED obrazovky osadenej na budove Ministerstva obrany. Platforma nielen priamo reagovala na túto tému, ale prezdieľala aj odvodené obsahy vytvorené samotnými sledovateľmi – napríklad firmy, ktoré si do obrazovky graficky vložili vlastnú reklamu – čím sa pôvodne politicko-ekonomická téma stala virálnym internetovým fenoménom a platforma tak posilnila mieru vzájomnej interakcie so svojím publikom. Satirický efekt teda vznikol až prostredníctvom ich zasadenia do nového významového kontextu doplneného krátkym komentárom alebo vizuálnou úpravou.

Významnú úlohu zohrával aj jazyk komunikácie, ktorý predstavuje jeden z najvýraznejších identifikačných prvkov platformy. Analýza potvrdila dominanciu neformálneho jazykového štýlu založeného na kombinácii spisovných a nespisovných jazykových prostriedkov, expresívnych výrazov, slangových pomenovaní, anglicizmov, vulgarizmov, metafor, hyperboly či ironických prezývok. Namiesto

oficiálnych mien politických predstaviteľov platforma pravidelne používa alternatívne pomenovania a zdrobneniny, napríklad 'Šípkový Andrejko', 'Váš Peťko' alebo 'Matúš Podaj Kvietok'. Tieto prezývky vychádzajú z konkrétnych výrokov, mediálnych vystúpení alebo vzhľadu daných osôb a ich opakovaným používaním dochádza k ich ustáleniu nielen v komunikácii platformy, ale aj medzi jej sledovateľmi.

Jazyk však neplní iba funkciu sprostredkovania informácie. Výsledky naznačujú, že prostredníctvom špecifického spôsobu vyjadrovania platforma buduje vlastnú identitu, vytvára pocit blízkosti so svojim publikom a zároveň podporuje spoločné chápanie komunikovaných udalostí. Charakteristický jazykový štýl sa tak stáva významným nástrojom diferenciacie platformy od tradičných médií a zároveň posilňuje jej rozpoznateľnosť v prostredí sociálnych sietí.

Osobitnú pozornosť si zasluhuje dialogický charakter komunikácie. Platforma pravidelne využíva priame oslovenie používateľov, spoločné zámená, rétorické otázky či neformálne výzvy, prostredníctvom ktorých vytvára dojem prirodzenej konverzácie s publikom. Príkladom je ustálené oslovenie sledovateľov 'Zomríčatá', ktoré používajú tak administrátori, ako aj samotní sledovatelia. Toto pomenovanie funguje ako prejav stotožnenia sa s platformou a jej hodnotami a zároveň stiera hranicu medzi tvorcami a publikom obsahu.

Výsledky ukázali, že používatelia nevystupujú iba ako príjemcovia publikovaného obsahu, ale sú systematicky motivovaní k jeho komentovaniu, zdieľaniu a spoluvytváraniu. Takýto spôsob komunikácie podporuje vznik digitálnej komunity založenej na spoločnom humore, podobných hodnotových postojoch a aktívnej participácii jej členov. Komunikácia platformy tak presahuje tradičný model jednostranného publikovania obsahu a približuje sa interaktívnemu modelu charakteristickému pre súčasné digitálne prostredie.

Kľúčovým prvkom analyzovanej komunikácie je satira, ktorá prestupuje všetkými identifikovanými komunikačnými stratégiami. Humor, irónia, hyperbola, metafory, slovné hračky či memetická kultúra nepredstavujú samostatné komunikačné techniky, ale vytvárajú komplexný systém interpretačných prostriedkov, prostredníctvom ktorých platforma reaguje na spoločenské a politické udalosti. Satira pritom neplní iba zábavnú funkciu. Analýza ukázala, že jej prostredníctvom platforma hodnotí konanie verejných aktérov, upozorňuje na spoločenské rozpory a vytvára alternatívny pohľad na aktuálne udalosti. Význam satiry preto spočíva predovšetkým v jej schopnosti prepájať humor s kritickou reflexiou verejného diania. Platforma zároveň v ojedinelých prípadoch komunikuje bez satirického podtónu. Príkladom je príspevok publikovaný pri príležitosti výročia vraždy investigatívneho novinára Jána Kuciaka a jeho snúbenice Martiny Kušnírovej, v ktorom platforma namiesto humoru vyjadrila priamy apel na podporu novinárskej práce a spravodlivosti. Absencia satiry v takýchto prípadoch potvrdzuje, že platforma prispôbuje komunikačný register závažnosti témy.

Výsledky zároveň naznačujú, že účinnosť komunikácie platformy nespočíva v jednotlivých komunikačných prvkoch, ale v ich vzájomnom prepájaní. Jednoduché vizuálne spracovanie, neformálny jazyk, satirická interpretácia a vysoká miera participácie používateľov vytvárajú konzistentný komunikačný model, ktorý je pre publikum ľahko rozpoznateľný a zároveň podporuje jeho aktívne zapájanie do online diskusie. Práve konzistentnosť komunikačného štýlu možno považovať za jeden z faktorov prispievajúcich k dlhodobej popularite platformy a jej stabilnému

postaveniu medzi najvýznamnejšími satirickými projektmi slovenského digitálneho prostredia.

3.3 Interpretácia výsledkov vo vzťahu k výskumným otázkam

Syntéza získaných výsledkov umožnila zodpovedať obe formulované výskumné otázky a zároveň identifikovať základné charakteristiky komunikačného modelu platformy Zomri.

Vo vzťahu k výskumnej otázke VO1 možno konštatovať, že publikovaný obsah platformy je charakteristický vysokou mierou aktuálnosti, tematickej rozmanitosti a kontextového prepájania spoločenských udalostí. Výsledky ukázali, že Zomri nepracuje s jednotlivými témami izolovane, ale systematicky ich prepája do širších významových celkov. Dominancia domácich politických a spoločenských tém spolu s využívaním meme formátu naznačuje, že platforma cielene vytvára obsah reflektujúci udalosti s vysokou spoločenskou relevanciou a zároveň prispôsobený spôsobu konzumácie informácií v prostredí sociálnych médií. Charakteristickým znakom publikovaného obsahu je tiež participatívny model jeho tvorby, v rámci ktorého sa na vzniku komunikovaných príspevkov podieľajú nielen administrátori platformy, ale aj samotní používatelia.

Výskumná otázka VO2 poukázala na to, že komunikácia platformy je založená na vzájomnom prepájaní viacerých komunikačných stratégií, ktoré spoločne vytvárajú konzistentný a ľahko rozpoznateľný komunikačný štýl. Satira predstavuje základný interpretačný princíp, prostredníctvom ktorého platforma reaguje na aktuálne spoločenské udalosti. Jej účinnosť je podporená minimalistickým vizuálnym spracovaním, neformálnym jazykovým štýlom a dialogickým spôsobom komunikácie, ktorý vytvára priestor na aktívnu participáciu používateľov. Výsledky zároveň naznačujú, že význam jednotlivých komunikačných stratégií nespočíva v ich samostatnom využívaní, ale v ich vzájomnej synergii, ktorá umožňuje efektívne prepájať informačnú, interpretačnú a zábavnú rovinu komunikácie.

Na základe získaných výsledkov možno konštatovať, že platforma Zomri predstavuje špecifický model digitálnej satirickej komunikácie, ktorého podstatou je prepojenie aktuálnosti, satiry, vizuálnej memetickej kultúry a participácie používateľov. Tieto prvky nevystupujú izolovane, ale vytvárajú ucelený komunikačný rámec, prostredníctvom ktorého platforma nielen reflektuje spoločenské udalosti, ale zároveň sa aktívne podieľa na ich interpretácii a sprostredkovaní verejnej diskusie. Identifikované komunikačné dimenzie a ich vzájomné prepojenia sú synteticky znázornené v konceptuálnom modeli komunikácie platformy Zomri (Obrázok 1).



Obrázok 1: Konceptuálny model komunikácie platformy Zomri
Zdroj: vlastné spracovanie, 2026

4. DISKUSIA

Vedecká štúdia ukazuje, že komunikáciu platformy Zomri nemožno redukovať na satirickú produkciu určenú výlučne na pobavenie publika. Výsledky naznačujú, že satira predstavuje základný interpretačný princíp, prostredníctvom ktorého platforma spracúva aktuálne spoločenské a politické udalosti. Nejde teda o alternatívu spravodajstva, ale o špecifický spôsob jeho interpretácie. Tento záver korešponduje s poznatkami Višňovského (2021), podľa ktorého satira prekračuje rámec humoru a plní významnú spoločenskokritickú funkciu. Zároveň nadväzuje na framingovú perspektívu Gürana a Özarslana (2022), ktorí poukazujú na to, že médiá neovplyvňujú iba výber tém, ale aj spôsob, akým sú udalosti interpretované. Výsledky predloženej štúdie ukazujú, že práve satira predstavuje mechanizmus, prostredníctvom ktorého platforma vytvára vlastný interpretačný rámec spoločenského diania.

Druhým významným zistením je dominantné postavenie internetových memov v komunikácii platformy. Výsledky potvrdili, že meme formát nemožno chápať iba ako atraktívny vizuálny prvok podporujúci virálne šírenie obsahu. Naopak, memy predstavujú komplexný komunikačný nástroj umožňujúci prepájať obraz, text a spoločenský kontext do jedného významového celku. Tento záver podporujú aj Rogers a Giorgi (2024), ktorí internetové memy charakterizujú ako špecifický jazyk digitálnej komunikácie založený na kultúrnych zdieľaných významoch. Podobne Pecníková a Pevčíková (2023) poukazujú na to, že humor internetových memov nemožno redukovať na zábavnú funkciu, keďže významne prispieva k spoločenskej reflexii aktuálnych udalostí. Výsledky predloženej štúdie tieto závery rozširujú tým, že ukazujú, ako sa meme komunikácia stáva dominantným nástrojom interpretácie spoločenského a politického diania v slovenskom online prostredí. Príkladom takejto dynamiky bola séria príspevkov založených na vizuálnej podobnosti slovenského premiéra so zahraničnou influencerkou, ktorá na obsah priamo zareagovala na svojom profile. Tento prípad ilustruje, akým spôsobom sa pôvodne humorový obsah môže prostredníctvom interakcie samotného objektu satiry stať súčasťou širšieho virálneho fenoménu presahujúceho hranice platformy aj krajiny.

Významným prínosom výskumu je identifikácia participatívneho modelu tvorby obsahu. Analýza ukázala, že komunikácia platformy nevzniká výlučne prostredníctvom administrátorov stránky, ale je výsledkom kontinuálnej interakcie medzi platformou a jej komunitou. Používatelia sa aktívne podieľajú na vytváraní podnetov, zasielaní fotografií či návrhov príspevkov, pričom administrátori tieto materiály následne editujú, reinterpretovali a začleňujú do vlastnej komunikačnej stratégie. Výsledky tak poukazujú na hybridný model tvorby obsahu, ktorý presahuje tradičné chápanie vzťahu medzi producentom a publikom. Tento záver je v súlade s poznatkami Vicenovej a Trottiera (2020), ktorí upozorňujú na rastúci význam participácie používateľov pri vytváraní internetovej kultúry založenej na memoch, humore a digitálnom aktivizme. Predložená štúdia zároveň ukazuje, že participácia nepredstavuje iba doplnok komunikácie, ale jednu z jej základných charakteristík.

Zároveň je potrebné poznamenať, že participatívny model tvorby obsahu, ktorý táto štúdia identifikovala, prináša aj isté interpretačné riziká. Napriek vysokej miere zapojenia sledovateľov do tvorby, interpretácie aj distribúcie obsahu totiž o výslednej podobe a výbere zverejneného obsahu rozhoduje výlučne malá skupina anonymných administrátorov. Tento mechanizmus, ktorý kombinuje prvky nastoľovania tém (agenda-setting) a riadenia prístupu k publicite (gatekeeping), znamená, že napriek zdaniu kolektívnej tvorby zostáva výsledná interpretácia spoločenského diania podmienená subjektívnymi hodnotovými postojmi obmedzeného počtu jednotlivcov. Kým Vicenová a Trottier (2020) tento aspekt vnímajú predovšetkým ako prínos pre digitálny aktivizmus, výsledky predloženej štúdie naznačujú, že rovnaký mechanizmus môže v kontexte satirickej platformy s dosahom na stovky tisíc používateľov oslabovať transparentnosť interpretačného rámca, keďže hranica medzi participáciou komunity a kontrolovanou redakčnou selekciou zostáva pre bežného sledovateľa prakticky nerozpoznateľná.

Výsledky zároveň poukazujú na meniace sa postavenie satirických platforiem v súčasnom mediálnom ekosystéme. Hoci Zomri nespĺňa charakteristiky tradičného spravodajského média, jeho komunikácia vykazuje viaceré funkcie, ktoré sú tradične spájané s médiami. Popri zábavnej funkcii plní aj funkciu informačnú, interpretačnú a korelačnú, keďže systematicky reflektuje aktuálne spoločenské udalosti a vytvára priestor pre ich spoločenskú interpretáciu. V tomto smere možno výsledky prepájať s charakteristikami funkcií médií podľa Ježeka a Jiráka (2014). Súčasne nadväzujú na zistenia Van Bavela et al. (2021) a Srbu et al. (2023), ktorí upozorňujú na rastúci význam digitálnych platforiem pri formovaní verejnej diskusie a interpretácii spoločenských tém. Výsledky preto naznačujú, že satirické platformy predstavujú samostatný typ digitálnych mediálnych aktérov, ktorých význam spočíva nielen v produkcii humoru, ale aj v sprostredkovaní spoločenskej reality prostredníctvom špecifického interpretačného rámca.

Prínos predkladanej štúdie spočíva v systematickej analýze komunikácie jednej z najvýznamnejších satirických platforiem slovenského online prostredia. Na rozdiel od doterajších prác sa výskum nezameriava iba na obsah alebo humor ako izolované fenomény, ale analyzuje komunikáciu platformy ako ucelený systém prepájajúci tematické zameranie, vizuálne spracovanie, jazykové prostriedky, satiru a participáciu používateľov. Štúdia tak rozširuje poznatky o fungovaní digitálnych satirických platforiem a poukazuje na ich význam v procese interpretácie spoločenského diania.

Určitým limitom výskumu je časové vymedzenie analyzovaného obdobia a zameranie na jedinú platformu. Získané výsledky preto nemožno automaticky generalizovať na všetky satirické projekty

pôsobiace v digitálnom prostredí. Budúci výskum by sa mohol zamerať na komparáciu viacerých satirických platforiem, dlhodobý vývoj ich komunikačných stratégií alebo na skúmanie recepcie satirického obsahu zo strany používateľov sociálnych médií.

5. ZÁVER

Predkladaná vedecká štúdia sa zamerala na identifikáciu charakteristických znakov komunikácie satirickej platformy Zomri v prostredí sociálnych médií s dôrazom na tematické zameranie publikovaného obsahu a komunikačné stratégie využívané pri reflektovaní spoločenského a politického diania. Prostredníctvom kvalitatívnej obsahovej analýzy, diskurzívnej analýzy a hermeneutickej interpretácie bolo možné komplexne charakterizovať spôsob, akým platforma vytvára, spracúva a sprostredkúva obsah svojim používateľom.

Výsledky výskumu ukázali, že komunikácia platformy je založená na systematickej reflexii aktuálnych spoločenských udalostí, ktoré sú interpretované prostredníctvom satiry, humoru a memetickej komunikácie. Charakteristickým znakom publikovaného obsahu je tematická hybridizácia, prepájanie viacerých spoločenských kontextov, dominantné zastúpenie domácich politických tém a využívanie vizuálne orientovaných formátov umožňujúcich rýchlu a zrozumiteľnú interpretáciu aktuálneho diania. Významným zistením je aj participatívny charakter tvorby obsahu, ktorý potvrdzuje aktívnu úlohu používateľov pri spoluvytváraní komunikácie platformy.

Analýza zároveň ukázala, že komunikáciu Zomri nemožno redukovať iba na humor alebo zábavný obsah. Satira predstavuje základný interpretačný princíp, prostredníctvom ktorého platforma rámcuje spoločenské udalosti, hodnotí konanie verejných aktérov a vytvára priestor pre spoločenskú reflexiu. Vzájomné prepájanie vizuálnych, jazykových a satirických prvkov vytvára konzistentný komunikačný model, ktorý podporuje vysokú mieru angažovanosti publika a odlišuje platformu od tradičných spravodajských médií aj od väčšiny digitálnych komunikačných projektov.

Prínos predkladanej štúdie spočíva v systematickom spracovaní komunikácie jednej z najvýznamnejších slovenských satirických platforiem a v identifikovaní jej charakteristických komunikačných princípov. Výskum zároveň poukazuje na skutočnosť, že satirické platformy predstavujú významných aktérov súčasného digitálneho mediálneho prostredia, ktorí prostredníctvom vlastných komunikačných stratégií vstupujú do interpretácie spoločenského diania a spoluvytvárajú online verejnú diskusiu. Získané poznatky tak prispievajú k lepšiemu pochopeniu fungovania digitálnej satirickej komunikácie a môžu predstavovať východisko pre ďalší výskum zameraný na vzťah medzi satirou, internetovými memami, participáciou používateľov a formovaním verejnej komunikácie v online prostredí.

Predložená štúdia zároveň naznačuje, že v podmienkach súčasného digitálneho mediálneho prostredia už satirické platformy nemožno vnímať iba ako alternatívnu formu online zábavy, ale ako špecifických mediálnych aktérov, ktorí prostredníctvom satiry a memetickej komunikácie aktívne vstupujú do interpretácie spoločenského diania a ovplyvňujú charakter verejnej diskusie. V širšom kontexte tak výsledky štúdie prispievajú aj k pochopeniu toho, akým spôsobom technologická interferencia pretvára neformálne spôsoby získavania a interpretácie informácií najmä u mladšej generácie používateľov sociálnych médií, ktorá satirický a memetický obsah čoraz častejšie vníma ako súčasť svojho každodenného informačného repertoáru.

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Strengthening the key competences of second stage elementary schools pupils by deepening their regional awareness

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Abstrakt The paper examines the development of cross-curricular competences among lower secondary school students through activities aimed at enhancing regional awareness. It presents a case study conducted in the Czech district of Příbram and the Slovak district of Piešťany, focusing on the assessment of quality of life in four municipalities of the local region. The educational activity integrated knowledge across subjects and promoted experiential learning. Although students' achievement levels differed (82% in the Czech sample and 70% in the Slovak sample), both groups demonstrated comparable development of key competences, particularly in communication, collaboration, and organizational skills. The findings suggest that regionally oriented education enhances geographical and critical thinking, strengthens problem-solving abilities, and fosters students' attachment to the local landscape.

Key words Cross-curricular competencies, local region, regional awareness, quality of life

1. INTRODUCTION

Human–environment relationships and people's attachment to place and landscape constitute one of the oldest and most fundamental themes in geography (Tuan, 1971, among others). Contemporary geography, as an interdisciplinary and multidisciplinary field, extends far beyond the traditional study and description of territories. Likewise, school geography has moved beyond the simple memorisation of geographical concepts and facts. Within the Slovak curriculum framework for the educational area *People and Society* (National Curriculum, 2023), geography education is increasingly oriented towards developing students' ability to understand phenomena in their spatial contexts, critically evaluate them, and apply their knowledge to solving real-world problems.

Geography teaching seeks to foster tolerance, openness to diverse perspectives and socio-cultural values, as well as the ability to ask questions and search for meaningful answers (Karvánková, 2013). At the same time, it contributes to the development of cross-curricular competences associated with life in the twenty-first century. In this context, the topic of the local landscape and quality of life represents a particularly valuable educational theme. Owing

to its multidisciplinary nature, it enables meaningful connections between geography and other school subjects and supports the implementation of integrated teaching approaches aimed at developing transferable competences across disciplinary boundaries. Furthermore, learning activities linked to the surrounding environment—an area with which students have developed a mental and emotional connection since early childhood—provide a natural and non-intrusive means of strengthening their attachment to the local region and fostering the development of regional identity (Tomčíková, 2023).

The present paper reports a case study that integrates two complementary lines of inquiry: (1) students' perceptions and evaluations of the local landscape and quality of life within it, and (2) the examination of students' practical application of competences through addressing issues and challenges directly related to their local environment. In doing so, it offers a model for incorporating these themes and approaches into the context of school geography education. Furthermore, it highlights the potential of these topics not only for strengthening students' geographical thinking but also for enhancing their regional awareness, while simultaneously fostering transferable competences and promoting the integration of knowledge across different subject areas.

2. THEORETICAL FRAMEWORK OF THE CASE STUDY

Investigating the characteristics, challenges, and potential solutions of the local region through the use of empirical evidence and contextual information represents an effective approach to fostering students' interest in their immediate environment. This process contributes to strengthening students' sense of place and their attachment to the local region. At the same time, the development of transferable competences, the promotion of interdisciplinary connections, and the integration of knowledge across subject areas serve as important mechanisms for fostering regional awareness and geographical thinking. These interrelated concepts form the theoretical foundation of the present article.

2.1 Transferable Competences and Interdisciplinary Connections

Transferable competences constitute one of the fundamental pillars of contemporary education. They bridge the gap between knowledge acquisition and its practical application. The concept of competence-based education can be traced back to the United States in the 1950s (Hodge, 2007, p. 182). In Central European educational systems, a similar concept of key competences was gradually adopted during the 1990s and became an essential component of graduate profiles designed to meet labour market demands (Blaško, 2010; Černá & Likavský, 2014).

The literature employs a variety of terms, including key, cross-curricular, transferable, transversal, and generic competences (Vančo et al., 2016). Despite differences in terminology, these concepts generally refer to an integrated set of knowledge, skills, and attitudes that enable individuals to successfully manage both professional and everyday life situations. The development of such competences is understood as a lifelong process that begins in early childhood and continues through all educational stages and school activities (DeSeCo, 2001). Janík et al. (2009) and Knecht (2010) argue that these competences transcend the boundaries of individual school subjects and possess a distinctly interdisciplinary character. Their development is considered more effective than the memorisation of isolated facts and subject-specific knowledge. Consequently, contemporary education increasingly emphasises the integration of theoretical knowledge with practical skills, collaboration, and problem-solving, thereby preparing learners to respond effectively to the complex challenges of the twenty-first century.

According to the DeSeCo framework (2001), three broad categories of key competences can be distinguished:

- the ability to use language, technology, and symbolic systems effectively and interactively;
- the ability to communicate and collaborate within socially and culturally diverse groups;
- the ability to act autonomously, responsibly, and reflectively.

In the context of school education, the Czech Framework Educational Programme (RVP, 2023, p. 10) specifies *key competences* as: learning competence, problem-solving competence, communicative competence, social and personal competence, civic competence, work competence, and digital competence. The development of these competences is not achieved in isolation within individual school subjects but rather through coordinated pedagogical strategies that integrate subject content across the curriculum, that is, through the implementation of interdisciplinary connections (Schulz et al., 2019). Key competences and interdisciplinary connections thus constitute the foundation of the contemporary constructivist model of education. Their integration into the teaching and learning process promotes learning through activities and experience, thereby stimulating students' imagination, fostering their curiosity and desire to discover, and nurturing their creativity (Savage, 2011).

2.2 The Local Landscape and Human Quality of Life

In the geographical, theoretical-methodological, and didactic literature, as well as in curriculum-related documents, two areas of ambiguity can be identified in relation to the teaching of large-scale regions.

First, ambiguity arises from the understanding and use of terminology associated with these relatively small spatial units. Within the Czech and Slovak educational context, such areas are commonly referred to as the *local landscape*, *local region*, *micro-region*, or *small region* (Frey, 1973; Kandráčková & Michaeli, 1997; Madžiková, 2002; Butola, 2023; Tomčíková, 2023, among others). Although these terms are frequently treated as synonyms, certain conceptual distinctions can be identified. Terms containing the word *region* generally refer to a spatial unit defined by administrative, natural, or functional boundaries within which interactions occur among its constituent elements. Such units may include municipalities, districts, river basins, or climatic zones. In contrast, the term *local landscape* places greater emphasis on the visible physical and cultural features of a particular place, including its appearance, character, and *genius loci*. Put simply, the distinction between a *local region* and a *local landscape* may be expressed as follows: a region concerns where a place belongs, whereas a landscape concerns what a place looks like and how it is experienced.

Second, ambiguity arises from methodological issues related to teaching the local region. Students often struggle to connect broad regional characteristics with their own everyday experiences. Consequently, one of the key challenges of local region education lies in balancing abstraction with concreteness and theoretical knowledge with lived experience. This challenge manifests itself in two main ways.

- (a) Although students are generally familiar with their immediate surroundings, they may find it difficult to understand how their municipality, neighbourhood, or district functions as part of a broader regional system. This gap between lived experience and conceptual understanding can result in fragmented or superficial geographical knowledge.
- (b) A further challenge stems from the tendency to present regions as static entities within educational practice. Such an approach overlooks the dynamic processes that shape local regions, including their historical development (Driver & Samuel, 1995), local governance and politics, migration, economic transformations, cultural interactions and interdependencies, as well as environmental issues and the quality of life of local inhabitants. As a result, students may fail to recognise the local region as a continually evolving socio-spatial system influenced by multiple interconnected factors.

Effective teaching of the local landscape is closely associated with field observation, map analysis, the use of local case studies, project-based learning, and other experiential approaches. Such methods enable students to actively explore their immediate and wider surroundings, acquire knowledge about the local area, develop a sense of familiarity with their environment, and establish meaningful connections to place. Through direct engagement with issues affecting their local communities, students can gain a deeper understanding of regional contexts, spatial relationships, and the interdependence between people and place, thereby strengthening their regional identity. Consequently, the local landscape serves as an important pedagogical tool for fostering not only spatial thinking and regional and cultural awareness, but also environmental awareness.

The concept of the local region is closely linked to quality of life, as everyday living conditions are most directly experienced and manifested at the local and micro-regional levels. The local region provides the territorial framework within which access to services, employment opportunities, social networks, and environmental conditions is shaped, all of which significantly influence both objective and subjective assessments of quality of life. At the same

time, a reciprocal relationship exists: the character of the landscape, its historical development, settlement patterns, demographic structure, socio-economic activities, as well as its *genius loci* and regional identity, contribute to individuals' sense of belonging and security. These factors represent important intangible dimensions of quality of life (Cummins, 2000). Quality of life can therefore be understood as the outcome of the interaction between spatial, social, and cultural factors that are concentrated within the local region and experienced through the everyday lives of its inhabitants (Ira & Andráško, 2007).

2.3 Geographical Thinking and Regional Awareness

A central aim of geography education is to ensure that students acquire not only a meaningful and essential body of general knowledge but also the ability to understand the world in terms of interconnected relationships and processes. Geographical thinking plays a crucial role in achieving this objective by enabling learners to interpret and make sense of the world through spatial perspectives (Karvánková, 2013). It offers a uniquely powerful framework for observing and analysing both the immediate environment and the wider world across multiple scales, from the local to the global, through the examination of physical characteristics, human activities, and the complex interactions that connect them (Jackson, 2006; Bendl et al., 2024).

Geographical thinking represents a key factor in the development of regional awareness, as it enables individuals to understand territory, spatial relationships, scale, and the interconnections between different places. Through geographical thinking, learners develop the ability to perceive landscapes and regions not merely as administratively defined units but as dynamic systems embedded within a hierarchical structure of spatial entities. The interplay between geographical thinking and regional awareness promotes a deeper understanding of one's own region while strengthening place attachment and fostering a sense of responsibility towards the environment in which individuals live. Regional awareness reflects the emotional relationship between people and a particular place and develops through the strengthening of place attachment, as well as through an understanding of its spatial patterns and historical continuity (Driver & Samuel, 1995; Nikisher, 2014).

3. RESEARCH AIMS AND OBJECTIVES

The primary aim of the study was to design an instructional resource focused on the quality of life in the local region. The resource was intended to facilitate the application of students' transferable competences, integrate geography with other school subjects, and incorporate selected cross-curricular themes defined in the Czech and Slovak national curricula. An additional objective was to direct students' attention towards the environment in which they live with their families and, in many cases, were born. Indirectly, the study also sought to foster students' interest in their local region, enhance their understanding of its characteristics, strengthen their emotional attachment to a familiar environment, and thereby deepen their regional awareness.

To achieve these objectives, a case study in the form of an instructional activity was designed and implemented. Within the activity, students assumed the role of applicants seeking employment at a District Department for Project Management and Funding. Their task was to determine which of four municipalities should receive financial support aimed at improving local quality of life. The position was to be awarded to the applicant who developed and presented the most convincing and well-founded proposal.

Students' performance was subsequently analysed using their responses recorded in the worksheet, as well as data obtained from questionnaire surveys administered to both students and the teachers who facilitated the activity.

The design of the case study was guided by a set of predefined criteria that the instructional activity was required to fulfil.

(a) The activity was anchored in a geographical area that is intrinsically familiar to the students. It focused on the district in which they live, attend school, and have their homes. The term local region, referring to the district under study, most accurately captures the spatial dimension of the case study and is therefore used throughout the remainder of the paper. Four municipalities within the local region were selected through quota sampling to ensure variation in terms of size, location, and character. Municipalities in which participating students attended school or were likely to reside were intentionally excluded. Nevertheless, students could still possess family, social, or other personal ties to these localities.

(b) Throughout the activity, students worked with authentic data relating to their local region. They engaged with real-world contexts that were familiar to them either through personal experience, travel, or indirect knowledge. The instructional tasks were based on the results of questionnaire surveys and interviews conducted with randomly selected residents of the four municipalities. The purpose of this prior research was to investigate local residents' perceptions of quality of life in their respective communities.

(c) The participants were ninth-grade students from selected lower secondary schools. At this stage of schooling, students are assumed to possess the broadest range of subject-specific knowledge, skills, and learning experiences acquired throughout compulsory education. They have already developed a variety of cognitive and procedural strategies and are therefore capable of integrating knowledge from different disciplines when addressing more complex educational tasks that transcend traditional subject boundaries. Such activities may consequently be regarded as an effective means of fostering transferable competences (Knecht, 2010).

(d) A further objective of the activity was to stimulate students' ability to apply transferable competences, with particular emphasis on problem-solving competence. The study did not seek to examine the full spectrum of transferable competences, as this domain encompasses a broad and heterogeneous range of knowledge, skills, and dispositions. Instead, students were required to understand a real-world problem associated with everyday life in the local region, conceptualise and represent the problem, propose and evaluate potential solutions, and critically compare their proposals with alternative approaches. These tasks were framed within the context of assessing the quality of life in selected municipalities. The activity thus reflected the principles of learning through activity and experience (Knecht, 2010; Savage, 2011).

(e) Finally, the activity was designed to encourage the use of geographical thinking, spatial reasoning, and the ability to identify relationships and interconnections. Through each stage of the learning process, students were encouraged to develop a stronger sense of belonging to the local landscape and region, thereby fostering the development of regional awareness.

4. RESEARCH METHODOLOGY

The investigation of students' problem-solving competence within an instructional activity focused on evaluating quality of life in the local region was conducted in two stages. The first stage took place in 2017 in the Czech district of Příbram as a pilot study, followed three years later by the second stage in 2020 in the Slovak district of Piešťany. In the Příbram district, the study involved two ninth-grade

classes from ZŠ pod Svatou Horou in the town of Příbram, comprising a total of 28 students (39% boys and 61% girls). In the Piešťany district, the activity was implemented in two schools located in municipalities with the highest and lowest populations among those containing lower secondary schools (ZŠ Drahovce and ZŠ Rakovice), as well as in one urban school, ZŠ Brezová in Piešťany. Altogether, 54 students from three ninth-grade classes participated in the activity (61% boys and 39% girls).

A qualitative research design incorporating selected quantitative elements was adopted. The instructional activity was implemented in several phases: (1) an introductory phase in which the teacher facilitated a discussion of key concepts and introduced the activity to students; (2) the main phase, during which students completed the assigned tasks; (3) a questionnaire survey administered to students immediately following the activity; (4) a questionnaire-based evaluation of the activity completed by participating teachers; and (5) a questionnaire survey examining teachers' views and experiences regarding the use of instructional activities and methods aimed at fostering transferable competences and interdisciplinary connections in their teaching practice. The fifth phase is not analysed in the present paper. The first three phases were completed within a single lesson.

4.1 Teacher Guidelines

The teacher was provided with detailed guidelines on how to facilitate students' work throughout the activity. During the first 10 minutes of the lesson, the teacher employed brainstorming as an introductory method to clarify key concepts associated with the activity. The teacher then introduced the topic and the local region under investigation, explained the task requirements, and familiarised students with the instructional materials, resources, and terminology relevant to the activity (e.g., quality of life and its determinants, project management department, funding schemes). The organisational structure and timing of the activity were also outlined.

Students were subsequently organised into groups of three to four members. The teacher specified the time allocated to each phase of the activity by displaying the schedule on the board: 15 minutes for group work, 15 minutes for individual work, and 5 minutes for completion of the questionnaire. The exact deadline for submitting all completed materials was also communicated to the students.

4.2 Implementation of the Instructional Activity

The instructional activity was designed to be engaging, unconventional, and motivating for students. Particular emphasis was placed on capturing students' interest by confronting them with information related to a geographical area that was familiar and personally relevant to them. Students worked with two instructional materials:

(a) Worksheet (Figure 1) – designed to investigate students' problem-solving competences. Within the activity, students assumed the role of employees of the District Department for Project Management and Funding. Their task was to decide which of four municipalities within their local region should receive financial support aimed at improving the quality of life of its residents.

(b) Supplementary Material to the Worksheet (Figure 2) – consisting of a district map displaying the settlement structure (location and size of municipalities) and transport network, together with statements provided by residents of the four municipalities. These statements represented a combination of personal views and

experiences regarding quality of life in the respective communities. Based on this information, students were required to determine which municipality should receive funding intended to improve local living conditions. Without these contextual data, the task could not have been completed.

The instructional activity combined both individual and collaborative learning. Group work was incorporated primarily due to the limited time available within a single lesson. A further reason was that collaborative work enabled the observation of additional student competences, including civic, social and personal, and communication competences. During the group-work phase, students discussed local issues and jointly proposed potential solutions to the problems identified in the selected municipalities. This was followed by an individual work phase, during which each student recorded their own proposal and provided a justification for allocating funding to one of the municipalities in the worksheet.

4.3 Student Questionnaire

Upon completion of the instructional activity, students were asked to complete the *Student Questionnaire on Problem-Solving Competences*, which was printed on the reverse side of the worksheet. The questionnaire was based on students' self-assessment and consisted of four thematic sections.

The first section focused on students' subjective evaluation of their success or difficulties in completing the activity. The second examined students' perceptions of the materials and information provided to support task completion. The third section explored the extent to which students drew upon knowledge acquired in other school subjects when solving the tasks, thereby addressing the cross-curricular dimension of the activity. Finally, the fourth section focused on students' evaluation of the collaborative work process and their experiences of working in groups.

The questionnaire was designed to provide insight into students' perceptions of their own learning processes, their use of transferable competences, and the contribution of interdisciplinary knowledge and collaborative learning to problem-solving in a geographically grounded educational context.

