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Teacher characteristics influencing plant biology education: age, perception, and practical engagement

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Abstract Plants are less attractive for students compared to other areas of biology, and teachers may improve this negative scenario. We aimed to investigate the influence of several characteristics of the teacher (e.g. gender, age or technical equipment) on (i) the activity of teaching plant biology, (ii) a number of physiological experiments used in teaching and, (iii) deficiencies in the knowledge of students in plant biology. For this purpose, data were extracted from previous more complex survey and analyzed by General Linear Model. The age, the teachers' perception of the students' knowledge and the teachers' awareness of the importance of the aids significantly correlated with the teachers' activity in education. Similarly, three teachers' characteristics (age, school's equipment and awareness of the importance of the aids) correlated with the number of implemented physiological experiments. In addition, two teachers' characteristics (age and perception of the students' knowledge) significantly correlated with the number of identified gaps in students' knowledge. In particular, we found that 51-yr-old (or above) teachers use more practical activities and physiological experiments, which may be the reason why they identified fewer gaps in students' knowledge. Therefore, these more active teachers should be replaced by young teachers of the same quality after their retirement to keep the quality of education.

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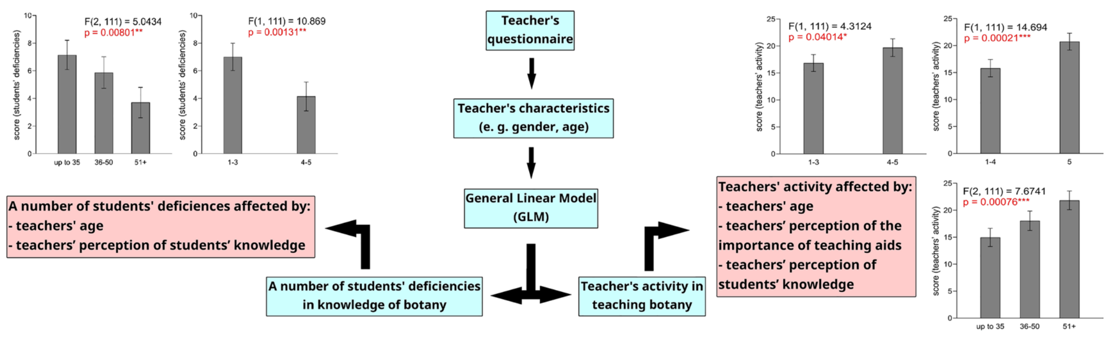
Graphical abstract



Keywords Botany · Motivation · Physiology · Practical activity · Science education

1 Introduction

Plant biology is less attractive for students compared to other areas of biology (Kováčik and Vydra 2023). This phenomenon, i.e. the neglect of plants at the expense of animals, is becoming widespread not only in schools but also in the whole society and is described by the term plant awareness disparity/PAD (Parsley 2020). One of the ways to reduce PAD is the implementation of practical activities in the teaching process. It is a practical activity in nature (Fančovičová and Prokop 2011) and direct contact of students with plants (Krell and Smidt 2022) that can have a positive effect on knowledge and at least partially eliminate PAD of students. University professors could be inspired by the "Plant Senses" course, which emphasizes the ecological significance and economic value of plants, in addition to professional literature, which is also based on popular science books (Krtková 2024).

An active teacher is required to implement practical activities for teaching plant biology. The activity of teachers depends on several factors. Men are probably more open to students working independently, while women use more demonstrations in teaching (Osuafor and Amaefuna 2016). It was also found that teachers do not implement laboratory activities in teaching due to various concerns and lack of experience with laboratory activities (Cossa and Uamusse 2015). One of the main conclusions of the review study investigating the laboratory experience of future teachers is that science teaching students should be better prepared for the needs of future pedagogical practice during laboratory courses (Prabha 2016). An analysis of students' answers to laboratory and theory questions included in exams between 2000 and 2012 revealed that university students answer correctly especially to theoretical questions (Vila and Sanz 2018).

Teachers can obtain laboratory experiences during their own university studies. For example, students from Department of Biology achieved higher scores in the areas of "*Practice of biological concepts and skills*" and "*Generalization to biology/other courses and analysis of knowledge*" than students studying at the Department of Biology Teaching (Ekici et al. 2012). Professional knowledge is an important characteristic of a teacher (Gess-Newsome et al. 2019). Older generations have better knowledge about plants (Stagg and Dillon 2022) and it is questionable whether knowledge accumulation also occurs among older teachers. Thus, better knowledge of older teachers can have an impact on the educational process.

Various deficiencies and misconceptions in plant biology education were identified (Wynn et al. 2017; Kováčik and Vydra 2023), but only a few works have been devoted to the influence of the teacher on these deficiencies. Based on recent studies, the teachers' enthusiasm in teaching a given topic, as well as knowledge about the subject matter, improve student performance (Mahler et al. 2018; Gess-Newsome et al. 2019). In addition, a positive correlation was identified between the number of teachers' deficiencies in the knowledge of plant biology and the number of deficiencies in the knowledge of their students (Kováčik and Vydra 2023).

Since it has been shown that a teacher can influence the number of gaps in students' knowledge, we analyzed in this work which teacher characteristics influence the number of these gaps in plant biology. In doing so, we formulate two main hypotheses: "*Older teachers (and thus teachers with longer experience and practice) implement more practical activities and physiological experiments in plant biology teaching*" and "*Older teachers (and thus more active teachers) identify fewer deficiencies in the students' knowledge about plants (and thus fewer misconceptions)*".

