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July 2020

Environmental management, land use, biodiversity

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# A REVIEW ON BIOLOGY AND AGRICULTURAL SIGNIFICANCE OF BIG-EYED BUGS (HETEROPTERA: LYGAEOIDEA: GEOCORIDAE)

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## ABSTRACT

The big-eyed bugs (Geocoridae) are peculiar representatives of the superfamily Lygaeoidea because of their highly specialized morphology and predatory feeding behaviour. Latter drew attention to them as subject of studies on the application of these insects as biocontrol agents in management of various arthropod pests harmful to crops and vegetables. Here, a review of literature on the biology and biocontrol applicability of these insects is presented.

**Keywords: Geocoridae, *Geocoris*, predator, biocontrol, pest management**

## INTRODUCTION

Implication of natural enemies as biocontrol agents is considered as an environmentally sustainable and effective method in management of arthropod pests (Sailor and Papavizas 1981, Bale et al. 2008, Rusch et al. 2010). However, it is occasionally involving the introduction of non-indigenous predators and parasites in agricultural ecosystems, which bears the risk that the introduced organism becomes established in the new environment and acts as an invasive pest itself (Pimentel et al. 1984). The most notable example on this situation is the invasion of *Harmonia axyridis* in Europe (Brown et al. 2007, Roy and Wanjberg 2008, Ukrainsky and Orlova-Bienkowskaja 2014). Therefore, studying the applicability of native taxa shall be a priority in developing integrated control practices.

The big-eyed bugs are unusual representatives of Lygaeoidea not only in terms of morphology but because of their unique feeding behaviour. Unlikely to representatives of other lygaeoid families which are almost exclusively sap- and seed-feeding, geocorids are known as generalist predators (Usinger 1936, Slater 1977, Sweet 2000). Some of the widely distributed species received attention as beneficial organisms in pest management researches in the past decades (Tamaki and Weeks 1972, Kumar and Ananthakrishnan 1985, Sweet 2000, Joseph 2006). Present article attempts to provide an outline for future studies through the review of available literature with an emphasis on the species distributed in Palaearctic region.

## MORPHOLOGY, CLASSIFICATION AND DIVERSITY

The family of big-eyed bugs (Geocoridae) is a world-wide distributed, moderately species-rich, morphologically heterogenous group of the true bug superfamily Lygaeoidea (Malipatil 1994, Kóbor 2019). Representatives of Geocoridae can be readily delimited from the remaining families based on the combination of the following characters: broad, pentagonal head with large, – often stylate – kidney-shaped eyes and posteriad curved sutures of abdominal tergites 4/5 and 5/6 (Henry 1997). Included taxa are currently classified into five subfamilies (Geocorinae, Henestarinae, Pamphantinae, Australocorinae and Bledionotinae) consisting of 30 valid genera of circa 290 valid species (Henry 2009, Malipatil 2012). The largest of subfamilies is the nominotypical Geocorinae including more than 220 described species of 16 genera (Brailovsky 2016, Kóbor 2019). However, taxonomy and systematics of the subfamily is not well-understood and most of the included taxa are in need of thorough revision (Malipatil 1994, author's unpublished data).

Representatives of the family inhabit most of the biomes with warm and moderate climate and can be found even in extreme biotopes e.g. deserts and high mountains. Taxon richness of the family peaks in the tropical regions. In the Carpathian Basin six species of two subfamily, belonging to two genera and three subgenera are presented according to the checklist published by Kondorosy (1999): *Henestaris halophilus* (Burmeister, 1835); *Geocoris* (*Piocoris*) *erythrocephalus* (Lepeletier et