4.4 Teacher Evaluation of the Instructional Activity

Students' *problem-solving competence* was assessed primarily through the analysis of the worksheet, which served as the main evaluation instrument. Assessment was conducted across three dimensions. The first concerned students' ability to identify, understand, and adequately describe the most significant issues affecting quality of life in the municipality. The second focused on the quality of the proposed solution, with particular attention paid to its realism, logical coherence, and practical feasibility. The third dimension examined students' ability to justify their proposed solutions through reasoned argumentation and to reflect on their potential consequences.

Although the study focused primarily on problem-solving competence, no competence can be developed or assessed in isolation. Consequently, several additional competences were observed throughout the activity. During discussions and collaborative work, particular attention was paid to communication competences. Group work also provided opportunities to observe students' interactions, willingness to cooperate, and ability to work effectively with others, thereby allowing aspects of social competence to be evaluated. During the individual work phase and

completion of the worksheet, work-related competences, such as time management, creativity, and independent task completion, were also assessed.

Communication competence was evaluated on the basis of the logical coherence and meaningfulness of students' written responses in the worksheet, as well as their overall ability to communicate during group work, as observed by the teachers. *Civic competence* was assessed through students' ability to formulate and defend arguments both within group discussions and in their written responses. Students' responses to the questionnaire also provided evidence of *social and personal competences*, particularly their capacity for self-reflection and reflection on the performance of their group. *Work-related competence* was evaluated according to students' ability to manage the allocated time effectively, organise their work, and estimate the time required to complete the assigned tasks.

Through their responses to the teacher questionnaire, teachers evaluated not only students' competences but also the overall implementation of the activity. Similar to the student questionnaire, teachers were invited to provide their personal views regarding students' success in completing the task, the adequacy of the time allocated, and the extent to which the amount and complexity of the information provided were appropriate for students to process and interpret.

5. DISCUSSION OF THE FINDINGS ON TRANSFERABLE COMPETENCES

The findings confirmed that the majority of students demonstrated an age-appropriate level of development of the transferable competences under investigation. This was evidenced by the analysis of the case study activity. During the introductory brainstorming session, students were generally able to explain the concept of a subsidy. In contrast, the concept of quality of life proved more challenging at the outset. Following classroom discussion, students began to associate quality of life with factors such as income, material well-being, health, environmental quality, traffic emissions, and green spaces. Students associated quality of life with concepts such as lifestyle, living standards, and financial well-being, as well as with environmental factors including traffic congestion and air pollution.

All students in the sample understood the task requirements and were able to work effectively with both the worksheet and the accompanying materials. They successfully identified local problems, and most were able to propose solutions and justify their decisions adequately. Student motivation may have been enhanced by the prospect of receiving the highest grade for the most successful solution, symbolically rewarded by the fictional position within the District Department for Project Management and Funding. For some participants, motivation also stemmed from personal familiarity with the selected municipalities; several students either knew the localities well or originated from them. Six students from the Czech sample (more than one-fifth of participants) and eight students from the Slovak sample (15%) produced particularly creative solutions that exceeded the quality of most other submissions. Their proposals were logical, realistic, well-structured, and innovative. For example, one student suggested using the funding in the municipality of Šípkové to purchase a community minibus that would transport elderly residents to shops and healthcare facilities in the district town on designated days while also serving neighbouring municipalities along the route. Approximately one quarter of students completed the activity at an insufficient level (18% of students in the Czech sample and 30% in

the Slovak sample). Although these students were generally able to identify existing problems—for example, the absence of healthcare services, retail facilities, or public transport connections—they often failed to propose meaningful and feasible solutions or were unable to justify their proposals adequately. Their responses were typically limited to general statements such as “build shops”, “establish a doctor's office”, or “create a bus stop”.

Within the Slovak sample, students' performance was also examined in relation to their most recent geography grades. On average, students with higher grades achieved better results in the activity. However, both across the entire sample and within individual schools, excellent achievement in geography (grades 1 and 2) did not automatically translate into the highest levels of success in the activity. This pattern was particularly evident among students with the highest grade in geography, who represented approximately one quarter of all participants. While most of the highest-quality solutions were produced by students with grade 1 in geography, only 15% of all students achieved the “very good” level of performance. The analysis further revealed gender differences in achievement, with girls outperforming boys by approximately 24%. Girls demonstrated higher levels of success than boys even when comparisons were made among students with equivalent geography grades. One possible explanation for this difference does not appear to be a lower level of competence among boys but rather lower engagement with the activity. Several boys explicitly stated that the most difficult aspects of the task were “thinking” about the problem and “doing the work” itself.

5.1 Students' Performance in the Instructional Activity

The overall success rate of Czech students in completing the instructional task was 82%. Of these, 21% achieved the highest evaluation category, *Very Good*, while 61% were assessed as *Average*. Conversely, 18% of students failed to complete the task successfully and received the evaluation *Insufficient*. In Slovakia, the task was successfully completed by 70% of students, representing a success rate 12 percentage points lower than that observed among Czech students. Slovak students achieved lower results than their Czech counterparts in both of the highest evaluation categories, with differences of 6 percentage points in each case. Specifically, 15% of Slovak students attained the *Very Good* evaluation, while 55% were assessed as *Average*. The proportion of students receiving the evaluation *Insufficient* reached 30% of the Slovak sample.

Although Czech students achieved a higher overall success rate, both groups demonstrated a comparable level of competence application during the activity. In certain aspects, Slovak students outperformed their Czech peers, particularly in their ability to navigate and interpret the information and supporting materials provided. Furthermore, Slovak students demonstrated a higher degree of task allocation and role distribution within their groups during collaborative work. However, these strengths were not reflected in higher overall levels of task performance or final achievement.

5.2 Assessment of Problem-Solving Competence

Students' success in completing the instructional task formed an integral part of the assessment of problem-solving competence. According to students' responses, 29% of Czech participants experienced difficulties in navigating the information and supporting materials provided. In contrast, only 7.4% of Slovak students reported similar difficulties. Furthermore, 71% of Czech

students indicated that the information contained in the supplementary materials was sufficient for successful task completion and that no additional information was required. Among Slovak students, satisfaction with the amount of information provided was even higher, reaching 80%.

In the Czech sample, six students indicated that they would have benefited from additional information. Three of them expressed a need for more detailed information regarding public transport connections, while the remaining three would have welcomed a larger number of responses from local residents. As potential sources of such information, two students identified the internet, whereas four students stated that they would have obtained the information through interviews with local inhabitants.

Within the Slovak sample, eleven students reported a need for additional information. Similar to the Czech respondents, three students suggested that a larger number of residents' statements would have been helpful, while two students indicated that information regarding the amount of available funding was missing. The remaining six students did not specify what additional information they would have required. When asked how they would obtain the missing information, most respondents referred to internet sources (five students), while six students stated that they would visit the municipality in person and seek information directly from local residents through interviews.

These findings suggest that the majority of students were able to work effectively with the information provided and demonstrated an ability to identify additional sources of information when required. At the same time, the responses indicate an awareness of the importance of both digital resources and direct engagement with local communities when addressing real-world problems in a geographical context.

5.3. Assessment of Communication Competence

Students demonstrated age-appropriate communication skills during group discussions and collaborative work. A similar level of verbal communication was observed among Slovak students. However, the assessment of written communication revealed some differences between the two samples.

In the Czech sample, 18% of students were unable to adequately justify their opinions and decisions. The corresponding proportion in the Slovak sample was 30%. Conversely, 21% of Czech students demonstrated a very high level of communication competence by effectively defending their viewpoints and supporting them with creative arguments. Among Slovak students, this level of performance was achieved by 15% of participants. The remaining responses were assessed as average, accounting for 61% of the Czech sample and 55% of the Slovak sample.

5.4 Assessment of Civic Competence

A comparison of the Czech and Slovak findings indicates a broadly similar level of civic competence in both groups. Most students actively participated in group work and classroom discussions. When presenting proposals and counterarguments, students demonstrated the ability not only to listen to and respect the opinions of others but also to engage collaboratively in the search for solutions that would serve the common good. These findings suggest that the activity provided opportunities for the development and application of civic competences associated with participation, cooperation, and responsible decision-making.

5.5 Assessment of Social and Personal Competences

Students' responses to the questionnaire, including several critical and self-critical comments, indicated a capacity for both reflection and self-reflection. Their evaluations of the outcomes and processes of group work demonstrated an ability to assess not only their own contributions but also the performance of their peers. The findings therefore suggest that students were capable of critically reflecting on their learning experiences, recognising strengths and weaknesses in collaborative work, and expressing informed opinions regarding both individual and group performance.

5.6 Assessment of Work-Related Competences

The evaluation of both studies confirmed that all participating students were able to manage the time allocated to the activity effectively and organise their work in a manner that allowed them to complete and submit the assigned tasks within the prescribed time limit. Teacher observations indicated, however, that the overall level of collaboration among students was relatively limited. During the group-work phase, students initially tended to examine the provided materials individually. Meaningful discussion generally emerged only during the latter half of the allocated time. Only a minority of groups divided the tasks among members as part of their collaborative work, and in some groups, little or no cooperation was observed.

According to students' responses, only 18% of Czech participants distributed tasks among group members and worked on designated parts of the assignment. Consequently, many groups did not fully utilise the potential benefits of collaboration, including more efficient use of time and opportunities for deeper discussion. Among Slovak students, 28% reported dividing tasks within their groups, representing a proportion 10 percentage points higher than that observed in the Czech sample. These findings suggest that Slovak students demonstrated a higher degree of cooperation, work organisation, and planning. However, this advantage was not reflected in higher overall performance outcomes (see Section 5.1).

5.7 Evaluation of Group Work by Teachers and Students

Students' evaluations of group work were remarkably similar in both countries. A majority of respondents considered collaborative work beneficial and believed that it contributed to successful task completion, including 71% of Czech students and 69% of Slovak students. Negative evaluations were likewise comparable, with 25% of Czech students and 24% of Slovak students reporting that group work did not assist them in solving the tasks. The remaining respondents were unable to express a clear opinion on the contribution of collaborative work to their performance.

These findings suggest that students generally perceived collaborative learning as a valuable component of the activity, despite the relatively limited level of cooperation observed by teachers during the implementation process. Students' responses in both studies revealed a tendency to evaluate their own contribution to group work positively. In the Czech sample, 89% of students believed that they had contributed a valuable solution to the task, while 75% reported that other members of their group had also proposed useful ideas. Similarly, 83% of Slovak students considered their own contribution to be beneficial, and 78% were convinced that the most effective solution had originated from within their group.

Particularly noteworthy were students' responses concerning participation in group discussions. A total of 14% of Czech students and 18% of Slovak students acknowledged that they had not actively participated in discussions or reported that no substantive discussion had taken place within their group. These findings suggest that although students generally perceived their own contributions positively, the quality and intensity of collaborative interaction varied considerably across groups.

5.8 Students' and Teachers' Evaluation of the Cross-Curricular Nature of the Instructional Activity

Analysis of the responses revealed substantial, yet expected, differences between students' and teachers' perceptions of the cross-curricular character of the instructional activity. Students themselves were often unaware of the extent to which the activity required the integration of knowledge from different subject areas. This was evident in approximately half of the Czech and Slovak student sample. Conversely, nearly one-fifth of students reported that they had consciously drawn upon knowledge and skills acquired in other school subjects when completing the task. Most of these students identified links with civic education, from which they had acquired an understanding of concepts such as subsidies (four students) and developed empathy-related skills (three students). One student referred to the application of basic financial literacy acquired in civic education lessons. Other students mentioned mathematics, particularly in relation to measuring distances on maps, and language education, specifically reading literacy skills developed in Slovak language classes. Approximately one-third of Slovak students and one-quarter of Czech students recognised connections between the activity and other subjects. However, despite acknowledging these links, they stated that they had not consciously applied any specific knowledge or skills from other disciplines while solving the tasks.

Teachers, in contrast, perceived the activity as having a considerably broader interdisciplinary dimension. More than half of the teachers in both the Czech and Slovak samples believed that students were required to draw upon knowledge and competences acquired in other subjects, particularly civic education and cross-curricular themes. They highlighted concepts such as subsidies, investment, and budgeting, as well as skills related to information analysis, logical reasoning, and argumentation. Teachers also emphasised the application of economic, financial, and civic literacy, which they considered integral to successful completion of the activity.

These findings suggest a discrepancy between students' and teachers' perceptions of interdisciplinary learning. While students tended to focus on the immediate task requirements, teachers were more likely to recognise the broader range of knowledge, skills, and competences embedded within the activity.

6. CONCLUSION

Contemporary geography education has moved beyond the traditional transmissive model based primarily on the memorisation of factual knowledge. Current curriculum frameworks in both the Czech Republic and Slovakia (RVP ZV; ŠVP) emphasise a competence-based approach, critical thinking, problem-solving abilities, and the meaningful integration of knowledge across subject areas. Within this framework, geography plays an important role in fostering students' spatial literacy and global competence. Topics with strong interdisciplinary potential, such as quality of life, provide opportunities to integrate natural, social, and environmental dimensions of learning.

As the immediate environment of students' everyday lives, the local landscape plays a crucial role not only in their cognitive and emotional development (Kühnlová, 1985; Madziková, 2002; Tomčíková & Čieľ, 2024), but also in the formation of personal characteristics, value orientations, and regional awareness. Geography education has traditionally created opportunities for students to explore their immediate surroundings; however, contemporary educational approaches increasingly promote a deeper understanding of sense of place, landscape perception, and students' attachment to their region. Influenced by the socio-cultural turn of the late twentieth century, behavioural and humanistic geography introduced concepts such as place identity, regional identity, and place attachment into geographical thinking. These concepts emphasise the emotional bonds between people and places while simultaneously offering new opportunities for educational practice (Chromý & Janů, 2003; Matlovič, 2010; Tuan, 2012).

The pilot study conducted in the Příbram district of the Czech Republic demonstrated the potential of this topic for the development of students' competences. At the same time, it provided a basis for comparison with research subsequently carried out in Slovak lower secondary schools in the Piešťany district. The empirical investigation of students' regional awareness and perceptions of the local landscape presented in this paper, together with the case-study-based instructional activities and their outcomes, may contribute to ongoing discussions concerning the more effective integration of geographical concepts into educational practice. Such an approach has the potential to foster students' personal, civic, geographical, and environmental literacy while promoting an understanding of sustainable landscape development.

Furthermore, the study offers insight into the extent to which students identify with their region, how they interpret quality of life within their local environment, and which mental constructs and value preferences shape their spatial perceptions. These aspects are important not only for learning processes but also for understanding the broader social and cultural relationships, as well as forms of civic engagement, that influence the development of children's regional identity and regional awareness.

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Revisiting the U.S. Emergency Management System: A Critical Analysis of the Monograph *U.S. Emergency Management in the 21st Century: From Disaster to Catastrophe* by the book's authors Cutter, Gall, and Rubin

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Abstract The monograph *U.S. Emergency Management in the 21st Century: From Disaster to Catastrophe*, published in 2025, examines the current structure, functioning, and limitations of the U.S. emergency management system at a time of escalating emergencies and crises. The authors combine empirical case studies (e.g., Hurricane Katrina, major tornadoes, and extensive wildfires in California) with an analysis of crisis management responses to these emergencies and disasters. In doing so, they evaluate the development of crisis policy in the United States, the role of FEMA (Federal Emergency Management Agency), the National Incident Management System (NIMS), and mechanisms of multi-level governance. From a legislative, legal, and institutional perspective, the monograph highlights the fragmentation of authority and the challenges associated with achieving effective integration in the absence of a unified legal framework. As such, the publication provides a valuable comparative basis for the study of integrated emergency response systems in other countries, including the Czech Republic. Although the monograph is positively evaluated for its clear writing style and empirical depth, it has also been criticized for its limited theoretical innovation and its more descriptive than explanatory analytical approach.

Key words Emergency management, integrated rescue system, U.S. emergency system, soft integration, formal integration, multi-level governance, Federal emergency management (FEMA), National Incident Management System (NIMS), comparative analysis, risk governance, disaster resilience, institutional fragmentation

1. CONCEPTUAL FRAMEWORK AND THEORETICAL FOCUS

The authors adopt the “hazard-risk-vulnerability” paradigm as the primary interpretative framework for understanding the emergency management system in the United States. Contemporary disasters are therefore understood not merely as natural phenomena, but as sociotechnical processes shaped by demographic development, land-use patterns, infrastructure, and public administration structures.

This perspective aligns the monograph with broader developments in disaster management theory, which has gradually shifted from a reactive and event-driven model toward a systemic understanding emphasizing resilience, preparedness, mitigation, and adaptive capacity.

The monograph relies primarily on an applied conceptual framework rather than on the development of an original theoretical model. The authors draw upon established concepts such as risk governance, institutional resilience, and multi-level governance. As a result, the book remains accessible to practitioners and policymakers; however, this accessibility somewhat limits its theoretical contribution.

Readers with legal or political science backgrounds will appreciate the publication's normative insights, although the text contains relatively few clearly defined analytical categories regarding institutional, legal, or organizational barriers in emergency management.

2. METHODOLOGY AND EMPIRICAL CERTAINTY

The methodological approach of the monograph can best be described as a case-study-oriented policy analysis.

The book examines numerous major disasters, including tornadoes (Joplin, Tuscaloosa-Birmingham, Moore), hurricanes (Sandy, Harvey, Irma, Maria), and California wildfires. These cases form the empirical basis for evaluating both the successes and failures of the U.S. emergency management system.

The use of case studies enables the authors to provide contextually rich insights into interactions among local, state, and federal institutions, including FEMA, NIMS, and the Incident Command System (ICS). Nevertheless, the monograph also demonstrates several methodological limitations.

Case selection appears influenced primarily by media visibility and political significance rather than by a systematically defined sampling strategy. Consequently, the analysis risks overemphasizing

highly publicized disasters while underrepresenting smaller yet structurally important emergencies.

Moreover, the integration of qualitative and quantitative data remains largely descriptive and is not sufficiently incorporated into a coherent analytical framework. The publication also fails to employ comparative case-study logic capable of isolating causal mechanisms behind successful or unsuccessful emergency responses.

From a critical academic perspective, the empirical strength of the publication lies primarily in the richness of its narrative and the policy-relevant lessons it offers, rather than in its contribution to rigorous causal explanation.

3. LEGAL AND GOVERNANCE ARCHITECTURE OF CRISIS MANAGEMENT

From the perspective of public law, the publication provides a valuable, albeit somewhat implicit, critique of the American legal framework for emergency management.

The authors repeatedly emphasize the fragmentation of authority among federal, state, and local actors, as well as the tensions between legal competence, institutional practice, and political responsibility.

Particularly significant is the analysis of FEMA's evolving role, which demonstrates how policy changes during the Trump administration contributed to the institutional weakening of the federal emergency management system's capabilities, including reductions in staffing capacity and strategic preparedness.

The publication implicitly addresses key public law concepts such as subsidiarity, federalism, and accountability; however, these concepts are not systematically theorized. A more legally focused analysis might have explored questions concerning the enforceability of federal obligations, judicial review of discretionary emergency decisions, or compensation mechanisms following catastrophic events.

Consequently, the monograph functions more as a sociological and policy-oriented analysis than as a fully developed legal-institutional study, despite providing substantial material for further legal interpretation.

4. ESTABLISHMENT OF AN INTEGRATED RESCUE SYSTEM

Throughout the monograph, the authors repeatedly emphasize the importance of interagency coordination, information sharing, and unified command structures based on NIMS and ICS. At the same time, however, they point to the persistent operational limitations of these systems during real-time emergency response operations.

The publication documents recurring problems related to interagency communication, overlapping jurisdictions, and differing levels of preparedness and training among participating agencies.

Conceptually, the book implicitly aligns with the understanding of an integrated emergency response system as a network of formally distinct yet functionally interdependent actors. Nevertheless, it does not define this concept with the same degree of terminological precision characteristic of Czech legislation governing the Integrated Rescue System.

The American emergency management framework can therefore be described as functionally integrated but formally fragmented. From the perspective of comparative legal analysis, the publication thus provides valuable indirect evidence regarding the extent to which integration may be achieved through governance mechanisms, operational coordination, and institutional practice rather than through a unified legal structure.

5. STRENGTHS AND WEAKNESSES OF THE PUBLICATION

For researchers and experts engaged in the comparative study of emergency management and integrated rescue systems, the principal strengths of the monograph lie in its empirical depth and policy-oriented analytical approach.

The publication provides a detailed and up-to-date account of the functioning of a highly decentralized emergency management system operating under conditions of increasing environmental and societal risk. The inclusion of recent disasters — particularly Hurricane Maria in Puerto Rico and the California wildfires — adds significant contemporary relevance to the analysis and illustrates the adaptation pressures confronting modern emergency management systems.

The concluding chapters of the monograph are explicitly devoted to identifying the shortcomings of the current system and outlining possible directions for future reform.

The authors identify three major interconnected challenges facing the United States:

1. the increasing scale and frequency of catastrophic events;
2. the institutional weakening of the federal emergency management system's capabilities; and
3. growing inequalities in societal vulnerability and post-disaster recovery outcomes.

In response to these challenges, the authors advocate for a more adaptive, resilient, and equitable emergency management system. They emphasize the necessity of long-term investments in mitigation strategies, community preparedness, and integrated recovery planning.

From a critical scholarly perspective, several aspects of this policy agenda deserve closer examination.

First, the authors' criticism of federal austerity measures occasionally appears politically prescriptive rather than analytically neutral. While this rhetorical approach strengthens the publication's persuasive impact, it simultaneously weakens the methodological objectivity expected from an academic monograph.

Second, the proposed reforms remain predominantly programmatic and insufficiently institutionalized. The authors repeatedly call for improved coordination, enhanced planning mechanisms, and stronger community engagement; however, they do not adequately elaborate on the legislative, administrative, or budgetary instruments necessary to implement these objectives effectively.

At the same time, the limitations of the publication are equally significant. The relatively limited degree of theoretical innovation, uneven methodological rigor, and insufficient engagement with legal-institutional analysis reduce the monograph's value as a standalone source for advanced comparative legal research.

The publication is therefore best understood as a supplementary analytical resource illustrating the operational reality of a highly fragmented yet operationally interconnected emergency management system, rather than as a comprehensive doctrinal or theoretical work.

For scholars focusing on the Czech Integrated Rescue System, the monograph primarily serves as a comparative reference point illustrating the contrast between a legally integrated but operationally complex system and a system that is operationally integrated but legally fragmented.

For readers familiar with public law theory, the book ultimately functions more as a diagnostic manifesto concerning the present condition of American emergency management than as a detailed institutional blueprint for reform.

6. OVERALL EVALUATION AND SCIENTIFIC CONTRIBUTION OF THE MONOGRAPH

Overall, *U.S. Emergency Management in the 21st Century: From Disaster to Catastrophe* represents a timely and intellectually relevant - albeit ultimately introductory, contribution to the academic and professional literature on emergency management.

Its principal value lies in synthesizing a broad spectrum of empirical evidence into a coherent account of the systemic vulnerabilities and institutional pathologies characterizing the U.S. emergency management system.

The publication successfully demonstrates the urgency of structural reform while simultaneously making the highly specialized field of emergency management more accessible to a broader audience, including students, practitioners, and policymakers.

From a critical academic perspective, however, the monograph does not provide a fully theorized, methodologically rigorous, or legally explicit analysis of the fundamental structures of emergency management governance.

For legal scholars interested in the comparative architecture of integrated emergency response systems, the publication should therefore be regarded primarily as a valuable empirical supplement suitable for secondary analysis - particularly in comparison with other national systems, including the Czech Integrated Rescue System, rather than as an independent theoretical foundation.

Despite these limitations, the monograph remains a useful and intellectually stimulating contribution to contemporary discussions concerning crisis governance, institutional resilience, and the future evolution of emergency management systems in democratic states.

Source:

1. CUTTER, Susan L.; GALL, Melanie a RUBIN, Claire B. *U.S. emergency management in the 21st century: from disaster to catastrophe*. 2nd edition. New York, NY: Routledge, 2025. ISBN 978-1032970509.

Regional Biodiversity and Environmental Education: Preliminary Outputs of the EFFUSE-win Project

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Abstract The EFFUSE-win project develops a cross-border model of field-based environmental education in the Slovak-Ukrainian border region. It connects universities, schools, experts and local communities through inquiry-based outdoor learning, laboratory activities, biodiversity documentation and digital educational tools. Pupils and students encounter scientific work directly: they observe organisms, use field and laboratory equipment, record data and interpret findings from their own region. Teachers gain methodological support and materials that can be transferred into school practice. Since April 2025, the project has involved more than 720 students from 12 schools through school events, field trips, a three-day educational programme and expert activities. Its preliminary outputs include a developing database of 183 documented organisms and a network of young scientists' laboratories supporting environmental awareness, scientific competencies and cross-border cooperation.

Keywords Environmental education, field-based learning, cross-border cooperation

1. INTRODUCTION

Environmental education is an important part of education for sustainable development, as it helps learners understand the relationship between human activities, natural processes and the condition of the environment. Cross-curricular topics such as environmental education require students to develop critical and creative thinking, including the ability to analyze problems and propose their own solutions (Sandanusová and Schlarmannová, 2020). This ability should be systematically cultivated if students are to engage in environmental protection later in life. Current challenges such as biodiversity loss, pollution, climate change, ecosystem degradation and the spread of invasive species require not only scientific and technical solutions, but also an informed society capable of responsible decision-making. Environmental education should therefore develop not only knowledge, but also attitudes, practical skills and responsibility toward nature.

This is particularly important for children and young people, whose direct contact with nature may be limited in a highly digital and technology-oriented society. If nature is experienced mainly through textbooks, screens or abstract examples, environmental problems can appear distant and unrelated to everyday life. Educational activities that bring pupils into direct contact with living organisms, habitats and local environmental issues can make nature protection more concrete, understandable and personally relevant.

Inquiry-based and field-based learning offer valuable opportunities in this context. Through observation, data collection, work with field and laboratory equipment, interpretation of findings and formulation of conclusions, pupils and students encounter science as an active process. At the same time, such activities develop broader competencies, including critical thinking, cooperation, communication, problem-solving and the ability to present one's own observations. These skills are especially relevant in environmental education, where complex problems require both knowledge and collaboration.

Cross-border regions provide a meaningful setting for this type of education. Rivers, watersheds, pollution, species distribution and ecosystem changes do not follow national borders, which creates shared environmental challenges and a need for cooperation. In the Slovak-Ukrainian border region, the Latorica and Bodrog river basin represents such a connected ecological space, where biodiversity, water quality, invasive species and human activities are relevant from scientific, educational and social perspectives.

Universities can play an important role in connecting scientific expertise with school education and public awareness. They provide access to current knowledge, laboratory infrastructure, scientific methods and methodological support for teachers. At the same time, they educate future teachers and scientists, which allows them to transform scientific knowledge into educational activities that are both accurate and applicable in school practice.

The EFFUSE-win project, *Environment For the Future by Scientific Education – work in nature*, responds to these needs by developing a cross-border model of field-based environmental education in the

Slovak-Ukrainian border region. The project connects universities, schools, experts and local communities through outdoor learning, laboratory activities, biodiversity documentation, digital educational tools and awareness-raising events.

The aim of this paper is to present the EFFUSE-win project as a case study of field-based environmental education in a cross-border region. The paper focuses on the project's educational concept, implementation process and preliminary outputs, with attention to inquiry-based learning, living laboratories, biodiversity documentation, teacher support and Slovak-Ukrainian cooperation. Since the project is still ongoing and formal evaluation of learning outcomes has not yet been conducted, the paper does not measure educational impact statistically, but analyses the project design, early implementation experience and educational potential of the model.

2. PROJECT CONTEXT AND CASE DESCRIPTION

The EFFUSE-win project is implemented as a cross-border educational and environmental initiative focused on biodiversity, environmental awareness and knowledge sharing in the Slovak-Ukrainian border region. The project belongs to the priority area of a resilient and green border region and addresses biodiversity protection and pollution reduction through joint education activities, awareness raising and cooperation between scientific, educational and regional institutions.

The project partnership is formed by Pavol Jozef Šafárik University in Košice as the Lead Partner, State University "Uzhhorod National University" and the Institute of Development of Carpathian Region. The partnership builds on previous cross-border cooperation, especially the earlier EFFUSE project, which focused on environmental protection through the study of bioindicators and their habitats in the border regions of Slovakia and Ukraine. EFFUSE-win extends this cooperation by placing stronger emphasis on educational activities, public awareness, field-based learning and the development of tools that can be used by schools and teachers.

2.1 Regional and environmental context

The regional context of the project is defined mainly by the shared natural environment of the Latorica and Bodrog river basin. River landscapes represent connected ecological systems in which changes in water quality, land use, biodiversity or the spread of invasive species can affect wider territories beyond national borders. For this reason, the project approaches the Slovak-Ukrainian border region not only as an administrative space, but also as a common ecological and educational area. This creates a meaningful basis for cooperation between institutions from both countries and for the development of shared educational content.

The project responds to several interconnected needs. From the environmental perspective, the region faces pressures related to pollution, biodiversity loss, invasive species, climate-related changes and human impact on river and landscape systems. From the educational perspective, pupils and students need more opportunities to experience nature directly, understand environmental problems in their local context and encounter scientific work in a practical and accessible way. Teachers also need methodological support, educational materials and examples that can help them connect school biology and environmental education with regional biodiversity.

2.2 Target groups and educational needs

The main target groups of the project are pupils, teachers, university students, future teachers, future scientists, experts and the wider public. Pupils and students participate in school events, field trips, laboratory activities and awareness-raising events. Teachers are involved as important mediators who can transfer selected methods, materials and experiences into school practice. University students and young researchers benefit from the connection between scientific work, educational practice and communication with non-specialist audiences. The wider public is addressed through project outputs, digital resources and activities aimed at increasing environmental awareness.

3. EDUCATIONAL MODEL OF THE EFFUSE-WIN PROJECT

The educational model of the EFFUSE-win project is built around the connection of four components: direct work in nature, laboratory-based activities, digital biodiversity resources and teacher support. These components are not implemented separately, but as linked parts of one educational process. Pupils first encounter environmental topics through observation and practical activity, then continue by working with collected or demonstrated material, interpreting findings and connecting them with broader questions of biodiversity, pollution and nature protection.

The model is designed to move learners from experience to understanding. Instead of presenting environmental problems only through explanation, the project creates situations in which pupils can observe organisms, habitats or selected environmental phenomena directly. This is followed by guided discussion, simple scientific description and interpretation. In this way, project activities connect sensory experience, scientific procedure and environmental meaning.

3.1 Direct contact with scientific work

A central element of the model is the opportunity for pupils and students to experience selected aspects of scientific work. During project activities, participants work with microscopes, field equipment, laboratory tools and biological material. They observe organisms, compare visible structures, record information and describe what they see. These activities help transform science from an abstract school subject into a practical activity based on observation, evidence and interpretation.

The educational value of this approach lies in its accessibility. Pupils are not expected to perform advanced research tasks, but they are introduced to the basic logic of scientific work. They learn that scientific knowledge begins with careful observation, precise description and questions about relationships in nature. This experience can support their understanding of biology and environmental topics, while also helping them recognize science as a possible part of their future studies or professional interests.

3.2 Development of scientific and transferable skills

EFFUSE-win activities support the development of scientific competencies such as observation, comparison, classification, work with data, use of instruments and formulation of simple conclusions. These skills are developed through concrete tasks rather than through theoretical instruction alone. For example, when pupils observe selected organisms or environmental samples, they must

focus attention, distinguish relevant features and communicate their findings.

The ability to identify organisms is considered one of the basic prerequisites for understanding biological diversity and ecological relationships (Randler, 2008). Since understanding the importance of biodiversity is one of the key goals of biology education, activities focused on observation and identification can help pupils connect practical work with broader ecological knowledge.

At the same time, many activities are organized in a way that supports transferable skills. Pupils often work in groups, divide tasks, discuss observations and present results. This strengthens communication, cooperation, responsibility within a team and the ability to explain one's own reasoning. These skills are important in environmental education because environmental problems are rarely solved individually; they require shared understanding, discussion and cooperation.

Topics related to biodiversity and organismal diversity are often difficult for students to understand because of their complexity. They include not only the taxonomic classification of organisms, but also ecological relationships and adaptations to the environment. For this reason, effective and innovative approaches are needed to make these topics more accessible to students (Gafur et al., 2024).

3.3 Role of teachers and transfer into school practice

Teachers are important participants in the project model, not only accompanying persons. Their presence allows project activities to become part of a wider educational process that can continue after a single event. During school events, field trips and laboratory activities, teachers can observe methods, tasks and forms of explanation that may be adapted for their own teaching.

The project also supports teachers through educational materials, video tutorials and examples connected with regional biodiversity. These resources are intended to make field-based and practical environmental education easier to implement in school conditions. They can help teachers introduce local organisms, field observation or simple scientific procedures into lessons, even when schools have limited equipment or time for outdoor activities.

3.4 Living laboratories for young learners

The planned network of young scientists' laboratories strengthens the practical dimension of the project. The biology living lab, environmental solution lab and science lab are designed as spaces where pupils and students can encounter scientific work in a more direct and structured way than is usually possible in regular classrooms. The laboratories provide access to equipment, expert guidance and activities that connect school knowledge with practical investigation.

Their function is not only technical, but also motivational. For many pupils, such laboratories may represent one of the first opportunities to work in an environment associated with real science. This can help reduce the distance between school biology and scientific practice. By involving students in activities where they can apply theoretical knowledge to real-world situations, laboratories can support the development of critical thinking and foster a sense of discovery and inquiry (Asad and Kramer, 2024). They also create conditions for repeated activities, teacher cooperation and the future development of educational programmes focused on biodiversity, environmental quality and nature protection.

3.5 Digital database as a bridge between fieldwork and education

Technological advancements and lifestyle changes increasingly influence educational practice, including the ways in which students encounter biological and environmental topics. An effective approach can combine experiential outdoor learning with instruction in specialized biology classrooms, while also using engaging elements such as computer technology (Sudzinová, 2021). In this context, digital tools can extend the value of field and laboratory activities by making collected information accessible for further teaching and learning.

The organism database developed within the project connects biodiversity documentation with educational use. Its purpose is not only to collect records of organisms from the studied cross-border region, but also to make regional biodiversity accessible to pupils, students and teachers. The database can serve as a source of examples for lessons, field activities and project-based school work.

By working with organisms documented in their own region, pupils can better understand the diversity of local nature. For teachers, the database provides practical support in preparing educational content that is regionally relevant and connected with real environmental surroundings. It extends the educational impact of field and laboratory activities beyond individual events. The use of digital technologies can improve and develop students' skills, increase motivation and engagement, and help them connect what they learn with the real world (Bartošovič and Tamášková, 2023). In this way, the database extends the educational impact of field and laboratory activities beyond individual events.

3.6 Linking environmental education with regional responsibility

The educational model of EFFUSE-win combines scientific experience with the idea of regional responsibility. Pupils are encouraged to see nature not as a distant object of study, but as part of the environment in which they live. By connecting observation, practical work, local biodiversity and cross-border cooperation, the project helps create conditions for a more informed and responsible relationship with nature.

