HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

THE CHANGES OF WEED SPECIES AND WEED COMMUNITIES IN HUNGARY BASED ON ARCHAEOBOTANICAL EVIDENCE

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1. BACKGROUND OF THE WORK AND OBJECTIVIES

Remains of plant species from the former environment carry important information about the past flora and climate (PÓSA et al. 2014). The Carpathian Basin is one of Europe's oldest cultural regions, where the relationship between crops and the environment has been determined by the way of life of the people who lived here and by climatic conditions. Humans came a long way from gathering edible plants to cultivating the land. In early societies, conscious selection started with the emergence of agriculture and gradually transformed the natural flora (ZOHARY et al. 2012), and later these ecosystems were replaced by novel agro-biocoenoses with a substantially simpler structure (GYULAI 2010).

The westernmost part of the Eurasian steppe belt is the Carpathian Basin, which, due to its specific climatic and ecological conditions, mosaicism, long history of cultivation of crops and the associated folk selection, has produced a high degree of diversity of cultivated plant species and varieties. The intensive cultivation and farming of our time and the spread of New World weed species have pushed some of our plant species back to the margins of arable land, including weed species whose conservation has become a genebank task (UDVARDY 2000).

Archaeobotany, which also deals with environmental change, studies plant remains from the Holocene. By processing archaeological and botanical finds from archaeological excavations, changes in the diversity of weed species can be traced (PÓSA and GYULAI 2019). This evidence helps us to understand the relationship between humans and the environment, and provides information on how humans transformed the environment and was the relationships between different cultures. Weeds grow in places and at times that people do not want. Therefore, any plant species can be considered as weeds, including cultivated species, if their presence is undesirable (PINKE and PÁL 2005). So we are talking about weeds first and foremost in relation to arable crops, horticulture and forestry.

As a result of agriculture, the plant world has changed considerably over time. Plants developed that could not tolerate the increasing cultural impacts at all, and these gradually became selected and disappeared. Plants have also appeared that have been able to co-exist undisturbed by the effects of culture. And some have adapted so well to them that they could not survive without them. This process has led to the development of weeds, which have been highly adapted to repeated and often extreme influences throughout the millennia of plant cultivation (UJVÁROSI 1973). As a consequence, I believe it is essential to explore and learn about the former weed flora in addition to the current study of the weed flora. Little is known about the origin, evolution and history of weeds. Our archaeobotanical data from archaeological excavations are still scarce, and there is no summary database containing up-to-date information. This is why it is timely to follow the emergence, distribution and development of these plant species and communities with the help of the methods of investigation that are widespread and applied in archaeobotany.

When I started my research, I set the following objectives:

1. To search for published and unpublished archaeobotanical data from Hungary in a variety of places and to update these collections. Incorporate my results into a novel database that will include the sites and important parameters of weed taxa occurring in our country from different archaeological periods.
2. After the creation of a basic database for analysis purposes, the weeds found in Hungarian archaeological sites will be classified according to their distribution area, and then evaluated according to the archaeological periods.
3. My task will be to investigate the stages of weed flora evolution in Hungary in the light of the development of agriculture, crop production practices, and crop-weed relationships.
4. To study the appearance of the first European weed association (*Bromo-Lapsanetum praehistoricum*) in Hungary in the Early and Middle Neolithic.
5. To evaluate the ecological distribution of weeds based on archaeobotanical data from Hungary, looking for answers to the time of segregation of weed species of autumn and spring sown cereals.
6. To complete the existing plant list of apophyte, archeophyte and neophyte weed flora of the Carpathian Basin (grouping weeds according to their chronological appearance).

The creation of a new database could prove useful for the historical understanding of changes in weed species and weed communities in Hungary. In the future, it could provide the basis for the creation of an even more comprehensive online database, which would include all available up-to-date information on Hungarian flora.

2. MATERIALS AND METHODS

To learn about the transformation of the weed flora of the Carpathian Basin, it is necessary to explore the changes that have occurred in agriculture and crop production over time, and especially in the crop(host)-weed relationship.