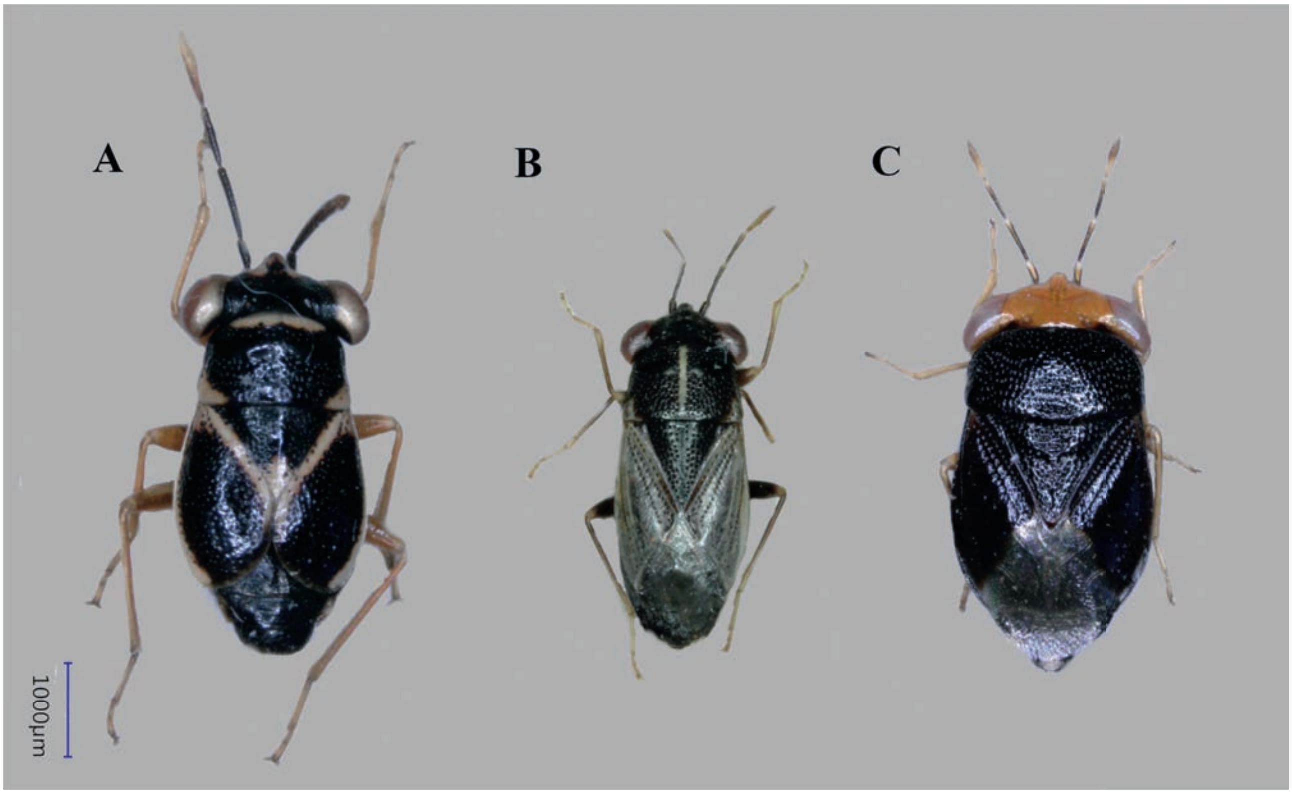


**Figure 1. Habitus of characteristic representatives of big-eyed bugs (Heteroptera: Lygaeoidea: Geocoridae) in the Carpathian Basin: A. *Geocoris* (*Geocoris*) *grylloides* L.; *Geocoris* (*Geocoris*) *ater* (Fabr.); *Geocoris* (*Piocoris*) *erythrocephalus* (Lepeletier et Serville, 1825).**

Serville, 1825), *Geocoris* (*Geocoris*) *grylloides* (Linnaeus, 1758), *G*. *dispar* (Waga, 1839), G. *megacephalus* (Rossi, 1790), *G*. *ater* (Fabricius 1787) (figure 1). However, the occurrence of Mediterranean species expanding northwards is plausible as result of climate change.

## STUDIED SPECIES

In regards of autecology and agricultural significance Nearctic representatives of the genus *Geocoris* Fallén, 1814 (e.g. *G. bullatus*, *G*. *uliginosus*, *G*. *pallens*, *G*. *punctipes*) are the most extensively studied (e.g. Champlain and Scholdt 1967, Dunbar and Bacon 1972, Tamaki and Weeks 1972, Crocker and Whitcomb 1980, Cohen 1985, Bugg et al. 1991, Braman et al. 2003, Torres et al. 2004, Torres and Ruberson 2006). A comprehensive review of literature was published by Sweet (2000) with an emphasis on the species listed above. The same study cites data available on *G*. *ochropterus* (Fieber, 1844) (Kumar and Ananthakrishnan 1985, Mukhopadhyay et al. 1996, Mukhopadhyay 1997), a species widely distributed in the Eastern Palaearctic and Indomalayan regions. Studies on the biology and biocontrol significance of *G*. *varius* (Uhler, 1860) and *G*. *proteus* Distant, 1883 (Saito et al. 2005) were published. The distribution areas of these species are overlapping with that of *G. ochropterus*. Furthermore, the development and survival of *G*. *lubra* Kirkaldy, 1907 a species common in Australian agricultural ecosystems was studied in relation to various environmental factors (Mansfield et al. 2007). Experimental data on the biology of *G. pallidipennis* (Costa, 1843) a species widely distributed in Asia, Mediterranean and Africa (Kim et al. 2012) and *Geocoris* (*Piocoris*) *superbus* (Montandon, 1907) a species common in the Indian subcontinent (Varshney and Ballal 2017) were published. Most recently, a study on the life history and development of Geocoris (*Piocoris*) *erythrocephalus* (Lepeletier and Serville, 1825) was published (Rajan et al. 2018). This species is distributed throughout the Palaearctic region and one of the most common Euro-Mediterranean species.