2 Material and methods

2.1 Data extraction

The aim of this work was to investigate the influence of teachers' characteristics on three areas (teachers' activity, a number of physiological experiments used in teaching by teachers and the number of deficiencies in students' knowledge of plant biology). Specific data of the questionnaire survey analyzed in this study were selected from a previous study (Kováčik and Vydra 2023). The score from the area of teachers' activity in teaching botany was obtained as the sum of the answers to six questions. These questions investigated what types of aids teachers use while teaching plant biology, what groups of plants they use in teaching, in which topics they use fixed and native microscopy, live plant material and physiological experiments (see supplementary Table S1). The score from the second area (the number of physiological experiments implemented in teaching) represents the number of answers to one question (Table S1). A score from the area of deficiencies in students' knowledge of plant biology was obtained as the sum of the answers to three questions. These questions investigated which areas of plant anatomy, plant physiology and the connection of knowledge between these two areas were problematic for students according to the teachers (Table S1). We used the scores of each participant from individual areas for further statistical analysis (see supplementary Excel file for details). These data represent the dependent variables. We also selected respondents' answers, which represent independent variables. The independent variables were: The founder of gymnasia, gender or age of teachers, type of faculty where they studied, perception of technical background (equipment) on their gymnasium, a year in which they teach plant anatomy and physiology of plants and the degree of agreement/disagreement with two scale questions: "*My students' knowledge of plant anatomy and physiology is mostly excellent*" and "*Interpretation of plant biology should be linked to practical aids/activities as much as possible*". Within the scaling questions, respondents were divided into two groups (although a 5-point scale was used) to achieve a similar number of respondents in compared groups. Respondents' answers to these questions are presented in supplementary Table S2, while these teachers' characteristics represented independent variables (see supplementary file 1 for details). A total of 124 gymnasium teachers completed the questionnaire. The gymnasium is a type of high school with a general focus on various subjects that prepare students for subsequent university studies.

2.2 Data analyses

General Linear Model (GLM) was used to determine the impact of mentioned factors (i.e. age and gender of respondents, type of gymnasium and perception of the equipment available to teachers) on the activity of teachers and the deficiencies of their students in plant biology. We worked with all factors as categorical predictors.

3 Results

3.1 Factors affecting the teachers' activity

In Slovakia, gymnasia are of state, church or private nature from the point of view of the founder. However, this factor did not significantly affect the activity of teachers (Fig. 1A). Similarly, gender did not influence teachers' activity (Fig. 1B). On the contrary, age significantly affected the teachers' activity, and older teachers are more active than their younger colleagues (Fig. 1C). In Slovakia, biology teaching can be studied at two types of faculties. Most gymnasium