The significance of my study in numbers:

- 145 years (1876–2021) of archaeological research in Hungary,
- review of the archaeobotanical material from 638 excavations,
- 21 618 596 botanical remains,
- and the evaluation of 894 plant taxa.

2.1. Quantitative and qualitative evaluation of botanical material

I carried out quantitative evaluation of plant remains from several excavations (e.g. Sárospatak, Miskolc-Hejő). After floating and drying the soil samples, I identified the seed and fruit remains under stereomicroscopy to different botanical taxa based on their morphological stamps (depending on their preservation), and then made an alphabetical species list with the number of remains. Further computer processing allows the calculation of the percentage of plant species in the sample, the percentage of plant species in relation to the total plant species and the seed concentration. This method can be used to answer questions such as what was the relationship between foraging and agriculture or crops and weeds in the area or archaeological period under study.

For the qualitative evaluation of the plant remains, I also used the plant sociological and ecological classification system of the plant species, the habitat grouping system, adapted from JACOMET et al. (1989) for archaeobotanical finds, based on EHRENDORFER (1973) and ELLENBERG (1979), which takes into account the habitat requirements of the plant species. With this study, I have systematized the subfossil plant remains according to different ecological criteria, and finally I have drawn some conclusions about the tanatocoenology. I considered it important to choose an analysis that takes into account that the composition of plant communities can change over time.

2.2. The archaeobotanical database

One of my most important tasks was the creation of the plant taxon list, as this was the basis for the data queries and evaluations. Then I compiled the novel information collection of the Hungarian Archaeobotanical Database, which contains the seed and fruit remains of all plant identified between 1876–2021 in Hungary.

The basic data are:

- age (e.g.: Early Neolithic, Late Bronze Age, Roman Age, etc.),
- site (e.g. Keszthely-Fenékpuszta, Edelény, Solt, etc.),
- the Hungarian, Latin and English names for the plant species,
- type of remains (e.g. seed, grain, acorn, etc.),
- condition of the remains (e.g. charred, not charred, etc.),

- quantitative information (in most cases this means number of pieces).

2.3. The weeds database

The Hungarian archaeobotanical dataset does not only contain species lists and numbers. In the course of my processing work, I studied the species according to several criteria.

By examining the composition of cereals, I can deduce the level of crop cultivation in the past, the way in which cereals were sown and cultivated, and the lifestyle characteristics, and the extent of weed species distribution, of the expertise of the crop growers of the past. I can find out whether the weeds belonged to autumn or spring-sown cereals, and even determine the method of harvesting. I have therefore selected the weed species from the Hungarian Archaeobotanical Database according to the ecological groups of JACOMET et al. (1989):

- spring-sown cereal/row crop weeds,
- autumn-sown cereal weeds,
- ruderal weeds.

This innovative database – the Hungarian Archaeobotanical Weed Database – contains the sites and important parameters of weed taxa from the Carpathian Basin from different archaeological periods.

2.4. The additional data

After grouping the species in the dataset, I also added other data: flora element, life form, residence time status, plant height. In addition, I have added to the dataset: the name of the culture per site and its age; the type of object from which the sample was taken; the sample number, sample volume or weight; the name of the excavating archaeologist; the year of excavation; the year the sample was collected and identified; the name of the published literature.

2.5. The statistical processing

The database was statistically analysed using IBM SPSS Statistics 26.0 and Golden Software - Grapher.

My statistical evaluation covered the following:

- relationship between cereals and weeds;
- fluctuation of changes in cereal weed species;
- distribution of cereal weed species, depending on whether or not they are present in the latest age, in terms of first appearance;
- distribution of cereal weed species by plant height, in terms of first appearance;
- distribution of cereal weed species by life form, in terms of first appearance;
- distribution of cereal weed species by area type.

3. RESULTS AND DISCUSSION

3.1. Creating the database

I searched for and added to the archaeobotanical data published and unpublished in various places in Hungary. I have organized these collections into a novel database. This dataset (Hungarian Archaeobotanical Database) contains the sites and important parameters of the weed taxa occurring in the Carpathian Basin from different archaeological periods. From the dataset I have selected weed species, which resulted in the first Hungarian Archaeobotanical Weed Database, a list of weed species by archaeological periods.