## REPRODUCTIVE ECOLOGY AND LIFE HISTORY

The extensive knowledge on reproductive ecology of predatory heteropteran insects is a key feature to understand their function within their environments, thus it is improving the ability to imply them in biological control programs. The reproductive success of these organisms is depending on the physiological characteristics of females and eggs and its interaction with the abiotic and biotic elements of the environment (Lundgren 2011).

Under natural circumstances big-eyed bugs overwinter as adults. Mated females lay their eggs on leaf sheats or stems of plants both gregarious or solitary (Hagler 2020, Lundgren 2011). Oviposition of *Geocoris* species was observed on both plant and artificial surfaces when

reared in laboratory (Naranjo and Stimac 1987, Varshney and Ballal 2017). Mean preoviposition period recorded in studies is 8-10 days, but short daylength can prolong this period (Ruberson et al. 2001). Realized fecundity is highly variable and is in strong correlation with physiological status of females. A range of 10 to 178 eggs laid by a single female was reported (Sweet 2000, Rajan et al. 2018). Hatching success of eggs is mainly influenced by temperature (Calixto et al. 2014).
Growth rate and survival of nymphs is found to be positively correlated with the increasing temperature up to a specific threshold (Oida and Kadono 2012). Nymphal development is slower by short daylength (light and dark period in hours: 10: 14), though photoperiod does not affect survival of nymphs (Mansfield et al. 2007). There's no specific data on importance of relative humidity in hatching or development of big-eyed bugs, though a value of 40-60% RH as ideal circumstance is supported by data on representatives of other predatory heteropteran insects (Javahery 1994).

## FEEDING

Big-eyed bugs are well-known generalist predators, though there is evidence on phytophagous feeding of these organisms (Tamaki and Weeks 1972, Eubanks and Denno 1999). Plant feeding in Geocoridae is considered to be related to low abundance or lack of prey (Sweet 1960). Stoner (1970) concluded that plant parts most suitable for *Geocoris* species to survive are seeds and pollens. This preference is correlated with the evolution of omnivory in heteropteran insects (Eubanks et al. 2003). Adults and nymphs of big-eyed bugs prey on various life stages of a wide range of arthropod pests. They are most known as predators of aphids and thrips (Kumar and Ananthakrishnan 1985); representatives of lepidopteran families (fig. 2) of twirler moths (Gelechiidae) (Bueno et al. 2016), owlet moths or armyworms (Noctuidae) (Torres et al. 2004), snout moths (Pyralidae) and hawk moths or hornworms (Sphingidae) (Schuman et al. 2013). Predation of Colorado beetle (*Leptinotarsa decemlineata*) was observed by Koss et al. (2004). Consumption of life stages of harmful phytophagous plant bugs (Heteroptera: Miridae: *Adelphocoris* sp., *Lygus* sp.) was recorded by Tong et al. (2011) and Tamaki et al. (2019). Multiple studies refer to them as predators of spider mites (Acari: Tetranychidae) (Oida and Kadono, 2007, Krey et al. 2017). Furthermore, intraguild predation of parasitic (*Eretmocerus eremicus*) (Bao-Fundora et al. 2016) and parasitoid wasp-species (*Trichogramma chilonis*) (Varshney and Ballal 2018) and predatory minute pirate bug species (*Orius tristicolor*) (Rosenheim 2005) was observed.

**Figure 2. Nymph of *G. ater* preying on caterpillar (photo: Nagy Zoltán, izeltlabuak.hu, licence: CC BY 4.0).**

Intraguild predation is a ubiquitous phenomenon in food webs of agroecosystems, yet its importance in biological pest control is not well understood (Janssen et al. 2006, Lucas 2013).
When reared in laboratory colonies of studied species were successfully reared by feeding a simple, meat-based artificial diet (Cohen 1983, 1985). Igarashi and Nomura (2013) concluded that *G. varius* can be reared with good results on both fresh and lyophilized artificial feed. However, lower developmental rate was observed in these cases than in control treatment fed with eggs of *Ephestia kuehniella*, a pyralid moth. On the other hand, application of powdered artificial feed is promoted the establishment of the species in green houses (Igarashi et al. 2013).