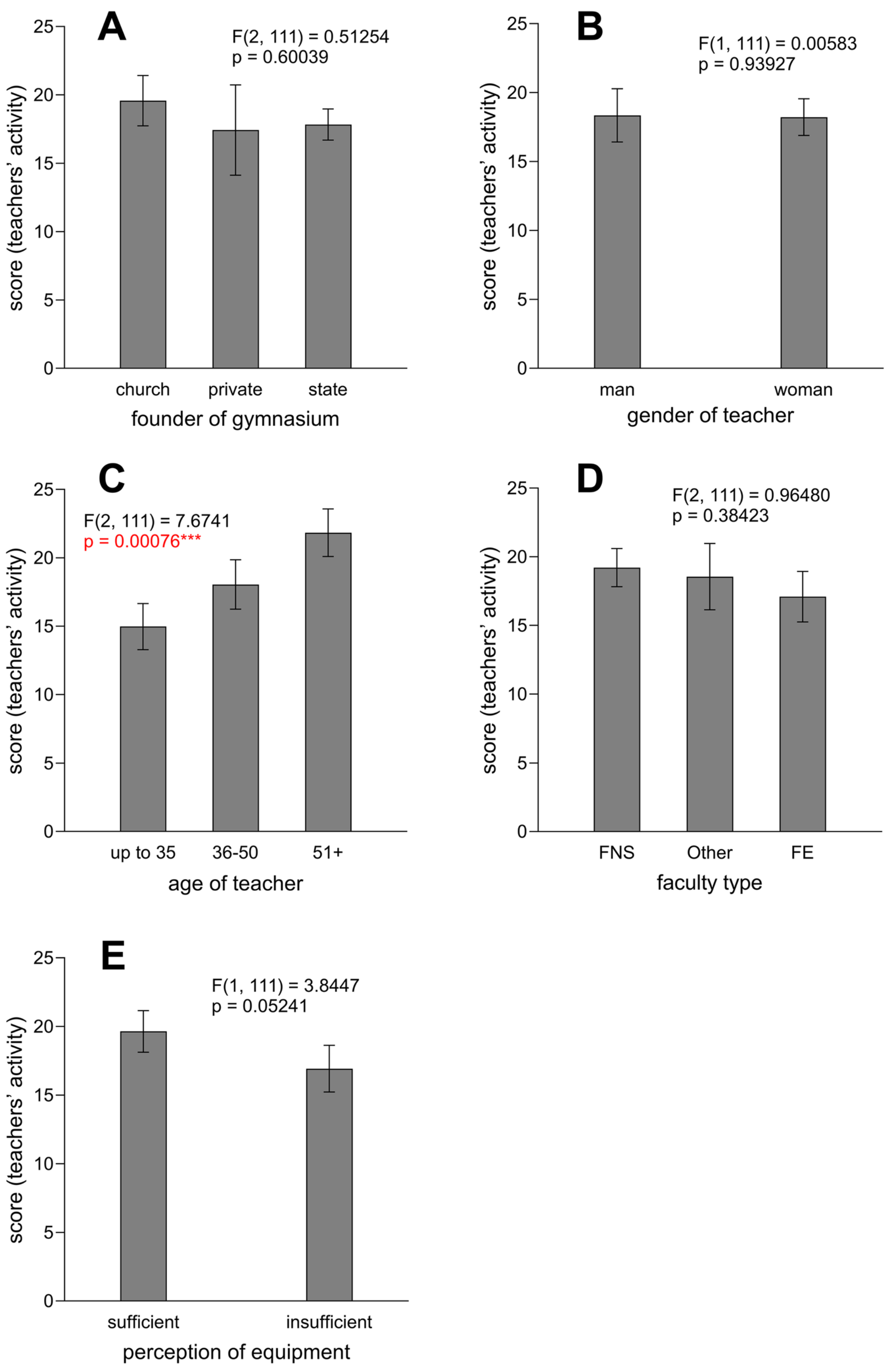


Fig. 1 Intensity of teachers' activity with respect to the founder of gymnasia (**A**), gender of teachers (**B**), age of teachers (**C**), faculty where teachers studied (**D**) and perception of equipment by teachers (**E**). *FNS* faculty of natural sciences, *FE* faculty of education. Data are means ± SEs. P value in red indicates a significant effect of the given variable on teacher activity at 0.001 (***) level according to GLM. P values in black are not significant according to GLM ($P > 0.05$)

teachers are graduates from the faculty of natural sciences (Table S2). However, the type of faculty where the teachers studied did not significantly affect the activity of teachers, although it seems that teachers of natural sciences faculties are slightly more active in teaching botany compared to graduates of pedagogical faculties (Fig. 1D). Another factor without a significant effect on the activity of teachers was the perception of technical equipment on the gymnasium where the teachers work, but it seems that teachers with sufficient equipment are slightly more active in the teaching process (Fig. 1E). At Slovak gymnasia, biology teachers may modify the curriculum for individual grades according to their preferences. Although we found no significant effect of the grade in which teachers teach plant anatomy and physiology, it appears that teachers who teach plant anatomy in the first year and plant physiology in the second year are slightly (but not significantly) more active in teaching (Fig. 2A and B). These results are not surprising and such a distribution of the curriculum is meaningful: teaching students about the processes that take place in plant tissues and cell organelles requires a basic knowledge of such structures.

Two other factors significantly influenced the teachers' activity in the teaching of botany. Not surprisingly, teachers who are more active in teaching plant biology are more likely to agree that their students' knowledge of plant biology is excellent (Fig. 2C). Teachers who are more aware of the importance of teaching aids are also more active in the teaching process (Fig. 2D). It is a positive finding that most teachers agree/strongly agree with the statement "*Interpretation of plant biology should be linked to practical aids/activities as much as possible*" (Table S2), but to implement practical activities, adequate equipment and expertise/knowledge of plant biology teachers are needed.

3.2 Activities in plant physiology education

The most frequent answers to the question "*If you carry out physiological experiments, please briefly give examples of tasks*" were (this was a question independent of the question "*What topic do you use physiological experiments for?*"): Macroscopic observation of osmotic phenomena in potato or carrot "fries", microscopic observation of osmotic phenomena on onion cells, observation of water movement (transpiration flow) in the plant through a colored solution, chromatography of photosynthetic pigments (Thin Layer Chromatography), observation of seed or plant respiration (detection of CO_2 generation through an indicator) and the effect of conditions on seed germination. To a lesser extent, teachers carry out experiments investigating the influence of abiotic factors on plant growth, isolation of secondary metabolites (e.g. from orange peel), evidence of the formation of O_2 by photosynthesis (through analytical instruments designed for schools), the influence of light wavelength on plant growth, observation of plant movements (e.g. using of diatoms) or observation of etiolation.

The age of the teachers positively affected the number of implemented physiological experiments (Fig. 3A), which means that older teachers are not only generally more active, but also use more physiological experiments. The second factor that significantly impacted the number of implemented physiological experiments was the perception of the equipment at the given school. Teachers who think that the equipment in their schools is sufficient use physiological experiments more often when teaching botany (Fig. 3B). However, the perception of the equipment was not significant for the teacher's overall activity (Fig. 1E). In addition, the degree of respondents' agreement with the statement "*Interpretation of plant biology should be linked to practical aids/activities as much as possible* ", impacted the number of physiological experiments used by teachers (Fig. 3C). In other words, teachers who are more convinced of the importance of practical activities in teaching botany use such aids more frequently in their lessons. Other investigated factors did not significantly impact the number of physiological experiments performed by teachers.