I have prepared and updated the list of apophyte, archeophyte and neophyte weeds in Hungary.

On the basis of this, I have succeeded in creating a database of such a size that it contains in tabular form the plant remains of all excavations, unpublished and published seed, crop, food and drink remains from the archaeological periods of the Carpathian Basin, 1876–2021.

With the creation of the database, it is possible to effectively track the transformations that have taken place in the history of plant production and the changes in weed communities over time in the use of the environment in Hungary over the past millennia.

I have processed and evaluated seed and crop remains from 638 Hungarian sites over the past 145 years. The more than 21.6 million seeds and fruits of the 894 plant taxa detected, although differently documented, have made Hungary one of the most archaeobotanically well researched countries in Europe.

3.2. The relationship between cultivated plants and cereal weeds

The relationship between cultivated crops and weeds is determined by the lifestyle of the population living in the Carpathian Basin and the climate. The cultivation of several plant species is linked only to a specific archaeological period or a specific culture. The people who settled here always brought their own plants with them and continued to cultivate them. In general, the result is that as the number of cultivated plants increases in each archaeological period, the number of weed species also increases (Figure 1).

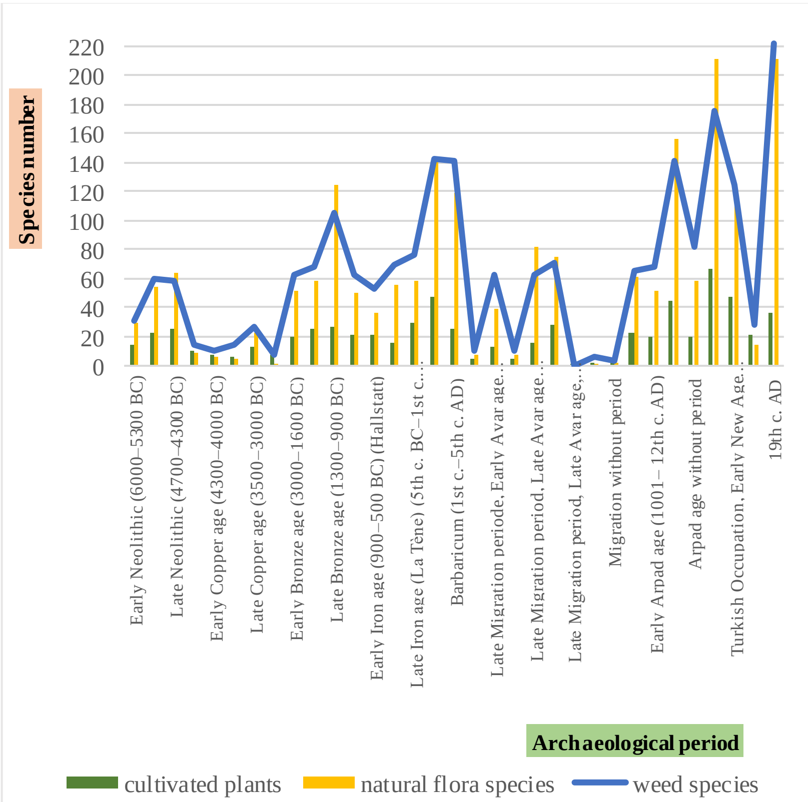

Figure 1: Distribution of plant groups by archaeological period

Our research shows that the weeds of autumn and spring-sown cereals did not separate in the Carpathian Basin, but arrived here as they did. At the beginning, the autumn-sown cereal weeds were more important. Later, with the spread of Bronze Age leguminous crops and Late Medieval horticultural crops, this ratio slowly shifted towards spring-sown cereal weeds (Figure 2).