## PESTICIDE SUSCEPTIBILITY

Generalist predators are considered to be highly susceptible to broad-spectrum insecticides. Experimental results published by Elzen (2001) concluded that imidacloprid, Tebufenozide, Azinphos-methyl and Spinosad are compatible with integrated pest management and can be applied safely while conserving population of beneficial insects e.g. big-eyed bugs. Results of Boyd and Boethel (1998) and Elzen (2001) showed that Malathion, Chlorfenapyr and Fipronil residues are the most harmful to big-eyed bugs. Satoh et al. (2012) evaluated the toxicity of eleven agrichemicals on 2$^{nd}$ instar nymphs of *G. varius* by both topical application and oral administration. Their results showed that when using topical application six agrichemicals (including Chlorfenapyr) were harmless or slightly harmful. Dichlorvos, Methomyl, Actemiprid, Pyridaben and two insect growth regulators (IGR) – Chlorfluazuron and Lufenuron – were found to be moderately harmful or harmful. Oral toxicity of Dichlorvos, Methomyl, Acetamiprid and Pyridalil had slight effect on the survival of nymphs. Application of sublethal dose of Chlorfenapyr, Pyridalyl, Sulfur and Triflumizole had no significant effect on development of nymphs comparing to untreated control.

## CONCLUSIONS

The review of available literature provides strong evidence on the agricultural significance of multiple widely distributed species of big-eyed bugs as predators of a relatively wide range of harmful arthropod pests. Results of the above cited experimental studies showed that life stages of these *Geocoris* species can consume a relatively large amount (dozens) of prey daily (Hagler and Cohen 1991). It is difficult to quantify the predation performance of big-eyed in the field, however results of Cohen (2000) suggest that there is no significant difference between the performance of reared and feral geocorines. Field survey results published by Schuman et al. (2013) may provide good reference for further studies on the assessment of performance and effectiveness of these predators in agroecosystems. According to recent knowledge it is to be concluded that representatives of Geocorinae should be considered as generalist, omnivorous lygaeoids with a strong preference on predatory feeding, because even though phytophagy is observed in this group, it is linked to disadvantageous circumstances e.g. absence or low abundance of prey, thus it is to be considered as survival strategy.
Results of studies on life history, reproductive ecology and rearing show that the studied species can be cultured relatively easily and cost-efficient for the purpose of augmentative biological control in closed growing systems (i.e. greenhouses). Implication of these organisms in fields and plantations, as part of integrative management of pests should be carefully planned with a particular regard on the use of agrichemicals.
Summarizing, review of literature data suggests that representatives of Geocorinae distributed in various regions of the World have similar potential as effective biocontrol agents and these taxa can be readily studied adapting the available knowledge on other species of interests. However, it has to be noted that such studies require infallible identification of subject organisms, thus the resolving of taxonomic uncertainties of Geocorinae are essential for the success of applied studies.
Despite of the extensive knowledge and relatively large number of positive results an extensive survey indicated that *Geocoris* species are not in commercial production presently (Hagler 2020), thus besides the further fundamental and applied studies, development of commercial rearing protocols is required for extensive application of these insects in biocontrol practices.

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# DEVELOPMENT OF ENVIRONMENTAL OLFACTOMETRY II.

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## ABSTRACT

Some of the production and technological activities involved in the emission of air pollutants can pollute the environment with odors. The resulting environmental pressure, the irritating odor effect caused by the odor emission around the source is one of the most difficult to measure, assess and control in terms of air pollution. Research into the causes of environmental disagreeable odor, its effects on humans, and its potential for odor measurement has a history of centuries. In our two articles on environmental olfactometry, we present the most important knowledge and practical applications that are currently available. In this article we deal with the presentation of field odor measurement, the operation and application possibilities of the electronic nose. Finally, based on what is described in our two articles, we review the practical application problems in the presented areas, the issues that guide further detailed research.

**Keywords: odour measurement, field olfactometry, electronic nose**

## FIELD OLFACTOMETRY

In the United States, research funded by the U.S. Public Health Service began in the late 1950s to develop a field odor measurement method and a field odor measurement device (Huey et al., 1960, St. Croix Sensory, Inc., 2005).