3.3 Factors affecting the students' deficiencies

The number of identified deficiencies was not influenced by the founder of the gymnasium or the gender of the respondent (Fig. 4A and B). However, private gymnasium teachers acknowledged fewer deficiencies (Fig. 4A), possibly because of the smaller number of respondents. Women identified more deficiencies in students' knowledge of plant biology than men, but the difference was not significant (Fig. 4B). The impact of teachers' age on the

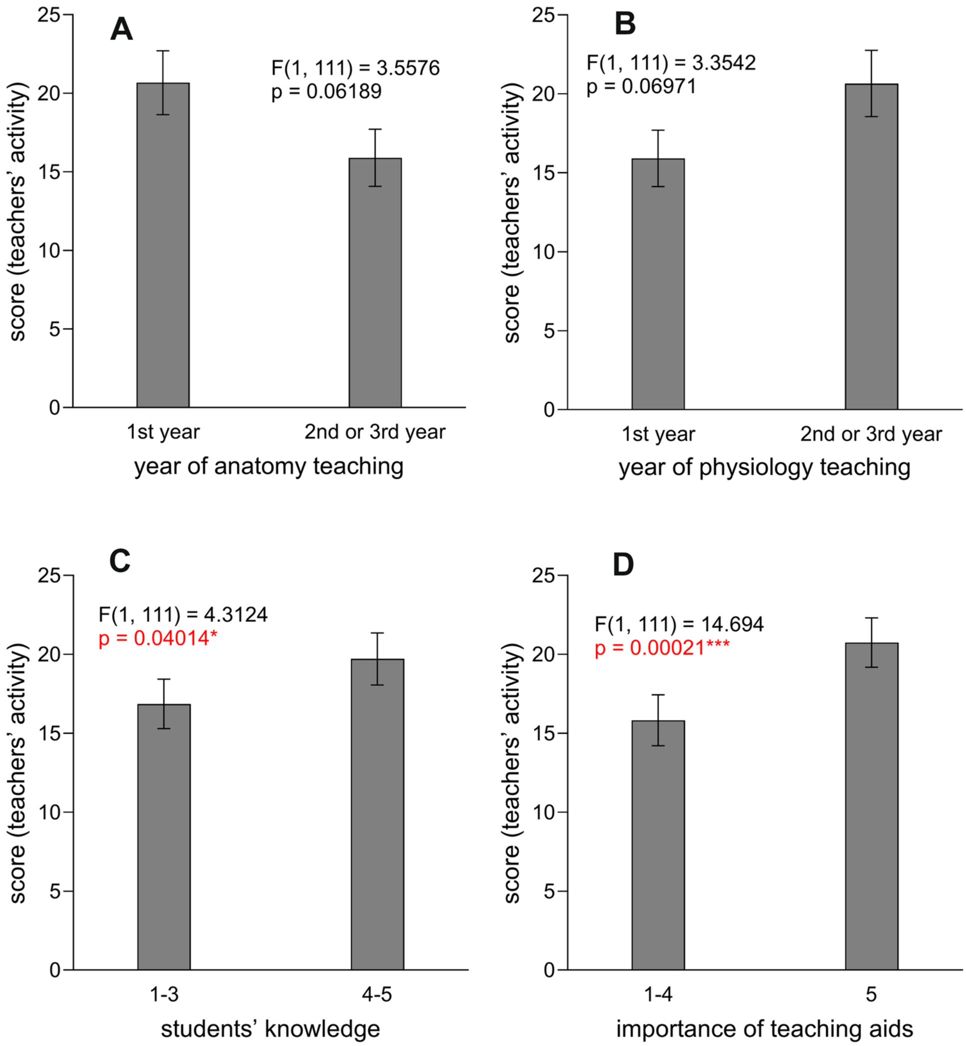


Fig. 2 Comparison of teachers' activity with respect to the year of plant anatomy (**A**) and plant physiology teaching (**B**), the teachers' perception of students' knowledge (**C**) and teachers' perception of the importance of teaching aids in plant biology education (**D**). 1–3 represents the answer: strongly disagree to uncertain, 4–5 represents the answer: agree or strongly agree to the statement: "*My students' knowledge of plant anatomy and physiology is mostly excellent*". 1–4 represents: strongly disagree to agree and 5 strongly agree to the statement "*Interpretation of plant biology should be linked to practical aids/activities as much as possible*". Data are means ± SEs. P values in red indicate a significant effect of the given variable on teacher activity at 0.05 (*) or 0.001 (***) level according to GLM. P values in black are not significant according to GLM ($P > 0.05$)

number of identified deficiencies was significant: younger teachers identified more deficiencies compared to older respondents (Fig. 4C). It is noteworthy that older teachers are generally more active and identified fewer student deficiencies, which highlights the importance of practical activities in teaching. In other words, more experienced teachers are more active and likely to teach their students more, and therefore students have fewer deficiencies. We analyzed the impact of age on teachers' activity in detail in Sect. 3.1. Other investigated factors that did not have a significant impact on the number of students' deficiencies were the type of faculty where the teachers studied (Fig. 4D), the perception of school equipment (Fig. 4E) and the year in which they teach plant anatomy and physiology