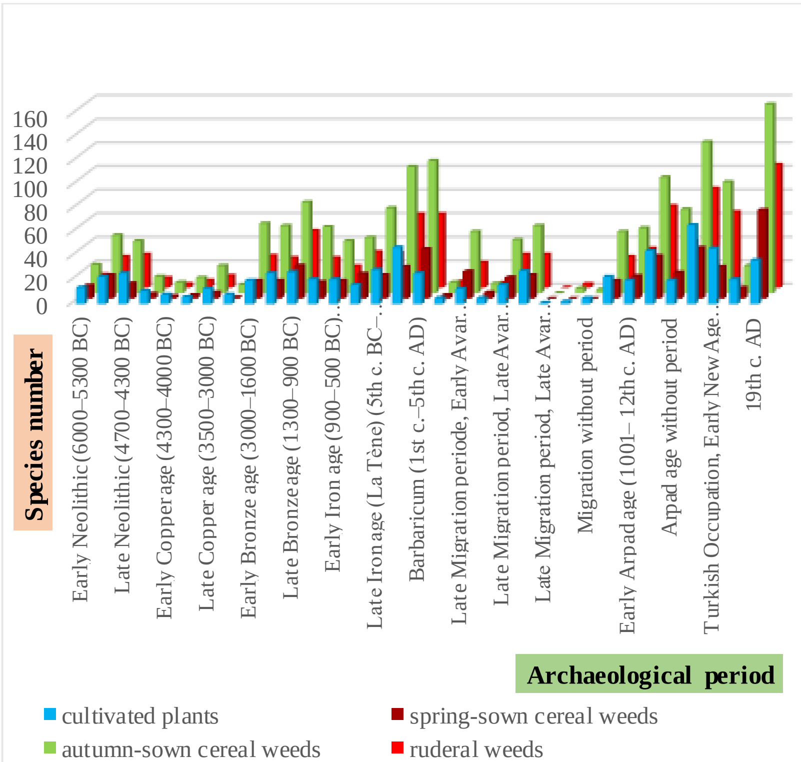

Figure 2: Distribution of crop and weed species by archaeological period

The remains of members of ruderal weed communities are largely from areas exposed to human impact. The remains of members of ruderal weed communities are largely from areas exposed to human impact. These remains can be used to infer where the culture settled. If we have the right amount of weed species, we can determine what environmental changes may have taken place at the site.

3.3. The residence time status of weed species

The analysis of archaeobotanical remains shows that apophyte and archeophyte weed species dominated until the Modern Age, followed by the successful colonisation and spread of neophyte weed species.

3.4. The relationship between cereals and cereal weeds

Most cereal species appeared in the Neolithic period, with new species being added in the Bronze Age, Roman Age and Late Medieval Period. This expansion, however, was slowly transformed by the ecological conditions of the Carpathian Basin and led to a decline in the number of cereal species.

The increase in the number of cereal weeds is linked to different periods: the Middle Neolithic, the Roman Age, the Late Medieval Period. The high number of species in the latter two periods may be related to fertilisation.

Cereals dominate until the Late Iron Age, and the number of cereal weed remains is negligible compared to the number of cereal grains (perhaps seed cleaning was effective). Nevertheless, this trend reverses from Roman Age onwards. The number of cereal weed remains becomes several times greater than that of cereal grains.

3.5. The distribution of cereal weed species by life form

The distribution of life form groups is dominated by annual spring germinating weed species (e.g. white goosefoot – *Chenopodium* *album* L.), and and early summer weed species that germinate in both autumn and spring (e.g. rye brome – *Bromus secalinus* L.).

3.6. The distribution of cereal weed species by area

The distribution of weed species is significantly influenced by climatic factors and the adaptability of the species. Initially, a warm, equable climate favoured the immigration of Mediterranean and sub-Mediterranean species (Figure 3), but over time the Mediterranean effect decreased and the number of Eurasian species increased.