Based on the results of the developments, the first field odor measuring device (field olfactometer) so called scentometer was manufactured by the Barnebey-Cheney Company and then the Barnebey Sutcliffe Corporation. Using the field olfactometer, a dilution series can be produced directly at the measurement site by mixing the tested odorous ambient air with odorless air (deodorized ambient air). Each dilution level in the dilution series is evaluated by measuring person, determining the so-called Dilution-to-Threshold. The value determined characterizes the strength of the odor, the odor concentration, in the ambient air tested in such a way as to give the dilution ratio at which the odor of the odor-polluted air can no longer be detected. The Nasal Ranger field olfactometer manufactured by St. Croix Sensory, Inc. also works on this principle (St. Croix Sensory, Inc., 2005). The use of the Nasal Ranger field olfactometer during odor measurement is shown in Figure 1 (Koplányi, 2014).

When using the field olfactometer, it is of course necessary to examine the olfactory ability of the measuring persons before the measurement, which can be done with the previously described method described in the standard for the odor measurement method (MSZ, 2003), but the so-called also a set containing olfactory pens developed for the examination of olfactory ability (Odour sensitivity test kit) (Józsa, 2014). Based on a predetermined measurement plan (measurement points, time and duration of measurement) with the field olfactometer can be used to determine the magnitude of the odor effect in the environment of the examined odor source and even the frequency of the disturbing odor effect in the case of a large number of measurements. The field olfactometer

**Figure 1. Field odour measurement by field olfactometer – Nasal Ranger (Koplányi, 2014)**

can be used even for the operator of the odor source to perform a self-check to determine the odor effect in the vicinity of the odor source (Béres et al., 2015)

## FIELD OLFACTOMETRY: ODOUR FREQUENCY TEST

The disturbing odour effect in the vicinity of each odour-emitting source can be characterized not only by the strength of the perceptible odour, the population's perception of the odor significantly depends on the frequency of the odor effect. When examining the odor frequency, in the first step the so-called the number of odour hours is determined. When determing the odour hours in the vicinity of the studied odor source, the so-called detection points are marked by placing a network (raster) of squares of the same edge length on a map. At pre-designated detection points, under specific operational and meteorological conditions (wind direction and wind speed), persons with tested olfactory abilities (Guillot et al., 2012) perform odor detection several times per point (at least 13 times in six months) (VDI, 2006). Only the perceptibility of the odor is examined in the nodes (whether the odor characteristic of the examined odor source can be detected, yes / no answer; of course, the appearance of other odors is also recorded). The observation lasts for 10 minutes at a time, within which 6 (for a total of 60) observations must be recorded. An odour hour is satisfied if at least 10% of the measurement time (6 cases in 10 minutes in the case of organoleptic detection) is considered to be "odorous", the odor characteristic of the source under investigation can be clearly detected at the detection point. The odour frequency measure is the quotient of the number of odor hours thus determined and the total number of hours in the total test period. If the odor frequency determined in this way exceeds the limit value for the appropriate frequency of use of the protected area (eg residential area, industrial zone), then the environmental odor effect caused by the investigated source is considered to be disturbing. (VDI, 2006, Richter et al., 2003, GIRL, 2008). The method is basically applicable to longer-term (eg annual) surveys. (Dentoni et al., 2013).

## FIELD OLFACTOMETRY: APPLICATION OF THE ODOUR PEN METHOD

Also the method that can be used during field odor measurement is the so-called odor pen method (EN 16841-2: 2016), which derives its name from the fact that the area affected by a disturbing odor effect at a given moment in the vicinity of an odor-emitting source, represented by a map, is typically bird-feather-shaped. The first step in the application of the odor pen method is the modeling of odor propagation, taking into account the emission and environmental and meteorological parameters, which can be performed on site with mobile IT tools. The result is the shape of the odour pen, its estimated area, which is represented on a map as a result of the modeling. The estimated limit of the odor pen is otherwise determined by the curve determined by the propagation modeling, along which the amount of odor concentration formed at the ground level decreases below a certain odor concentration value (eg 3-6-10 SZE / m$^3$) due to the odor emission of the examined odor source. After this, the measurements can be performed using the static or dynamic pen method (Figure 2).