This model does not depend on one isolated activity. Its strength lies in the combination of repeated school events, field experiences, laboratory infrastructure, teacher support and digital outputs. In science education, hands-on, student-centered instruction is essential because it enables a better understanding of natural phenomena through direct experience and supports a deeper grasp of biological concepts (Šorgo and Špernjak, 2012).

Together, these elements form a practical educational framework that can support environmental awareness and scientific competencies while remaining connected to the real environmental context of the Slovak-Ukrainian border region.

4. IMPLEMENTATION AND PRELIMINARY OUTPUTS

The EFFUSE-win project started its implementation on 15 April 2025. Since then, several types of educational, field-based and expert activities have been carried out in Slovakia and Ukraine. These activities were designed to connect school education with practical experience in nature, scientific observation and environmental awareness.

By the current stage of implementation, the project has organized 15 school events, including 3 events in Ukraine, 4 field trips, including 2 in Ukraine, 1 three-day outdoor educational event and 7 expert field trips. The activities differed in their specific content and setting, but they shared a common aim: to bring environmental topics closer to pupils and students through direct experience, practical tasks and contact with scientific methods.

School events focused mainly on introducing pupils to selected biological and environmental topics in an accessible and practical form. Field trips allowed participants to observe organisms, habitats and environmental relationships outside the classroom. Expert field trips supported the documentation of biodiversity and contributed to the preparation of educational content and database materials. The three-day educational programme combined several forms of learning, including field activities, scientific tasks and experiential contact with the aquatic environment.

4.1 Participation of schools and students

The project has so far involved more than 720 students from 12 schools in Slovakia and Ukraine. This participation indicates the educational reach of the project and its ability to involve pupils from different parts of the cross-border region. The activities were implemented with the participation of teachers, who played an important role in connecting project events with the school environment.

The involvement of schools from both countries is important for the cross-border character of the project. It allows environmental education to be connected with a shared regional context and supports the idea that river landscapes, biodiversity and environmental problems should be understood beyond national borders. Although the current outputs do not yet measure changes in students' knowledge or attitudes, the number and diversity of implemented activities show that the project has created a functional platform for further educational work.

4.2 Biodiversity documentation and database development

An important preliminary output of the project is the documentation of organisms in the studied cross-border region. So far, 183 organisms have been documented. This number includes 13 microorganisms, 30 higher plant species, 116 invertebrate species and 24 vertebrate species. The collected data provide valuable visual material that can support organism identification. This is consistent with studies on the effectiveness of visual identification guides; for example, Wäldchen et al. (2022) pointed out that recognition based on visual elements may be more successful than recognition based on verbal descriptions.

The organism database has both educational and informational value. From an educational perspective, it provides teachers and pupils with regional examples that can be used in lessons, field activities and project-based learning. From a broader perspective, it contributes to raising awareness of the biodiversity present in the Slovak-Ukrainian border region. The database also supports digital education, as it makes information about local organisms accessible through the project website and related educational materials.

4.3 Educational materials and digital outputs

In addition to field and school activities, the project develops educational materials intended to support teachers and students.

These include resources available through the project website and video tutorials focused on selected methods and organism groups. Some materials demonstrate how to capture, observe and present selected invertebrates and other organisms in a way that can be adapted to school conditions.

These outputs are important because they extend the project beyond individual events. Teachers can return to the materials after the activities and use them as support for their own teaching. Digital resources also help make the project outputs more accessible to schools that may not be able to participate directly in every field or laboratory activity. In this way, the project strengthens the sustainability and transferability of its educational approach.

4.4 Preliminary educational observations

Formal evaluation of learning outcomes has not yet been conducted; therefore, the project's educational impact cannot be interpreted statistically at this stage. However, informal responses from participating students and teachers suggest that practical work with organisms, scientific tools and field activities is perceived positively. Teachers have particularly appreciated the practical character of the activities and the possibility of using selected methods, materials and regional examples in school education.

These observations should be understood as preliminary implementation experience rather than verified research results. They nevertheless indicate that the project model has potential to support students' interest in biology, environmental topics and scientific work. Future stages of the project should include systematic evaluation, for example through questionnaires, interviews, observation protocols or analysis of student outputs.

4.5 Cross-border implementation experience

The implementation of project activities has also confirmed the importance and complexity of cross-border cooperation. Slovak and Ukrainian partners contribute complementary expertise, methodological approaches and institutional capacities. The joint development of the organism database, educational activities and project outputs supports the creation of a shared educational space focused on regional biodiversity and environmental awareness.

At the same time, the project has been influenced by practical constraints. Direct travel from the Slovak university side to Ukraine is currently restricted, which limits opportunities for in-person observation of partner activities in Ukraine. Part of the cooperation has therefore moved to online communication. In-person meetings remain possible mainly on the Slovak side, where Ukrainian partners have already participated and where further joint meetings are planned. This experience shows that flexible forms of cooperation are necessary for maintaining cross-border educational projects under changing external conditions.

Overall, the preliminary outputs of the EFFUSE-win project demonstrate progress in three connected areas: educational outreach, biodiversity documentation and institutional cooperation. The implemented activities have created a basis for further development of field-based environmental education, while the database, laboratory infrastructure and teaching materials provide tools that can continue to support schools and teachers in the next stages of the project.

5. CONCLUSIONS

The EFFUSE-win project demonstrates how environmental education can be strengthened when it is connected with direct experience, scientific practice and regional relevance. Its main value lies in creating an educational model in which pupils do not encounter nature only as curriculum content, but as a living environment that can be observed, studied and understood through practical activity. Fieldwork, laboratory tasks, biodiversity documentation and digital resources together create conditions for more active and meaningful learning.

The project also shows the importance of cooperation between universities and schools. Universities provide scientific expertise, equipment, methodological support and access to current knowledge, while schools bring this knowledge into the educational reality of pupils and teachers. This connection is especially valuable in biology and environmental education, where practical experience is often limited by school infrastructure, time or available resources.

A significant strength of the project is its cross-border dimension. The Slovak-Ukrainian border region shares environmental systems and challenges that cannot be understood only from a national perspective. By focusing on regional biodiversity and river landscapes, the project helps present environmental protection as a shared responsibility. The developing organism database, educational materials and planned laboratory network create outputs that can remain useful beyond individual events.

At the current stage, the project results should be interpreted as preliminary implementation outputs, not as evidence of measured educational impact. The number of involved students, schools and activities confirms the project's educational reach, while informal feedback suggests positive reception among participants and teachers. However, future work should include systematic evaluation of learning outcomes, changes in environmental attitudes, motivation toward science and the practical use of project materials in schools.

Despite implementation challenges, including limited mobility and administrative processes, EFFUSE-win provides a transferable example of environmental education based on cooperation, local biodiversity and active learning. Its experience suggests that bringing scientific work closer to pupils can support environmental

awareness, strengthen scientific competencies and help build a more responsible relationship with nature in cross-border regions.

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The Effectiveness of NotebookLM Podcasts in ESP Classes

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Abstract The study evaluates the contribution of AI-generated podcasts from Google NotebookLM to English for Specific Purposes (ESP) instruction. A six-week quasi-experiment examined listening comprehension and technical vocabulary acquisition among 20 engineering students at the Faculty of Mechanical Engineering at the University of Žilina in Žilina. Technical texts were converted to podcast format using the Audio Overview feature. Student progress was assessed through three tools of increasing cognitive demand: a listening comprehension test, an inferential reasoning task, and a written summary requiring productive use of terminology. The findings suggest that AI-generated podcasts can effectively support listening development and terminology acquisition, provided that the pedagogical approach accounts for differences between proficiency levels.

Key words NotebookLM, ESP listening comprehension, terminology acquisition, AI-generated podcast, cognitive load

1. INTRODUCTION

Students at the Faculty of Mechanical Engineering, University of Žilina, face several challenges that present a significant pedagogical issue for teachers of English for Specific Purposes (ESP). One identified challenge is the insufficient availability of authentic audio materials targeting the specific domains of mechanical engineering. Commercially available audio materials are typically too general and do not contain the technical terminology and discipline-specific discourse required in ESP instruction. Audiovisual materials documenting technological processes, by contrast, offer valuable visual context but frequently contain only limited spoken specialist discourse. ESP teachers, therefore, find themselves in a position where they must either work with materials that do not match the professional profile of their students or invest considerable time in developing their own resources. As a result, students have limited opportunities for the systematic development of listening skills and the acquisition of terminology through audio materials. The insufficient availability of such materials consequently restricts the development of their professional communicative competence in English.

This identified gap prompted an investigation into the potential of the Google NotebookLM platform as a tool for creating audio materials. The platform's Audio Overview feature enables

the transformation of technical texts into podcast format. Unlike conventional generative tools, the outputs generated by NotebookLM are grounded in the source documents, which, according to available studies, reduces the risk of hallucinations and contributes to the preservation of domain-specific terminological register (Reyna, 2025; Tufino, 2025). The platform, therefore, represents a promising means of addressing the identified gap.

Before integrating the platform into instruction in the winter semester of 2026, we first considered it essential to evaluate its effectiveness to ensure that it would meaningfully support students' learning. The current research literature does not provide convincing evidence that AI-generated podcasts develop language skills. There are additional grounds for caution. Albrecht-Crane (2025) warns that overly fluent and frictionless content may reduce students' cognitive effort. When content does not present an adequate challenge, students may process it in a predominantly passive manner. Passive reception of information alone, however, is not sufficient for effective learning. From the perspective of cognitive psychology, managing an appropriate level of cognitive load is a necessary precondition for the durable acquisition of linguistic structures. In other words, the high fluency of AI-generated content may create an illusion of learning, leading students to believe they have understood the material even though they have not engaged in the deeper cognitive processing necessary for meaningful learning.

This tension between ease of engagement and the conditions required for learning became the central question of our study. Over six weeks, we examined whether the regular integration of AI-generated podcasts into ESP instruction improved listening skills and terminology acquisition among B1- and B2-level students. Student progress was assessed through three tasks of increasing cognitive demand. The first verified basic comprehension of the audio text. The second targeted the ability to draw inferences not explicitly stated in the podcast. The third task assessed the ability to use terminology productively in written output. The combination of these three metrics enables distinguishing between situations in which AI-generated podcasts genuinely support learning and those in which they create the appearance of learning.

2. COGNITIVE CHALLENGES OF AI

Whether artificial intelligence supports learning depends on its capacity to generate contextualised and adaptive interaction, rather than on the mechanical transmission of knowledge. Therefore, the value of modern educational technology lies not in providing ready-made information, but in its capacity to adapt dynamically to learners' needs in real time. This premise is supported by Kestin et al. (2024), who found that personalised learning through AI tutors had significantly better post-test results than traditional forms. Although that research was conducted in the exact sciences, its methodological conclusions carry broader didactic relevance. They suggest that when technology functions as a partner in the learning process, it can substantially increase instructional effectiveness. This capacity for adaptive interaction provides the foundation for contemporary foreign language teaching methodologies designed to develop complex communicative competencies.

This opening argument leads directly to the question of technological reliability and accuracy, which is particularly important in ESP instruction. The integration of platforms based on retrieval-augmented generation (RAG) architecture represents a significant step towards ensuring terminological consistency and subject-matter precision. Unlike generative models that draw on open data sources, RAG-based systems restrict output generation exclusively to documents explicitly uploaded by the user. Reyna (2025) situates Google NotebookLM within the paradigm of adaptive learning and emphasises that its RAG architecture anchors all outputs to user-provided sources, substantially reducing the risk of hallucinations. In the context of ESP instruction, this feature is particularly significant, as factual and terminological inaccuracies represent the main barriers to trust in AI tools. Addressing these risks creates a more reliable environment in which students can confidently develop terminology and professional competencies.

Despite these advantages, the formal fluency of AI outputs carries a risk of cognitive offloading that may paradoxically reduce critical thinking and lower language acquisition. When technology assumes too large a share of the cognitive load, it can weaken the active processing of information that sustained learning requires. Polverini and Gregorcic (2024) highlight the limitations of AI as an autonomous problem-solving tool, while Albrecht-Crane (2025) and Gerlich (2025) further point out that the immediate availability of answers may reduce students' cognitive engagement and limit deeper learning processes. In language learning, this issue relates to Krashen's (1985) input hypothesis ($i+1$), which proposes that meaningful progress occurs when learners are exposed to language input that slightly exceeds their current level of competence. This tension between technological fluency and the requirement for cognitive challenge forms the core of our study. For this reason, relying solely on assessments of basic text comprehension is insufficient, given that such measures may be confounded by passive content reception. Therefore, we decided to examine the depth of inferential processing and students' ability to apply terminology productively in new contexts. Only the combination of these three metrics enables us to determine whether AI-generated content within the NotebookLM environment supports the development of listening skills and terminology.

3. METHODOLOGY

3.1 Research Design and Hypotheses

The primary methodological aim of the study was to verify the effectiveness of AI-generated podcasts for developing listening skills and acquiring mechanical engineering terminology

in a university context. To capture the fine-grained temporal dynamics of student progress, all three assessed metrics were monitored longitudinally over six weeks. Effectiveness was evaluated based on the systematic increase in students' scores across the assessment period. For each group and each week, basic descriptive statistics were calculated, specifically the mean and standard deviation, both for the sample as a whole and separately for the B1 and B2 proficiency levels. This step enabled the formulation of two research hypotheses. The first hypothesis tested whether exposure to the podcasts produced a statistically significant monotonically increasing trend in weekly scores, examined separately for the B1 and B2 groups. The second hypothesis examined whether both groups followed the same developmental trajectory over time or whether their learning curves diverged to a statistically significant extent.

3.2 Statistical Methods

To test the first hypothesis, Page's trend test was selected in preference to the more commonly used Friedman test. This choice was methodologically justified by the greater statistical power of Page's test for verifying pre-specified ordinal hypotheses that assume a clearly defined ascending trend from W1 to W6 (Hendl, 2006; Rublík, 2011). Testing was conducted independently for each metric and for each proficiency group at a significance level of $\alpha = 0.05$. As no single standardised effect size index exists for Page's test, practical significance was quantified using the standardised z-score derived from Page's L statistic (Peng and Chen, 2015). The generalised Spearman rank correlation coefficient ρ was calculated, and results were interpreted according to Cohen's scale (Cohen, 1988; Field, 2026).

The second hypothesis was tested through profile analysis (Anděl, 1998; Lehmacher, 1978). Profile analysis enabled a comparison of the score development trajectories of the two independent groups by examining their parallelism, overall level, and changes over time. When the analysis revealed differences between the groups' score trajectories, it was further used to determine the specific weeks in which statistically significant divergences occurred. All tests were conducted at a significance level of $\alpha = 0.05$. The profile analysis allows the six-week process to be treated as a single integrated dynamic system. This comprehensive statistical approach therefore provides methodological evidence for determining whether AI-generated podcasts reduce differences among students or whether the benefits of their implementation remain dependent on students' initial levels of language proficiency.

3.3 Participants and Intervention Procedure

The research sample consisted of 20 students enrolled in the degree programmes Mechanical Engineering Technologies and Computer-Aided Design and Simulation, taking the compulsory course Technical English for Engineers 2 at the University of Žilina. Participants' initial level of language proficiency was assessed using the standardised Oxford Quick Placement Test (OQPT), which provided the data necessary to divide the sample analytically into two equal groups reflecting distinct proficiency levels: ten students at B1 level with a mean score of 32.4 (SD = 2.1), and ten students at B2 level with a mean score of 44.7 (SD = 3.3).

Each week constituted one measurement cycle. Teachers uploaded a weekly text compiled from authentic English-language engineering articles to NotebookLM and used it to generate a two-host conversational podcast with an average duration of 9.4 minutes. Each podcast was checked for factual accuracy before deployment,

following the quality-control protocol recommended by Tufino (2025). Students listened to the podcast twice. The first listening focused on comprehension, the second on noting terminology. Student progress was quantified using three assessment metrics with progressively increasing cognitive demands, enabling the tracking of development from accurate recognition of linguistic forms and inferential reasoning to the productive use of terminology.

3.4 Metrics

The first metric was a combined listening comprehension test (M1), designed to assess two different levels of receptive sub-skills. The metric comprised two task types, a cloze test and a multiple-choice test, to eliminate the risk of distortion from a one-sided methodology. The cloze task contained ten gaps selected from the podcast transcript. For example, in the unit on ultrasonic machining, one item stated: *"In ultrasonic machining, the abrasive ____ is circulated between the vibrating tool and the workpiece,"* requiring students to identify the precise technical term *slurry*. The multiple-choice test assessed global comprehension through questions such as *"What is the main advantage of ultrasonic machining over conventional machining according to the podcast?"*, where the selection of the correct option (c), *the ability to machine hard and brittle materials without significant thermal damage*, depended on following an argument developed across multiple speaking turns. The combination of these tasks made it possible to capture not only the immediate decoding of a specific linguistic form, but also the student's capacity to reconstruct broader informational relationships within discourse. Metric M1 thus provided a reliable quantitative basis for evaluating listening comprehension and the basic retention of explicitly presented information.

The second metric was a five-item inferential reasoning task (M2), designed to elicit a qualitatively distinct and cognitively deeper level of processing. The defining constraint was that the correct answer to each question was never stated directly in the podcast. Each item required the student to independently derive a logical conclusion that was implicitly entailed by the content but never verbally expressed. One item from the ultrasonic machining unit illustrates this: *"The podcast states that ultrasonic machining removes material through abrasive action rather than cutting and produces minimal heat... What can you infer about its suitability for machining heat-sensitive materials compared to conventional machining?"* Since the podcast does not directly address the suitability for heat-sensitive materials and only describes the material removal mechanism, arriving at the correct solution requires students to integrate multiple pieces of information presented across different sections of the podcast. Whereas M1 primarily assessed auditory memory, M2 examined deeper comprehension by determining whether students could independently process a received concept and transform it into new logical relationships. Therefore, the introduction of the inferential metric M2 marked a substantive cognitive boundary between passive text decoding and active intellectual processing.

The third and most demanding metric was a written summary of the podcast content in the student's own words (M3), evaluated according to the frequency and appropriateness of productive use of target terminology. Unlike the preceding tasks, this exercise was completed without access to notes or written support to maximise the demands placed on the student's ability to convert passively retained lexical units into active vocabulary. In the unit on ultrasonic machining, the monitored terminological register included the terms *abrasive slurry*, *vibrating tool*, *material removal rate*, *brittle materials*, and *surface finish*. The difference in production quality

was pronounced. A B2-level student integrated the terminology into a structurally complex response: *"In ultrasonic machining, a vibrating tool transmits high-frequency oscillations to the abrasive slurry, so we can machine hard and brittle materials with a perfect surface finish"*, achieving a high type-token ratio (TTR). A lexically impoverished response with a low TTR, by contrast, consisted only of the mechanical repetition of basic phrases: *"The tool vibrates. The machine removes material."* Within the overall research design, metric M3 served as the final productive indicator of terminological acquisition.

4. DISCUSSION

Initial analysis of the obtained data indicated a clear performance differentiation between the two proficiency levels, with B2 students consistently achieving higher mean scores across all three metrics. As shown in Table 1, for basic listening comprehension (M1), the B2 group achieved a mean score of 72.89 (SD = 4.58), while the B1 group value was 63.69 (SD = 4.58). A similar but more significant gap was for inferential accuracy (M2), where B2 students achieved a mean of 54.51 (SD = 9.21), while the B1 group stagnated at 39.49 (SD = 5.33). The most substantial difference was observed in productive lexical density (M3). The B2 group absorbed and applied terminology at a mean level of 0.48 (SD = 0.38), whereas the B1 group showed near-zero initial and mid-term production, with an overall mean of only 0.03 (SD = 0.38). These data show that task cognitive demand amplifies the gap between the groups. Whereas for passive decoding (M1) the difference in means is approximately 9 points, for complex deductive reasoning (M2) and active vocabulary use (M3) the asymmetry becomes the dominant characteristic of the distribution.

Table 1: Descriptive statistics for individual metrics in the B1 and B2

Metric	Mean B1	SD B1	Mean B2	SD B2	Mean B1+B2	SD B1+B2
M1	63,69	4,58	72,89	4,58	68,29	7,04
M2	39,49	5,33	54,51	9,21	46,99	10,63
M3	0,03	0,38	0,48	0,38	0,26	0,36

A detailed examination of results across the time horizon from week one to week six (W1 to W6) revealed a consistent upward trend in mean scores for both groups, though with differing internal dynamics. This increase is captured in Table 2 and visually verified by the figures (Figures 1 to 3), which confirm a steady progression towards higher performance. Analysis of basic comprehension (M1; Figure 1) indicates that both groups experienced a significant increase between the initial two weeks (W1–W2) and the final two weeks (W5–W6), with the B1 group reaching a final score of 71.69 and the B2 group 76.98. In inferential reasoning (M2; Figure 2), the B1 group demonstrated progress mainly between the initial phase and the final week, achieving a score of 43.64, whereas the B2 group showed a stronger and more consistent upward trajectory, reaching 67.51 in W6. The most critical pattern was observed for lexical production (M3; Figure 3). B1 students demonstrated no productive lexical output from W1 to W4; the first evidence of actual term acquisition appeared only in W5 (0.01), followed by a substantial increase in W6 (0.19). The B2 group, by contrast, accelerated productive term use continuously from W1 (0.06) through to a final value of 0.94 in W6. This weekly distribution reveals a key analytical finding: the growth trend is not internally homogeneous. The stagnation of the B1 group means for metric M3

during the first four weeks provides both visual and mathematical evidence of a latent learning phase, in which the absence of visible performance masks an internal accumulation of knowledge that was fully released only in the final block. Analysis of the weekly profiles clearly shows that AI-generated podcasts stimulate progress in all students. The trajectory of the transformation from passive listening to active written production is non-linear and dependent on the student's initial level of proficiency.

Table 2: Descriptive statistics for individual metrics by week

	M1		M2		M3	
	Mean B1 (SD)	Mean B2 (SD)	Mean B1 (SD)	Mean B2 (SD)	Mean B1 (SD)	Mean B2 (SD)
W1	56,36 (4,35)	67,70 (3,24)	37,46 (3,37)	41,97 (2,97)	0 (0)	0,06 (0,08)
W2	59,40 (3,51)	69,49 (2,77)	34,54 (3,67)	47,81 (3,99)	0 (0)	0,31 (0,25)
W3	62,83 (2,90)	73,22 (4,49)	38,04 (5,17)	52,99 (4,13)	0 (0)	0,28 (0,24)
W4	63,36 (3,18)	73,48 (3,97)	40,30 (2,83)	56,28 (3,90)	0 (0)	0,45 (0,21)
W5	68,52 (1,80)	76,47 (2,31)	42,94 (5,57)	60,47 (4,97)	0,01 (0,03)	0,84 (0,26)
W6	71,69 (2,92)	76,98 (2,10)	43,64 (4,19)	67,51 (3,84)	0,19 (0,19)	0,94 (0,19)

4.1 Metric 1: Listening Comprehension

Longitudinal analysis from W1 to W6 revealed a consistent upward trend in both groups. For basic comprehension (M1), the B1 group ended the experiment at 71.69 and the B2 group at 76.98. Page's trend test confirmed a highly significant upward direction over time for both groups. The B1 group displayed a pronounced ordinal trend: $L = 888$; $p < 0.001$; $ES = 6.18$; $\rho = 0.87$, indicating a large effect size. The B2 group achieved an analogously significant, though more moderate, upward trend: $L = 855$; $p < 0.001$; $ES = 4.85$; $\rho = 0.69$. Profile analysis confirmed that the growth curves of both groups followed the same trajectory over time. Both groups thus progressed at a comparable rate, regardless of entry-level proficiency. The larger effect in the B1 group suggests that the audio input held higher relative value for these students and functioned as a more powerful accelerator of progress. The results for metric M1 confirm that AI-generated podcasts function as a reliable tool for improving basic comprehension across the full sample.

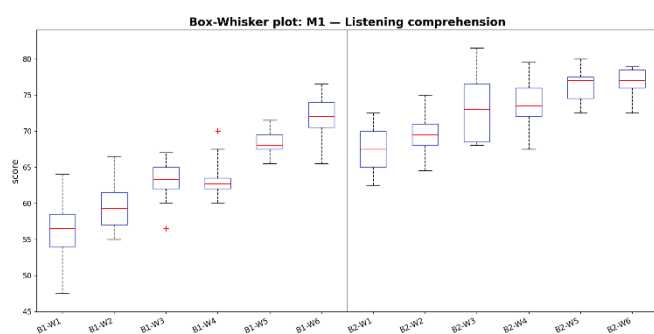


Figure 1. Weekly M1 score values for the B1 and B2 groups.

4.2 Metric 2: Inferential Accuracy

Analysis of the ability to draw logical conclusions from text (M2) revealed a different dynamic. Although Page's test confirmed a significant upward trend in both groups, the B2 group showed a considerably steeper rate of progress than the B1 group. The B2 group achieved maximum effect strength: $L = 896$; $p < 0.001$; $ES = 6.51$; $\rho = 0.92$. The B1 group demonstrated a substantially weaker, though still significant, progression: $L = 836$; $p < 0.001$; $ES = 4.08$; $\rho = 0.58$, which on Cohen's scale corresponds to a medium effect size. Profile analysis confirmed that the developmental trajectories of the two groups differed significantly, with the key divergence point identified as early as W1. The explanation, in our view, is straightforward. Logical inference places greater cognitive demands on students than the first task type. The continuous speech stream placed demands on the B1 group that exceeded their capacity for deep processing. In contrast, the B2 group possessed sufficient linguistic proficiency to draw implicit inferences from the beginning and therefore benefited more from this task. The implication for pedagogical practice is unambiguous. The effectiveness of AI-generated podcasts for cognitively demanding tasks depends largely on students' initial language proficiency, which affects both comprehension depth and active content processing. B1-level students should therefore receive additional methodological support, for example, pre-listening activities to help them bridge the linguistic gap.

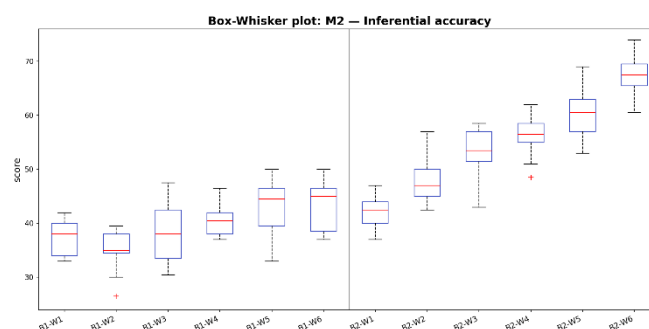


Figure 2. Weekly M2 score values for the B1 and B2 groups.

4.3 Metric 3: Lexical Density

The greatest asymmetries in learning trajectories emerged for productive use of terminology (M3). The B2 group showed linear growth from W1 (0.06) to W6 (0.94). Page's test confirmed a highly significant trend with a large effect size: $L = 876.5$; $p < 0.001$; $ES = 5.72$; $\rho = 0.81$. The B1 group followed a fundamentally different course. From W1 to W4, production remained at zero. The first evidence of active use of terminology did not appear until W5 (0.01), followed by a significant increase in W6 (0.19). Page's test for the B1 group revealed only small practical significance: $L = 799.5$; $p = 0.0092$; $ES = 2.61$; $\rho = 0.37$. Profile analysis confirmed that the developmental trajectories diverged significantly at both W1 and W5, after which W6 saw a sharp convergence. We describe this behaviour as cognitive incubation. New terminology remained stored in passive memory for an extended period and was transferred into written production only after six weeks of listening. The B2 group consistently transformed auditory input into productive language output throughout the study. The B1 group exhibited a prolonged period of apparent stagnation before showing a significant increase in performance. This asymmetry has important implications for interpreting the results. Had the intervention lasted only four weeks, the B1 group's M3 performance might have been

misinterpreted as regression, when it reflected a transitional phase of intensive but still latent language acquisition.

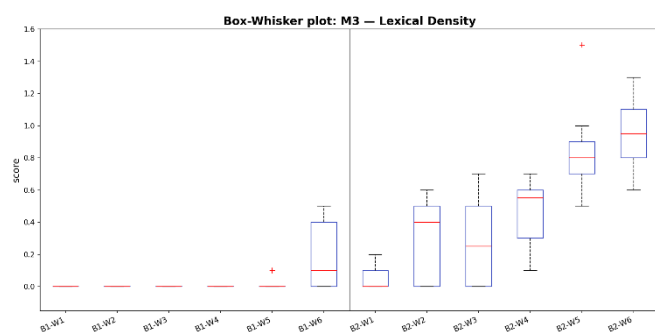


Figure 3. Weekly M3 score values for the B1 and B2 groups.

5. STUDENTS' PERSPECTIVES

5.1 Data Collection

After the six-week intervention, a qualitative focus group interview was conducted with all twenty participants. The discussion was held in Slovak, lasted approximately 60 minutes, and was audio-recorded for subsequent textual transcription. The role of moderator was taken by the teacher, who guided the discussion using open questions organised around three main areas: students' personal experience of listening to the podcasts, their perceptions of the specific assessment tasks, and their overall evaluation of the intervention. Through these areas, we examined more closely how students perceived the difficulty of the tasks, what they found supportive, and where they encountered obstacles. The aim of this procedure was not to quantify students' responses, but to gain a comprehensive understanding of how they experienced each task.

5.2 Data Processing

Student responses were analysed using the established methodology of thematic analysis as set out by Braun and Clarke (2006). In the initial phase, the audio recording was transcribed, and each statement was assigned a descriptive code capturing its core meaning. In the second step, these codes were systematically organized into broader thematic categories according to the assessment task they addressed and the type of student experience they reflected. This process identified three themes: perceived task manageability, cognitive load during content processing, and the relationship between passive comprehension and active production. Representative student statements are presented in their original form, each accompanied by a brief interpretive commentary. This final step situates students' qualitative accounts within the broader context of the quantitative findings.

5.3 Metric 1: Listening Comprehension

Most participants described the M1 task as requiring little additional effort, largely because they were already familiar with this type of task format. This pattern is confirmed by typical student responses, in which the word-completion mechanism was perceived as automatic: *"I am used to this type of task. We did it at primary school and basically almost every time we did listening..."* Another student added: *"This task is very easy for me, you just listen and write the missing word... You don't even need to understand*

everything; you just need to hear the order of the words." Quantitatively, performance on this task differed little between the B1 and B2 groups, and both groups followed similar growth trajectories. However, the qualitative findings revealed an important difference in how students experienced the task. Several B1-level students reported initial difficulty keeping pace with the speed of delivery: *"We are really trained for this type of task, but the speed seemed higher to me... You didn't stop the recording after each gap, so I couldn't quite manage to write the word... and listen to what was coming next at the same time."* Detailed analysis of these responses indicates that the obstacle was not the task type itself, but the cognitive load associated with writing simultaneously while listening continuously without pauses. This detail ultimately makes clear that although task M1 did not differentiate the proficiency groups statistically, the experience of the listening process was not the same for both groups of students.

5.4 Metric 2: Inferential Accuracy

With task M2, the responses and strategies of B1 and B2 students began to diverge markedly. While students in the B2 group described the task as intellectually stimulating and as requiring an active change of approach, the B1 group encountered its cognitive limits. Authentic responses from both groups clearly illustrate this contrast. B2 respondents reflected on the need for deeper textual comprehension and deductive reasoning: *"I enjoyed this task, but it also frustrated me... I was really pleased when I got full points, because this isn't about parroting, you must understand,"* while several of them reported that during the second listening they began actively searching for information: *"I didn't realise I had to deduce something different from the individual pieces of information... But once I understood what you wanted... I already knew while listening, right, so this is probably going to be there."* Among B1 students, by contrast, a persistent and frustrating sense prevailed that the text did not contain the answer: *"I didn't like this task... I kept feeling that the information wasn't there, even though I felt I understood what was being said."*

This perception of missing information among the B1 group was not attributable to unclear task instructions. Instead, it reflected a depletion of cognitive resources during processing. At the theoretical level, this mechanism is precisely predicted by Krashen's (1985) input hypothesis (i+1), according to which language acquisition occurs when input only slightly exceeds current competence. When it exceeds that competence substantially, the capacity for deeper content processing is lost. In terms of cognitive load theory (Sweller, 1988), working memory has a limited capacity, and in B1 students, the lexical and syntactic decoding of spoken discourse consumed so large a share of that capacity that inferential operations, the drawing of conclusions not directly stated in the text, became cognitively unavailable to them.

The outcome of incorrect or absent responses among the B1 group was therefore not caused by a failure to understand the nature of the task, but by a limit on working memory capacity. This distinction has direct implications for pedagogical practice. The appropriate response is not to simplify the inferential tasks themselves, but to reduce the cognitive load associated with language decoding. This can be achieved by incorporating pre-listening activities that activate the necessary cognitive schemas and free up students' mental capacity for more demanding reasoning operations.

5.5 Metric 3: Lexical Density

Students' responses to task M3 offered the deepest insight into the learning process, revealing a clear gap between immediate productive capacity and the process of cognitive incubation. B2-level students described this synthesis task as a natural and liberating extension of listening: *"This suited me most, because I could show that I really understand... I wasn't constrained in any way... I use the technical words in my sentences"*, for the B1 group, M3 was primarily a source of pronounced frustration during the first four weeks (W1 to W4). This initial phase was characterised by zero or minimal production, which some students attributed to the language barrier or to a pragmatic view of their future profession: *"I didn't like this exercise... I'm fine with understanding that on the shop floor you don't need to communicate... I know the terms, and I can explain the process, but in Slovak."*

Gradually, however, a significant shift occurred in a portion of the B1 students, as they came to understand that the goal was not grammatical complexity but terminological precision: *"...gradually it started working, when I realised that I didn't need to use those complex tenses, it's enough to capture the essence, but with the right terms. Then it made sense why I should use sintering instead of baking."* These statements are the most precise verbal expression of the phenomenon of cognitive incubation. The passive memory trace was genuinely present in the students' minds, but active production required time. The statistical inflection point that analysis identified at W5 and W6 was described by students themselves at the end of the semester as a moment of surprise at their own progress: *"...at the last lesson I got the most points on the final exercise, and basically I just combined what we had learned in technology classes with the vocabulary you wanted from us... that task seemed the best to me, because I could write what I wanted."*

This observation has a central pedagogical implication for the design of ESP instruction. It demonstrates that zero productivity in the early phases of the intervention is not a failure of the method, but a necessary latent period during which new linguistic material is being internalised in memory. If a teacher does not recognise this specific dynamic process, the initial silence may be misread as failure, prompting the premature introduction of excessive scaffolding. Interrupting this process prematurely cuts short the necessary absorption period, preventing a deeper and more lasting understanding of the new technical vocabulary.

6. CONCLUSION

The study produced three significant and interconnected empirical findings regarding the integration of AI tools into ESP instruction. The results show that although NotebookLM AI-generated podcasts demonstrably improve students' listening comprehension and terminology acquisition, the nature and pace of this progress vary considerably according to their initial language proficiency. Quantitative analysis confirmed statistically significant progress across all three metrics (M1, M2, M3); however, the B1 and B2 groups responded to identical audio input with different dynamics, and the divergence intensified as the cognitive demand of the tasks increased. This variation was most significant in the written summary task (M3), where the B1 group experienced an extended latent phase followed by a marked improvement in performance during the final week of the intervention. This pattern of cognitive incubation demonstrates that the absence of immediate visible performance gains does not necessarily indicate an absence of learning. For educational research, this carries a consequential warning against the risk of premature evaluation of AI tool

effectiveness, which may lead to the unwarranted rejection of innovative pedagogical methods.