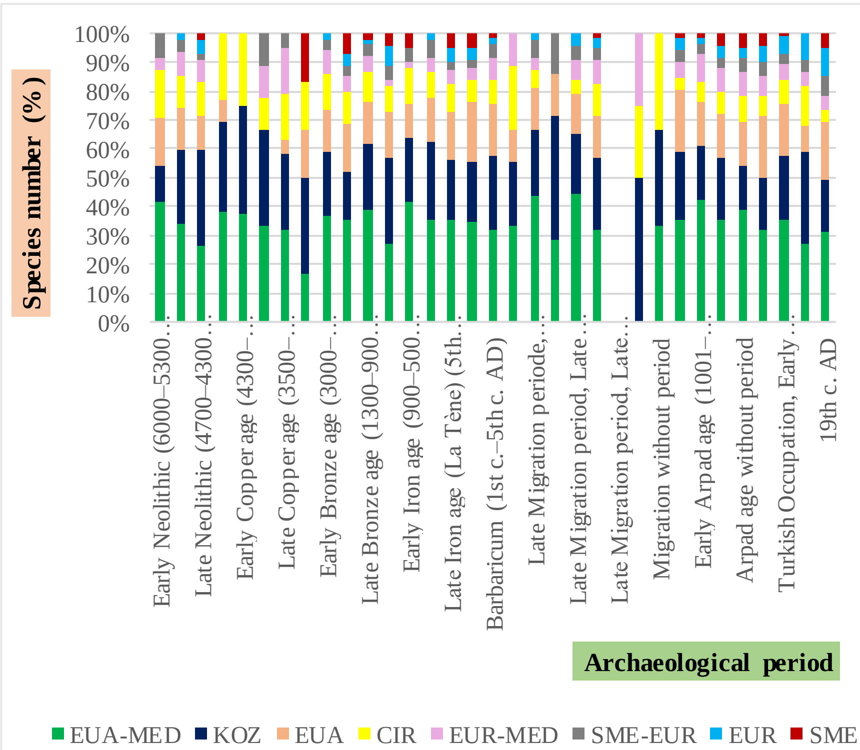

Figure 3: Percentage distribution of cereal weed species by area (climate impact) per archaeological period

(Note: EUA-MED: Euroasian-Mediterranean, KOZ: Cosmopolitan, EUA: Euroasian, CIR: Circumpolar, EUR-MED: European-Mediterranean, SME-EUR: South Mediterranean-European, EUR: European, SME: South Mediterranean)

3.7. The height of cereal weed species

The first European weed association (*Bromo-Lapsanetum praehistoricum*) was described by KNÖRZER (1971) from the Rhineland on the basis of archaeobotanical finds. This association has not yet been confirmed for our country, instead the term *Bromo-Fallopietum praehistoricum* is netter used for Hungary in the Early and Middle Neolithic.

Several arable weed species arrived from the southeast in the Neolithic with crop cultivators, most of which were present in Hungarian archaeobotanical samples until the Migration Period. Most weed species disappeared during the Roman Age and the Late Medieval period, i.e. the cereal weed flora was extensively changed. In these two periods, ploughshare and manuring became widespread. Seed cleaning led to a reduction in the number of cereal weed species and, over time, to the disappearance of some species.

The composition of the weed communities was also influenced by the way the cereals were harvested. In the beginning, the arable weeds were torn or broken off (PINKE 2005). At the beginning of the Iron Age, however, several new cereal weed species appeared, typically lower-stemmed weeds. In Hungary, the medieval archaeobotanical finds show that weed species reached their present species composition during the Medieval period, the maximum of their diversity before the strong ruderalisation of the Modern Age.

The development, increase and rearrangement of the number of cereal weeds is undoubtedly related to the way of life of the cultures living in Hungary, the spread of ploughing, the development of soil conservation and changes in land use.

3.9. The career of the "seven evils"

There are also seven weeds in my database that were present in significant numbers of remains and were continuously present in the daily lives of ancient people: black blind-weed (*Fallopia convolvulus* (L.) Á. Löve), false cleavers (*Galium spurium* L.), field brome (*Bromus arvensis* L.), rye brome (*Bromus secalinus* L.), common wild oat (*Avena fatua* L.), white goosefoot (*Chenopodium album* L.) and common corncockle (*Agrostemma githago* L.).

4. CONCLUSIONS AND SUGGESTIONS

4.1. Conclusions

The studies and analyses carried out have shown that the transformation of the Carpathian Basin has been ongoing since the Neolithic. With the emergence of the Körös culture, alien, new plant species also appeared in the landscape. This is linked to crop cultivation. The emergence of cereals provided a solid basis for the development of different crops. The emergence of new metals (Copper Age, Bronze Age, Iron Age) led to an increase in the transformation of the environment, but also to changes in the way of life: settlement, the production process, stock farming. In agriculture, the emergence of the sickle as a harvesting tool led to radical changes.