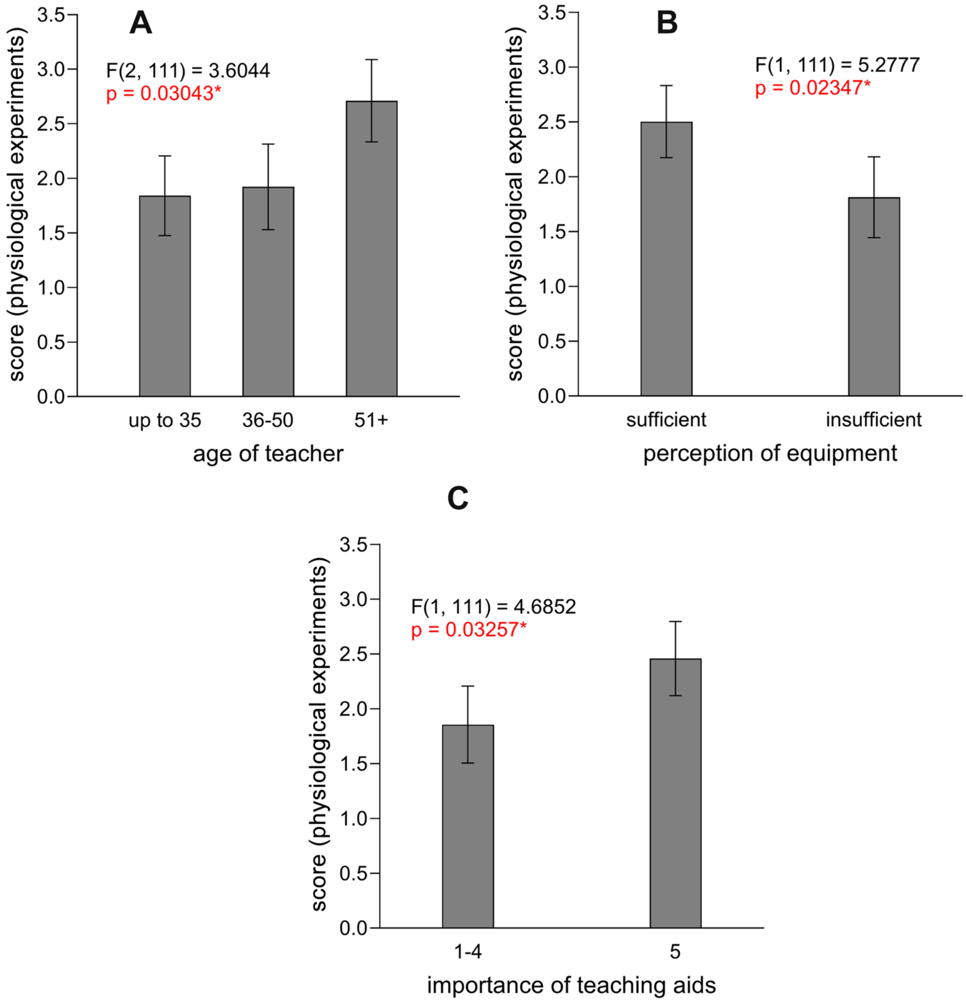


Fig. 3 Comparison of implementation of physiological experiments by teachers with respect to the age of teachers (**A**), perception of equipment by teachers (**B**) and teachers' perception of the importance of teaching aids in plant biology education (**C**). 1–4 represent answers: strongly disagree to agree and 5 strongly agree to the statement "*Interpretation of plant biology should be linked to practical aids/activities as much as possible*". Data are means ± SEs. P values in red indicate a significant effect of the given variable on teacher activity at 0.05 (*), 0.01 (**), and 0.001 (***) level according to GLM. Only those parameters that have a significant impact on the implementation of physiological experiments by teachers are presented (GLM $P < 0.05$)

(Fig. 5A, B). However, it is important to note that teachers with insufficient equipment in their schools identified slightly more deficiencies (but without a significant difference) in their students' knowledge. Therefore, we emphasize once again the importance of equipment and devices that will enable teachers to implement even more demanding practical activities (e.g. spectrophotometric analyses), which can foster a positive attitude not only toward plants but also toward science. Within scaling questions, teachers who agreed with the statement "*My students' knowledge of plant anatomy and physiology is mostly excellent*" identified fewer shortcomings (Fig. 5C). The degree of agreement with the second scaling question "*Interpretation of plant biology should be linked to practical aids/activities as much as possible*" was not significant, although teachers who strongly agreed identified fewer deficiencies of students in plant biology (Fig. 5D).