The quantitative growth trajectories are further explained by qualitative feedback, which reveals how students themselves perceived changes in their knowledge development. Subjective reflections collected at the end of the intervention confirm that the three assessment tasks elicited different forms of engagement, with responses varying markedly not only between the B1 and B2 proficiency levels but also within each group. While most students perceived the listening comprehension (M1) as manageable or even routine, requiring only memory, the inferential reasoning task (M2) and written summary (M3) became explicit points of cognitive conflict. B2-level students described inferential analysis (M2) as intellectually stimulating, whereas B1-level students experienced the same task as cognitively overloading. Their ability to draw inferences was constrained by the substantial linguistic demands to decode the language itself. Therefore, the perceived fluency of M1 constitutes a pedagogical risk, consistent with Albrecht-Crane's (2025) argument that a task perceived as too easy may not generate the depth of information processing required for durable knowledge consolidation.

From the perspective of the acquisition process, the most notable feature was the connection between statistical stagnation and students' emotional experience of the written summary (M3). Data analysis showed that this productive task divided the two groups most sharply. Furthermore, for B1-level students, it was a primary source of frustration in the early weeks. Students in this group repeatedly reported that although they understood the podcast content, they were unable to transform it into their written production. A turning point occurred in weeks five and six, when respondents began spontaneously describing the moment when terms they had previously only recognised started flowing naturally into their written output. This qualitative transformation provides direct evidence of a latent learning phase. Furthermore, it confirms that the emotions associated with initial task difficulty represent a natural part of the cognitive restructuring that precedes the development of higher levels of language competence.

The findings carry direct and applicable implications for curriculum design and pedagogical practice in ESP. The research demonstrates that while AI-generated podcasts function as a reliable tool for developing basic comprehension independently of proficiency level, a differentiated pedagogical approach is necessary for cognitively more demanding tasks. In practice, this means that for B1-level students, teachers must incorporate targeted pre-listening tasks designed to reduce cognitive load and activate relevant lexical schemas. For B2-level students, podcasts can serve as a primary source of acquisition input without additional scaffolding if assessment tasks require the productive use of terminology rather than its passive recognition. A correct understanding of the latent period also prevents premature teacher intervention, giving students sufficient time for deeper and more durable knowledge consolidation.

Despite these contributions, the conclusions presented here should be interpreted in the context of several methodological limitations. The research design was constrained by the absence of a control group, a relatively small sample size ($n = 20$), and a six-week intervention period without a delayed post-test. These limitations prevent the formulation of unequivocal causal conclusions and restrict the assessment of long-term retention. Future research should address these issues through replication studies including control groups, larger samples, and longitudinal measurements with extended follow-up periods. A particularly promising direction for further investigation is to determine whether the observed

phenomenon of cognitive incubation in M3 can be replicated across other academic disciplines and whether appropriately designed pre-listening activities can effectively shorten this latent period among B1 learners.

In conclusion, the availability of a sophisticated AI tool does not automatically guarantee academic success. The effectiveness of such technology depends on several factors. These include the learners for whom it is designed, the way it is integrated into the instructional process, and the extent to which it engages students in active and deep cognitive processing. As NotebookLM-generated podcasts become an increasingly common component of ESP education, the central question is no longer whether they should be incorporated. Instead, the focus should be on how they can be implemented effectively. Successful AI integration in education requires an approach that is responsive to students' current proficiency levels while systematically providing cognitive challenges that extend slightly beyond their existing capabilities.

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Self-Efficacy of School Special Educators in the Field of Pedagogical Diagnostics of the Family Environment

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Abstract The study addresses the issue of pedagogical diagnostics of the family environment. The aim of the qualitative research was to identify the key factors that determine the level of self-assessment among school special educators in the field of pedagogical diagnostics of the family environment. The research sample consisted of 15 school special educators working in different types of schools, with whom two online focus groups were conducted. The findings identified the main determinants of school special educators' self-assessment (self-confidence) in this area. The analysis of the focus group data revealed four main categories influencing school special educators' self-efficacy in assessing pupils' family environments: (1) communication skills and pre-service training; (2) practice and experience in family assessment; (3) social factors; and (4) personal vision and professional ambitions. The results showed that practical experience with parents, communication competencies and support from the school environment play an important role in the perception of professional competence. The findings confirm the need for further professional development and the expansion of practical experience in this area of educational activity, particularly for beginning school special educators.

Keywords school special educators, special educators' competencies, pedagogical diagnostics of the family, self-efficacy, self-assessment

1. INTRODUCTION

In contemporary education and pre-service teacher training, increasing emphasis is placed on the integration of teacher's professional expertise, personal characteristics and self-regulatory mechanisms. Among the key concepts in this regard is teacher's perceived self-efficacy. Drawing on Albert Bandura's social cognitive theory, self-efficacy refers to teachers' professional belief in their own ability to successfully organise and carry out professional activities in order to achieve desired educational outcomes for pupils (Van Staden-Payne & Nel, 2023).

These beliefs fundamentally influence cognitive processes, behavior as well as the goals individuals choose, and the amount of effort they invest in achieving them. In the school environment, teacher

self-efficacy is a key factor in the successful implementation of educational processes (Kazanopoulos et al., 2022).

Teacher's work is conceptualized through professional competencies, which represent an integrated set of knowledge, skills, attitudes and values. In the context of this study, particular attention is paid to diagnostic competence. Pedagogical diagnostics is no longer perceived merely as a summative process aimed at grading (classification) but rather as a continuous and formative process of identifying the conditions, course and outcomes of education (Dorozhovets & Hladush, 2021).

Diagnostics occupies a crucial position in educational work, both in the domain of knowledge construction and in educational practice. It initiates all other pedagogical activities, guides them, and is continuously refined throughout these processes. An educator's professionalism is demonstrated, among other things, through their knowledge of pedagogical diagnostics, their ability to apply it effectively, and their competent and ethical conduct in relation to diagnostic activities (Opozda, 2019).

One of the most important and demanding sub-competencies within pedagogical diagnostics is the diagnostics of the pupil's family environment. From the perspective of Bronfenbrenner's ecological systems theory, the school and the family represent two key microsystems whose interaction (the mesosystem) fundamentally influences child development. According to Wray et al. (2022), three key sets of competencies are essential for functioning effectively in contemporary education focused on inclusion: content and pedagogical knowledge; classroom management; and the ability to cooperate with parents and teacher assistants.

While diagnostic activities are important for teachers in general, they constitute a cornerstone of the work of school special educators. The development of diagnostic competence, with particular attention to in-depth diagnostics of the family environment, therefore emerges as a key professional priority. When pedagogical and professional staff possess a high level of self-efficacy in this area, the school environment ceases to be a place of selection and becomes a space for genuine inclusion (Dorozhovets & Hladush, 2021). Current educational discourse explicitly addresses the discrepancy between the demands placed on teachers' diagnostic competence and the practical limitations of educational

settings, including large class sizes and limited time allocated to in-depth pedagogical diagnostics.

Empirical findings (Kazanopoulos et al., 2022) demonstrate a significantly higher level of perceived self-efficacy in key areas of inclusive education. This difference is explained by the more targeted focus of their pre-service and academic preparation, which aims to equip future professionals with the competencies necessary to work effectively in heterogeneous and inclusive educational environments.

The literature contains a number of studies addressing teacher self-efficacy with a particular focus on inclusive education and the pupil's family environment. Savolainen et al. (2012) identified professional preparation, continuing education, and support as important determinants of the level of teacher self-efficacy in inclusive education. A higher level of perceived teacher self-efficacy has been associated with more active participation of family members in the educational process (Krizman, 2013), as well as with more developed forms of cooperation between schools and families. Hansuvadha (2009) points to the limited amount of research linking teacher self-efficacy with the quality of family-school relationships, although such connections can reasonably be assumed.

The present study focuses on the self-efficacy of school special educators, specifically in relation to the diagnostics of pupil's family environment. The self-efficacy of school special educators develops gradually, and its level is conditioned by multiple factors. Concerning professional growth, both the level of competencies and the degree of self-reflection of the school special educators increase. Based on these theoretical foundations, the present study further explores this issue through empirical research.

2. METHODS

The aim of the present qualitative study was to identify the factors determining the level of school special educators' self-assessment of their professional competence in the field of pedagogical assessment of the family environment.

Participants:

The sample consisted of 15 school special educators working in different types of schools. The sampling procedure was non-random. Two online focus group interviews involving 15 school special educators were conducted until the criterion of theoretical data saturation was reached (Strauss & Corbin, 1997). The authors of this study served as moderators of the focus groups.

Methods of data collection:

Given the nature of the research problem and the aim to explore the unique experience of school special educators, the method of qualitative focus group was employed. Qualitative data are authentic, complex and rich, providing valuable insight into the phenomenon under investigation. A set of open-ended questions was developed based on previous research in this area. Group interactions that emerged during the moderated interviews added an important dynamic to the exploration of the phenomenon – anything that had been said could be confirmed, supported or challenged within the group discussion. The data of the online focus groups were digitally recorded and subsequently transcribed verbatim.

Methods of data analysis:

The data was analyzed using the grounded theory approach proposed by Strauss & Corbin (1997). Two independent coders analyzed the data to identify as many aspects of studied

phenomenon as possible, and to enhance the credibility of the findings. Their preliminary results were subsequently compared and discussed in order to reach a shared interpretation of the phenomenon. They used multi-level coding of participants' statements. In the next phase, central categories and subcategories were developed, relationships among them were explored and the findings were incorporated into a conceptual model (Miovský, 2006).

3. RESULTS

The analysis of the focus group data revealed three main categories that explain how Slovak school special educators perceive their self-efficacy and their role as professionals responsible for assessing pupils' family environments. These categories include communication skills – pre-service training versus practical experience, social factors as determinants of school special educators' self-efficacy, and the personal vision and professional ambitions of school special educators. An overview of the main categories and subcategories is presented in the following model (Fig. 1). The relationships between the categories and their definitions are briefly described below.

3.1 Communication Skills – Pre-Service Training versus Practical Experience

- pre-service training in communication with families,
- personal professional experience,
- the ability to handle sensitive information,
- the ability to manage conflict situations and communicate effectively.

3.2 Social Factors as Determinants of the Self-Efficacy of School Special Educators

- diverse types of parents,
- family – parents' unwillingness,
- school – the approach of the school leadership,
- the type of school.

3.3 Personal Vision and School Special Educators' Professional Ambitions

- attitude and activity,
- improvement of diagnostic competencies related to the pupil's family environment.

Figure 1: Main Categories and Subcategories of Factors Determining School Special Educators' Self-Efficacy

3.1 Communication Skills – Pre-Service Training versus Practical Experience

The self-perception of school special educators as “professionals responsible for assessing pupil's family environment” is primarily shaped by the quality of their pre-service training and their practical experience.

An important factor influencing the self-efficacy of school special educators is the limitations resulting from their professional preparation, particularly in the area of communication with families. Respondents participating in the focus groups pointed out that working with parents and assessing pupil's family environment

require specific competencies that are not sufficiently developed during university studies. School special educators often perceive a gap between theoretical preparation and the actual demands of professional practice. At the same time, a lack of practical experience in communicating with parents reduces their confidence when dealing with challenging situations.

In this context, respondents emphasized that their **pre-service training** in this area was predominantly theoretical and did not provide sufficient opportunities to practice specific real-life situations. In particular, they highlighted a lack of model interviews, conflict management training and opportunities to reflect on communication with parents. As a result, practical experience played a more significant role in the development of self-efficacy than university preparation itself. Respondents stated that it was often only through direct practical experience that they learnt how to communicate effectively with different types of parents.

Respondents further emphasized the importance of **practical experience as a key source of professional learning**. They stated that many skills were acquired only through practice and highlighted the importance of gradually gaining confidence through real-life situations. At the same time, this process was perceived as demanding and, in some cases, also as a source of uncertainty, particularly at the beginning of their professional careers. *“At university, we learned a lot about diagnostics, but very little about how to talk to a parent who is angry or unwilling to cooperate.”* *“It was only practice that taught me how to respond in real-life situations.”*⁹

An important subcategory was the ability to **work with sensitive information**. Respondents described feelings of uncertainty when communicating serious findings related to the pupil or the family environment. They expressed concerns about using inappropriate wording or being misunderstood by parents. In this regard, they highlighted high demands put on them as well as the importance of empathetic communication with parents.

“Sometimes it is very difficult to tell a parent that the child’s problem may also be related to the situation at home.”
“You have to choose your words very carefully so that the parent does not feel accused.”

Another significant determinant of self-efficacy was the **ability to manage conflict situations**. Educators reported that the most challenging situations arise when parents disagree with diagnostic conclusions, reject the school’s recommendations, or have had negative experience with another school. Increased pressure in such situations may lead to feelings of uncertainty and fear of professional failure.

*“When a parent raises their voice or starts blaming the school, suddenly you are no longer sure how to react appropriately.”*¹²
*“The most difficult thing is to remain calm when a parent refuses any form of cooperation.”*³
*“[...] I do not always know how to conduct a conversation with a parent properly, especially when sensitive topics are involved.”*⁷

The findings highlight the need for targeted preparation of school special educators in the area of working with families, extending beyond the framework of traditional pedagogical competencies. An important part of professional preparation should therefore include practice-oriented communication training, model situations, the development of mediation skills, and supervisory guidance reflecting real-life professional experience.

3.2 Social Factors as Determinants of the Self-Efficacy of School Special Educators

An important category of factors influencing the self-efficacy of school special educators consisted of social factors related to both the family and the school environment. Respondents participating in the focus groups stated that their ability to assess effectively the pupil’s family environment and cooperate with the family is determined not only by their individual competencies but also by broader school conditions, parental attitudes and the family’s social environment. Educators pointed out that the quality of cooperation with families significantly influences their professional confidence, the effectiveness of interventions and their overall perception of their own effectiveness.

One of the most prominent subcategories concerned **different types of parents** and the challenges associated with adopting an individual approach to each family. Respondents pointed to the need to communicate effectively with different types of parents. They emphasized that every family has a unique social and cultural background, which always requires an individual approach. School special educators perceived establishing cooperation as particularly challenging when working with parents from socially disadvantaged backgrounds, parents with low level of trust in schools as well as with parents with limited proficiency in Slovak and parents whose previous life experiences had negatively affected their attitudes towards educational institutions.

*“You need to communicate differently with every parent. Some want precise facts, while others mainly need support and understanding. We also have parents from Ukraine who are very reserved, and working with them is much more demanding.”*¹¹
*“The hardest thing is to gain the trust of parents who have already had a negative experience with school.”*¹

A significant barrier on the family side was **parental unwillingness to cooperate**. Respondents stated that some parents refused to follow the recommendations of school special educators regarding how to work with their child at home. In some cases, parents also questioned the professional recommendations of specialists or denied the existence of their child’s special educational needs. Such situations reduced school special educators’ sense of professional efficacy and complicated the implementation of interventions aimed at supporting the pupil.

*“The most difficult thing is when a parent completely denies the problem and refuses any kind of help.”*⁶
*“We have parents who do not attend a single meeting, yet at the same time expect the school to solve everything on its own.”*¹³
*“When parents do not cooperate, you feel that your work has no real impact.”*²

Another significant determinant of self-efficacy involved barriers within the school environment and broader systemic conditions. Respondents pointed out that the effective work of school special educators depends not only on their own competencies but also on the **organizational conditions of the school**, the support provided by school leadership and the overall structure of the educational system. They identified a high administrative workload, insufficient time for individual work with families, and ambiguously defined professional responsibilities as particularly problematic.

*“We spend a lot of time on administration, and then there is not enough space left for actual work with families.”*⁵
*“Sometimes we feel that the system expects too much from us, but does not provide clear rules.”*¹⁰

The **approach of school leadership** also emerged as an important factor. Respondents emphasized that support from school leadership significantly influences their professional confidence. They perceived leadership positively when it respected the professional opinions of school special educators and created opportunities for communication with families. Conversely, insufficient support from school leadership was associated with feelings of isolation and a lack of professional recognition.

*"When the school leadership trusts our work, you feel more confident also in working with families."*⁷

*"If the leadership does not realize the importance of our work, it is difficult to implement the necessary measures."*¹¹

The findings also suggested that **the type of school** in which a school special educator works may influence their self-efficacy. Respondents working in special schools stated that these institutions place greater emphasis on systematic assessment and more intensive cooperation with families. This suggests that the subjective perception of the school special educator's role in relation to parents varies according to the school environment and the special educational needs of the pupils.

*"In a special school, cooperation with the family is a natural part of the work, and parents are more prepared to communicate."*³

*"In a mainstream school, we have much less space to devote in-depth attention to one family."*¹⁴

The findings suggest that the self-efficacy of school special educators is significantly shaped by the social context of both the school and the family. Effective assessment of the family environment therefore requires not only the educator's individual professional competencies but also supportive systemic conditions and adequate support from school leadership.

3.3 Personal Vision and Professional Ambitions of School Special Educators

An important category influencing the self-efficacy of school special educators was their personal vision of the profession and their professional ambitions. The respondents' statements suggest that they do not perceive pedagogical assessment of the family environment merely as a technical or administrative part of their work, but rather as an important tool for supporting the overall development of the pupil.

Respondents also pointed out that high-quality assessment of the family environment requires not only professional knowledge but also an appropriate personal attitude of the educator (**attitude and activity**), a high level of empathy, the ability to communicate with parents and a willingness to continuously develop their professional competencies. They perceived this area of practice as demanding, yet at the same time as an important part of their professional identity.

*"[...] we are like a bridge between the school and the family."*¹

*"If we truly want to help the family and the child, I myself must believe that I can do it. I also need to be active in order to encourage the parents."*¹⁰

An important subcategory concerned the need to **improve diagnostic competencies related to the pupil's family environment**. Respondents repeatedly highlighted the need for further professional development, methodological support and practice-oriented training in the area of working with families. They were aware of the limitations of their own preparation and

emphasized the need for the systematic development of their competencies.

*"More practical training would help, for example, within lifelong learning programs focused on conversations with parents and managing difficult situations."*¹⁵

The findings suggest that school special educators are interested in further professional development and recognize the need for continuous improvement of their competencies. This aspect reflects their commitment to the quality of their work and their responsible approach to their profession.

4. DISCUSSION

The aim of the present study was to identify the key factors that determine the level of self-assessment among school special educators in the field of pedagogical diagnostics of the family environment. Through qualitative research employing focus group interviews with 15 school special educators, several factors were identified and subsequently classified into three main categories.

The findings revealed that the level of professional self-confidence (self-efficacy) among school special educators is influenced by limitations in their professional preparation, particularly in the area of communication with family members. Similarly, Hansuvadha (2009) identified self-efficacy among beginning school special educators, who primarily reported insufficient preparation for cooperation with parents. A lack of self-confidence and less developed communication skills complicate effective cooperation with families. Given the nature of a school special educator's work, professionals are expected to communicate sensitively about complex situations and often emotionally demanding issues, including various diagnostic findings.

Corresponding factors were also identified in the next area, where school special educators emphasized experiencing uncertainty, anxiety, and fears of failure when confronting parents. Limited parental involvement negatively affects educators' perceptions of their own professional confidence. At the same time, active parental involvement in a child's educational process represents a key prerequisite for effective development and successful learning (Sapungan & Sapungan, 2014).

The analysis also identified another important domain, namely social factors influencing the self-efficacy of school special educators in their work with families. Effective cooperation between schools and families is significantly influenced by the fact that there is no universal approach to family backgrounds in educational practice. Instead, educators encounter diverse types of parents (Kong & Lu, 2024). This diversity reflects differences in their pedagogical engagement, communication competencies and attitudes toward educational institutions, requiring school special educators to apply communication and intervention strategies flexibly according to the characteristics of individual families.

This diversity of family backgrounds may also be understood in the context of broader social changes affecting contemporary families. Líšková (2014) points out that modern families are exposed to various social, economic, and cultural pressures, which contribute to increasing diversity in family functioning, communication patterns, and parental involvement in children's education. These changes may create additional challenges for school special educators and further emphasize the importance of understanding the wider family context when conducting pedagogical diagnostics.

The focus group findings also highlighted the role of the school itself, particularly those factors within the school environment that influence the self-efficacy of school special educators. Similarly, Hansuvadha (2009) states that school administration and interpersonal relationships in the workplace are among the key factors influencing teachers' professional confidence. In the context of school leadership, respondents emphasized an urgent need for recognition, respect and trust from school management. The absence of such support may significantly hinder the effective implementation of inclusive educational practices.

Another empirically identified group of factors concerns the personal vision and professional ambitions of school special educators. High-quality diagnostic assessment of the family environment requires not only professional competencies but also specific personal characteristics, including engagement, a high level of empathy, well-developed communication skills for interacting with parents, and a commitment to continuous professional development.

Similarly, Herber and Hund (2026) emphasize the importance of personal characteristics and interpersonal skills in establishing positive relationships with parents. These skills primarily include positivity, mutual respect, openness in communication, the ability to see another person's perspective, honesty, transparency, and the active development of collaborative relationships.

A similar emphasis can be found in Sender (2020), who described communication with parents, cooperation with families, and the provision of individualized support as core dimensions of the school special educator's professional role. Such responsibilities require advanced interpersonal and communication skills and may contribute to the development of professional self-efficacy when working with pupils and their families.

The findings of the present study highlight the factors that determine school special educators' perceived self-efficacy in their work with families. Understanding these factors is important for improving professional preparation, educational practice and continuing professional development. Within the school environment, school special educators represent professionals for whom the assessment of a pupil's family environment constitutes an important source of information. Therefore, it is essential to strengthen the development of diagnostic competencies and enhance self-efficacy in this area. This requires adequate professional preparation, appropriate personal characteristics, communication skills based on respect and empathy, and systematic support from schools.

5. CONCLUSION

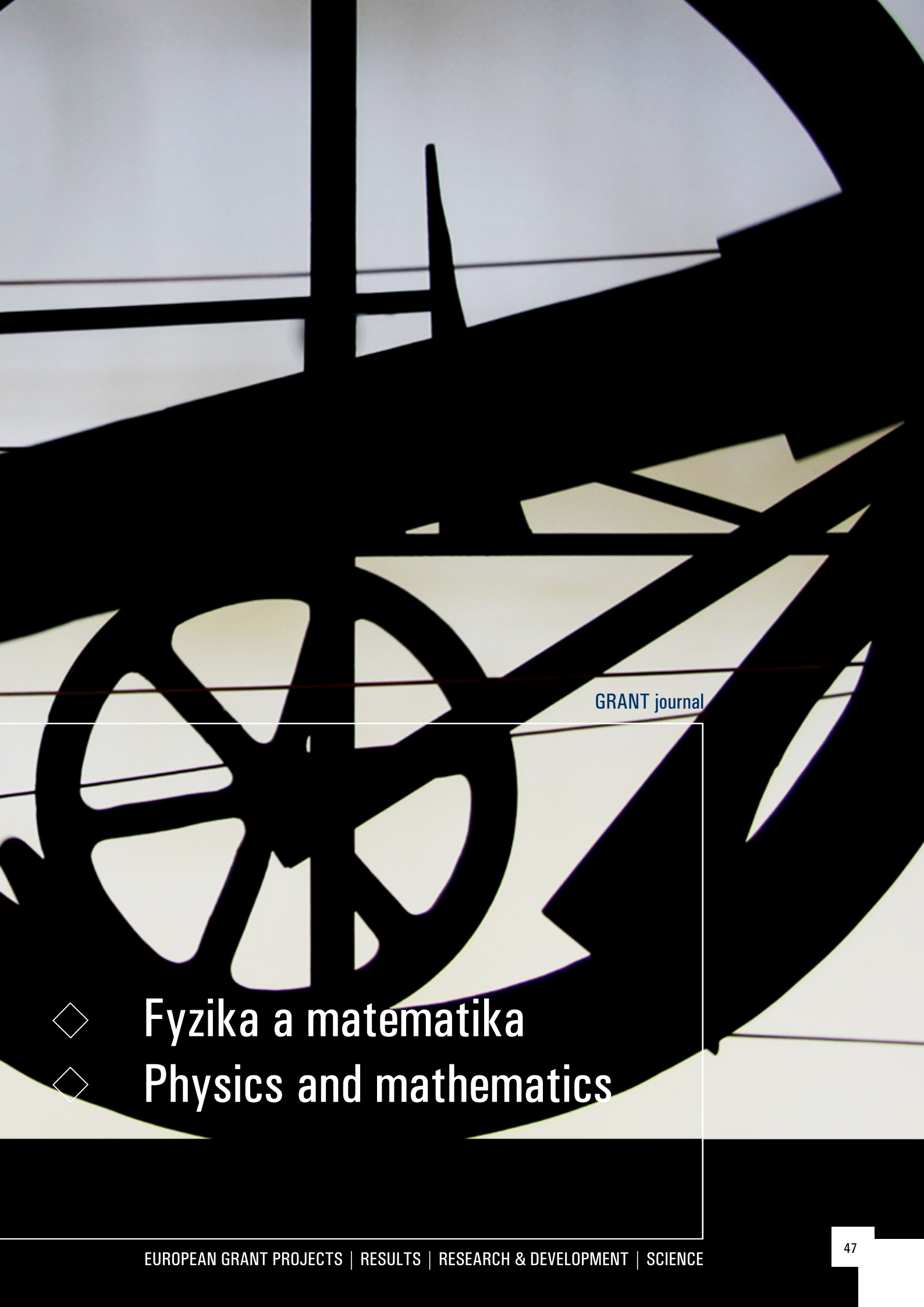
The present study highlights that the perceived self-efficacy of school special educators in the field of pedagogical assessment of the family environment is determined by a complex set of factors operating at the levels of their pre-service and academic preparation, social aspects and personal professional vision. The findings clearly point to existing limitations in communication competencies and to the uncertainty experienced by school special educators when working with diverse types of parents. At the same time, the results indicate that personal characteristics such as empathy, engagement and continuous professional self-development, together with an open and respectful approach on the part of both schools and families, represent key foundations for effective cooperation. For educational practice, these findings suggest the need for more targeted development of the diagnostic and interpersonal competencies of future school special educators, as well as the strengthening of their professional confidence through recognition

and support within the workplace. Such measures may enable the diagnostics of family environments to become a more effective tool for supporting the cognitive, social and emotional development of pupils.

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Modelling the annual maxima discharges of the Jihlava river applying Weibull probability distribution

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Abstract Reliable prediction of extreme hydrological events, such as floods, requires two key elements – a sufficiently long continuous series of observations and selection of an appropriate probability distribution. Here, we analyze a 98-year long continuous series of average daily discharge records of the Jihlava River at the Dvorce gauging station. The dataset of annual block maxima is modeled by a two-parameter Weibull distribution. The distribution parameters are estimated using the maximum likelihood method. The Kolmogorov-Smirnov and Anderson-Darling goodness-of-fit tests are employed to verify the agreement between the theoretical model and the observed data. Based on the p-values of both tests, which exceed the 0.05 significance level, we can conclude that the selected probability distribution adequately models the annual maximum of average daily discharges in the analyzed section of the Jihlava River.

Keywords block maxima, Weibull probability distribution, gauging station Dvorce

1. INTRODUCTION

Systematic monitoring of daily river discharge holds strategic importance for safety, the economy, and environmental protection. Long-term records enable more accurate modeling for designing infrastructure such as bridges, dams, and levees. Monitoring is also crucial for early warning systems against extreme hydrological events like floods or the onset of drought, providing the time needed to minimize their impact. Effective risk management relies on a dependable probabilistic model. For flood management, such a model serves as the foundation for estimating the magnitude and return period of extreme flows, their frequency over time, and the probability of exceeding specific extreme thresholds.

The range of probability distributions applicable to modeling extreme events is quite limited. Commonly used options include the Weibull, Gumbel, and Fréchet distributions (collectively known as the generalized extreme value distribution), the Pearson type III and log-Pearson type III distributions, and the generalized Pareto distribution. In [1], maximum annual discharges were modeled at seven hydrological stations in India's Brahmani and Baitarani river basins. The authors compared the goodness of fit between measured flows and four probability distributions: the generalized extreme value, Gumbel, log-Pearson type III, and log-normal distributions. They estimated parameters using the maximum likelihood, moments, and L-moments methods. In [2], the authors compared parametric and non-parametric models for the highest annual peak flows across 18 stations in the Punjab region of Pakistan, evaluating how well empirical observations fit the generalized Pareto, generalized extreme value, and generalized logistic distributions. Karim et al. [3] applied five probability distributions to data from 24 gauging stations in the Great Barrier Reef lagoon catchments, while also comparing frequency estimates derived from the block maxima and peak-over-threshold methods. Coufal and Hornová [4] evaluated N-year discharges at three gauging stations (Raškov, Kroměříž, and Strážnice) in the Morava River basin, approximating the maximum annual flow series with four distributions (log-normal, Pearson type III, generalized extreme value, and Gumbel) and comparing their accuracy using mean squared error.

Our objective is to investigate the applicability of the 2-parameter Weibull distribution for modeling the annual maxima of average daily discharges on the upper reaches of the Jihlava River at the Dvorce hydrological station. The distribution parameters are estimated via the maximum likelihood method using MATLAB R2020b software. Finally, the fit of the Weibull distribution to the empirical data is verified using the Kolmogorov-Smirnov and Anderson-Darling goodness-of-fit tests.

2. STATISTICAL MODEL

There are two main approaches to selecting maximum values from a dataset: the block maxima method and the peak-over-threshold method.

The block maxima method divides a time-series dataset into equal, non-overlapping intervals, or blocks (such as a day, month, or year). Extracting the highest value from each block creates the set of block maxima. Choosing sufficiently long blocks helps ensure the observations are not correlated—which is important since shorter blocks often capture seasonal patterns common in hydrological data. However, a key disadvantage is that only one maximum is chosen per block. This can lead to ignoring significant second or third highest values in a specific block, even if they are much larger than the maximum of a different block.

Alternatively, the peak-over-threshold method sets a specific baseline, and any observation exceeding it is included in the dataset. This prevents the data loss associated with the block maxima method. The main drawback here is that these observations can be correlated, such as when a single flood wave spans several consecutive days. Selecting the right threshold value is also a challenge. [3, 5, 6]

The chosen selection method directly dictates which probability distributions apply. According to the Fisher-Tippett-Gnedenko theorem [7, 8], the probability distribution of block maxima converges to one of three distributions:

- Gumbel distribution,
- Fréchet distribution,
- Weibull distribution.

2.1 2-parameter Weibull distribution

The probability density function $g(x)$ and the cumulative distribution function $G(x)$ of the 3-parameter Weibull distribution are defined, respectively,

$$g(x) = \frac{a}{b^a} x^{a-1} \exp\left(-\left(\frac{x}{b}\right)^a\right)$$

and

$$G(x) = 1 - \exp\left(-\left(\frac{x}{b}\right)^a\right)$$

for $x > c, a > 0, b > 0$. Parameter a is the shape parameter, parameter b is the scale parameter and parameter c is the location parameter.

The maximum likelihood estimates of the parameters are obtained by solving the system of equations

$$\frac{1}{a} - \frac{\sum_{i=1}^n x_i^a \ln x_i}{\sum_{i=1}^n x_i^a} + \frac{1}{n} \sum_{i=1}^n \ln x_i = 0,$$

$$b = \left(\frac{1}{n} \sum_{i=1}^n x_i^a \right)^{\frac{1}{a}}.$$

2.2 Goodness-of-fit tests

To verify agreement between the theoretical and empirical distribution, two goodness-of-fit tests are used: The Kolmogorov-Smirnov test and the Anderson-Darling test. Let $\hat{F}(x)$ be the estimated distribution function, and $x_{(1)}, x_{(2)}, \dots, x_{(n)}$ be

a realization of a random sample ordered in ascending size, $x_{(1)} \leq x_{(2)} \leq \dots \leq x_{(n)}$.

We test the null hypothesis:

H_0 : the random sample originates from the theoretical distribution against the alternative

H_1 : the random sample does not originate from the theoretical distribution.

The test statistic for the Kolmogorov-Smirnov test is given by

$$D = \max_{1 \leq i \leq n} \left[\left| \hat{F}(x_{(i)}) - \frac{i-1}{n} \right|, \left| \frac{i}{n} - \hat{F}(x_{(i)}) \right| \right].$$

The test statistic for the Anderson-Darling test is given by

$$A^2 = -n - \sum_{i=1}^n \frac{2i-1}{n} \left[\ln(\hat{F}(x_{(i)})) + \ln(1 - \hat{F}(x_{(n+1-i)})) \right].$$

We use the p -value to test agreement. Hypothesis H_0 is rejected at significance level α if $p\text{-value} < \alpha$.

3. DESCRIPTION OF STUDIED LOCATION

The Jihlava River originates in the Bohemian-Moravian Highlands in hilly terrain near the village of Jihlávka. The total length of the river is 184.5 km; the basin area is 2998 km². Together with the Svratka River, it empties into the Nové Mlýny middle reservoir. The largest tributaries of the Jihlava River are the Oslava (left-bank tributary) and Rokytá (right-bank tributary) rivers. Major towns located along the course of the river are Jihlava, Třebíč, Ivančice, Dolní Kounice, and Pohořelice. Two reservoirs were constructed on the river—Dalešice and Mohelno—which also serve as a water supply for the Dukovany Nuclear Power Plant. [9, 10]



Fig. 1. Hydrological station 465000 Dvorce – map location (upper); station detail (lower). [11]

Hydrological gauging station 465000 Dvorce (49° 22' 50.18", 15° 30' 15.38") is located near the village of the same name. The station lies at river kilometer 150.64, i.e., approximately 34 kilometers from the river source, at an elevation of 501.17 m a.s.l. (gauge datum zero). The station itself is situated on the right bank of the river, 50 m below the bridge at an old dead-end road (Fig. 1). The station operator is Povodí Moravy Brno. The first records from this station date back to 1928. Currently, water level is recorded at the station, and water discharge is calculated from the water level. The average annual water level is 39 cm, corresponding to a discharge of 1.77 m³/s. Over the course of measurements, several floods were recorded in this reach. The highest water level of 272 cm (discharge 53.40 m³/s) was measured on April 1, 2006, during a flood that affected most of the Czech Republic. [11, 12]

3.1 Data characteristics

Continuous records of average daily discharges exist for the Dvorce station from the beginning of measurements in 1928 up to and including 2025. Thus, the dataset used [13, 14] contains 35,795 records (from January 1, 1928, to December 31, 2025). From these data, a set of maximum annual discharges comprising 98 values was created using the block maxima method. The block size was one calendar year (daily averages from January 1 to December 31 of each calendar year). Descriptive statistics for daily averages as well as annual maxima are summarized in Table 1.