For a time, the former flora elements were present alongside the weeds imported by seeds in different eras. The elements of natural vegetation were and are in competition with cultivated plants grown in the field. Many native species may have become weeds in this way.

Archaeobotanical finds from the Middle and Late Neolithic period in Hungary are very rich, with a considerable number of alien weed species migrating into the central parts of Europe, and this is linked to the increase in the number of settlements and population. The associations of archeophyte and apophyte species dominated the landscape until the Modern Age.

The people of the early cultures certainly did not specialise in the cultivation of a single cereal, and mixed sowing helped certain weeds to spread. There are several periods in the archaeological record when the number of species cultivated declined

dramatically (e.g. Early Copper Age). Although crop production did take place during this period, its importance decreased. This may have been due to the impact of an extremely unfavourable climate (cold, wet). High temperatures (during the Early and Late Migration Period) also had a negative impact on crop production.
Based on the plant remains found, we can conclude that from the Neolithic to the Modern Age, the amount of seeds and fruits in the ground generally increases as a result of human activity, and the appearance of cultivated plants can be linked to archaeological periods associated with climate changes. When crop cultivation has been carried out under more modest conditions, a reduction in weed communities can also be observed in analyses of plant remains.
The increase in the number cereal weed species and their rearrangement is related to the increase in the number of crop species, ploughing, other tillage operations and changes in the quality of crop production (e.g. manuring). However, the reduction or eventual disappearance of cereal weed species is not only due to changes in climate, but also to effective seed cleaning. This process selects weeds with extremely short life and germination vigour. However, infestations of common corncockle (*Agrostemma githago* L.) and common wild oat (*Avena fatua* L.) were significant in cereals. Their seeds and grains were difficult to remove using the cleaning methods of the time, while for the other species it was much easier. This may explain why the remains of other cereal weed species (e.g. field poppy – *Papaver rhoeas* L., redshank – *Polygonum persicaria* L., wild radish –

Raphanus raphanistrum L.) are often so low in the archaeobotanical remains.

Based on the archaeobotanical data, the presence of autumn cereal weed species was initially more significant, then with the spread of the late medieval catch crops, the development and strengthening of the catching culture, this proportion slowly began to shift towards spring-sown cereal/row crop weeds. The increase in the number of ruderal species is closely linked to the increase in the number of settlements and the population.

There is a high fluctuation in the distribution by area. However, it can be said that the number of plants belonging to the Eurasian-Sub-Mediterranean flora element is particularly high.

Based on the height analysis of weed species, the medium and tall species were initially dominant, with few low-growing species. This suggests that from the beginning of the Neolithic period until the Late Medieval period, harvesting was done with sickles. Thereafter, from the Early Modern Age onwards, the proportion of lower-growing weeds begins to increase. This meant a shift to harvesting close to the ground surface, using the scythe. The increase in the number of lower-growing weeds is linked to the close-to-ground harvesting method and also to livestock farming, with the use of straw.

Based on archaeobotanical finds in Hungary, the earliest predominant Neolithic weed species are: common corncockle (*Agrostemma githago* L.), common wildoat (*Avena fatua* L.), field brome (*Bromus arvensis* L.), rye brome (*Bromus secalinus* L.), white goosefoot (*Chenopodium album* L.), black bindweed

(*Fallopia convolvulus* (L.) Á. Löve), false cleavers (*Galium spurium* L.).

In botanical remains from certain archaeological periods (Bronze Age, Late Migration Period), the number of weed remains is so high that it cannot be explained by weed enrichment due to some unusual phenomenon. Such species were secondary crops under selection pressure. They were found in conspicuously large amounts of cereal residues and cannot therefore be considered as fodder for scarcity.