Using the dynamic method, the panel members are traversing the plume, while conducting single measurements at frequent intervals. By successively entering and exiting the plume and in this way determining the transition between absence and presence of recognizable odour, the extent of the plume is defined. This approach helps to avoid adaptation. For both the stationary and

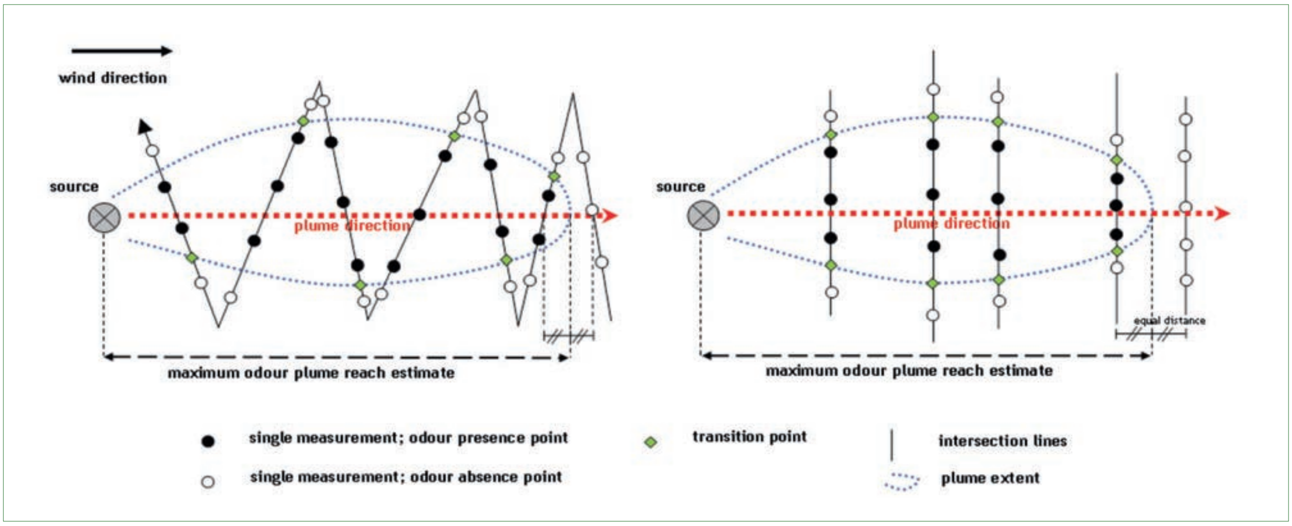


**Figure 2. Dynamic (left) and stationary (right) plume measurement (Eusebio et al., 2013)**

the dynamic method the plume extent is defined by the transition points. A transition point is the point halfway between the last odour absence point and the first odour presence point for the odour type under study. In order to prevent possible adaptation effects causing incorrect observations, transition points are in the dynamic plume method only determined while entering the plume, and not while exiting (Dentoni et al., 2013).

Using the stationary method, the panel members are located at specific intervals along intersection lines perpendicular to the plume direction. Each panel member determines the percentage odour time in the course of one single measurement. If the result of a single measurement reaches a percentage odour time <10%, the odour is considered as being absent; at higher values the odour is present. All observations at one intersection line are conducted simultaneously.. At least one intersection line has to be at sufficient distance to ensure that no recognizable odour is present at any measurement point to be able to determine the maximum odour plume reach (Dentoni et al., 2013).

The odor pen method is also suitable for determining the actual odor load in the vicinity of the odor source in a short time (Dentoni et al., 2013).

The studies described above are performed on individuals with tested olfactory ability (Guillot et al., 2012)

## THE ELECTRONIC NOSE

The method of olfactometry used in odor measurement described above allows only instantaneous sampling and measurement, not continuous measurement. However, in the field of environmental protection, the problem of continuous measurement of odor has arisen on a daily basis: for example, the continuous monitoring of the odor emissions of a technological activity and the operation of odor emission control systems. In addition, in the field of food industry and food analytics, there has been a need to perform fast, easy, non-destructive tests to determine the quality of materials and products; but it is also an important task in the cosmetics industry to continuously examine the quality of the products produced, such as their scent (Capelli et al., 2014).

The concept of the operation of the electronic nose, which is suitable for performing the tasks above, was developed in the early 1970s. A description of the working principle of the first device for continuous measurement, which was essentially similar to the operation of human odor detection, appeared almost a decade later (Persaud and Dodd, 1982). The results of the research were of great scientific and professional interest and the study of the application of the electronic nose in special fields was started: in the field of medicine and diagnostics (Persaud, 2005; Dragonieri et al., 2019), in the food industry (Schaller et al., 1998), in the cosmetics industry (Dubreuil et al., 2001) and in the field of environmental protection (Hodgins, 1995).