The lowest average daily discharge of 0.02 m³/s was recorded at the station on October 31, 1951. On the preceding two days, the second lowest average discharge in measurement history was recorded at 0.04 m³/s. Conversely, the largest average daily discharges occurred during devastating floods at the turn of March and April 2006 (from March 30 to April 1, average daily discharges reached 38.70 m³/s, 41.50 m³/s, and up to 45.10 m³/s). The third largest average daily discharge was recorded on March 20, 1947, at 39.50 m³/s, caused by an ice flood. As shown in Fig. 3, the year 2025 can be considered hydrologically the weakest, when the maximum of all average daily discharges reached only 2.26 m³/s. Similarly, dry years were 2018 (maximum average daily discharge was 3.04 m³/s) and 2016 (maximum average daily discharge was 3.97 m³/s).

The mean value of annual maxima is 15.547 m³/s. The values exhibit a high degree of variability, which is confirmed by a coefficient of variation of 56.54%. The skewness coefficient for annual maxima indicates a positively skewed probability distribution (Fig. 2); the kurtosis coefficient indicates a leptokurtic distribution.

Table 1. Descriptive statistics of the dataset of average daily discharges and annual maximum discharges.

	Average Daily Discharge	Annual Maxima of Average Daily Discharge
Mean (m ³ /s)	1.873	15.547
Standard Deviation (m ³ /s)	2.192	8.791
Lower Quartile (m ³ /s)	0.80	9.49
Median (m ³ /s)	1.26	13.50
Upper Quartile (m ³ /s)	2.10	19.40
Kurtosis	52.991	1.015
Skewness	5.588	1.088
Minimum (m ³ /s)	0.02	2.26
Maximum (m ³ /s)	45.10	45.10
Coefficient of Variation (%)	117.05	56.54
Number of Measurements / Blocks	35 795	98

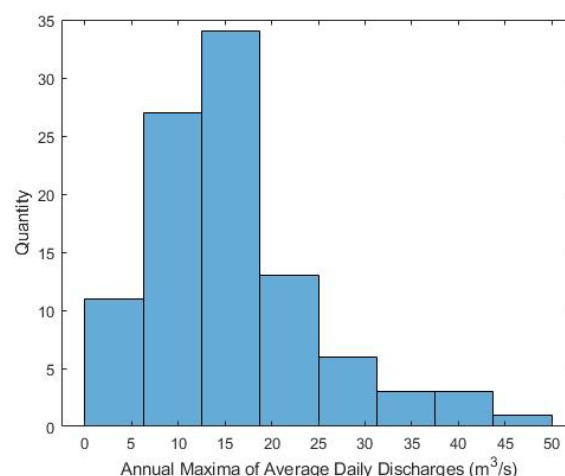


Fig. 2. Histogram of annual maxima of average daily discharges.

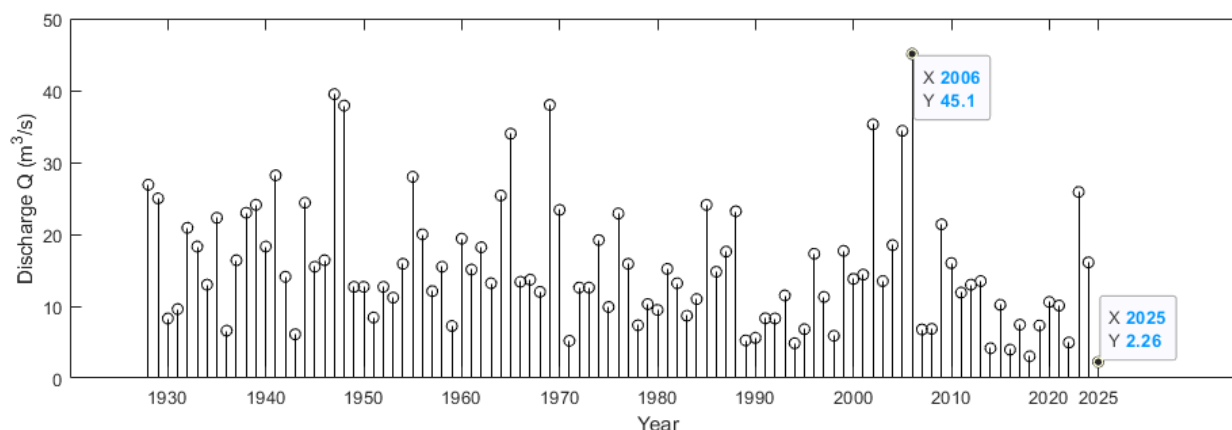


Fig. 3. Annual maxima of average daily discharges at the Dvorce station.

4. RESULTS

Parameter estimation for the 2-parameter Weibull distribution is summarized in Table 2.

Tab. 2. Parameter estimates.

shape parameter $\hat{a}$	1.895
scale parameter $\hat{b}$	17.601

Results for the Kolmogorov-Smirnov and Anderson-Darling goodness-of-fit tests are presented in Table 3.

Tab. 3 Goodness-of-fit tests.

	Test Statistic	p-value
Kolmogorov-Smirnov test	0.080	0.526
Anderson-Darling test	0.092	0.648

The p-value for both tests is greater than the chosen significance level $\alpha = 0.05$, which means we do not reject hypothesis H_0 . Block maxima of average daily discharges on the Jihlava River follow a Weibull distribution, as confirmed by the histogram overlaid with the distribution curve (Fig. 4) as well as the Q-Q plot (Fig. 5).

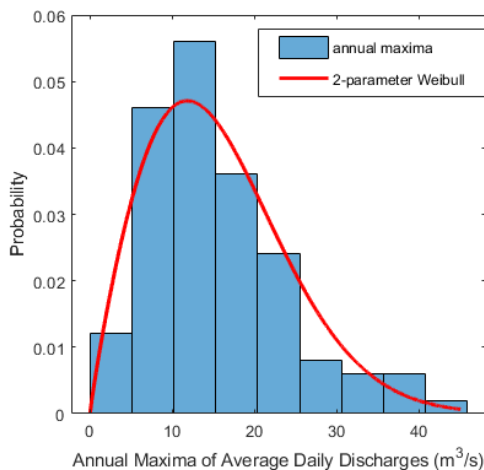


Fig. 4. Histogram for annual maxima of average daily discharge overlaid with the estimated Weibull distribution curve.

5. RETURN PERIOD AND RETURN LEVEL

The return level Q_N is the value that is exceeded on average once in N years with the probability [15, 16]

$$p = \frac{1}{N}$$

The probability that the discharge exceeds the return level is then defined as

$$P(Q > Q_N) = 1 - G(Q_N) = p$$

where $G(x)$ denotes the cumulative distribution function. Thus, the return level represents the quantile of the cumulative distribution function

$$Q_N = G^{-1}\left(1 - \frac{1}{N}\right).$$

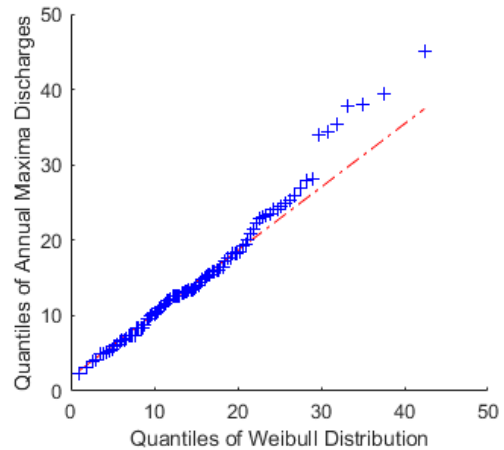


Fig. 5. Q-Q plot - quantiles of maxima discharges (blue cross), quantiles of Weibull distribution (red line).

For the 2-parameter Weibull distribution it is calculated as [16]

$$Q_N(N) = b \left(-\ln \left(1 - \frac{1}{N} \right) \right)^{\frac{1}{a}}.$$

The return period, N , is typically set at 2, 5, 10, 20, 50 or 100 years to determine N -year flood flows. For the estimation of the N -year discharge to be reliable, a time series of the measurements with a length of approximately $5N$ is required. [15]

In Table 4, we provide N -year discharges for $N = 5, 10, 20, 50$ and 100 years. Since we have 98 annual maxima available, estimation up to 20 years can be considered reliable, whereas higher return periods are less reliable. For example, in a 100-year long time series, the probability of Q_{100} occurring at least once is 63%. [15]

Table 4. Estimates of the N -year discharges at the hydrological station Dvorce.

N	5	10	20	50	100
Q_N (m³/s)	22.62	27.34	31.42	36.17	39.43

6. CONCLUSION

In this paper, we modeled extreme discharges on the Jihlava River using the block maxima method. Nearly a century of continuous average daily discharge records from the Dvorce hydrological station were used for the analysis. By choosing a block length of one year, 98 values — representing maximum average daily discharges for the years 1928 through 2025 — were extracted. A 2-parameter Weibull probability distribution was used to model the dataset. Distribution parameters were estimated using the maximum likelihood method (shape parameter $a = 1.895$, scale parameter $b = 17.601$). Agreement between the theoretical distribution and empirical data was confirmed by two goodness-of-fit tests. The p-value of the Kolmogorov-Smirnov test (0.526) and the Anderson-Darling test (0.648) consistently demonstrated that H_0 cannot be rejected at significance level $\alpha = 0.05$. Adequacy of the estimated Weibull distribution for block maxima of average daily discharges was also confirmed by the Q-Q plot and the distribution curve fitted over the histogram of observations.

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Verifikácia bioluminiscenčnej metódy v procese výroby mliečnych produktov

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Abstrakt Klasické mikrobiologické metódy v modernej mliekarenskej prevádzke z hľadiska rýchlosti poskytnutia výsledkov nespĺňajú požiadavky praxe, keď sa vyžaduje, čo najrýchlejšie hodnotenie účinnosti sanitácie, hygieny výroby alebo kvality hotového výrobku. Pre výrobu je optimálne spojenie permanentného monitoringu hygienickej úrovne s poskytnutím výsledkov laboratórneho vyšetrenia ešte v čase, kedy sa dajú v prípade nepriaznivých zistení vykonať validované nápravné opatrenia tak, aby sa predišlo znehodnoteniu výrobku a kontaminácii výrobných priestorov. Práve táto skutočnosť potvrdzuje opodstatnenosť tejto metodiky v systémoch riadenia kvality. V súčasnosti sa do sanitčných protokolov implementujú rýchle metódy na báze bioluminiscencie ATP (adenozíntrifosfát), charakteristické vysokou senzitivitou, analytickou rýchlosťou a nízkou personálnou náročnosťou. Cieľom našej práce bolo hodnotenie sanitácie a hygieny prostredia pomocou bioluminiscenčnej metódy v monitorovanej potravinárskej prevádzke orientovanej na výrobu mliečnych produktov (tvarohu a jogurtov). Na základe získaných výsledkov možno konštatovať, že dezinfekčný proces v monitorovanej mliekarenskej prevádzke bol celkovo účinný. Po dezinfekcii došlo v oboch sledovaných častiach výroby k štatisticky významnému zníženiu hodnôt ATP ($p < 0,001$), čo potvrdzuje vysokú účinnosť sanitácie pri odstraňovaní organických zvyškov z povrchov technologických zariadení.

Kľúčová slová: hygiena, mikroorganizmy, biofilm, ATP, dezinfekcia, mliekareň

1. ÚVOD

Sanitačný režim je jednou z najdôležitejších súčastí kontrolného systému HACCP (Hazard analysis and critical control points).

Čistenie a dezinfekcia ako súčasť každodennej výrobnéj praxe sú nepostrádateľné pre správne fungovanie výroby potravín v súlade s legislatívnymi požiadavkami. Kontrola hygieny a kvality čistenia a dezinfekcie je rozhodujúcim faktorom pri splnení základných požiadaviek systému HACCP v potravinárskych prevádzkach (Vojtaššák, 2003).

Účinnosť sanitačných postupov sa tradične hodnotí pomocou rôznych metód (Griffith, a kol., 2000). Výber najvhodnejšej metódy mikrobiologickej analýzy povrchov je podmienený typom vyrábaných potravín a infraštruktúrou laboratória. Je dôležité použiť najlepšiu metódu na izoláciu a detekciu mikroorganizmov v biofilmoch a kvapalných médiách (Salo et al 2006).

Výšetrenia klasickými mikrobiologickými metódami z hľadiska rýchlosti poskytnutia výsledkov nespĺňajú požiadavky praxe, ktorá požaduje, čo najrýchlejšie vyhodnotenie účinnosti sanitácie, stavu hygieny výroby alebo kvality hotového výrobku (Vojtaššák, 2003). Mikrobiologické metódy môžu trvať až 48 hodín, nevýhodou je, že v čase zistenia chyby môže byť vyrobené a predané veľké množstvo neuspokojivých alebo nebezpečných potravín (Moore a Griffith, 2002).

Pre výrobu je optimálne spojenie permanentného monitoringu hygienickej úrovne s poskytnutím výsledkov laboratórneho vyšetrenia ešte v čase, kedy sa dá v prípade nepriaznivých zistení vykonať náprava tak, aby sa predišlo znehodnoteniu výrobku a kontaminácii výrobných priestorov, čo by mohlo zabrániť rozsiahlejším ekonomickým škodám a predovšetkým ohrozeniu zdravia konzumentov, prípadne vzniku alimentárnych ochorení (Lopašovský, 2006).

V súčasnosti sa čoraz v širšom meradle začínajú používať metódy na báze bioluminiscencie (Suková, 2002). Bioluminiscenčné metódy

sú nové moderné metódy, ktorých prednosťami sú predovšetkým rýchlosť, jednoduchosť, časová i personálna nenáročnosť, ľahká manipulácia. Bioluminiscenčná poskytuje odhady celkovej kontaminácie povrchu v reálnom čase. Táto technika sa ukázala byť obzvlášť užitočná vo veľkých výrobných závodoch, kde pravidelné a časté monitorovanie môže poskytnúť manažmentu údaje o trendoch v úrovni hygieny čo umožňuje rýchle výsledky o množstve organických zvyškov a mikrobiálnej kontaminácii na povrchoch prevádzok (Chen, 2000). Hoci táto metóda neidentifikuje množstvo mikroorganizmov alebo druhov kontaminantov, môže sa použiť ako prostriedok na monitorovanie hygieny a overovanie čistoty (Calvert a kol., 2000).

Cieľom našej práce bolo hodnotenie hygieny výrobného prostredia mliečnych produktov pomocou bioluminiscenčnej metódy a analýza rizík spojených s bezpečnou výrobou potravín.

2. MATERIÁL A METODIKA

2.1 Kontrola účinnosti sanitácie pomocou ATP metódy

Práca sa zameriava na kontrolu účinnosti sanitácie v monitorovanej mliekarenskej prevádzke pomocou bioluminiscenčnej metódy. Vzorky sterov sme odoberali počas výroby a po dezinfekcii z vybraných povrchov technológií v časti výroby tvarohu (tvarohárska vaňa, separátor tvarohu, balička) a jogurtov (plnička džemu, plnička jogurtu, balička).

Na meranie bioluminiscencie sme použili systém HY – LITE od firmy Biotrace, pozostávajúci z prenosného zariadenia luminometra a slúži na vyhodnotenie množstva emitovaného svetla vzniknutého v reagenčnej komore odberového pera dodávaného výrobcom. Tieto perá dodávané výrobcom boli použité na stieranie vyšetrovanej plochy 100 cm². Po reakcii ATP obsiahnutého vo vzorke s enzýmom luciferáza v reagenčnej komore pera bola intenzita emitovaného svetla stanovená luminometrom v relatívnych jednotkách RLU (Relative Light Unit).

Na každom odberovom mieste bolo vykonaných päť opakovaných ATP meraní, pričom výsledná hodnota predstavuje aritmetický priemer týchto meraní. Odbery boli realizované na 25 odberových miestach v časti výroby tvarohu a 25 odberových miestach v časti výroby jogurtov, spolu teda na 50 odberových miestach, pričom vzorky boli odoberané počas výroby aj po aplikácii dezinfekčných prostriedkov.

Na hodnotenie výsledkov boli použité odporúčané limity pre mliekarensku prevádzku: vyhovujúce hodnoty < 150 RLU/100 cm², hraničné hodnoty 151–299 RLU/100 cm² a nevyhovujúce hodnoty > 300 RLU/100 cm². Výsledky boli štatisticky spracované pomocou opisnej štatistiky a vyjadrené ako aritmetický priemer ± smerodajná odchýlka (SD), medián, minimálna a maximálna hodnota. Na porovnanie hodnôt ATP nameraných počas výroby a po dezinfekcii bol použitý párový Studentov t-test. Štatistická významnosť rozdielov bola stanovená pri hladine významnosti $p < 0,05$.

2.2 Použité čistiace a dezinfekčné prostriedky

Monitorovaná mliekareň má integrovaný sanitálny program v rámci systému HACCP, pričom čistenie prebieha bezprostredne po ukončení výroby. Kľúčovým prvkom sanitácie je striedanie alkalických a kyslých čistiacich prostriedkov prostredníctvom uzavretého CIP systému. Súčasný nastavený program začína predoplachom teplou vodou (50 °C). Nasleduje vŕhanie 1,5 % roztoku hydroxidu sodného (NaOH), toto alkalické čistenie pre

maximálny účinok vyžaduje vysokú teplotu (70–80 °C) a turbulentné prúdenie na mechanické odlepenie mliečného tuku. Po mechanickom umytí sa všetky rozoberateľné časti ponoria do 0,2 % roztoku Pedoxu na dobu 15 – 30 minút. Tento dezinfekčný režim sa pravidelne strieda s aplikáciou 10 % chlórnanu sodného, čím sa predchádza vzniku mikrobiálnej rezistencie.

V prvej fáze boli aplikované alkalické (hydroxid sodný) a kyslé detergenty (kyselina dusičná). Hydroxid sodný je práškový koncentrát, ktorý obsahuje 98 % účinnej látky NaOH, práškové polyfosfáty a iné stabilizačné látky. Používa sa ako pracovný roztok v koncentrácii 1 – 1,5 % s časovou expozíciou 15 minút na dezinfekciu potrubia, nádrží a strojového zariadenia s cieľom eliminovať tukové a bielkovinové nánosy mliečného kameňa z povrchu nerezovej ocele. Pôsobí na vegetatívne baktérie, kvasinky, plesne a vírusy, a na spóry v kombinácii s vysokou teplotou. Svetovým výrobcom a dodávateľom pre mliekareň v SR je spoločnosť Ecolab, s.r.o.

Sanitácia zariadení prebiehala v dvoch fázach:

V prvej fáze sa využíva alkalické a kyslé čistenia. Ako alkalický detergent sa aplikuje práškový koncentrát hydroxidu sodného od spoločnosti Ecolab, s.r.o., ktorý obsahuje 98 % účinnej látky NaOH, práškové polyfosfáty a špeciálne stabilizátory. V CIP systéme sa dávkuje pri pracovnej koncentrácii 1,0 až 1,5 % pri dĺžke cyklu 15 minút. Tento krok slúži na úplné odstránenie tukov a bielkovín z nerezových potrubí a nádrží. Minerálne usadeniny a mliečny kameň sa v nasledujúcom kroku odstraňujú kyselinou dusičnou. Roztok NaOH pôsobí deštruktívne na vegetatívne bunky baktérií, kvasinky, plesne a vírusy. Na elimináciu vysoko odolných bakteriálnych spór je nutné roztok lúhu kombinovať s vysokou teplotou (nad 75 °C). Kyslým detergentom je kyselina dusičná, do mliekarní sa dodáva ako 53 % až 65 % roztok. Pracovný roztok v CIP staniaciach sa automaticky riedi vodou na koncentráciu 0,5 % až 1,5 %. Teplota lúhu pre pasteurizátory sa zvyčajne zahrieva na 50 až 70 °C. Vyrába ho firma Ecolab, s.r.o. Používa sa na elimináciu minerálnych nánosov mliečného kameňa z povrchu nerezovej ocele a špecifickú vnútornú dezinfekciu technológií, z dôvodu baktericídneho pôsobenia.

V druhej fáze bola dezinfekcia prevedená oxidačnými dezinfekčnými prostriedkami Pedox a Chlórnan sodný. Pedox PAA/30 je viaczložkový prípravok na báze kyseliny peroxyoctovej a peroxidu vodíka. Má baktericídne, fungicídne, sporicídne a vírusinaktivačné účinky. Používa sa dezinfekcia povrchov, priestorov a predmetov, ktoré sú rizikové z hľadiska množenia sa mikroorganizmov. Je určený na v rámci hygienického režimu na udržiavanie hygieny priestorov mliekarní. Výrobcom je Polychem s.r.o., Prievidza, SR. Chlórnan sodný je vysoko koncentrovaný tekutý dezinfekčný prostriedok, ktorý obsahuje 14 % aktívneho chlóru. Pôsobí na baktérie, vírusy, plesne, kvasinky a odbúrava organické nečistoty. Výrobcom je Centralchem s.r.o., Banská Bystrica, SR.

3. VÝSLEDKY

V tabuľke 1 sú uvedené výsledky meraní ATP na povrchoch technologických zariadení v časti výroby tvarohu pred a po dezinfekcii. Priemerná hodnota ATP počas výroby dosiahla 153,88 ± 102,94 RLU/100 cm², pričom hodnoty sa pohybovali od 21 do 351 RLU/100 cm². Po vykonaní dezinfekcie sa priemerná hodnota ATP významne znížila na 6,56 ± 5,58 RLU/100 cm², pričom minimálna hodnota bola 0 RLU/100 cm² a maximálna 17 RLU/100 cm². Párový t-test preukázal štatisticky vysoko významný rozdiel medzi

hodnotami nameranými počas výroby a po dezinfekcii ($p < 0,001$), čo potvrdzuje vysokú účinnosť vykonanej dezinfekcie.

Tabuľka 1. Štatistické vyhodnotenie ATP sterov na testovaných povrchoch technológií pri výrobe tvarohu

Parameter	Počas výroby	Po dezinfekcii	p-hodnota
Priemer $\pm$ SD (RLU/100 cm ²)	153,9 $\pm$ 102,9 ^a	6,56 $\pm$ 5,58 ^b	< 0,001
Medián	144	5	–
Minimum	21	0	–
Maximum	351	17	–
Párový t-test	-	t(24) = 7,30	< 0,001

Poznámka: SD – smerodajná odchýlka; t(24) – Studentov párový t-test (24 stupňov voľnosti);

$p < 0,05$ – štatisticky významný rozdiel. Hodnoty označené rôznymi písmenami (a, b) sa štatisticky významne líšia ($p < 0,05$).

Tabuľka 2 prezentuje výsledky meraní ATP na povrchoch technologických zariadení vo výrobe jogurtov pred a po dezinfekcii. Priemerná hodnota ATP počas výroby bola 29,88 $\pm$ 11,34 RLU/100 cm², pričom namerané hodnoty sa pohybovali v rozmedzí od 12 do 52 RLU/100 cm². Po dezinfekcii sa priemerná hodnota znížila na 10,64 $\pm$ 21,53 RLU/100 cm², pričom minimálna hodnota bola 0 RLU/100 cm² a maximálna 110 RLU/100 cm². Vyššia smerodajná odchýlka po dezinfekcii bola spôsobená jednou odľahlou hodnotou (110 RLU/100 cm²), ktorá môže súvisieť s nedostatočnou dezinfekciou alebo sekundárnou kontamináciou sledovaného povrchu. Napriek tejto odľahlej hodnote párový t-test preukázal štatisticky vysoko významné zníženie ATP po dezinfekcii (t(24) = 4,53; $p < 0,001$), čo potvrdzuje celkovú účinnosť dezinfekčného procesu.

Tabuľka 2. Štatistické vyhodnotenie ATP sterov na testovaných povrchoch technológií pri výrobe jogurtov

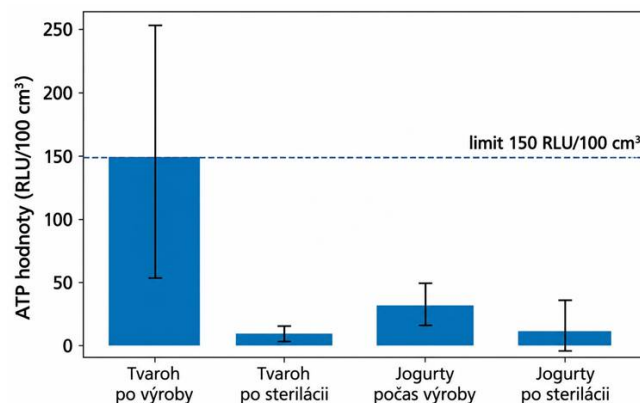
Parameter	Počas výroby	Po dezinfekcii	p-hodnota
Priemer $\pm$ SD (RLU/100 cm ²)	29,9 $\pm$ 11,3 ^a	10,64 $\pm$ 21,53 ^b	< 0,001
Medián	27	5	–
Minimum	12	0	–
Maximum	52	110	–
Párový t-test	-	t(24) = 4,53	< 0,001

Poznámka: SD – smerodajná odchýlka; t(24) – Studentov párový t-test (24 stupňov voľnosti);

$p < 0,05$ – štatisticky významný rozdiel. Hodnoty označené rôznymi písmenami (a, b) sa štatisticky významne líšia ($p < 0,05$).

Graf č. 1 znázorňuje vizuálne porovnanie priemerných hodnôt ATP na sledovaných technologických zariadeniach počas výroby a po dezinfekcii. Z grafu je zrejмый výrazný pokles hodnôt ATP po aplikácii dezinfekčných prostriedkov v oboch sledovaných výrobných úsekoch. Súčasne je viditeľná väčšia variabilita hodnôt počas výroby tvarohu v porovnaní s výrobou jogurtov, čo dokladajú vyššie hodnoty smerodajnej odchýlky. Po dezinfekcii boli priemerné hodnoty ATP v oboch výrobných úsekoch výrazne nižšie ako odporúčaný hygienický limit pre mliekarenskú prevádzku, čo poukazuje na správne nastavený sanitálny proces.

Graf 1. Grafické znázornenie priemerných hodnôt ATP sterov počas výroby a po dezinfekcii v procese výroby mliečnych produktov



4. DISKUSIA

Choroby prenášané potravinami sú prioritou verejného zdravia, pretože každý rok ochorie veľký počet ľudí v dôsledku konzumácie nebezpečných potravín. Hlavné obavy zvyčajne súvisia s prítomnosťou fyzikálnych a chemických kontaminantov, ako aj patogénnych mikroorganizmov (Newell et al. 2010; Petruzzelli, et al 2010). Mikrobiologickú kontamináciu potravín možno pripísať prirodzene kontaminovaným surovinám (Petruzzelli kol., 2014) alebo krížovej kontaminácii (Gorman et al., 2002; Osimani et al., 2013). Aby sa predišlo negatívnym dopadom na spotrebiteľa, rýchla kontrola čistoty povrchov technológií pomocou ATP metódy počas výrobného procesu má svoje opodstatnenie hlavne z dôvodu rýchleho vykonania nápravného opatrenia.

Hoci sa v literatúre diskutuje o limitoch priamej kvantifikácie, viacerí autori potvrdili vysokú mieru zhody medzi výsledkami bioluminiscenčného stanovenia ATP a klasickými kultivačnými postupmi. Tento vzťah bol demonštrovaný tak v podmienkach spracovateľských mliekarenských podnikov (Murphy a kol., 1998), ako aj priamo v prvovýrobe na mliečnych farmách (Vilar a kol., 2008). Pri porovnaní oboch metód, napriek istým obmedzeniam v presnosti, je kľúčovým benefitom ATP metódy jej rýchlosť. Schopnosť identifikovať kritické miesta kontaminácie priamo počas sanitálneho auditu predstavuje zásadnú výhodu pre manažment bezpečnosti potravín (Tebbutt a kol., 2007).

Zo získaných výsledkov našej štúdie sme došli k nasledujúcim záverom. V časti výroby tvarohu boli po dezinfekcii všetky namerané hodnoty ATP nižšie ako odporúčaný hygienický limit 150 RLU/100 cm², čo poukazuje na výskor vykonanie sanitácie. Podobné výsledky boli zaznamenané aj vo výrobe jogurtov, kde väčšina meraní po dezinfekcii spĺňala stanovené hygienické kritériá. Jedna odľahlá hodnota (110 RLU/100 cm²) síce zvýšila variabilitu výsledkov, avšak neprekročila odporúčaný limit pre mliekarenskú prevádzku a neovplyvnila celkové hodnotenie účinnosti dezinfekcie. Vysoký štandard hygieny v pracovnom prostredí (povrchy, zariadenia a náčinie) je základným predpokladom prevencie mikrobiálnych kontaminácií nakoľko patogény vrátane *Staphylococcus aureus*, *Listeria monocytogenes*, *Salmonella spp.*, *Campylobacter jejuni*, *Yersinia enterocolitica* a enteropatogénne kmene *Escherichia coli*, môžu prežiť na rôznych povrchoch po dobu od niekoľkých hodín do niekoľkých dní (Martinon a Croin, 2012; Shi a Zhu, 2009; Simoes a kol., 2010) a dokonca tvoriť biofilmy, v ktorých mikrobiálne bunky môžu pretrvávajú a prežiť dekontaminačné postupy, čím predstavujú potenciálny rezervoár kontaminácie potravín. V závodoch na výrobu potravín sa tvorba biofilmov vo všeobecnosti začína, keď sa čistiace a sanitálne postupy nevykonávajú správne, a zvyšky potravín, ktoré zostávajú

na nedostatočne vyčistených povrchoch, predstavujú zdroj živín pre mikroorganizmy, ktoré môžu byť prítomné (Srey a kol., 2013).

5. ZÁVER

Hodnotenie úrovne hygieny a sanitácie v potravinárskej prevádzke musí nadväzovať na jednotlivé odvetvia a výrobné postupy, zohľadňujúce ich špecifitu, pre objektívne hodnotenie zistených výsledkov. Najobjektívnejším ukazovateľom je zisťovanie mikrobiologickej kontaminácie, na základe, ktorej môžeme hodnotiť účinnosť použitého dezinfekčného prostriedku, resp. účinnosť predchádzajúcej mechanickej očisty, ktorá výrazne ovplyvňuje účinnosť sanitčných prác a prijíma opatrenia na zlepšenie hygieny. Bioluminiscenčná metóda je vhodná na rýchlu kontrolu účinnosti sanitácie priebežne počas pracovnej smeny. V krátkom čase podá výsledok o hygiene povrchov a zároveň slúži na vyhľadávanie nedostatkov v sanitácii. Získané výsledky potvrdzujú, že ATP bioluminiscenčná metóda je vhodným nástrojom na rýchle overovanie účinnosti sanitácie technologických zariadení v mliekarenskej výrobe. Jej využitie umožňuje okamžitú kontrolu hygienického stavu povrchov, včasnú identifikáciu potenciálnych nedostatkov a prijatie nápravných opatrení ešte pred začiatkom ďalšieho výrobného procesu. Významne tak prispieva k zabezpečeniu zdravotnej bezpečnosti potravín a podporuje efektívne fungovanie systému HACCP. Aj keď ATP metóda nenahrádza klasické mikrobiologické vyšetrenia, predstavuje ich vhodný doplnok pri rutinnom monitorovaní hygieny. Jej zavedenie do sanitčných programov môže zvýšiť efektívnosť kontroly čistoty technologických zariadení, prispieť k prevencii vzniku biofilmov a znížiť riziko mikrobiálnej kontaminácie potravín.

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Radiačná záťaž pri dentálnom CBCT a jej porovnanie s inými zobrazovacími metódami v zubnom lekárstve

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Abstrakt V posledných desaťročiach sledujeme exponenciálny nárast využívania zdrojov ionizujúceho žiarenia v medicíne po celom svete. Radiačná záťaž pacienta predstavuje dôležitý faktor pri indikovaní a realizácii zobrazovacích vyšetrení v stomatológii. CBCT predstavuje v súčasnosti štandardnú metódu v dentálnej rádiológii. V našej štúdií sme analyzovali veľkosť plošných dávok pacientov pri CBCT a OPG vyšetrení prostredníctvom aplikovanej plošnej dávky (DAP) pri rôznych parametroch vyšetrenia. Dospeli sme k záveru, že pacienti, ktorí podstupujú vyšetrenie pomocou OPG majú podstatne nižšiu radiačnú záťaž ako pacienti vyšetrení CBCT prístrojom. DAP pri CBCT vyšetreniach sa pohyboval v rozpätí 150 – 1 550 mGy.cm² a pri OPG vyšetreniach 30 - 135 mGy.cm². Naše výsledky sme porovnali so zahraničnými štúdiami.

KLúčové slová Radiačná záťaž, plošná dávka, kuželová počítačová tomografia (CBCT)

1. ÚVOD

Diagnostika s využitím ionizujúceho žiarenia predstavuje neoddeliteľnú súčasť modernej stomatologickej praxe a takmer každé diagnostické hodnotenie či terapeutický postup si vyžaduje rádiologické zobrazenie poskytujúce cenné informácie z hľadiska prevencie, presnej diagnostiky ochorení, monitorovania priebehu liečby, hodnotenia liečebných výsledkov a následného kontrolného sledovania pacientov (recall).

V posledných rokoch sa pozornosť odborníkov stále viac sústreďuje na problematiku radiačnej záťaž pacienta v dentálnej praxi, najmä s ohľadom na používanie modernej zobrazovacej technológie, akou je kuželová počítačová tomografia (cone-beam computed tomography, CBCT). Táto technológia poskytuje trojrozmerné priestorové zobrazenie s vysokým rozlíšením, ktoré významne zlepšuje diagnostiku a plánovanie liečby, avšak je spojená s vyšším ožiaraním pacienta v porovnaní s konvenčnými metódami, ako sú intraorálny a panoramatický röntgen. Tieto tradičné zobrazovacie

modality zostávajú základnými diagnostickými nástrojmi v zubnom lekárstve a poskytujú nevyhnutný referenčný rámec pre hodnotenie dávok žiarenia pri porovnaní s CBCT.

Cieľom tejto štúdie je analyzovať radiačnú záťaž pacienta pri použití CBCT v porovnaní s intraorálnym a panoramatickým röntgenom, identifikovať faktory ovplyvňujúce veľkosť dávky a navrhnúť možnosti jej optimalizácie v súlade s princípom ALARA (As Low As Reasonably Achievable).