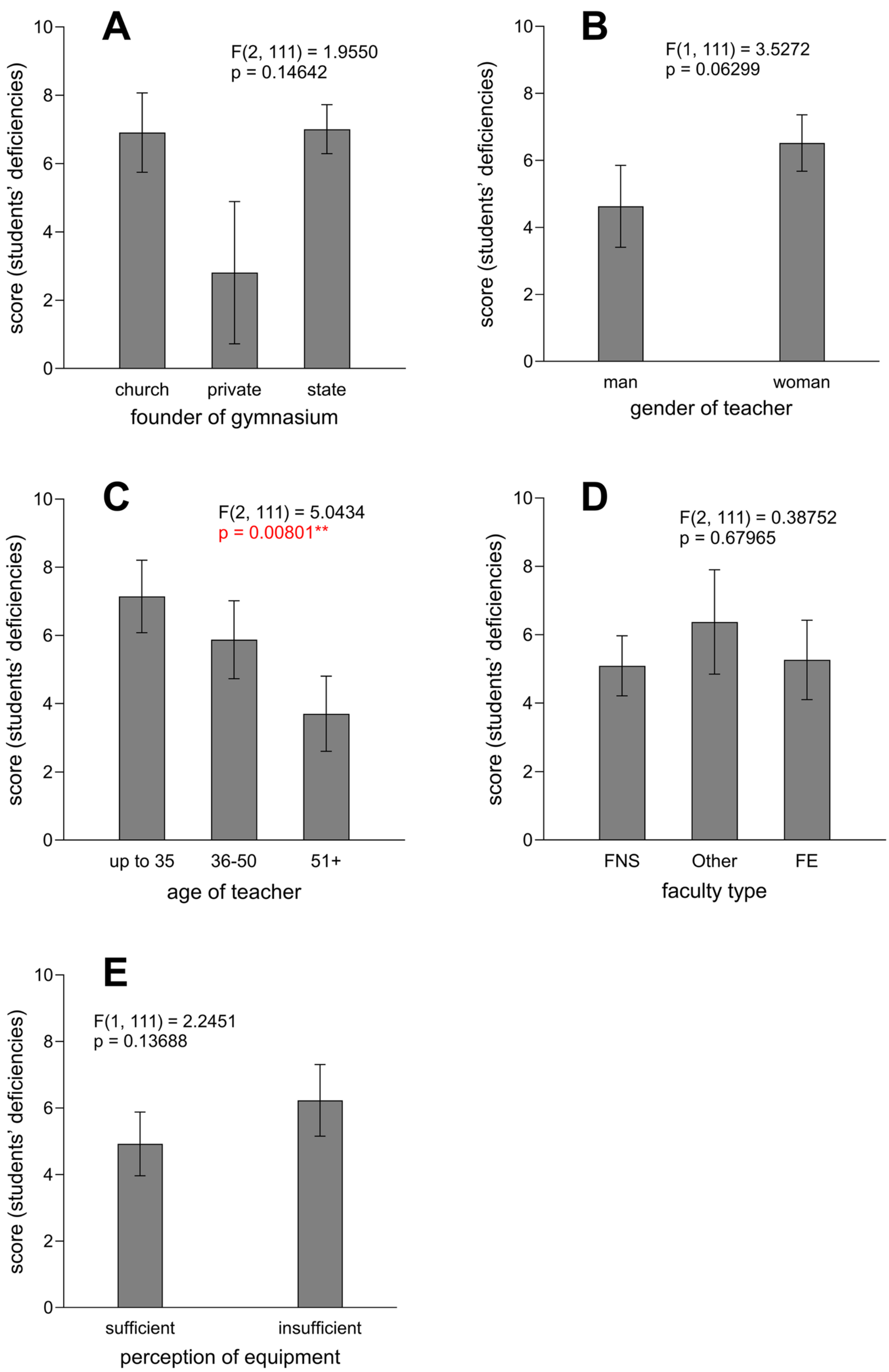


Fig. 4 Comparison of number of students' deficiencies identified by respondents (the number of problem areas identified by the teachers) with respect to the founder of gymnasia (**A**), gender of teachers (**B**), age of teachers (**C**), faculty where respondents studied (**D**) and perception of equipment by teachers (**E**). *FNS* faculty of natural sciences, *FE* faculty of education. Data are means ± SEs. P value in red indicates a significant effect of the given variable on number of students' deficiencies at 0.01 (**) level according to GLM (general linear model). P values in black are not significant according to GLM ($P > 0.05$)