The operation of the electronic nose (Fig. 7) is based on a series of chemical sensors that selectively show significant sensitivity for each group of compounds. In the case of a mixture of odorous substances and groups of compounds, the sensors provide different responses and "measurement results". In most cases, this very complex set of signals can only be evaluated using a relatively complex multivariate mathematical-statistical procedure. Accordingly, an electronic nose consists of three main units: a unit containing sensors, a signal processing unit, and an evaluation unit for handling algorithms for identifying odors based on processed signals (Farkas and Dalmasi, 2013).

The electronic nose test starts primarily with a learning-training process, the calibration. During the measurement, it is not only the response signals provided by the sensors at that time that are the test results, but the comparison of the actual response signals of the sensors with the stored response signals of the previously measured samples during calibration. Therefore in the actual measurement, we do a comparative test, the electronic nose compares the smell of the sample being tested with the smells we have already learned. Based on this, it will be able to provide, for example, a measurement result that will help determine whether the food being tested meets certain quality requirements for it. Thereby the device may also be suitable for signaling when located in the vicinity of odor-emitting sources (eg. biogas plant), if the strength of the odor measured there already raises the possibility that in the wider environment of the source, in the inhabited area, the disturbing odor of the odor source may also appear (Capelli et al., 2014, Béres et al.,


**Figure 7. The electronic nose – OMD 98 from Dr. Födisch Umweltmesstechnik AG**

2014b). In the field of electronic nose, the development is unbroken, it is increasingly used even in the diagnosis of cancer (Roine et al., 2014).

## CONCLUSIONS AND FUTURE TRENDS

Due to the odor emission from different technologies, the disturbing odor effect in the source  environment is it is considered to be one of the most difficult to measure, assess and regulate from the point of view of environmental pressure and air pollution effect. In the case of each odor-emitting technology, the technological factors influencing the odor emission and the possibilities of reducing the odor emission have been determined. The problem of odor emissions has emerged among the criteria for determining Best Available Techniques (BAT) in relation to each technology, but also at a horizontal level (Environment Agency, 2011). Human smell and its characteristics have been dealt with at the research level for centuries, and research into the characteristics and operation of smell is still an important field. This is reflected by the fact that in 2004 the American Nobel Prize in Medicine was awarded to Richard Axel and Linda B. Buck of the United States for their pioneering achievements in exploring the structure and function of the olfactory system (Buck and Axel, 1991, Honti and Vécsei, 2005).

The initial, highly subjective methods used in the second half of the last century to measure odor have now been replaced by a well-reproducible, well-applied, worldwide standardized measurement method, the olfactometry. Using the measurement method, the odor emission of odor-emitting sources and the efficiency of the applied odor reduction systems can be examined with adequate efficiency and accuracy. In addition to the odor measurement method, which requires laboratory conditions, field odor measurement procedures and tools are available that allow resource operators to continuously monitor the environmental odor impact of their activities (Koplányi, 2014, Béres et al, 2015). In addition, a well-regulated method for example determination of the frequency of odors is already available for the assessment of the frequency of odor effects in the vicinity of the source in terms of the assessment of disturbing environmental odor effects (determination of the frequency of odors) (VDI, 2006).

As a result of the need for continuous measurement of odors, odor effects, concentrations of special odors or groups of odors, the principles of electronic nose function were developed at the end of the last century, and the first devices that could be used in practice appeared (Persaud and Dodd, 1982). Electronic noses have been used and are still being used successfully in many walks of life, such as medical diagnostics, the food industry, the cosmetics industry, and of course the environment. In the future, in the case of this measuring device, further rapid development, with the increasing importance of quality assurance and cost-effectiveness aspects, the method is expected to become comprehensive.

What are the practical application problems in each of the areas presented in our script, and questions for further in-depth research? In our opinion, the most important of these are the following.

- In connection with olfactometric odor measurements, the sampling method to be applied at external sources, the development of the sampling strategy and the sampling plan, the relevant part of the standard need to be reviewed and further refined. In the case of surface sources, the selection of the appropriate sampling points and sampling parameters is extremely important and crucial for the determination of the specific odor emission (Bokowa, 2010, Guillot, 2012, Laor, 2014).
- An important issue is to investigate the well-founded practical applicability of field olfactometry (Benzo et al., 2012). The method of field olfactometry, provided that its reliability can be adequately substantiated by standard olfactometric measurements and propagation modeling results, can be a good tool for use in odor management systems (Environment Agency, 2011), for operators of odor sources to carry out self-monitoring of environmental odors (Béres et al., 2015).
- The next important step in the environmental application of the electronic nose will be the standardization of certain areas of the method. In connection with this, it would be important to standardize the characteristics describing the device, the requirements for the data provided during the measurement and the conditions of applicability. (Capelli et al., 2014). The standardization process has already started, and the first document dealing with the issue of the environmental applicability of the electronic nose, regulating the most important technical issues, has already been published by the Netherlands Standardization Institute (NTA, 2014).
- An important challenge for the future is to develop a uniform EU odor control regulation. There are currently no relevant uniform regulatory principles in the EU, and "passive odor protection" is currently preferred in most states: the basic requirement is to avoid disturbing environmental odors.  To ensure this, operators of odor sources in most cases focus on reducing odor emissions - often with official regulations in mind - , but its effectiveness is monitored only periodically, in many cases only annually. Therefore, the problem of the raising of a disturbing odor effect is