Prečo riešime otázku zvyšujúcej sa radiačnej záťaž v zubnej ambulancii:

- nárast počtu zubných lekárov (rok 2009 počet ZL bol 2633, rok 2024 počet ZL je 2966, tj. 12 % nárast) Zdroj: SKZL, (2025).
- väčšia dostupnosť ošetrovateľských posádok v zubnej ambulancii (moderné postupy)
- narastajúci záujem o ošetrovanie v zubnej ambulancii
- vykonávanie komplikovanejších zákrokov hlavne v oblasti dentálnej implantológie
- väčší počet per operačných aj post operačných komplikácií
- s tým spojený nárast prístrojov využívajúcich ionizujúce žiarenie na korektnú diagnostiku
- narastajúce radiačné zaťaženie pacientov

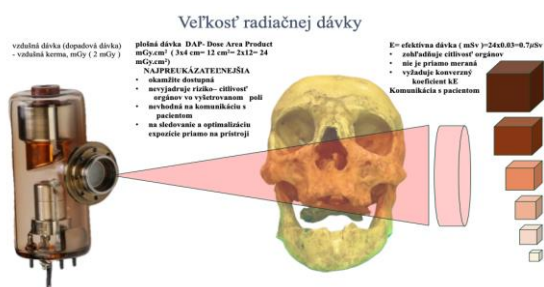
Potreba zhotovenia rtg v zubnej ambulancii:

- preventívne prehliadky (kariézne lézie, kostné lézie, patologické procesy)
 - deti do 18 r. 2 x ročne
 - dospelý od 18 r. života 1 x ročne (každé 2 roky BW RTG, každé 3 roky OPG)
- kariológia
- endodontická terapia
- chirurgická terapia
- čeľusná ortopédia
- parodontológia
- dentálna hygiena
- protetická terapia

2. METÓDY

Na hodnotenie veľkosti radiačnej záťaže sa v tejto práci použijú dve základné dozimetrické veličiny (obr. 1). Prvou z nich je plošná dávka – **dose area product (DAP)**, resp. **vzdušná kerma**, udávaná v jednotkách $\text{mGy} \cdot \text{cm}^2$, ktorá sa javí ako jedna z najpraktickejších a najlepšie reprodukovateľných veličín. Pri moderných röntgenových zariadeniach je hodnota DAP dostupná okamžite, napríklad na ovládacom paneli nástenného intraorálneho röntgenového prístroja alebo na monitore rádiologického softvéru pri OPG a CBCT vyšetreniach. Jej výhodou je možnosť priameho monitorovania a optimalizácie radiačnej záťaže priamo na prístroji. Nevýhodou však zostáva skutočnosť, že DAP nevyjadruje biologické riziko ani rozdielnu radiosenzitivitu jednotlivých orgánov v ožiarennej oblasti, a preto nie je vhodná na komunikáciu rizika s pacientom.

Druhou hodnotenou veličinou používanou na komunikáciu rizika z ožiarovania je **efektívna dávka (E)**, vyjadrovaná v jednotkách mSv (resp. mSv). Na rozdiel od plošnej dávky zohľadňuje rozdielnu citlivosť jednotlivých tkanív a orgánov na ionizujúce žiarenie, a preto predstavuje vhodný nástroj na hodnotenie celkového biologického rizika a jeho komunikáciu s pacientom. Efektívna dávka však nie je meraná priamo, ale je vypočítavaná pomocou konverzných koeficientov odvodených z experimentálnych a simulačných modelov.



Obr. 1. Znázornenie kužeľovitého **zvázku žiarenia**, vychádzajúceho zo zdroja ionizujúceho žiarenia, prechádzajúceho vyšetřovanou oblasťou a dopadajúceho na plochý detektor. **DAP (Dose Area Product)**.

Pri návšteve stomatologickej ambulancie sa pacient najčastejšie stretáva s tromi základnými typmi rádiologických zobrazovacích zariadení. Na Slovensku však, na rozdiel od viacerých krajín Európy a sveta, nie je súčasťou povinného materiálno-technického vybavenia stomatologickej ambulancie trojrozmerný (3D), panoramatický ani intraorálny röntgenový prístroj inštalovaný priamo v miestnosti, v ktorej je pacient vyšetřovaný. Z tohto dôvodu sú pacienti často referovaní na iné pracoviská disponujúce príslušným technickým vybavením.

Otázka efektivity tohto postupu zostáva predmetom diskusie. Z hľadiska diagnostických možností ošetrojúceho lekára, ako aj komfortu pacienta, je však možné jednoznačne konštatovať, že prítomnosť minimálne intraorálneho diagnostického röntgenového prístroja predstavuje nevyhnutný štandard. Jeho dostupnosť umožňuje rýchlu a efektívnu diagnostiku bez potreby odosielania pacienta na iné špecializované pracovisko.

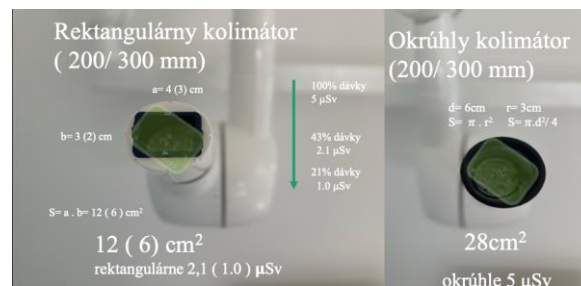
Okrem výrobcom prednastavených expozičných parametrov má zubný lekár, rádiologický technik, alebo rádiológ viacero možností, ako ovplyvniť a optimalizovať radiačnú záťaž pacienta bez zníženia kvality diagnostického výsledku. Medzi najdôležitejšie patrí:

1. **Výber typu detektora** – použitie digitálnych senzorov typu CCD/CMOS alebo fotostimulačných fosforových platničiek

umožňuje dosiahnuť diagnosticky vyhovujúci obraz pri nižšej dávke v porovnaní s klasickými filmami.

2. **Nastavenie kolimácie** – voľba kruhového alebo rektangulárneho kolimátora a jeho správne umiestnenie môže významne redukovať ožiarenu plochu, čím sa priamo znižuje dávka (Obr. 2).
3. Úprava vzdialenosti medzi zdrojom žiarenia a povrchom vyšetřovanej oblasti vedie k zníženiu plošnej dopadovej dávky v súlade so zákonom inverzného štvorca.
4. **Výber zobrazovanej oblasti a projekcie** – správnym výberom lokalizácie (napr. frontálna vs. distálna oblasť) a typu projekcie (periapikálna vs. bitewingová) sa minimalizuje ožiarenie okolitých tkanív.
5. **Prispôsobenie expozičných parametrov pacientovi** – úprava napätia (kV), prúdu (mA) a doby expozície podľa veku, veľkosti a telesnej konštitúcie pacienta umožňuje znížiť dávku pri zachovaní diagnostickej kvality obrazu.
6. **Správne umiestnenie a fixácia detektora alebo filmu** – zamedzenie pohybu počas expozície minimalizuje potrebu opakovaných snímok.

Všetky tieto kroky spoločne umožňujú **optimalizovať radiačnú záťaž pacienta** a dodržiavať princíp ALARA (As Low As Reasonably Achievable), pričom neznižujú kvalitu diagnostického výsledku.

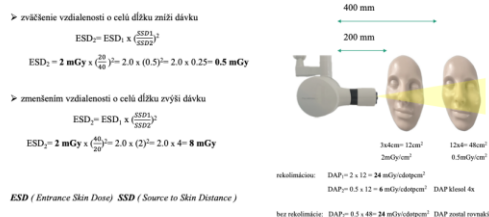


Obr. 2. Ovpłyvnenie veľkosti radiačnej záťaže správnou voľbou kolimačného zariadenia a jeho nastavením.

Veľmi dôležitým parametrom ovplyvňujúcim veľkosť radiačnej dávky pacienta je výber kolimačného zariadenia. V intraorálnej rádiológii sa štandardne používa kolimátor kruhového tvaru s dĺžkou približne 200 mm, avšak s možnosťou rektangulárnej kolimácie. Tvar kolimačného zariadenia má zásadný vplyv na veľkosť radiačnej záťaže, pričom prechod z kruhového na rektangulárny kolimátor môže viesť k redukcii dávky žiarenia až päťnásobne.

Na druhej strane, použitie rektangulárneho kolimátora si vyžaduje správnu voľbu držiekov snímokovacích platničiek alebo senzorov kompatibilných s daným typom kolimátora. Nesprávne nastavenie filmu alebo digitálneho detektora môže viesť k chybnjej projekcii a potrebe opakovanej expozície, čím sa pôvodná výhoda zníženia radiačnej dávky eliminuje.

Ovplyvnenie veľkosti radiačnej dávky vzdialenosťou



Obr. 3. Dôležitosť nastavenia vzdialenosti od zdroja žiarenia po povrch kože vyšetřovaného objektu.

Mnohí diagnostickí pracovníci sa pokúšali redukovať radiačnú záťaž pacienta zmenou vzdialenosti medzi zdrojom ionizujúceho žiarenia a povrchom vyšetřovaného úseku. Je však potrebné si uvedomiť, že zmenou tejto vzdialenosti dochádza aj k zmene veľkosti ožiarenej plochy. Pri zväčšení vzdialenosti zo 200 mm na 400 mm klesá hodnota vstupnej dávky podľa zákona inverzného štvorca, teda zo 2 mGy na 0,5 mGy. Naopak, pri zmenšení vzdialenosti zo 400 mm na 200 mm sa hodnota vstupnej dávky štvornásobne zvyšuje, konkrétne z 2 mGy na 8 mGy.

Pri správnej rekolimácii však dochádza pri zväčšení vzdialenosti medzi zdrojom žiarenia a povrchom tela k zníženiu plošnej dopadovej dávky, ako je znázornené na obr. 3. Typ použitého detekčného systému predstavuje významný faktor ovplyvňujúci veľkosť radiačnej dávky pacienta pri intraorálnych rádiologických vyšetřeniach.

V klinickej praxi sa využívajú analógové röntgenové filmy rôznych tried citlivosti (D, E, F), fotostimulačné fosforové platničky (PSP) a digitálne detektory typu CCD/CMOS, pričom jednotlivé systémy sa výrazne líšia svojou detekčnou účinnosťou a expozičnými nárokmi a sú v súčasnosti postupne nahrádzané digitálnymi technológiami, ktoré v porovnaní s analógovými filmami môžu viesť k redukcii dávky až o 60–80 % (Obr. 4).

Ovplyvnenie radiačnej dávky použitým druhom detektorov



Obr. 4. Výber správneho detekčného zariadenia rovnako okrem kvality výsledného diagnostického obrazu má vplyv na veľkosť radiačnej záťaže.

Optimalizácia expozičných podmienok zohráva kľúčovú úlohu pri minimalizácii radiačnej záťaže a zároveň prispieva k efektívnemu využitiu zobrazovacieho systému a predstavuje základný predpoklad bezpečného a kvalitného vykonávania rádiologických vyšetření. (Tab. 1).

Tab. 1. Hodnoty plošnej dávky (DAP) v závislosti od nastavených expozičných parametrov.

Intraorálny rtg prístroj Dentsply Sirona Heliodent Plus

	kruhový tubus ø 6 cm				obmedzené pole 3x4 cm				2x3 cm
	200 mm	300 mm	200 mm	300 mm	200 mm	300 mm	200 mm	300 mm	200 mm
	60 kV	70 kV	60 kV	70 kV	60 kV	70 kV	60 kV	70 kV	60/70 kV
	mGy/cm²	mGy/cm²	mGy/cm²	mGy/cm²	mGy/cm²	mGy/cm²	mGy/cm²	mGy/cm²	mGy/cm²
Čas expozície (sekundy)									
0.01	3	1	3	2	1	1	1	1	
0.05	13	7	17	9	6	3	7	4	
0.06	16	8	21	10	7	3	9	4	
0.08 DR, CR	22	11	28	14	9	5	12	6	% dávky
0.10	27	13	34	17	12	6	15	7	
0.16 Film	43	22	55	28	18	9	24	12	% dávky
1.0	269	134	344	172	115	58	148	74	
2.0	538	269	689	344	230	115	295	148	
2.50	672	336	861	431	288	144	369	185	
3.20	860	430	1102	551	369	184	472	236	

Tak ako ovládací panel intraorálneho röntgenového prístroja, aj ovládací rozhranie panoramatického (OPG) a CBCT prístroja poskytuje možnosť individuálneho prispôbenia expozičných parametrov. Priemerná radiačná záťaž pri panoramatickom rádiologickom vyšetření sa pohybuje približne v rozmedzí hodnôt DAP 70–130 mGy·cm², a to za predpokladu, že je snímovaná celá horná a dolná čeľusť v plnom rozsahu (Tab. 2). Uvedené hodnoty môžu byť ovplyvnené viacerými faktormi, ako sú použité expozičné parametre, typ a generácia prístroja, morfológické charakteristiky pacienta, ako aj zvolený snímovací protokol. Významným optimalizačným nástrojom je možnosť zúženia zorného poľa (Field of View, FOV), ktorá je dostupná pri panoramatickom snímovaní, no predovšetkým pri CBCT vyšetřeniach (Tab. 3, Tab. 4). Redukcia veľkosti zorného poľa umožňuje cielejšie zobrazenie vyšetřovanej oblasti, čím dochádza k výraznému zníženiu radiačnej dávky pre pacienta pri zachovaní dostatočnej diagnostickej výpovednej hodnoty obrazu. Zvýšenie prístorového rozlíšenia je spravidla spojené s nárastom expozičných parametrov, a tým aj s vyššími hodnotami dávky. Z tohto dôvodu je nevyhnutné dôsledne zvážiť klinickú indikáciu CBCT vyšetřenia, respektíve diagnostickú oblasť, ktorá má byť zobrazovaná. Voľba rozlišovacej schopnosti (Obr. 5) by mala byť prispôbená konkrétnemu diagnostickému účelu, ako je endodontická diagnostika, ortodontické plánovanie, kariologické vyšetřenie alebo chirurgické zákroky.

Tab. 2. Hodnoty DAP pri zhotovení OPG čeľuste a sánky.

OPG- hodnoty DAP (Dose Area Product- súčin dávky a plochy) Expozičia 2D Pan

Program	Maximálny efektívny čas žiarenia	Hodnoty naprogramované výrobcom							
									
	Sekundy	kV/ mA	DAP mGy/cm ²	kV/ mA	DAP mGy/cm ²	kV/ mA	DAP mGy/cm ²	kV/ mA	DAP mGy/cm ²
P1	14.1	63/6	51	63/8	68	69/12	121	72/14	151

Tab. 3. DAP pri zhotovení CBCT veľkosti FOV 5 x 5.5cm, rôznej rozlišovacej schopnosti a rozdielneho veku a telesných charakteristík pacienta.

CBCT- 5cm x 5.5cm, Expozície 3D, pevné nastavenie 85 kV a hodnota prúdu 4-13 mA

Program SD	85/7	85/7	85/10	85/13
kV/mA	85/7	85/7	85/10	85/13
Čas žiarenia	2.6s	4.4s	4.4s	4.4s
mGy/cm ² 5 cm x 5.5 cm	79	135	193	250

Program Low dose	85/6	85/7	85/10	85/13
kV/mA	85/6	85/7	85/10	85/13
Čas žiarenia	2.2s	2.2s	2.2s	2.2s
mGy/cm ² 5 cm x 5.5 cm	17	19	27	35

Tab. 4. DAP pri zhotovení CBCT veľkosti FOV 17 x 13 cm, rôznej rozlišovacej schopnosti a rozdielneho veku a telesných charakteristík pacienta.

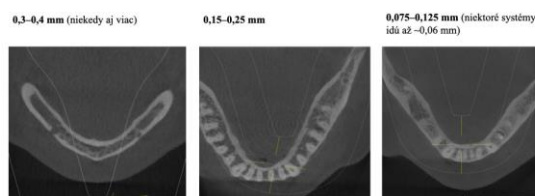
CBCT- 17cm x 13cm, Expozície 3D, pevné nastavenie 85 kV a hodnota prúdu 4-13 mA

Program SD	85/7	85/7	85/10	85/13
kV/mA	85/7	85/7	85/10	85/13
Čas žiarenia	4.5s	5.9s	5.9s	5.9s
mGy/cm ² 17 cm x 13 cm	444	586	836	1087

Program Low dose	85/6	85/7	85/10	85/13
kV/mA	85/6	85/7	85/10	85/13
Čas žiarenia	3.9s	3.9s	3.9s	3.9s
mGy/cm ² 17 cm x 13 cm	152	178	254	329

Rozsah hodnôt dávkového plošného súčinu (DAP) je jednoznačne najširší pri použití CBCT v porovnaní s intraorálnym a panoramatickým röntgenovým vyšetrením. Táto výrazná variabilita je podmienená najmä rozdielmi v použitých zobrazovacích protokoloch, veľkosti zorného poľa (Field of View, FOV), nastavení rozlišovacej schopnosti, veku a telesných charakteristikách pacienta, ako aj voľbou expozičných parametrov a technickými vlastnosťami jednotlivých CBCT zariadení. Významný vplyv na výslednú radiačnú záťaž má taktiež klinická indikácia vyšetrenia a rozsah zobrazovanej anatomickej oblasti.

Priestorové rozlíšenie HD, SD, Low dose
- má low dose svoje opodstatnenie ?



Obr. 5. Rozdiel v kvalite výsledného 3D rádiologického obrazu zobrazeného na snímke v axiálnej rovine. Priestorové rozlíšenie sledujeme v HD, SD a LOW DOSE kvalite.

3. DISKUSIA

Radiačná záťaž pri stomatologických röntgenových vyšetreniach patrí k najnižším v oblasti diagnostickej rádiológie. Efektívne dávky pri bežne používaných metódach, ako sú intraorálne röntgenové snímky, panoramatické röntgenové vyšetrenie (OPG) či CBCT

s malým zorným poľom, sa pohybujú v rozmedzí jednotiek až desiatok mikrosievertov. Tieto hodnoty sú porovnateľné s dávkami, ktorým je človek vystavený v rámci prirodzeného radiačného pozadia alebo počas bežných aktivít, napríklad pri leteckej doprave (Obr.6).

Na ilustráciu relatívnej veľkosti dávky možno stomatologické vyšetrenia porovnať k príjmu prirodzene rádioaktívneho draslíka obsiahnutého v potravinách, najmä v banánoch, alebo k expozícii kozmickému žiareniu počas krátkych letov. Jedna intraorálna stomatologická snímka zodpovedá približne dávke prirodzeného pozadia za jeden deň, zatiaľ čo panoramatické vyšetrenie je porovnateľné s dávkou prijatou počas krátkeho európskeho letu.



Obr. 6. Porovnanie radiačnej záťaže pri niektorých dentálnych röntgenových vyšetreniach s prírodným radiačným pozadím.

4. ZÁVER

Cone Beam Computed Tomography (CBCT) predstavuje efektívnu trojrozmernú rádiologickú zobrazovaciu metódu, ktorá umožňuje presné a detailné zobrazenie štruktúr tvrdých zubných a kostných tkanív v troch rovinách. CBCT poskytuje obrazy s vysokou diagnostickou kvalitou, vysokou rozmerovou presnosťou a minimálnou mierou geometrického skreslenia, čo umožňuje jej široké uplatnenie v stomatologickej diagnostike.

Z dostupných údajov vyplýva, že systematické sledovanie radiačnej záťaže pri dentálnych CBCT vyšetreniach na Slovensku v súčasnosti nie je možné bez zavedenia samostatného kódového označenia výkonov v systéme zdravotných poisťovní. Absencia samostatného kódu znemožňuje presné monitorovanie počtu realizovaných CBCT vyšetrení, analyzovanie trendov nárastu radiačných expozícií, sledovanie rozdielov v používaní protokolov zorného poľa (Field of View, FOV) medzi jednotlivými pracoviskami, ako aj systematickú implementáciu a kontrolu optimalizačných postupov radiačnej ochrany.

Zavedenie samostatného výkonového kódu pre dentálne CBCT vyšetrenia by zároveň umožnilo porovnávanie klinickej praxe s diagnostickými referenčnými úrovňami (DRÚ) a vytvorilo by predpoklady pre stanovenie národných DRÚ, ktoré v súčasnosti pre dentálne CBCT vyšetrenia na Slovensku absentujú.

Je jednoznačne preukázané, že použitie CBCT je spojené so zvýšenou radiačnou záťažou pacienta v porovnaní s konvenčnými dentálnymi zobrazovacími metódami, a to približne 10- až 13-násobne. Z tohto dôvodu je nevyhnutné zvyšovať povedomie zubných lekárov a ostatných zdravotníckych pracovníkov o princípoch radiačnej ochrany, nakoľko správna voľba expozičných parametrov a rozsahu zobrazovanej oblasti predstavuje kľúčový faktor optimalizácie radiačnej ochrany v stomatologickej rádiológii v súlade s princípom ALARA.

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Posúdenie antioxidačnej kapacity u koní plemena American Quarter Horse

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Oborové zamčrení: GH – Výživa hospodárskych zvierat

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Abstrakt Oxidačný stres predstavuje významný faktor ovplyvňujúci zdravotný stav, reprodukciu, fyzickú výkonnosť a adaptačné mechanizmy koní. Cieľom tejto štúdie bolo vyhodnotiť vybrané biomarkery antioxidačného statusu u klinicky zdravých koní plemena American Quarter Horse. Do štúdie bolo zaradených 13 klinicky zdravých koní (7 kobýl a 6 valachov) vo veku 4 až 15 rokov, využívaných na chov a rekreačné účely. Celkový antioxidačný status (TAS) a koncentrácia malondialdehydu (MDA) boli stanovené v sére, aktivita glutatiónperoxidázy (GPx) v heparinizovanej plnej krvi. Priemerná hodnota TAS bola $2,42 \pm 0,53$ mmol/l, aktivita GPx 862 ± 265 U/l a koncentrácia MDA $0,131 \pm 0,022$ μ mol/l. Výsledky poukazujú na priaznivý antioxidačný profil a absenciu známkov zvýšeného oxidačného stresu u sledovaných koní. Výsledky tejto štúdie prispievajú k rozšíreniu poznatkov o antioxidačnom statuse plemena American Quarter Horse v podmienkach Slovenska.

Kľúčová slova oxidačná rovnováha, antioxidačná ochrana, American Quarter Horse

1. ÚVOD

Oxidačný stres vzniká pri narušení rovnováhy medzi tvorbou reaktívnych foriem kyslíka (ROS) a antioxidačnou obranou organizmu. Nadmerná produkcia ROS vedie k oxidatívnejmu poškodeniu lipidov, bielkovín a nukleových kyselín, čím nepriaznivo ovplyvňuje bunkovú homeostázu a funkciu tkanív. U koní sa oxidačný stres podieľa na fyziologických adaptačných procesoch, ovplyvňuje zdravotný stav, reprodukčné funkcie aj športovú výkonnosť a jeho intenzita sa mení v závislosti od metabolickej záťaže a podmienok prostredia (Shono et al., 2020; Arfuso et al., 2022).

Dôležitou súčasťou enzymatickej antioxidačnej ochrany je glutatiónperoxidáza (GPx), ktorá katalyzuje redukciu peroxidu vodíka a organických hydroperoxidov. Celkový antioxidačný status (TAS) poskytuje komplexnú informáciu o antioxidačnej kapacite organizmu, zatiaľ čo malondialdehyd (MDA), konečný produkt

lipidovej peroxidácie, patrí medzi najčastejšie využívané ukazovatele oxidatívneho poškodenia (Bottegaro et al., 2018; Yildirim a Apaydin Yildirim, 2023).

Produkcia ROS fyziologicky narastá počas svalovej práce v dôsledku zvýšeného aeróbného metabolizmu. Ak tvorba reaktívnych foriem kyslíka presiahne kapacitu antioxidačného systému, dochádza k rozvoju oxidačného stresu sprevádzaného zmenami koncentrácií biomarkerov oxidatívneho poškodenia. Predchádzajúce štúdie preukázali, že intenzita fyzickej záťaže významne ovplyvňuje antioxidačný status športových a vytrvalostných koní, pričom rozsah zmien závisí od úrovne tréningu, kondície a adaptačnej schopnosti organizmu (Bottegaro et al., 2018; Arfuso et al., 2022).

Významným faktorom ovplyvňujúcim antioxidačnú kapacitu je výživa. Dostatočný prísun stopových prvkov zabezpečuje optimálnu aktivitu antioxidačných enzýmov a prispieva k udržiavaniu redoxnej homeostázy. (Latham et al. 2021) preukázali, že suplementácia komplexne viazanými stopovými prvkami zvýšila aktivitu antioxidačných enzýmov a zlepšila fyziologickú odpoveď mladých koní na transportný stres.

Napriek rastúcemu záujmu o hodnotenie biomarkerov oxidačného stresu u koní zostávajú údaje o antioxidačnom statuse klinicky zdravých jedincov plemena American Quarter Horse chovaných v podmienkach Slovenska obmedzené. Cieľom tejto štúdie bolo vyhodnotiť celkový antioxidačný status, aktivitu glutatiónperoxidázy a koncentráciu malondialdehydu u klinicky zdravých koní plemena American Quarter Horse chovaných v podmienkach Slovenska a poskytnúť základné údaje využiteľné v ďalšom výskume aj klinickej praxi.

2. MATERIÁL A METODIKA

2.1 Zvieratá, odber a spracovanie vzoriek

Do štúdie bolo zaradených celkovo 13 klinicky zdravých koní plemena American Quarter Horse. American Quarter Horse je plemeno pochádzajúce zo Spojených štátov amerických, ktoré sa

začalo výraznejšie rozširovať v krajinách strednej Európy po spoločenských zmenách na prelome 80. a 90. rokov 20. storočia. Napriek rastúcej popularite tohto plemena sú informácie o antioxidačnom stave koní plemena American Quarter Horse chovaných v podmienkach Slovenskej republiky stále obmedzené. Monitorovanú skupinu tvorilo sedem kobýl a šesť valachov vo veku od 4 do 15 rokov, využívaných na chovné a rekreačné účely. Telesná hmotnosť koní sa pohybovala v rozmedzí od 470 do 540 kg. Telesná kondícia všetkých zvierat bola hodnotená pomocou 9-bodového systému Body Condition Score (BCS) a zodpovedala normálnej telesnej kondícii (BCS = 5) (Potter et al., 2024).

Kone pochádzali z farmy nachádzajúcej sa v regióne Spiš na východnom Slovensku a boli ustajnené v podmienkach vonkajšieho ustajnenia. Štúdia bola realizovaná počas zimného obdobia, keď sa zvieratá nenachádzali na pastve. Krmná dávka pozostávala predovšetkým z lúčneho sena pochádzajúceho od miestneho dodávateľa, ktoré tvorilo hlavnú zložku krmnej dávky. Počas celého obdobia štúdie mali kone neobmedzený prístup k pitnej vode.

Všetky zvieratá boli pravidelne odčervované v súlade s odporúčaným veterinárnym programom. Pred zaradením do štúdie boli všetky kone podrobené klinickému vyšetreniu a nevykazovali žiadne príznaky ochorenia ani iné zdravotné poruchy, ktoré by mohli ovplyvniť hodnotené parametre. Počas trvania štúdie boli všetky zvieratá chované v porovnateľných podmienkach manažmentu a ustajnenia.

2.2 Odber krvi a spracovanie vzoriek

Vzorky krvi boli odobraté z *vena jugularis* všetkých vyšetrovaných koní za štandardných podmienok s dôrazom na minimalizáciu stresu zvierat počas odberu. Krv určená na biochemické a antioxidačné analýzy bola odoberaná do skúmaviek so separačným gélom na získanie séra (SST). Ďalšie vzorky krvi určené na stanovenie aktivity glutatiónperoxidázy (GPx) boli odoberané do heparinizovaných skúmaviek.

Po odbere boli vzorky transportované do laboratória a spracované čo najskôr za štandardných laboratórnych podmienok. Vzorky krvi odobraté do SST skúmaviek boli následne centrifugované pri 3500 otáčkach za minútu počas 10 minút s cieľom získať sérum. Oddelené sérum bolo použité na stanovenie vybraných antioxidačných parametrov, zatiaľ čo heparinizovaná plná krv bola využitá na stanovenie aktivity glutatiónperoxidázy (GPx).

Obrázok 1. Laboratórny postup pri stanovení antioxidačných parametrov.



2.3 Stanovenie celkového antioxidačného statusu (TAS)

Celkový antioxidačný status bol stanovený pomocou súpravy Randox Total Antioxidant Status NX2332 (Randox Laboratories Ltd., Spojené kráľovstvo). Metóda je založená na inhibícii tvorby katiónového radikálu ABTS®. Absorbancia bola meraná spektrofotometricky pri vlnovej dĺžke 600 nm pomocou UV-VIS spektrofotometra ONDA V-10 PLUS (Giorgio Bormac S.r.l., Taliansko). Hodnoty TAS boli vypočítané podľa pokynov výrobcu s využitím kalibračných postupov a vyjadrené v mmol/l.

2.4 Stanovenie aktivity glutatiónperoxidázy (GPx)

Aktivita glutatiónperoxidázy bola stanovená pomocou súpravy Ransel RS504 (Randox Laboratories Ltd., Spojené kráľovstvo). Metóda je založená na oxidácii redukovaného glutatiónu kuménhydroperoxidom za prítomnosti glutatiónreduktázy a NADPH. Pokles absorbancie NADPH bol sledovaný pri vlnovej dĺžke 340 nm pomocou UV-VIS spektrofotometra ONDA V-10 PLUS (Giorgio Bormac S.r.l., Taliansko). Priemerná zmena absorbancie za minútu bola vypočítaná podľa nasledujúcej rovnice:

$$\Delta A/\text{min} = (A1 - A3) / 2$$

Aktivita GPx bola vypočítaná podľa vzťahu:

$$\text{GPx (U/l)} = 8412 \times (-\Delta A/\text{min})$$

Výsledky boli vyjadrené v jednotkách U/l hemolýzátu.

2.5 Stanovenie koncentrácie malondialdehydu (MDA)

Koncentrácia malondialdehydu bola stanovená metódou reaktívnych látok s kyselinou tiobarbiturovou podľa Ohkawa et al. (1979). Malondialdehyd reaguje s kyselinou tiobarbiturovou za vzniku farebného komplexu MDA-TBA, ktorý bol meraný spektrofotometricky pri vlnovej dĺžke 532 nm pomocou UV-VIS spektrofotometra ONDA V-10 PLUS (Giorgio Bormac S.r.l., Taliansko) (Ohkawa et al., 1979).

Koncentrácia MDA bola vypočítaná podľa Beerovho-Lambertovho zákona pomocou nasledujúcej rovnice:

$$\text{MDA } (\mu\text{mol/l}) = A \times 6,41$$

kde A predstavuje absorbanciu nameranú pri vlnovej dĺžke 532 nm.

2.6 Štatistická analýza

Získané údaje boli štatisticky vyhodnotené pomocou základných metód opisnej štatistiky. Pre všetky hodnotené parametre boli vypočítané priemerné hodnoty, smerodajné odchýlky, minimálne hodnoty a maximálne hodnoty.

3. VÝSLEDKY A DISKUSIA

Tabuľka 1. Individuálne hodnoty antioxidantných parametrov u koní plemena American Quarter Horse.

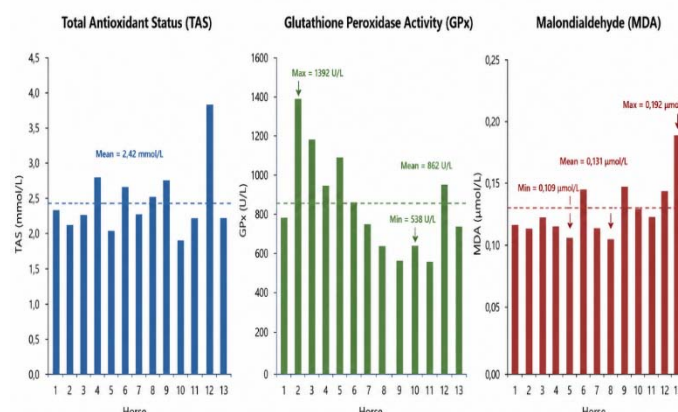
Kone	TAS (mmol/L)	GPX (U/L)	MDA (μ mol/L)
1	2.31	770	0.115
2	2.12	1392	0.115
3	2.23	1178	0.122
4	2.77	967	0.115
5	2.04	1102	0.109
6	2.69	833	0.141
7	2.46	736	0.122
8	2.73	652	0.109
9	1.92	538	0.135
10	2.23	648	0.128
11	1.81	551	0.160
12	3.85	1106	0.135
13	2.27	736	0.192

Tabuľka 2. Základné štatistické ukazovatele vybraných biomarkerov antioxidantného stavu

Parameter	Priemer $\pm$ SD	Minimum	Maximum
TAS (mmol/L)	2.42 $\pm$ 0.53	1.81	3.85
GPX (U/L)	862 $\pm$ 265	538	1392
MDA (μ mol/L)	0.131 $\pm$ 0.022	0.109	0.192

Hodnoty celkového antioxidantného statusu (TAS) sa pohybovali v rozmedzí 1,81–3,85 mmol/l, pričom priemerná hodnota dosiahla $2,42 \pm 0,53$ mmol/l (Tabuľka 1). Zistená variabilita hodnôt TAS bola nízka, čo poukazuje na relatívne homogénny antioxidantný status sledovanej skupiny. Celkový antioxidantný status odráža súhrnnú antioxidantnú kapacitu organizmu, pričom vyššie hodnoty indikujú efektívnejšiu ochranu pred účinkami reaktívnych foriem kyslíka. Získané výsledky korešpondujú so zisteniami Bottegara et al. (2018), podľa ktorých je antioxidantný status koní ovplyvnený najmä metabolickou aktivitou a intenzitou fyzickej záťaže.

Obrázok 2. Individuálne hodnoty vybraných antioxidantných biomarkerov u koní plemena American Quarter Horse



Poznámka: TAS – celkový antioxidantný stav; GPx – glutatiónperoxidáza; MDA – malondialdehyd.

Aktivita glutatiónperoxidázy sa pohybovala v rozmedzí od 538 do 1392 U/l, pričom priemerná hodnota dosiahla 862 ± 265 U/l. Najnižšia aktivita bola zaznamenaná u koňa č. 9, zatiaľ čo najvyššia aktivita bola zistená u koňa č. 2. Vyššia aktivita GPx môže naznačovať efektívnejšie enzymatické mechanizmy antioxidantnej obrany. Pozorovaná variabilita medzi jednotlivými zvieratami poukazuje na rozdiely v enzymatickej antioxidantnej obrane. GPx zohráva významnú úlohu pri detoxikácii peroxidu vodíka a lipidových hydroperoxidov, čím chráni bunkové štruktúry pred oxidačným poškodením. (Latham a kol. 2021) preukázali, že aktivita antioxidantných enzýmov u koní môže byť ovplyvnená nutričným stavom a podmienkami prostredia. Podobné zistenia uviedli aj (Niedźwiedz a kol. 2014), ktorí zaznamenali zmeny v aktivitách antioxidantných enzýmov u koní vystavených oxidačnému stresu.

Priemerná koncentrácia MDA dosiahla hodnotu $0,131 \pm 0,022$ μ mol/l, pričom hodnoty sa pohybovali v rozmedzí od 0,109 do 0,192 μ mol/l. Najvyššia koncentrácia bola zaznamenaná u koňa č. 13, zatiaľ čo najnižšie hodnoty boli zistené u koní č. 5 a č. 8.

MDA sa považuje za významný marker lipidovej peroxidácie a oxidačného poškodenia. Relatívne nízke koncentrácie zistené v tejto štúdii môžu naznačovať nízky stupeň oxidačného stresu u vyšetrovaných koní. Podobné výsledky uviedli (Yildirim a Apaydin 2023), ktorí pozorovali nižšie koncentrácie MDA u koní s priaznivým antioxidantným stavom. Zvýšené koncentrácie MDA boli spojené s rôznymi patologickými stavmi a zvýšeným oxidačným stresom u koní.

Celkovo získané výsledky naznačujú priaznivý antioxidantný profil charakterizovaný relatívne vysokými hodnotami TAS, primeranou aktivitou GPx a nízkymi koncentraciami MDA. Zistené hodnoty môžu slúžiť ako predbežné referenčné údaje pre klinicky zdravé kone plemena American Quarter Horse chované v porovnateľných podmienkach.