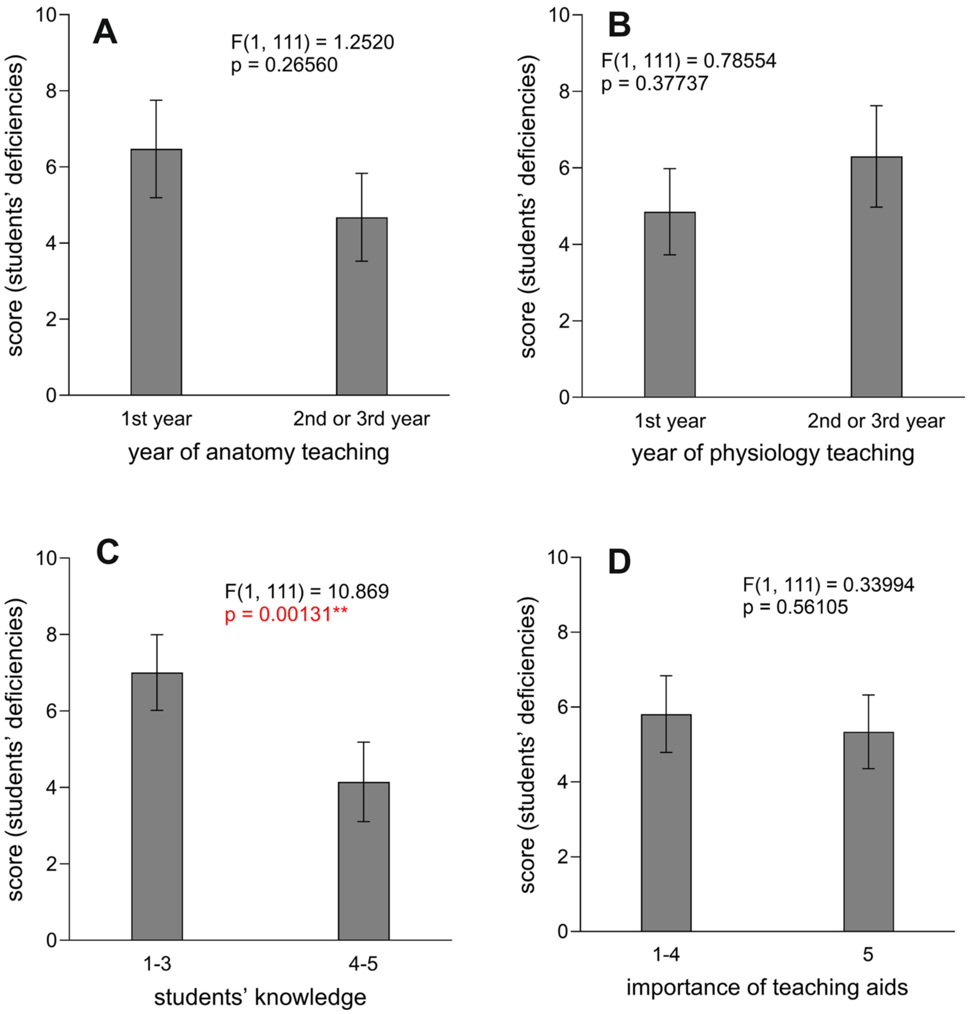


Fig. 5 Comparison of number of students' deficiencies identified by respondents (the number of problem areas identified by the teachers) with respect to the year of plant anatomy (**A**) and plant physiology teaching (**B**), the teachers' perception of students' knowledge (**C**) and teachers' perception of the importance of teaching aids in plant biology education (**D**). 1–3 represents the answer: strongly disagree to uncertain, 4–5 represents the answer: agree or strongly agree to the statement: "*My students' knowledge of plant anatomy and physiology is mostly excellent*". 1–4 represents: strongly disagree to agree and 5 strongly agree to the statement "*Interpretation of plant biology should be linked to practical aids/activities as much as possible*". Data are means ± SEs. P value in red indicates a significant effect of the given variable on number of students' deficiencies at 0.01 (**) level according to GLM (general linear model). P values in black are not significant according to GLM ($P > 0.05$)

4 Discussion

Biology and other science subjects contain many concepts and their correct understanding by students and the relationships between them require teachers to use various practical activities. In addition to the development of knowledge, the teaching of biology also emphasizes the development of various skills and attitudes towards nature. To achieve this goal, it is necessary for teachers to use creative teaching methods. The role of teachers in the development of various skills is even more important in the context of the main conclusions coming from the textbooks analyses. The analysis of seven textbooks for high schools in the USA revealed that they do not provide sufficient support to the development of understanding aspects such as NOS (nature of science) and SI (scientific inquiry). In the analyzed textbooks, there are mainly implicit instances of NOS and SI, which require interpretation and deeper understanding from students and teachers (Campanile et al. 2015). Similar findings emerge from an analysis of six Chinese high school textbooks, with the authors recommending that the textbooks better cover all aspects of NOS (Li et al. 2023). In the context of botany, an analysis of four university textbooks revealed that animal images (number in textbooks 80 to 150) are more often selected as examples of biological concepts when compared to plant images (number 20 to 50; Brownlee et al. 2023). This emphasizes the crucial role of teachers in teaching botany, as textbooks probably do not provide sufficient support for developing various skills and building a connection with plants.

The higher activity of teachers in plant biology teaching can be influenced by their own knowledge. Teachers with better knowledge of botany can implement more practical activities than teachers whose knowledge is limited, without positive attitudes toward plant biology. A review paper analyzing the effect of gender on plant knowledge found that women presented more knowledge in 18 papers, men in 13, and no difference was found in 15 papers. Thus, it seems that gender differences in knowledge are common, but according to the authors of the given work, knowledge was directly correlated with plant experience (Stagg and Dillon 2022). Higher activity of older teachers is probably related to better knowledge about plants in older generations (Fig. 1C). A positive correlation between age and plant knowledge was observed in 26 of 35 publications analyzing this factor (Stagg and Dillon 2022). It was also found that age positively influences plant identification ability and 70-year-old people are capable of identifying the most plants across generations (Pilgrim et al. 2008). This points to a better knowledge of older generations, but in the last few decades, a decline in the overall interest in botany has been observed. For example, between 1983 and 2011, primary school students' interest in botany decreased by 12% (Randler et al. 2012). If this phenomenon also occurs at higher levels of education, it may be the reason for the lower interest of younger teachers in this area and thus less intensive implementation of practical activities in the teaching of plant biology. Two case studies revealed that the education of US teachers is currently less oriented to fieldwork and to the use of living organisms in teaching (Entress 2023), which may be another reason for lower activity of younger teachers. Such teaching and other mentioned factors may be the reason for teachers' weaker knowledge. For example, Swiss teachers were able to correctly identify only 51.7% of plant and 61.2% of animal species, while *Salix alba* or *Larix decidua* were identified by only 46.2% of teachers and an even smaller percentage of teachers identified e.g. *Taxus baccata*, *Plantago lanceolata* or *Silene vulgaris* (Jaun-Holderegger et al. 2022). However, it seems that teachers are aware of deficiencies in their knowledge, and approximately 45% of Slovak gymnasium teachers admitted deficiencies in their knowledge in plant anatomy or physiology (Kováčik and Vydra 2023). In this context, a questionnaire survey of teachers carried out in Greece revealed a positive correlation between age and job satisfaction and, conversely, a negative correlation between age and emotional exhaustion or burnout syndrome (Anastasiou and Belios 2020).

We also found that teachers who are aware of the importance of practical activities in teaching plant biology implement these activities thoroughly and significantly. In line with our data, on a sample of 48 teachers and 1036 students from Germany, it was found a positive influence of enthusiasm (measured by a questionnaire) for teaching the subject (the ecosystem of Wadden Sea) on students' performance (measured by a test and concept maps; Mahler et al. 2018). The attitude towards botany is low when compared to other areas, e.g. German and Austrian students were the least interested in botany and the most in human anatomy (Elster 2007), or none of the 124 teachers identified plant biology as attractive to students (Kováčik and Vydra 2023). This unattractiveness of botany not only for students but probably also for their teachers and weak enthusiasm in teaching botany probably affects the activity of the teachers themselves, which contributes to the development of the so-called PAD (plant awareness disparity). One way to eliminate PAD is to pay more attention to botany in teaching. In Great Britain, a positive correlation was found between university students' awareness of plants (88 students) and the amount of botany-focused curriculum (Batke et al. 2020). To eliminate PAD, it is also important that teachers make the curriculum accessible in an active form through practical activities. In the literature, in addition to proposals for laboratory activities (e.g. Vydra and Kováčik 2024a), other principles and procedures aimed at increasing students' interest in plants are presented, e.g. the use of technologies, specifically thermal cameras (Wong and Subramaniam 2022), mobile devices (Finger et al. 2022), computer games (Southgate et al. 2019) or IT-based image analysis (Vydra and Kováčik 2024b).