It is important to mention that many of the former archeophyte weeds are now on the verge of extinction in the Hungarian flora, mainly due to large-scale farming. The study of these weeds is part of the task of historical agrobiodiversity, and their conservation is a national task. The results of the archaeobotanical analyses and evaluations carried out so far on the plant remains, and of further studies, will be of great help in analysing the effects of climate change on crop production in the present era.

4.2. Suggestions

The creation of the database is only a first step, and I recommend its further completion and development. For the future, it would be useful to create an online database with open access and up-to-date information on a wide range of subjects, which would be backed up by the data I have compiled.

The database I have created can be used to reconstruct the habitat of former populations, thus helping the climate-flora-human community relationship sciences.

I consider it useful to continue morphogenetic studies of the available and intact seed and crop remains, because it would be possible to detect changes in the diaspore dimensions of weed species occurring in different archaeological periods, and the environmental and anthropogenic influences on them.

5. NEW SCIENTIFIC RESULTS

1. I updated the Hungarian Archaeobotanical Database, which contains all the seed and fruit remains of the last 145 years of archaeological research; most importantly, I was the first in Hungary to create the Hungarian Archaeobotanical Weed Database.
2. I have listed the apophyte, archeophyte and neophyte weeds of Hungary. No significant difference in the ratio of apophyte to archeophyte weeds. The appearance of weed species is connected to certain archaeological periods and phases (Neolithic, Roman Age, Late Medieval period).
3. I have made a list of weeds according to their distribution area. The distribution of weed species is significantly influenced by climatic factors. For the cereal weeds I have studied, there is a strong Mediterranean effect from the Early Neolithic onwards, but this effect decrease by time.
4. I monitored the most important weed species for plant remains from the Neolithic to the Early Modern Age. As a consequence, the *Bromo-Lapsanetum praehistoricum* association is currently not verified for our country. The earliest Neolithic arable weeds to become dominant, based on seed reamains, are common corncockle (Agrostemma githago L.), common wild oat (*Avena fatua* L.), field brome (*Bromus arvensis* L.), rye brome (*Bromus secalinus* L.), white goosefoot (*Chenopodium album* L.), black bindweed (*Fallopia convolvulus* (L.) Á. Löve), false cleavers (*Galium spurium* L.) and common knotgrass (*Polygonum aviculare*

agg.). These species formed the weed community of *Bromo-Fallopietum praehistoricum* in the Early and Middle Neolithic of Hungary.

5. The increase in the number of cereal weed species and changes in their proportions are linked to cultivation, mainly ploughing, tillage, changes in crop production (e.g. manuring) and the opening up of new areas.
6. Weed species of autumn and spring-sown cereals have not been separated in the Carpathian Basin. Their separation occurred earlier, arriving in the area from the beginning of the Neolithic period.

6. PUBLICATIONS RELATED TO THE DISSERTATION

Peer-reviewed journal articles with impact factor:

SONKOLY, J., TÓTH, E., BALOGH, N., BALOGH, L., BARTHA, D., BATA, K., BOTTA-DUKÁT, Z., BÖLÖNI, J., CSECSERITS, A., CSIKY, J., CSONTOS, P., DANCZA, I., DEÁK, B., E-VOJTKÓ, A., GYULAI, F., HORVÁTH, F., HÖHN, M., JAKAB, G., KELEMEN, A., KIRÁLY, G., KIS, SZ., KOVACSICS-VÁRI, G., KUN, A., LEHOCZKY, É., LENGYEL, A., LHOTSKY, B., LÖKI, V., LUKÁCS, B. A., MATUS, G., MCINTOSH-BUDAY, A., MESTERHÁZY, A., MOLNÁR, V. A., MOLNÁR, ZS., PAPP, L., **PÓSA, P.**, RÉDEI, T., SCHMIDT, D., SZMORAD, F., TAKÁCS, A., TIBORCZ, V., TÓTH, K., TÓTMÉRÉSZ, B., VALKÓ, O., VIRÓK, V., WIRTH, T., TÖRÖK, P. (2022): Introducing PADAPT 1.0, the Pannonian Database of Plant Traits. In: *Journal of Vegetation Science*, in prep. (2022) (IF in 2022: 2.685)

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