4. ZÁVER

U klinicky zdravých koní plemena American Quarter Horse bola priemerná hodnota TAS $2,42 \pm 0,53$ mmol/l, aktivita GPx dosiahla 862 ± 265 U/l a koncentrácia MDA predstavovala $0,131 \pm 0,022$ μ mol/l. Nízke koncentrácie MDA spolu s primeranou aktivitou GPx a vyššími hodnotami TAS poukazujú na zachovanú antioxidantnú ochranu a nízku úroveň oxidačného stresu. Vzhľadom na rastúcu

popularitu westernového jazdenia a zvyšujúci sa záujem o chov koní plemena American Quarter Horse na Slovensku prispievajú predložené výsledky k rozšíreniu poznatkov o antioxidačnom statuse tohto plemena, pre ktoré sú údaje získané v miestnych podmienkach zatiaľ obmedzené.

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Vplyv prídavku *Urtica dioica* do diét na črevnú mikroflóru prasiatok

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Oborové zameralenie: GH - Výživa hospodárskych zvierat

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Abstrakt Cieľom tejto štúdie bolo sledovať vplyv prídavku mletých listov prhl'avy dvojdomej (*Urtica dioica*) do krmiva na črevný mikrobióm rastúcich ošípaných. Celkovo 18 prasiat bolo rovnomerne rozdelených do dvoch skupín. Experimentálna skupina bola kŕmená krmivom s prídavkom mletých sušených listov prhl'avy v množstve 2,5 %. Analýza črevnej mikrobioty sa vykonala zo vzoriek stolice po šiestich týždňoch experimentu. V experimentálnej skupine bol počet enterických baktérií v porovnaní s kontrolnou skupinou signifikantne nižší. Na druhej strane, počet LAB nebol významne ovplyvnený. Pomer enterických baktérií k LAB v experimentálnej skupine bol však v porovnaní s kontrolnou skupinou signifikantne nižší. Pridávanie žihľavy dvojdomej do kŕmnej zmesi pre prasiatka počas šiestich týždňov malo v našom experimente pozitívny vplyv na črevný mikrobióm prasiatok.

Kľúčová slova ošípaná, kŕmna prísada, prhl'ava dvojdomá, črevný mikrobióm

1. ÚVOD

Kŕmne doplnkové látky sa používajú vo výžive hospodárskych zvierat za účelom udržania produkčného zdravia a zlepšenia produkčných parametrov. Od zákazu používania antibiotických stimulantov rastu v Európe od roku 2006 (Nariadenie Európskeho parlamentu a Rady (ES) č. 1831/2003) je v záujme odbornej verejnosti hľadať a skúmať rôzne doplnkové látky prírodného pôvodu. Medzi takéto látky, ktoré by pozitívne ovplyvnili zdravie zvierat a zlepšili produkčné ukazovatele, patrí aj skupina látok rastlinného pôvodu, takzvané fytobiotiká, získané z rôznych rastlín,

bylín alebo korenín. Obsahujú množstvo bioaktívnych zlúčenín vrátane esenciálnych olejov, polyfenolov, terpenoidov a flavonoidov (Biswas a kol. 2024).

Z doplnkových látok prírodného pôvodu môže mať značný potenciál aj prhl'ava dvojdomá (*Urtica dioica*). Prhl'ava sa ako prírodný liek používa už viac ako 2000 rokov (Bhusal a kol. 2022). Avšak jej liečivý potenciál začal byť plne oceňovaný až po analýze chemického zloženia a postupnom objasňovaní farmakologických vlastností jej hlavných aktívnych zlúčenín. Prhl'ava má množstvo prospešných vlastností vrátane antioxidačných, protizápalových, antiproliferatívnych, analgetických, hypotenzívnych a imunostimulačných (Said a kol. 2015). Má pomerne vysoký obsah proteínov, lipidov, sacharidov, vitamínov a stopových prvkov (Rutto a kol. 2013). Pri 30 %-nom podiele bielkovín v sušine má prhl'ava výrazne väčší profil aminokyselín ako ostatné zelené rastliny. Taktiež obsahuje vysoké množstvo polynenasýtených mastných kyselín (60 %), z ktorých polovicu tvorí kyselina linolová (C18:2), omega-6 mastná kyselina, ktorá má pozitívny vplyv na imunitný systém, čím zvyšuje odolnosť organizmu voči bakteriálnym a vírusovým infekciám (Upton 2013).

Priaznivé účinky jej podávania na produkčné ukazovatele boli zaznamenané u rôznych hospodárskych zvierat (Disler a kol. 2014). Pridanie prhl'avy do krmiva brojlerov viedlo k ich zvýšenému rastu a vyššej jatočnej výťažnosti. Nosnice vykazovali zvýšenú produkciu vajec (Melese a kol. 2015). Khanal a kol. (2017) zaznamenali kvantitatívne a kvalitatívne zlepšenie produkcie mlieka u hovädzieho dobytku. Zdokumentované je aj podávanie prhl'avy ošípaným na zvýšenie odolnosti voči infekčným chorobám (Viegi a kol. 2003).

2. MATERIÁL A METODIKA

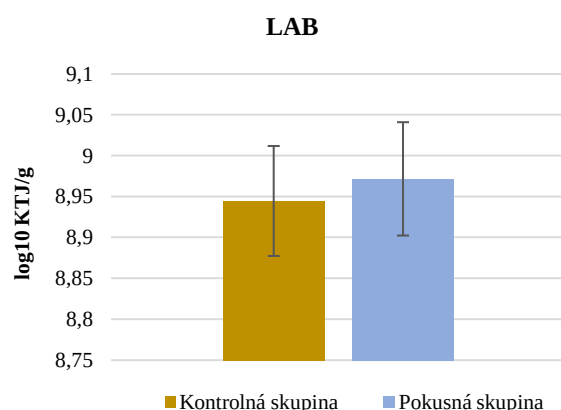
Do pokusu bolo zaradených celkovo 18 prasíat krížencov slovenskej bielej ošípanej a Landrase vo veku 43 dní s priemernou hmotnosťou 15,4 kg/prasa. Zvieratá boli rovnomerne rozdelené do dvoch skupín po 9 prasíat: kontrolnej a experimentálnej. Kontrolná skupina bola kŕmená kŕmnom zmesou bez prídania prhl'avy a experimentálna skupina kŕmnom zmesou s 2,5 %-ným prídavkom mletých sušených listov prhl'avy dvojdomkej. Po šiestich týždňoch experimentu boli od zvierat odobraté vzorky trusu za účelom vykonania analýzy črevnej mikrobioty.

Pre stanovenie počtu LAB platňovou metódou bol použitý MRS agar (Biolife, Taliansko) a pre stanovenie počtu ENT bol použitý MacConkey agar (HiMedia, India). Každá vzorka trusu o množstve 1 g bola nariadená 9 ml fyziologického roztoku (Mikrochem, Slovensko) a dôkladne homogenizovaná použitím stomachera (IUL, Instruments, Spain). Následne boli zhomogenizované vzorky riedené decimálnym riedením fyziologickým roztokom a očkované na príslušné agary v množstve 100 μ l. Pripravené platne boli vložené do termostatu a kultivované pri 37 °C: MRS agar bol kultivovaný po dobu 48 hodín v anaeróbnom prostredí a MacConkey agar bol kultivovaný po dobu 24 hodín v aeróbnom prostredí. Počty baktérií sú vyjadrené ako logaritmus kolónie tvoriacich jednotiek na gram trusu ($\log_{10}$ KTJ/g). Štatistická analýza bola vykonaná použitím nepárového t testu v softvéri GraphPad Prism 8.0 (GraphPad Software, Inc., USA).

3. VÝSLEDKY A DISKUSIA

Použitie prhl'avy dvojdomkej vo výžive zvierat a sledovanie jej účinku bolo prezentované v niekoľkých štúdiách, no len málo z nich sa venovalo vplyvu prhl'avy na črevnú mikroflóru ošípaných alebo iných druhov zvierat. Po vykonaní našich analýz bol v truse prasíatok pokusnej skupiny (kŕmených kŕmnom zmesou s prídavkom sušených listov prhl'avy dvojdomkej) zistený vyšší počet baktérií mliečného kvasenia v porovnaní s trusom prasíatok kontrolnej skupiny (Graf 1). Tento rozdiel ale nebol štatisticky významný.

Graf 1. Porovnanie počtu baktérií mliečného kvasenia v truse prasíat

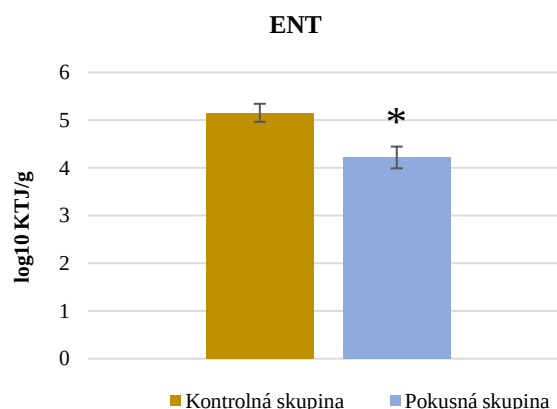


Signifikantné zvýšenie počtu baktérií mliečného kvasenia bolo zaznamenané v obsahu slepých vakov hrubého čreva brojlerových kurčiat kŕmených zmesami s 1 %, 2 % a 3 % prídavkom prhl'avy dvojdomkej (Pedraza a kol. 2025). Najvyšší počet laktobacilov v porovnaní s kontrolou bol v tejto štúdii pozorovaný pri podávaní kŕmnej zmesi s 1-percentným prídavkom sušenej prhl'avy.

Pri hodnotení počtu enterických baktérií v truse prasíatok v rámci nášho experimentu bol v pokusnej skupine zaznamenaný

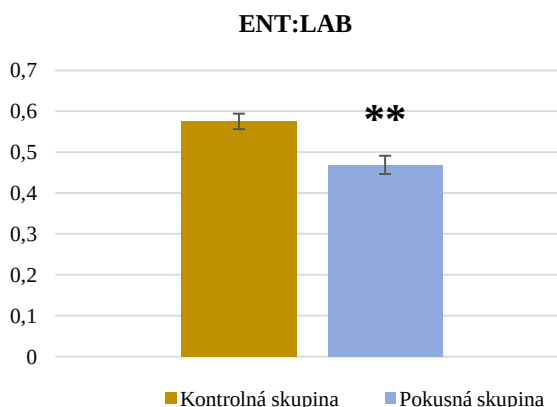
signifikantne nižší počet týchto baktérií oproti kontrolnej skupine ($p < 0,05$) (Graf 2).

Graf 2. Porovnanie počtu enterických baktérií v truse prasíat



Vyšší počet baktérií mliečného kvasenia a nižší počet enterických baktérií v pokusnej skupine v porovnaní s kontrolou ovplyvnilo aj ďalší hodnotiaci parameter - pomer ENT:LAB. Tento pomer bol v pokusnej skupine signifikantne nižší než v kontrolnej skupine ($p < 0,01$) (Graf 3.).

Graf 3. Vyjadrenie pomeru enterických baktérií k baktériám mliečného kvasenia v truse prasíat



Nižší počet Escherichia coli v črevnom obsahu oproti kontrole, hoci bez štatistickej významnosti bol pozorovaný u prasíatok, ktorým bol podávaný rastlinný vodný extrakt s 30 % podielom prhl'avy (Hanczakowska a Swiatkiewicz 2012). Pozitívny vplyv suplementácie krmiva rastlinným extraktom sa prejavil na vyššej intenzite rastu, nižšej úmrtnosti a vyššej finálnej hmotnosti prasíatok. Zaznamenaná bola aj väčšia výška klkov v ileálnej časti tenkého čreva.

Vyššia intenzita rastu prasíatok v porovnaní s kontrolnou skupinou bola pozorovaná aj v štúdií, kde bola časť (12,5 – 25 %) kŕmnej zmesi nahradená pomletým sušeným prhl'avovým senom (Fesenko a kol. 2022). U týchto experimentálnych prasíatok bol ovplyvnený aj hematologický profil, pričom došlo k nárastu počtu erytrocytov, zvýšeniu hemoglobínu aj celkového proteínu v krvi.

Vplyv na hematologické a biochemické parametre krvi prasíatok bol sledovaný aj v experimentálnej štúdii s použitím 40 % etanolového extraktu prhl'avy dvojdomkej (Buchko a kol. 2024). Prídavok tohto extraktu pozitívne ovplyvnil proteínový a metabolický profil prasíatok. Podobne, ako v predošlej štúdii, bola nameraná vyššia

koncentrácia hemoglobínu, vyšší počet erytrocytov a leukocytov, vyššia koncentrácia celkového proteínu a glukózy, ale aj vyššie aktivity enzýmov (transamináz, alkalické fosfatázy a kreatín kinázy). Okrem toho prasiatka v experimentálnej skupine vykazovali vyššiu živú hmotnosť a vyššie denné prírastky.

Podobne ako v našej štúdii na prasiatkach, signifikantne nižší počet koliformných baktérií v obsahu slepých vakov hrubého čreva bol pozorovaný v už spomínanej štúdii na brojlerových kurčatách (Pedraza a kol. 2025). Najnižší počet koliformných baktérií bol pozorovaný v skupine kurčiat, ktorým bolo podávané krmivo s 1-percentným prídavkom prhl'avy dvojdomkej.

4. ZÁVER

Kŕmenie prasiatok zmesou s prídavkom prhl'avy dvojdomkej po dobu šiestich týždňov malo pozitívny vplyv na ich črevný mikrobióm. Z výsledkov doposiaľ vykonaných štúdií je možné usúdiť, že prídavok prhl'avy dvojdomkej alebo jej extraktov do diéty prasiatok môže v pozitívnom smere ovplyvňovať zdravotný stav a produkčné parametre. Je možné predpokladať, že účinok prhl'avy je intenzívnejší, ak sa použije vo vyšších koncentráciách. Na overenie tohto tvrdenia bude potrebné vykonať ďalšie štúdie s použitím prhl'avy dvojdomkej, či už vo forme extraktov alebo sušených rastlín.

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Produkcia a kvalita ovčieho mlieka v podmienkach meniacej sa klímy a rozdielnych systémov chovu

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Název grantu: Bezantibiotické prístupy kontroly mastitíd dojnic so zvýšením hygieny prostredia na produkčných farmách a Zvýšenie vysokoškolského vzdelávania a praktických skúseností pre študentov veterinárneho zamerania z predmetov Zootechnika a Plemená a chov spoločenských zvierat

Oborové zamčrení: GG – chov hospodárskych zvierat

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Abstrakt The aim of this study was to compare milk yield, lactation performance, and the basic quality parameters of sheep milk on three farms applying different production systems (extensive, semi-intensive, and semi-extensive) during the grazing season. The evaluated parameters included total milk yield, average monthly milk production, and the contents of fat, protein, lactose, and solids-not-fat (SNF) from May to September. The highest milk yield was recorded on the farm employing a semi-intensive production system with the Lacaune breed (246.7 kg per ewe). However, this farm also exhibited the most pronounced decline in milk production during the summer months characterized by high temperatures and low precipitation. In contrast, the semi-extensive production system based on crossbred ewes showed a more stable lactation curve and more favorable milk quality parameters throughout the grazing season. Fat content was the most variable milk component, whereas lactose remained the most stable. Protein and solids-not-fat concentrations increased progressively as lactation advanced, with the highest values recorded at the end of the monitoring period. The results confirmed that breed, production system, nutrition, and climatic conditions significantly influenced both milk yield and the compositional quality of sheep milk. The findings suggest that, under current climate change conditions, a semi-extensive production system utilizing genetically adapted crossbred ewes represents a promising strategy for maintaining production stability and milk quality. Furthermore, supplementation of the diet with high-quality forage, such as alfalfa hay and clover-grass silage, appears to be an effective measure for mitigating the adverse effects of reduced pasture availability during periods of drought.

Kľúčová slova dairy sheep, milk yield, milk quality, grazing management, production system, climate change

1. ÚVOD

Produkčná úžitkovosť oviec z hľadiska produkcie mlieka, mäsa a vlny je výsledkom komplexnej interakcie genetických predispozícií, výživy a podmienok prostredia. Dosiahnutie vysokého genetického potenciálu mliekovej úžitkovosti závisí predovšetkým od zabezpečenia dostatočného prísunu energie, bielkovín a ostatných živín počas laktácie. V posledných desaťročiach však rastúci vplyv klimatických zmien predstavuje významný limitujúci faktor produkcie. Zvýšené teploty vzduchu v kombinácii s nedostatkom zrážok znižujú produkciu aj nutričnú hodnotu pasienkových porastov, čím nepriamo ovplyvňujú produkciu a kvalitu ovčieho mlieka. Napriek neustálemu genetickému pokroku a intenzívnym šľachtiteľským programom sa potenciál zvierat v čoraz väčšej miere dostáva do konfliktu s nepriaznivými environmentálnymi podmienkami. Dôsledky globálneho otepľovania sa čoraz výraznejšie prejavujú aj v podmienkach mierneho klimatického pásma vrátane strednej Európy. Na Slovensku je ich vplyv umocnený členitým reliéfom krajiny, ktorý spôsobuje výrazné regionálne rozdiely v priebehu počasia. Rastúca frekvencia extrémnych teplôt, dlhodobých období sucha a nepravidelného rozloženia zrážok zvyšuje variabilitu produkčných podmienok a negatívne ovplyvňuje rast a obnovu pasienkových porastov. Hoci sú ovce považované za druh s vysokou adaptačnou schopnosťou a dobrou toleranciou voči rôznym environmentálnym podmienkam, viaceré štúdie potvrdzujú negatívny vplyv tepelného stresu na produkciu a zloženie mlieka. Vysoké teploty znižujú príjem krmiva, narúšajú energetickú bilanciú organizmu a následne vedú k poklesu mliekovej úžitkovosti. Na druhej strane, aj keď je problematika chladového stresu v podmienkach strednej Európy menej skúmaná, jeho negatívne účinky nemožno opomenúť, najmä v tradičných systémoch horského a podhorského chovu. Pri extenzívnom pasení v horských oblastiach od apríla do októbra sú zvieratá dlhodobo vystavené pôsobeniu nepriaznivých poveternostných podmienok, ktoré môžu významne ovplyvniť ich zdravotný stav, produkčnú výkonnosť a celkovú biologickú efektívnosť (Margetin et al., 2021).

Cieľom predkladanej štúdie bolo porovnať mliečnu úžitkovosť a základné kvalitatívne ukazovatele ovčieho mlieka počas pastevnej sezóny v troch chovoch oviec s rozdielnym systémom manažmentu a plemenou skladbou stád. Osobitná pozornosť bola venovaná hodnoteniu vplyvu letného tepelného stresu a klimatických podmienok na produkciu a kvalitu mlieka v podmienkach Banskobystrického kraja.

2. MATERIÁL A METODIKA

Táto štúdia skúmala tri ovčiarske mliekarenské podniky v strednom Slovensku v blízkosti Banskej Bystrice so zameraním na produkciu a spracovanie mlieka. Farmy sa líšili v postupoch prevádzkového manažmentu a v plemennej skladbe stád:

Farma 1 (extenzívny systém chovu): Chov plemena cigája. Na začiatku laktácie (v apríli) bola aplikovaná maštalná krmná dávka v množstve 5 kg/ks/deň, pozostávajúca z lucernovej senáže, kukuricovej siláže, ovsenej slamy, lúčneho sena, sójového šrotu a pívovarského mláta. Koncentrovanú zložku tvoril drvený ovos a jačmeň. Popoludňajšia dávka obsahovala lúčne seno (3 kg/ks/deň) a lucernovú siláž (1,5 kg/ks/deň). Počas letného obdobia prešli bahnice na extenzívny systém chovu v alpských podmienkach Národného parku Veľká Fatra. Primárnym zdrojom živín bol horský pasienkový porast, pričom ustajnenie bolo zabezpečené tradičným košarovaním

Farma 2 (polointenzívny systém chovu): Chov čistokrvných mliekových oviec plemena lacaune v podhorskej oblasti. Bahnice boli počas celej pastevnej sezóny držané v maštalných podmienkach na farme. Pred prechodom na pastvu pozostávala objemová zložka krmnej dávky z lúčneho sena a zmesi šťavnatých krmív (lucernová, trávna a kukuričná siláž). V dojárni boli ovce prikrmované koncentrovanou zmesou pozostávajúcou z drveného jačmeňa, bielkovinového koncentráta a granulovaných kukuričných kľíčkov. Po prechode na pastvu boli šťavnaté krmivá z dávky vylúčené a zvieratá boli prikrmované výlučne lúčnym senom a slamou *ad libitum*.

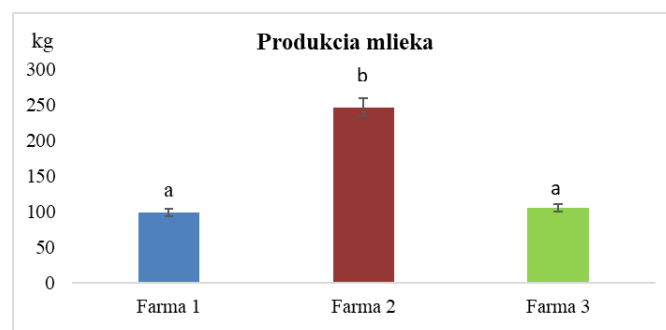
Farma 3 (poloextenzívny systém chovu): Chov plemien cigája a zošľachtená valaška, ako aj ich krížencov s plemenami lacaune a slovenská mliečna ovca. Počas zimného obdobia boli ovce ustajnené v maštali a kŕmené kukuričnou, lucernovou a trávnu silážou, lúčnym senom a koncentrátmi (drvený ovos a jačmeň). V apríli stádo prešlo na pastvový manažment s nočným košarovaním. Počas pastevného obdobia pozostávala krmná dávka výlučne z pasienkového porastu bez akéhokoľvek ďalšieho prídavku objemového krmiva.

Monitorovanie fariem sa vykonávalo v mesačných intervaloch od apríla do septembra. V pravidelných časových intervaloch sa zaznamenával priemerný denný nádoj mlieka (súčet ranného a večerného dojenia) a z monitorovaných fariem sa odoberali vzorky bazálneho mlieka. Obsah tuku, bielkovín, laktózy a tukového bezvodého zvyšku (SNF) v odoberatých vzorkách sa stanovoval v súlade s metodickými postupmi opísanými v práci Záhumenská et al. (2024). Súčasne sa sledovali klimatické ukazovatele, konkrétne priemerné denné teploty vzduchu a úhrny zrážok pre dané obdobie, s využitím údajov Slovenského hydrometeorologického ústavu (SHMÚ).

3. VÝSLEDKY A DISKUSIA

Komparácia mliečnej úžitkovosti (Obr. 1), priemernej mesačnej produkcie mlieka (Obr. 2) a kvalitatívnych ukazovateľov mlieka

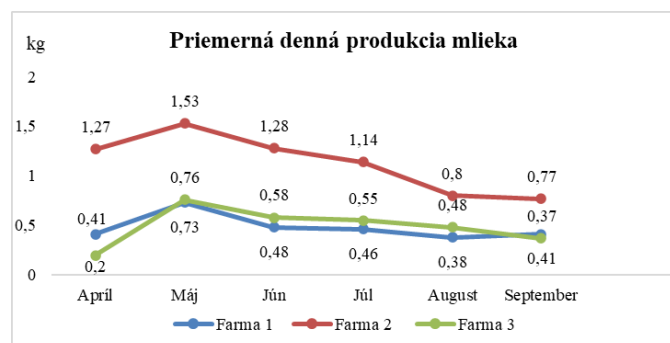
(Tab. 1) poukazuje na výraznú variabilitu sledovaných parametrov počas pastevnej sezóny v závislosti od systému chovu, plemennej skladby stád a klimatických podmienok. Získané výsledky naznačujú, že v hodnotených podmienkach predstavuje najvhodnejší kompromis medzi produkciou a stabilitou poloextenzívny systém využívajúci krížence oviec. Naopak, špecializované mliečne plemená, reprezentované plemenom Lacaune na farme 2, dosahovali síce najvyššiu produkciu mlieka, avšak zároveň vykazovali vyššiu citlivosť na dlhodobý deficit zrážok a vysoké teploty, ktoré obmedzujú rast pasienkových porastov a znižujú ich nutričnú hodnotu. Tradičné plemená s kombinovanou úžitkovosťou sa ukázali ako lepšie adaptované na nepriaznivé podhorské a horské podmienky. Na zabezpečenie stabilnej produkcie mlieka počas období so zníženou produkciou pastvy je preto opodstatnené dopĺňať krmnú dávku kvalitným lucernovým senom a d'atelinovo-trávnou silážou. Zároveň možno predpokladať, že význam extenzívneho systému chovu bude v dôsledku klimatických zmien, postupnej degradácie vysokohorských pasienkov a chronického nedostatku pracovnej sily naďalej klesať.



Obrázok 1 Porovnanie mliečnej úžitkovosti oviec

Poznámka: Farma 1 – extenzívny spôsob chovu, Farma 2 – polointenzívny spôsob chovu, Farma 3 – poloextenzívny spôsob chovu; ^a, ^b – rôzne písmená nad stĺpcami označujú štatisticky významné rozdiely ($P < 0,05$).

Najvyššia mliečna úžitkovosť bola zaznamenaná na farme 2 (246,7 kg/bahnicu), kde bol uplatňovaný polointenzívny systém chovu plemena Lacaune (Obr. 1). Na tejto farme bola zároveň dosiahnutá najvyššia priemerná mesačná produkcia mlieka. V porovnaní s farmami 1 a 3 však vykazovala najvýraznejší pokles laktačnej krivky počas letných mesiacov (jún až august) (Obr. 2), čo poukazuje na vyššiu citlivosť špecializovaného mliečného plemena na nepriaznivé klimatické podmienky. Vo všetkých sledovaných chovoch dosiahli bahnice vrchol laktácie v máji, po ktorom nasledoval postupný pokles dojivosti, najmä v období s najvyššími teplotami vzduchu a minimálnym množstvom zrážok. Tento trend pravdepodobne súvisel so zhoršovaním kvality a produkcie pasienkových porastov v dôsledku sucha. Napriek poklesu produkcie sa na farmách 2 a 3 v priebehu laktácie postupne zvyšovala koncentrácia hlavných zložiek mlieka.



Obrázok 2 Porovnanie priemernej dennej produkcie mlieka oviec z monitorovaných fariem v závislosti od pastevnej sezóny

Poznámka: Farma 1 – extenzívny spôsob chovu, Farma 2 – polointenzívny spôsob chovu, Farma 3 – poloextenzívny spôsob chovu.

Tabuľka 1 Hodnotenie základných ukazovateľov ovčieho mlieka v závislosti od jednotlivých mesiacov

Parameter	OF	Monitorované obdobie					Mean±SD
		5	6	7	8	9	
Tuk %	1	8.78	8.01	8.51	7.51	9.97	8.56±0.71 ^a
	2	6.77	7.63	7.98	7.85	8.91	7.83±0.85 ^a
	3	9.12	8.12	8.72	9.93	11.17	9.41±0.52 ^b
Laktóza %	1	4.65	4.87	4.65	4.74	4.42	4.67±0.37
	2	4.93	4.9	4.81	4.69	4.47	4.76±0.54
	3	4.87	4.99	4.76	4.58	4.35	4.71±0.28
Bielkoviny %	1	5.66	5.55	6.01	6.97	7.43	6.32±0.55
	2	5.45	5.53	5.77	6.19	7.15	6.01±0.64
	3	5.52	5.46	5.72	6.4	8.07	6.23±0.78
SNF %	1	10.96	11.42	11.56	12.94	12.86	11.97±1.07
	2	11.17	11.29	11.45	11.79	12.6	11.66±0.86
	3	11.25	11.3	11.35	11.92	13.48	11.86±0.45

Poznámka: ^{a, b} – rôzne písmená nad stĺpcami označujú štatisticky významné rozdiely (P<0,05); SNF – beztuková sušina, OF – ovčia farma, 5-9 máj až september

Obsah tuku predstavoval najvariabilnejší kvalitatívny ukazovateľ mlieka, pričom bol ovplyvnený predovšetkým výživou, plemenou príslušnosťou a klimatickými podmienkami. Pokles koncentrácie tuku v úvodnej fáze laktácie môže súvisieť s negatívnou energetickou bilanciou (NEB), hoci mobilizácia telesných tukových rezerv môže prechodne vyvolať aj jeho zvýšenie (Kalyankar et al., 2016). V súlade s výsledkami Keresteša et al. (2016) sa obsah tuku ku koncu laktácie zvyšoval. Najvyššiu priemernú koncentráciu tuku dosiahla farma 3 (9,41 ± 0,52 %), pričom medzi farmami 1 a 3 boli zistené štatisticky významné rozdiely (P < 0,05).

Počas obdobia s vysokými teplotami a nedostatkom zrážok (jún až august) vykazovalo stádo plemena Lacaune na farme 2 nižší obsah tuku aj beztukovej sušiny v porovnaní s čistokrvnými cigájami a krížencami na farmách 1 a 3. Tento výsledok podporuje predpoklad, že špecializované mliečne plemená sú citlivejšie na environmentálny stres, najmä pri extenzívnejšom spôsobe využívania pasienkov.

Koncentrácia bielkovín a beztukovej sušiny sa počas laktácie postupne zvyšovala, pričom najvyššie hodnoty boli zaznamenané na farme 3 v závere pastevnej sezóny. Na rozdiel od obsahu tuku je koncentrácia bielkovín menej ovplyvňovaná krátkodobými zmenami prostredia a vo väčšej miere závisí od genetických faktorov, zloženia krmnej dávky a štádia laktácie (Keresteš et al., 2005). Nižší obsah bielkovín na začiatku laktácie pravdepodobne súvisel s negatívnou energetickou bilanciou bahníc (Freer a Dove, 2002). Výsledky zároveň potvrdzujú poznatky Hamanna et al. (2004), podľa ktorých genotypy s vyššou produkciou mlieka spravidla dosahujú nižšie percentuálne zastúpenie základných zložiek mlieka.

Laktóza sa potvrdila ako najstabilnejšia zložka ovčieho mlieka. Jej koncentrácia počas celej laktácie kolísala len minimálne, avšak ku koncu pastevnej sezóny bol na všetkých farmách zaznamenaný mierny pokles. Tento trend možno vysvetliť nižším príjmom energeticky bohatých krmív, keďže nedostatok škrobu obmedzuje syntézu laktózy a následne aj celkovú produkciu mlieka, zatiaľ čo relatívny podiel tuku a bielkovín sa zvyšuje (Maskaľová et al., 2024).

Celkovo výsledky potvrdzujú, že produkčné aj kvalitatívne parametre ovčieho mlieka sú výsledkom vzájomného pôsobenia genetických faktorov, systému chovu, výživy a klimatických podmienok. Hoci polointenzívny systém s plemenom Lacaune zabezpečil najvyššiu produkciu mlieka, poloextenzívny systém s krížencami preukázal vyššiu produkčnú stabilitu a lepšiu adaptabilitu na meniace sa klimatické podmienky. Z pohľadu udržateľnosti chovu oviec v podhorských a horských oblastiach sa preto javí ako perspektívnejšia kombinácia geneticky adaptovaných zvierat a cielenej suplementácie objemových krmív počas období so zníženou produkciou pasienkov.

4. ZÁVER

Výsledky štúdie potvrdili, že mliečna úžitkovosť a kvalitatívne zloženie ovčieho mlieka sú významne ovplyvnené plemenou príslušnosťou, systémom chovu a klimatickými podmienkami počas pastevnej sezóny. Hoci najvyššia produkcia mlieka bola zaznamenaná na farme s polointenzívnym chovom plemena Lacaune, mlieko oviec chovaných v extenzívnom a poloextenzívnom systéme dosahovalo vyšší obsah tuku, bielkovín a ďalších pevných zložiek, ktoré sú rozhodujúce z hľadiska technologického výťažnosti pri spracovaní mlieka na syry. Získané výsledky zároveň poukazujú na vyššiu citlivosť špecializovaných mliečnych plemien na nepriaznivé klimatické podmienky, predovšetkým na obdobia s vysokými teplotami a deficitom zrážok, ktoré negatívne ovplyvňujú produkciu aj kvalitu pasienkových porastov. Naopak, plemená s kombinovanou úžitkovosťou a ich krížence preukázali lepšiu produkčnú stabilitu a vyššiu adaptabilitu na podhorské a horské podmienky. Pri rozhodovaní o vhodnom systéme chovu je preto potrebné zohľadňovať nielen produkčný potenciál jednotlivých plemien, ale aj ich schopnosť adaptácie na lokálne klimatické a environmentálne podmienky. V podmienkach pokračujúcich klimatických zmien bude nevyhnutné uplatňovať komplexné adaptačné opatrenia zahŕňajúce optimalizáciu výživy, efektívne využívanie pasienkov, cieľnú suplementáciu objemových krmív počas období sucha, zlepšenie manažmentu chovu a šľachtenie zvierat na vyššiu odolnosť voči environmentálnemu stresu. Implementácia týchto opatrení môže významne prispieť k zachovaniu produkčnej efektívnosti, kvality ovčieho mlieka a dlhodobej udržateľnosti chovu oviec.

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Vplyv pastevnej sezóny a laktácie na zdravie mliečnej žľazy a kvalitu mlieka oviec

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Oborové zamčrení: GG - Chov hospodárskych zvierat

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Abstrakt Cieľom štúdie bolo vyhodnotiť vplyv sezónnych faktorov a veku bahníc na výskyt mastitíd a zloženie mlieka. Pre tento účel bolo monitorované stádo 200 ks bahníc plemena lacane a východofrízskca ovca, ktoré sa nachádzalo na strednom Slovensku. Vyšetrenie vemena a odbery vzoriek mlieka na detekciu patogénov mliečnej žľazy sa vykonali trikrát počas pastevnej sezóny a to na začiatku, v strede a na jej konci. Na porovnanie produkcie mlieka a zloženia podľa veku bolo počas rovnakých vyšetrení vybraných 32 zdravých bahníc rozdelených do štyroch skupín na základe poradí laktácie: 1., 2., 3. a 4. laktácia. Výsledky štúdie poukazujú, že prevalencia mastitíd v stáde sa pohybovala od 7,7 do 11,0 %, pričom subklinické formy predstavovali 4,5 – 8,5 % a klinické formy 2 – 5 %. Z hľadiska kvality mlieka a výskytu mastitíd sa ako najvhodnejšie ukázali bahnice na 2. a 3. laktácii, ktoré vykazovali najvyššie hodnoty tuku a bielkovín, maximálnu produkciu mlieka a optimálny počet somatických buniek.