Laboratory activities implemented in teaching develop not only students' knowledge but also other aspects, such as critical thinking, science process skills, and can also represent a tool leading to an understanding of the significance of plants (Ward et al. 2014; Shin et al. 2021; Schnell et al. 2021). The weak emphasis on the importance of plants for humans and the development of life on Earth was also confirmed by the analysis of the Greek curriculum (Amprazis and Papadopoulou 2018). Considering these deficiencies in the curriculum, the teacher per se is even more important in the teaching process. It is the teacher who can explain the significance of these organisms to the students. Some authors recommend that selected plant topics can be included in sustainability curricula (Stagg and Dillon 2023). The teaching of university students focused on the interaction of the three concepts Plants, People, Planet, with the aim of highlighting the interrelationships between human activities, plant diversity, and ecosystem health had a positive effect on students' attitudes and interest in plants (Fiel'ardh et al. 2023).

Within plant biology, laboratory activities in the form of various experiments can be used by teachers especially when teaching physiology. Based on the recent survey, physiological experiments are used in teaching by only 2/3 of high school/gymnasium teachers in Slovakia (Kováčik and Vydra 2023). Based on our findings, it can be concluded that simpler procedures (microscopy, macroscopic observation of plant material, which require less equipment) are implemented to a comparable extent by all teachers. On the contrary, more complex procedures, specifically physiological experiments (more equipment is needed to carry them out, such as scales, glass, chemicals) are implemented in the teaching process mainly by teachers who have such tools at their disposal. These results bring us back to one of the main problems of Slovak education, i.e. financing. As a part of physiological experiments, secondary school teachers in Slovakia implement these experiments mainly when teaching osmosis, water regime and germination, to a lesser extent when teaching photosynthesis and plant respiration (Kováčik and Vydra 2023). Based on these results, we may deduce that teachers use physiological experiments in procedures that require basic equipment (e.g. water regime—representation of transpiration using a colored solution) and to a lesser extent in procedures that require, for example, devices for measuring oxygen concentration (photosynthesis, respiration).

Although many misconceptions and deficiencies in students' knowledge of plant biology have been identified (e.g. Wynn et al. 2017), studies examining the impact of teachers on the number of deficiencies have not been carried out. Paradoxically, students in some classes exhibited more accurate ideas about biological evolution before teaching this topic than the teachers themselves (Yates and Marek 2014). Based on this study, there is no doubt that teachers can be a source of misconceptions. Other studies revealed the relationship e.g. between teachers' enthusiasm and their students' performance (Mahler et al. 2018), between teachers' subject matter knowledge and their students' performance (Gess-Newsome et al. 2019), or between teachers' pedagogical knowledge and students' cognitive activation and results of a neurobiology knowledge test (Förtsch et al. 2016). Within plant biology, a positive correlation was found between the number of deficiencies in teachers' knowledge and the number of deficiencies in their students' knowledge (Kováčik and Vydra 2023). Our results did not reveal the influence of the teacher's gender on the number of identified deficiencies among students. Similarly, a questionnaire survey did not detect the influence of gender on the self-efficacy of secondary school teachers from India (Islahi and Nasreen 2013). The results of several studies suggest that the teacher is a key factor in removing deficiencies in students' knowledge (Mahler et al. 2018; Gess-Newsome et al. 2019). Given the fact that deficiencies have been found in curricula (Amprazis and Papadopoulou 2018), textbooks (Campanile et al. 2015; Brownlee et al. 2023; Li et al. 2023) and peer-reviewed journals for science teachers (which are more often devoted to the topic of animals than plants; Patrick and Matteson 2017), the role of teacher in teaching plant biology is even more important. Therefore, it is also important to pay attention to the training and quality of teachers. Professional development of in-service biology teachers is one way to improve the teachers' skills and effectiveness (Shaaban and Abou Ali 2018).

5 Conclusions

The present study highlighted the impact of some characteristics of teachers (e.g. age and perception of the essentiality of teaching aids) on the amount of implemented practical activities, physiological experiments in botany teaching and deficiencies in students' knowledge. The significant effect of age on the teachers' activity and implementation of physiological experiments indicates the importance of pedagogical experience in teaching plant biology. The perception of the equipment of the given gymnasium by the teachers had a non-significant impact on the overall activity of the teachers but impacted the number of used physiological experiments. Based on these results, we may conclude that teachers with better equipment implement more activities with a more complex procedure. These results, all together with the significant effect of the respondents' age on the number of gaps in students' knowledge, emphasize the need to maintain the highest possible quality during the university education of future teachers. We also emphasize that the development of teachers' knowledge in botany during in-service training should be provided by experts who can stimulate the interest of teachers and refine their knowledge of botany.

Author contributions Data analyses and manuscript draft preparation (MV), source data collection and manuscript revision (JK).

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Data availability Supporting data are presented in the supplementary materials. The source data analyzed in this work are presented in the supplementary Excel file.

Declarations

Conflict of interest None.

Ethical approval The teachers were informed about the objectives in the introductory part of the online questionnaire and by filling it out, they agreed to participate.

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