Kľúčová slova bahnice, spôsob chovu, pastva, mastitída, laktácia, kvalita mlieka

1. ÚVOD

Ovčie mlieko patrí medzi najhodnotnejšie druhy mlieka. Je žltkastej farby, má typickú vôňu a sladkú chuť a je významným zdrojom bielkovín a minerálnych látok (Ca, P, Zn). Zloženie ovčieho mlieka sa výrazne líši od kravského aj kozieho. Obsahuje zhruba 20% sušiny, priemerne 5% bielkovín, z toho 80% tvorí kazeín a približne 8% tuku. V mlieku sa ďalej nachádzajú rôzne vitamíny skupiny B, enzýmy (najmä amylázy), aminokyseliny, mastné kyseliny, dusíkaté látky nebielkovinového pôvodu, hormóny, bunkové elementy a mikroorganizmy (Flis a Molik, 2021). Charakteristické mikrobiálne, chuťové a pachové vlastnosti mlieka sú do určitej miery podmienené

jeho chemickým zložením, najmä odlišným obsahom fosfolipidov. Ovčie mlieko je základnou surovinou na výrobu ovčieho hrudkového syra, z ktorého sa vyrába najznámejší produkt slovenského ovčiarstva, bryndza (Herian, 2024).

Produkcia a kvalita ovčieho mlieka sú ovplyvnené viacerými faktormi, najmä výživou, štádiom laktácie, vekom bahníc a zdravotným stavom mliečnej žľazy (Dudríková a Výrostková, 2024).

Zo zdravotného hľadiska, zápal mliečnej žľazy - mastitída patrí medzi najzávažnejšie ochorenia oviec, keďže znižuje kvalitu mlieka a spôsobuje ekonomické straty pre farmárov s častým vyradovaním oviec (Contreras a kol., 2007).

Okrem priamej straty mlieka, mastitída bahníc spôsobujú aj zvýšené náklady na liečbu, laboratórne vyšetrenia, selekciu a vyradzovanie zvierat so zníženou produktivitou. Predovšetkým subklinické formy sú často podceňované, no ich kumulatívny efekt má výrazný ekonomický dopad na farmu. Znížená produkcia mlieka negatívne ovplyvňuje rast a vývoj cicajúcich mláďat (Bergonier a kol. 2003). Prevencia, včasná diagnostika a správne manažérske opatrenia sú preto kľúčové na udržanie vysokej kvality mlieka a zníženie výskytu mastitíd u bahníc (Vršková a kol., 2015).

Vzhľadom na rozmanitosť environmentálnych a fyziologických faktorov, ktoré vplyvajú na produkciu mlieka, bolo cieľom štúdie vyhodnotiť výskyt a etiológiu mastitíd v chove bahníc počas pastevnej sezóny, ako aj porovnať zloženie mlieka podľa ich veku.

2. MATERIÁL A METODIKA

2.1 Monitorovaný chov oviec

Pre účel štúdie bola vyhodnotená pastevná sezóna 2024 na farme oviec lokalizovanej na strednom Slovensku neďaleko Brezna. Pre 200 ks oviec dojných plemien Lacaune a Východofrízka ovca a ich krížencov z monitorovanej farmy sa prevažne používa polointenzívny systém chovu. Ovce dosahujú produkciu mlieka 180 až 220 litrov za laktáciu, čo si vyžaduje nielen vhodný plemenný typ, ale aj dostatočnú výživu. Pastva sa vykonáva v blízkosti farmy na intenzívnych alebo polointenzívnych pasienkoch, ktoré sa pravidelne hnoja. Využívanie pasienkov môže zahŕňať dohľad pastiera alebo oplotené výbehy. Po pasení sa ovce zhromaždia späť na farmu, kde sú ustajnené do nasledujúceho dňa a strojovo sa doja v paralelnej dojárni.

2.2 Vyšetrenie bahníc a odber vzoriek

Počas jednej pastevnej sezóny bol v chove oviec na strednom Slovensku monitorovaný výskyt mastitíd s detekciou najvýznamnejších pôvodcov tohto ekonomicky závažného ochorenia. Všetkých 200 ks oviec bolo 3-krát komplexne vyšetrených v trojmesačných intervaloch (na začiatku, v strede a na konci pastevnej sezóny), pričom vyšetrenie pozostávalo z klinického vyšetrenia vemena, posúdenia NK-testu a odberu vzoriek mlieka. Pred odberom mlieka boli všetky bahnice podrobené klinickému vyšetreniu vemena, ktoré zahŕňalo aspekciu a palpáciu so zameraním na tvar, symetriu, konzistenciu, bolestivosť, teplotu a prítomnosť patologických zmien. Súčasne sa vykonalo senzorické hodnotenie mlieka a NK-test z oboch polovic vemena samostatne ako základné vyšetrenie zdravotného stavu mliečnej žľazy (Vršková a kol., 2015). Zároveň v rovnakých intervaloch od monitorovaných bahníc bolo vybraných 32 klinicky zdravých jedincov, rozdelených do 4 skupín (8 bahníc v každej skupine) podľa poradí laktácie: 1, 2, 3, a ≥ 4 laktácia.

Pri pozitívnom skóre NK-testu boli na bakteriologické vyšetrenie odobraté vzorky mlieka zo zdravej aj postihnutej polovice vemena. Na kultiváciu pôvodcov mastitídy boli použité platne MicroMast a krvný agar. Suspektné kolónie boli naočkované na selektívne agary na ďalšiu identifikáciu bakteriálnych pôvodcov mastitíd. Hodnotila sa tvorba hemolýzy a pigmentu. Jednotlivé izoláty boli identifikované prostredníctvom biochemických testov STAPHYtest 24, STREPTOtest 24 alebo ENTEROtest 24 a následne vyhodnotené pomocou programu TNW ProAuto 7.0 (Erba-Lachema, Brno, ČR), pričom pravdepodobnosť správnej identifikácie presahovala 90 %. Na základe klinického vyšetrenia vemena, skóre NK-testu a laboratórnej diagnostiky boli intramamárne infekcie mliečnej žľazy kategorizované na subklinické a klinické formy.

Vzorky mlieka od vybraných skupín bahníc na stanovenie jeho zloženia boli odoberané asepticky do sterilných 50 ml skúmaviek a transportované pri teplote 4 °C do laboratória na ďalšiu analýzu. Stanovenie základných zložiek mlieka vo vzorkách od vybraných bahníc, ako je obsah tuku, bielkovín, laktózy a beztukovej sušiny (SNF), bolo testované pomocou FTIR spektroskopie s použitím prístroja MilkoScan FT 6000 (Foss Analytical A/S, Hillerød, Dánsko) podľa Záhumenskej a kol. (2024).

2.3 Štatistická analýza

V štatistickom vyhodnotení boli porovnané rozdiely v produkcii mlieka a v kvalitatívnych parametroch medzi sledovanými

skupinami bahníc. Výsledky boli vyhodnotené pomocou programu MS Excel (Microsoft, Redmond, Washington, USA). Základné štatistické charakteristiky, ako sú priemer a štandardná odchýlka, boli vypočítané pre numerické údaje. Štatistická analýza bola vykonaná jednofaktorovou analýzou rozptylu. ANOVA a Tukeyho test pre viacnásobné porovnania priemerov s intervalom spoľahlivosti nastaveným na 95 % boli vykonané pomocou štatistického softvéru GraphPad Prism 8.3.0.538 (GraphPad Software, San Diego, CA, USA).

3. VÝSLEDKY A DISKUSIA

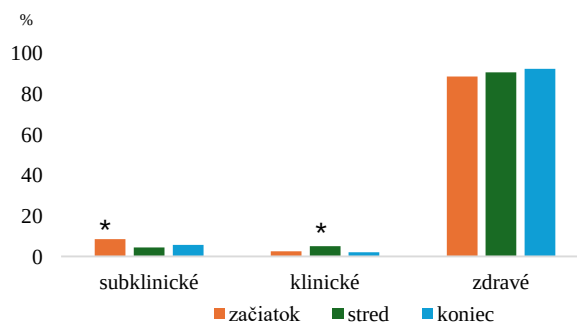
Výsledky hodnotenia NK-testu na 200 ks bahníc počas pastevnej sezóny sú znázornené v tabuľke 1. Pri prvom vyšetrení (začiatok pastevnej sezóny) bol NK-test pozitívny u 6,2% vyšetrených polievkemien. Z vyšetrených polovic boli odobraté vzorky mlieka, z ktorých v 19 bol zistený bakteriálny pôvodca mastitídy. Najnižší výskyt polovic s pozitívnym skóre NK-testu bol zaznamenaný na konci dojenej sezóny. Naopak, najviac pozitívnych polovic na NK-test a infekčných patogénov bolo v strede dojenej sezóny (Tab. 1). V tomto období (stred sezóny) bolo zaznamenaných najviac prípadov klinických mastitíd (5%). Subklinické formy sa vyskytovali najmä na začiatku sezóny (8,5%). Najnižší výskyt klinických foriem bol zaznamenaný na konci sezóny (2%; Obr. 1) v dôsledku vyradenia 6 ks oviec s klinickou mastitídou spôsobenou *S. aureus* po druhom odbere.

Tabuľka 1. Vyhodnotenie NK-testu a laboratórneho vyšetrenia

Pastevná sezóna	Počet oviec	Negatívny NK-test		Pozitívny NK-test		Infekčné polovice vemena*	
		n	%	n	%	n	%
začiatok	200	375	93,8	25	6,2	19	4,8
stred	200	363	90,8	37	9,2	22	5,5
koniec	194	380	95,0	20	5,0	15	3,8

Poznámka: NK-test – California mastitis test robený z každej polovice vemena; Infekčné polovice vemena* – pozitívny NK-test s kultiváciou patogénov vemena.

Celkovo bol počas sezóny zaznamenaný výskyt mastitíd na úrovni 7,7 – 11,0 % s výskytom subklinických foriem na úrovni 4,5 – 8,5 % a klinických foriem na úrovni 2 – 5%. Hlavnými izolovanými patogénmi boli stafylokoky, ktoré tvorili až 61,1% z celkového počtu pozitívnych vzoriek. *S. aureus* bol izolovaný najmä z klinických mastitíd, zatiaľ, čo koaguláza-negatívne stafylokoky (KNS) boli prevažne izolované zo subklinických foriem. Podľa Contreras a kol. (2007) sú subklinické a perzistentné mastitídy častým zdrojom stafylokokov, ktoré sa ťažko liečia vzhľadom na ich potenciál tvorby biofilmu a rezistenciu na antibiotiká.



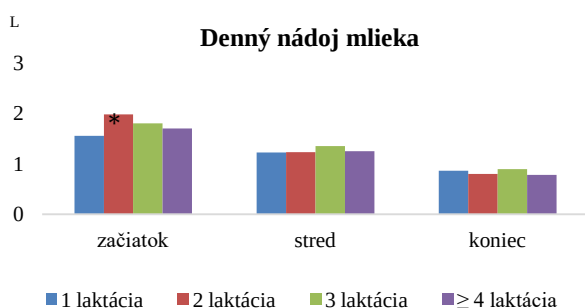
Obrázok 1. Výskyt mastitíd počas pastevnej sezóny

Environmentálne vplyvy, ako sú vlhkosť, teplo a časté zmeny mikroklimy počas pastvy, vytvárajú vhodné podmienky pre ich rast a šírenie v prostredí farmy a dojárne. Celkovo počas celej dojenej sezóny boli klinické mastitidy na úrovni 2-5%, pričom až v 80% bol pôvodcom *S. aureus*. Tento výskyt je porovnateľný s hodnotami uvádzanými u dojného plemena Lacaupe, ktoré popisuje Gonzalo a kol. (2002) vo svojej štúdii. Okrem stafylokokov boli izolované aj gram-negatívne baktérie ako je *E. coli* a *Enterobacter* sp. (Tab. 2). Výsledky druhej časti štúdie porovnávajú vplyv veku bahníc a štádia laktácie na množstvo a kvalitu ovčieho mlieka. Môžeme vidieť, že na začiatku laktácie v apríli, po odstave jahniat, bol denný nádoj mlieka (DMY) najvyšší u všetkých monitorovaných bahníc, keďže v tomto období bola najkvalitnejšia pastva. Signifikantné rozdiely v najvyššom DMY na začiatku sezóny boli v skupine oviec na druhej laktácii (Obr. 2). Potom DMY mierne klesal u všetkých monitorovaných skupín, čo je zapríčinené hlavne klimatickými podmienkami vplyvujúcimi na kvalitu pastvy (suché obdobie) a zároveň aj fyziologickými funkciami bahníc (tepelný stres). Ku koncu laktácie DMY klesá z dôvodu kratšej laktácie niektorých, najmä starších bahníc. Priemerná ročná produkcia mlieka (AMY) za laktáciu dosiahla 285,5 kg mlieka na bahnicu, pričom najvyššia AMY v skupine bahníc bola na druhej laktácii (294 L).

Tabuľka 2. Vyhodnotenie bakteriálnych pôvodcov mastitíd z pozitívnych vzoriek

Pastevná sezóna	<i>S. aureus</i> n/%		KNS ¹ n/%		G ⁻ baktérie ² n/%	
	SBK	KLN	SBK	KLN	SBK	KLN
začiatok (19)	0/0	8/42,1	9/47,4	0/0	0/0	2/10,5
stred (22)	2/9,1	5/22,7	12/54,5	0/0	1/4,5	2/9,1
koniec (15)	0/0	3/20,0	7/46,7	2/13,3	2/13,3	1/6,7
Spolu (56)	0	16/10,7	28/50,0	2/3,4	3/5,4	5/8,9

Poznámka: KNS¹ – koaguláza-negatívne stafylokoky zastúpené *S. warneri*, *S. chromogenes* a *S. epidermidis*; G⁻ baktérie² – zastúpené *E. coli* a *Enterobacter* sp.; SBK – subklinická mastitída; KLN – klinická mastitída.



Obrázok 2. Porovnanie mliečnej produkcie monitorovaných oviec
Poznámka: *p < 0,05.

Zo zloženia mlieka bol hodnotený obsah tuku, bielkovín a laktózy. Z kvantitatívnych parametrov bol vyhodnocovaný PSB (Tab. 3).

Tabuľka 3. Vyhodnotenie jednotlivých zložiek mlieka

Parameter	1. laktácia	2. laktácia	3. laktácia	≥ 4. laktácia
Tuk (%)	5,58±0,42 ^a	5,85±0,38	6,43±0,54 ^b	6,12±0,57

Bielkoviny (%)	4,25±0,28	4,23±0,35	4,52±0,32	4,01±0,25
Laktóza (%)	5,15±0,29	5,22±0,26	5,72±0,30	5,41±0,32
PSB.10 ³	232,6±31,1	183,5±23,7	531±42,3	1179±128,5

Bahnice boli rozdelené do štyroch skupín podľa počtu laktácií: 1., 2., 3. a ≥ 4. laktácií. Najstabilnejšie hodnoty a nižší PSB dosahovali bahnice v 1. a 2. laktácii. So zvyšujúcim sa vekom bahníc narastal PSB, pričom najvyššie hodnoty boli zistené u bahníc v štvrtej a vyššej laktácii. Najlepšie výsledky v zložení mlieka boli zistené u bahníc v 3. laktácii, ktoré dosiahli najvyšší obsah tuku (P < 0,05; 6,43%). Ostatné zložky neboli ovplyvnené vekom bahníc (Tab. 3). Podobné zistenia zaznamenali vo svojej štúdii Paape a kol. (2007). So zvyšujúcim sa vekom bahníc narastal počet somatických buniek ako aj výskyt subklinických mastitíd, pričom najvyššie hodnoty boli zistené u bahníc v piatej a vyššej laktácii.

4. ZÁVER

Štúdia potvrdila významný vplyv sezónnosti na výskyt mastitíd. Najrizikovejším obdobím pre vznik nových prípadov mastitíd bol začiatok sezóny po odstave jahniat, pričom dominantnými patogénmi boli stafylokoky. Nevenovaním pozornosti chovateľa subklinickým mastitídami zapríčineným najmä *Staphylococcus aureus* na začiatku pastvej sezóny, sa väčšina z nich vyvinula na klinické formy, ktoré boli ťažko liečiteľné. Je preto vhodné, aby chovatelia po detekcii patogénov v mlieku si dali urobiť aj doplnkové vyšetrenie na ich druhovú identifikáciu a citlivosť na používané antibiotiká.

Rozbory zloženia mlieka preukázali, že so zvyšujúcim sa vekom bahníc narastal PSB. Najvhodnejšie pre produkciu kvalitného mlieka sa ukázali bahnice v druhej a tretej laktácii, ktoré vykazovali najvyššie hladiny mliečného tuku a bielkovín. Získané výsledky poukazujú na potrebu vhodnej voľby plemena, systému chovu a efektívneho manažmentu stáda počas celej pastvej sezóny s cieľom zachovať kvalitu mlieka a znížiť výskyt mastitíd v chovateľskom prostredí.

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Průmysl



Industry

Model-Based Analysis of Combustion Characteristics for Future Split-Injection Hydrogen-Gasoline Engines

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Abstract Hydrogen enrichment represents one of the most promising approaches for improving the efficiency and environmental performance of spark-ignition engines while maintaining compatibility with existing combustion technologies. The present study investigates the influence of hydrogen addition on combustion characteristics and engine efficiency under lean-burn operating conditions using a combination of experimental measurements and numerical modelling. The analysis focuses on heat release rate, in-cylinder pressure evolution and brake thermal efficiency for various hydrogen-gasoline blends operating at different excess-air ratios. Experimental data were used to validate a simulation model capable of predicting combustion behaviour and identifying key parameters affecting engine performance. The results showed that increasing the hydrogen fraction accelerated the combustion process, shifted the peak heat release rate towards earlier crank angles and promoted earlier occurrence of maximum cylinder pressure. Furthermore, hydrogen enrichment enabled stable operation at leaner mixtures and increased brake thermal efficiency, with the highest values observed at $\lambda \approx 1.6$ for hydrogen-rich blends. The numerical model demonstrated good agreement with experimental measurements and successfully reproduced the observed combustion trends. Based on the obtained results, a conceptual framework for future split-injection control strategies is proposed, where model-based prediction of combustion characteristics can be used to optimize fuel delivery, ignition timing and air-fuel ratio management. The findings confirm that hydrogen-assisted combustion combined with advanced model-based control approaches offers significant potential for the development of next-generation low-emission spark-ignition engines.

Keywords hydrogen enrichment, spark-ignition engine, combustion modelling, engine control, lean-burn combustion

1. INTRODUCTION

The automotive industry is currently undergoing a significant transformation driven by increasingly stringent emission regulations, global decarbonization targets and the growing demand for sustainable transportation systems. Although battery-electric vehicles are expected to play a major role in future mobility, internal combustion engines remain an essential technology for many transportation sectors, including heavy-duty vehicles, hybrid powertrains and off-road machinery. Consequently, considerable research efforts are focused on improving engine efficiency and reducing environmental impacts through advanced combustion concepts and alternative fuels [1].

Hydrogen has emerged as one of the most promising alternative fuels due to its carbon-free combustion, high gravimetric energy density and favorable combustion characteristics. Compared with conventional gasoline, hydrogen exhibits a significantly higher laminar flame speed, lower ignition energy and wider flammability limits, allowing stable combustion even under very lean operating conditions [2,3]. These properties can contribute to improved thermal efficiency, lower fuel consumption and reduced greenhouse gas emissions while maintaining compatibility with existing internal combustion engine architectures.

Numerous studies have demonstrated that hydrogen enrichment accelerates flame propagation, shortens combustion duration and enhances combustion stability. Furthermore, hydrogen-assisted combustion can improve lean-burn capability and increase engine efficiency by enabling more favorable combustion phasing and reducing cycle-to-cycle variations [4,5]. However, the introduction of hydrogen into spark-ignition engines also alters heat release characteristics, pressure development and overall combustion dynamics, creating new challenges for engine calibration and control.

Modern engine development increasingly relies on numerical modelling techniques capable of predicting in-cylinder processes with high accuracy. Model-based approaches provide valuable insights into combustion phenomena, pressure evolution and thermal efficiency while reducing the need for extensive experimental testing. When properly validated against experimental measurements, simulation models can become an important component of advanced engine control systems and real-time combustion management strategies.

One of the promising concepts currently being investigated for future hydrogen-gasoline engines is split fuel injection. In such systems, the total fuel quantity is divided into multiple injection events to improve mixture preparation, combustion phasing and engine efficiency. The effectiveness of split-injection strategies strongly depends on a detailed understanding of combustion behaviour and accurate prediction of key combustion parameters, including heat release rate, maximum cylinder pressure and thermal efficiency. Therefore, the development of future model-based control algorithms requires comprehensive experimental and numerical analysis of combustion processes under various operating conditions.

The objective of this study is to perform a model-based analysis of combustion characteristics in a hydrogen-gasoline spark-ignition engine operating under lean-burn conditions. Experimental measurements and numerical simulations are used to evaluate heat release rate, in-cylinder pressure development and brake thermal efficiency for different hydrogen-gasoline blends. The obtained results are further discussed from the perspective of future split-injection control strategies and adaptive engine management systems for next-generation low-emission combustion engines.

2. MATERIALS AND METHODS

The experimental investigation was carried out on a spark-ignition engine operating with hydrogen-gasoline fuel blends under various lean-burn conditions. The objective of the measurements was to evaluate the influence of hydrogen enrichment on combustion development, heat release characteristics, in-cylinder pressure evolution and brake thermal efficiency. The engine was equipped with a combustion analysis system enabling crank-angle resolved pressure measurements, which served as the primary source of data for subsequent combustion analysis and numerical model validation. The tested operating conditions covered both stoichiometric and lean mixtures, with the excess-air ratio ranging from $\lambda = 1.0$ to $\lambda = 2.2$. Such a range was selected to investigate the combustion behaviour from conventional operation to ultra-lean conditions, where the beneficial effects of hydrogen become increasingly significant. Several hydrogen-gasoline blends with different hydrogen fractions were examined in order to evaluate the influence of fuel composition on combustion performance and engine efficiency.

To support the experimental investigation, a numerical combustion model was developed and calibrated using the measured engine data. The model was designed to reproduce the main thermodynamic processes occurring within the cylinder and to predict key combustion parameters, including heat release rate, in-cylinder pressure development and brake thermal efficiency. Particular attention was devoted to the prediction of combustion phasing and maximum cylinder pressure because these parameters represent important inputs for future model-based engine control systems. The accuracy of the model was assessed by comparing simulated and measured pressure traces under identical operating conditions.

The experimental pressure data were further used for heat release analysis in order to evaluate the rate and timing of energy release during combustion. The resulting combustion characteristics were subsequently correlated with brake thermal efficiency and analyzed with respect to varying hydrogen concentration and excess-air ratio. The obtained results provide valuable information regarding the relationship between fuel composition, combustion behaviour and engine efficiency. Furthermore, the validated model creates a foundation for the future development of adaptive control strategies and split-injection concepts, where accurate prediction of combustion processes is required for optimization of fuel delivery, ignition timing and overall engine operation.

3. RESULTS AND DISCUSSION

The combustion analysis revealed a significant influence of hydrogen concentration on the development of the combustion process and the associated thermodynamic parameters. Figure 1 presents the comparison of heat release rate profiles obtained for fuel blends containing different hydrogen fractions. The results indicate that increasing the hydrogen content substantially affects the timing of energy release during combustion. While both investigated fuel blends reached similar peak heat release rates of approximately 50 J/°CA, the hydrogen-rich mixture exhibited an earlier occurrence of the maximum heat release rate. The peak was shifted by approximately 5°CA towards top dead centre compared to the low-hydrogen blend, indicating a significantly faster combustion process.

The observed behaviour can be attributed to the favorable combustion properties of hydrogen, particularly its higher laminar flame speed and lower ignition energy. These characteristics promote faster flame propagation and shorten the combustion duration. As a consequence, a larger portion of the fuel energy is released closer to the optimum crank angle region, which contributes to improved thermodynamic efficiency. The results shown in Fig. 1 therefore confirm that hydrogen enrichment accelerates combustion development and alters combustion phasing, which must be considered in future engine control strategies and injection system design.

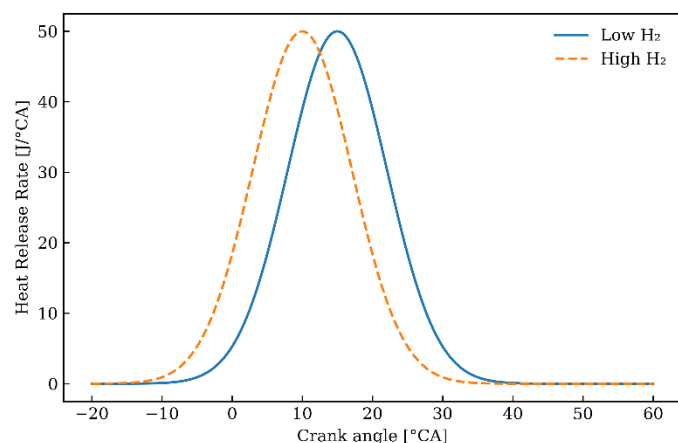


Figure 1 - Comparison of heat release rate profiles for low- and high-hydrogen fuel blends under lean-burn operating conditions

The influence of accelerated combustion is further reflected in the in-cylinder pressure development presented in Fig. 2. A comparison between experimental measurements and numerical simulations demonstrates a high level of agreement throughout the combustion cycle. The experimental pressure trace reached a maximum value of approximately 41 bar, whereas the simulation predicted a slightly higher peak pressure of approximately 43 bar. Furthermore, the simulated pressure maximum occurred approximately 2°CA earlier than the experimentally observed peak.

Despite these minor deviations, the numerical model successfully reproduced the overall pressure evolution, including the pressure rise during combustion, the maximum pressure region and the subsequent expansion phase. The relatively small difference between experimental and simulated results indicates that the model accurately captures the dominant physical processes governing combustion and energy conversion within the cylinder. Such agreement is particularly important for future model-based control applications, where reliable prediction of combustion behaviour is required for real-time optimization of engine operation.

The combined analysis of heat release rate and pressure development demonstrates a clear relationship between hydrogen concentration and combustion dynamics. Earlier heat release leads directly to an earlier pressure rise and higher peak pressure values, resulting in more favorable combustion phasing. From the perspective of future hydrogen-gasoline engines equipped with split-injection systems, these findings provide valuable information for determining optimal injection timing and fuel distribution strategies. Since hydrogen enrichment significantly modifies combustion speed and pressure development, future control algorithms will need to continuously adapt fuel injection parameters to maintain optimal combustion phasing and maximize engine efficiency.

The validation results presented in Fig. 2 also confirm that the developed numerical model can be used as a predictive tool for further investigations of advanced combustion concepts. Such model-based approaches are expected to play an increasingly important role in the development of adaptive engine management systems, where combustion parameters can be predicted and optimized before actual combustion occurs. Consequently, the presented model provides a suitable foundation for future research focused on split-injection hydrogen-gasoline combustion systems and advanced model-based control algorithms.

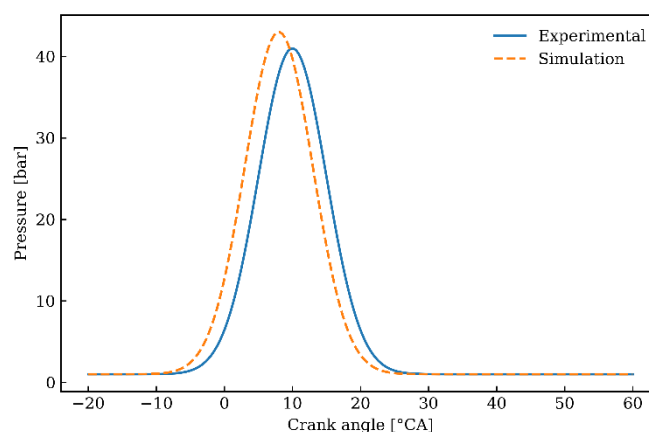


Figure 2 - Comparison of experimentally measured and simulated in-cylinder pressure traces used for numerical model validation

The influence of combustion characteristics on overall engine performance can be further evaluated through the brake thermal efficiency results presented in Fig. 3 and Fig. 4. The obtained data demonstrate that both hydrogen concentration and excess-air ratio significantly affect the efficiency of the combustion process. For all investigated fuel blends, brake thermal efficiency increased as the mixture became leaner, reaching an optimum operating point before gradually decreasing under ultra-lean conditions.

The behaviour observed in Fig. 3 indicates that low-hydrogen fuel blends achieved their highest brake thermal efficiency at approximately $\lambda = 1.4$. At stoichiometric operation, the efficiency remained close to 34 %, while progressive mixture leaning resulted in a noticeable improvement in thermal efficiency. The maximum values approached approximately 37 %, after which further increase in excess-air ratio caused a gradual decline. This reduction can be associated with decreasing combustion temperatures, slower flame propagation and reduced combustion stability under extremely lean conditions.

A different trend can be observed for the hydrogen-rich fuel blends shown in Fig. 4. In this case, the optimum operating point was shifted towards significantly leaner mixtures. The highest brake thermal efficiency was achieved at approximately $\lambda = 1.6$, where values close to 38 % were recorded. Compared to the low-hydrogen blends, the hydrogen-rich mixtures exhibited both higher maximum efficiency and an extended lean operating range. These results clearly demonstrate the beneficial effect of hydrogen on combustion stability and energy conversion efficiency.

The improved performance of hydrogen-enriched mixtures can be explained by the combustion characteristics discussed previously. As shown by the heat release analysis in Fig. 1, hydrogen promotes faster energy release and advances combustion phasing. The resulting pressure development, illustrated in Fig. 2, enables a greater proportion of the released energy to be converted into useful work during the expansion stroke. Consequently, the combination of accelerated combustion and improved combustion stability allows efficient operation even at higher excess-air ratios.

Another important observation is the excellent agreement between experimental measurements and numerical predictions presented in both Fig. 3 and Fig. 4. The simulation model successfully reproduced the efficiency trends over the entire investigated operating range, including the location of the efficiency maxima and the subsequent decrease under ultra-lean conditions. The relatively small deviations between measured and simulated values confirm the capability of the model to capture the dominant mechanisms

governing hydrogen-assisted combustion. Such predictive capability is particularly important for future model-based engine control systems, where combustion parameters must be estimated continuously under varying operating conditions.

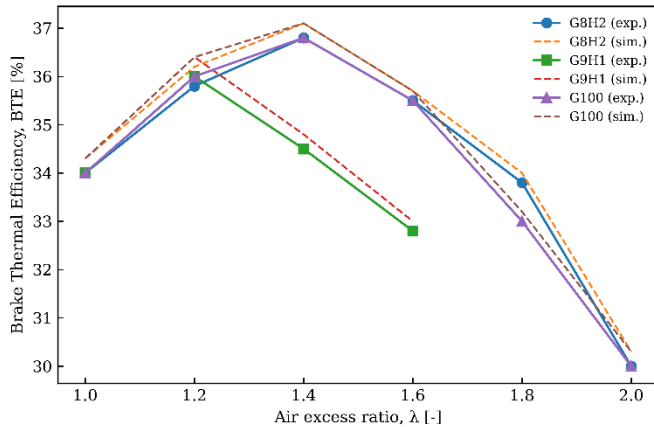


Figure 3 - Brake thermal efficiency as a function of excess-air ratio for low-hydrogen gasoline blends: comparison of experimental and simulation results.

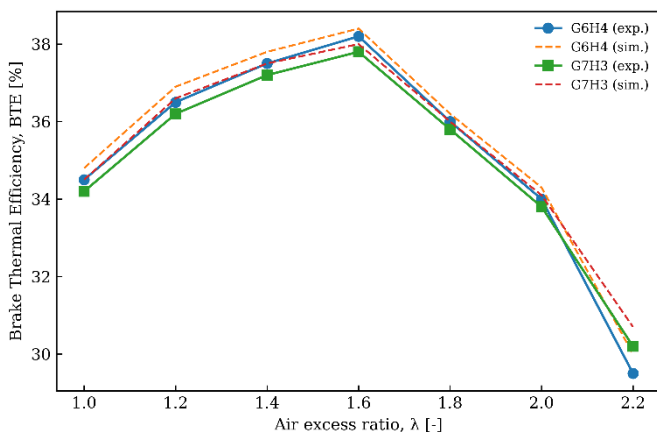


Figure 4 - Brake thermal efficiency as a function of excess-air ratio for hydrogen-rich gasoline blends: comparison of experimental and simulation results.

From the perspective of future split-injection hydrogen-gasoline engines, the obtained results provide valuable information regarding optimal combustion phasing and fuel delivery strategies. The shift of the efficiency optimum from $\lambda \approx 1.4$ to $\lambda \approx 1.6$ with increasing hydrogen concentration suggests that the fuel management system should dynamically adapt injection parameters according to both fuel composition and operating conditions. A split-injection strategy could utilize an initial pilot injection to improve mixture preparation followed by a main injection event responsible for achieving the desired combustion phasing. Such an approach would allow the engine control unit to compensate for the faster combustion behaviour associated with hydrogen enrichment while maintaining optimal efficiency and combustion stability.

The presented results therefore demonstrate that hydrogen concentration significantly influences not only combustion dynamics but also the location of the optimum operating point. These findings confirm the necessity of adaptive model-based control approaches capable of continuously adjusting injection timing, fuel distribution and ignition parameters. The validated simulation model developed in this study provides a suitable platform for future investigations focused on split-injection

strategies and advanced combustion control concepts for low-emission hydrogen-gasoline engines.

4. CONCLUSIONS

This study presented a model-based analysis of combustion characteristics in a hydrogen-gasoline spark-ignition engine operating under lean-burn conditions. The investigation combined experimental measurements and numerical simulations to evaluate the influence of hydrogen enrichment on heat release rate, in-cylinder pressure development and brake thermal efficiency. Particular attention was devoted to assessing the capability of the numerical model to reproduce the observed combustion behaviour and to identifying parameters relevant for future model-based engine control systems.

The results demonstrated that hydrogen addition significantly modifies combustion dynamics. The heat release rate analysis revealed that increasing the hydrogen fraction accelerates combustion and shifts the peak heat release rate towards earlier crank angles. Compared to low-hydrogen operation, the hydrogen-rich fuel blend exhibited a heat release peak occurring approximately 5°CA earlier, indicating faster flame propagation and shorter combustion duration. This behaviour was reflected in the pressure development, where earlier combustion phasing resulted in an earlier occurrence of maximum cylinder pressure.

The comparison between experimental and simulated pressure traces confirmed the validity of the developed numerical model. Although the simulation slightly overpredicted the maximum cylinder pressure, the overall agreement between measured and predicted pressure evolution was very good. The model successfully reproduced the main combustion characteristics and captured the influence of hydrogen concentration on pressure development throughout the engine cycle.

The brake thermal efficiency analysis showed that hydrogen enrichment not only improved combustion stability but also shifted the optimum operating point towards leaner mixtures. While the maximum efficiency for low-hydrogen blends was achieved at approximately $\lambda = 1.4$, hydrogen-rich mixtures reached their highest efficiency at approximately $\lambda = 1.6$. The highest brake thermal efficiency approached 38 %, confirming the potential of hydrogen-assisted combustion for improving engine performance under lean-burn conditions.

The obtained results indicate that future hydrogen-gasoline engines will require adaptive control strategies capable of responding to changing combustion characteristics and fuel composition. The validated numerical model developed in this work provides a suitable foundation for the future development of model-based combustion control systems and split-injection fuel delivery strategies. Future research will focus on integrating predictive combustion models into advanced engine control algorithms capable of optimizing injection timing, fuel distribution and ignition control under dynamically changing operating conditions.

Acknowledgement

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