typically not revealed during the periodic review of odor emission and odor reduction systems, but the complaints of the population living in the vicinity of the source are the first indications that draw attention to the problem. With this in mind, the principle of uniform EU regulation should be „active odor protection": continuous monitoring of odor emissions, the extent of the environmental odor effect caused by the source of the odor, using either a continuously operating electronic nose or frequent self-monitoring by the operator (eg field olfactometric measurements) (Environment Agency, 2011, Ledent et al., 2013, Reiter et al., 2014). Only this will help to prevent the operator and the competent environmental authority from being informed of the occurrence of a disturbing odor effect only on the basis of complaints from the population living in the vicinity of the source.

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# BREEDING RESPONSES TO CLIMATE CHANGE IN VEGETABLE BREEDING

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## ABSTRACT

In the last years, the climate change has been a big impact of the success of a vegetable production farm. As a vegetable breeding company, we have a big responsability to create new vegetable varieties, which varieties have good answer for the climate change anomalies. It is not an easy job, but we do a hard work to achieve our goals. In the following, we show you the breeding answers in our four bred species.

**Keywords: breeding, climate change, traits, sweet-pepper, cucmber, green peas**

## EFFECTS OF CLIMATE CHANGE ON PLANTS

The annual yield of a crop production is determined by the soil, the weather and the agronomic techniques used, including the quality of the seeds sown and the nutrient replenishment. While the latter factor reflects the decision and competence of farmers, the first two factors are characteristic of the place of production.
Agricultural science is trying to quantify the impact of weather on agricultural crops in many ways. The success of the methods usually depends on how well their developers know about the living nature (the actual species) and how rich mathematical apparatus they can handle and provide real data with which they can simulate the complexity, of the non-linear nature relationship between climate and yield.
Table 1. summarizes the adverse effects on crop production by season following Terbe (2009).
In spring, the first problem is caused by late frosts. The vegetative period of the plants is expected to start earlier due to climate change, their developmental phases will occur earlier, which will increase their exposure to early frosts. Premature warming interrupts the dormant phase of the plants, and the usual cooling in late April and early May can be very dangerous for all planted vegetables.
In the summer, drought is the main cause of crop failure, but floods are also common over a large area, with hail in some places. However, as the intensity of precipitation increases, not only does runoff increase, but so does soil erosion. Due to improper tillage and soil protection in many places, we must be afraid not only of erosion caused by water but also by wind. Increased solar radiation can degrade crop quality, cause color defects, sunburn, and interfere with nutrient uptake and nutrient transpiration.
Autumn can also cause damage from prolonged growing seasons and early frosts.
The harsh colds of winter will ease, the snow cover will become more precarious, the period of extreme cold will be less. The temperature at the lower boundary of the snow cover is significantly higher than at its surface, and the temperature fluctuation is also greater in the upper layer. Due to the low thermal conductivity of the snow cover, it reduces the cooling of the soil, which allows the plants to overwinter. Snow-covered soils are thus less likely to develop low temperatures that would damage plant organs and soil-dwelling pests in the soil.
The future development of vegetation is in any case influenced by the fact that the carbon dioxide concentration increases, which enhances the photosynthesis of the plants. As a result, biomass increases and yields also but in lesser extent. The ratio of individual plant parts may change. Higher $CO_2$ concentrations reduce the specific evaporation capacity of plants, thus improving the utilization of available water.

**Table 1. Adverse climate impacts threatening vegetation based on Terbe (2009)**

| Spring | Summer | Autumn | Winter |
|---|---|---|---|
| premature warming early wake up, frost, flooding | drought, deflation, flood soil erosion, hail, new pests from the south, southeast, sunburn, | prolonged vegetation period, early frosts, flooding | without snow cover a damage to overwintering plants, low water reserves, flooding |

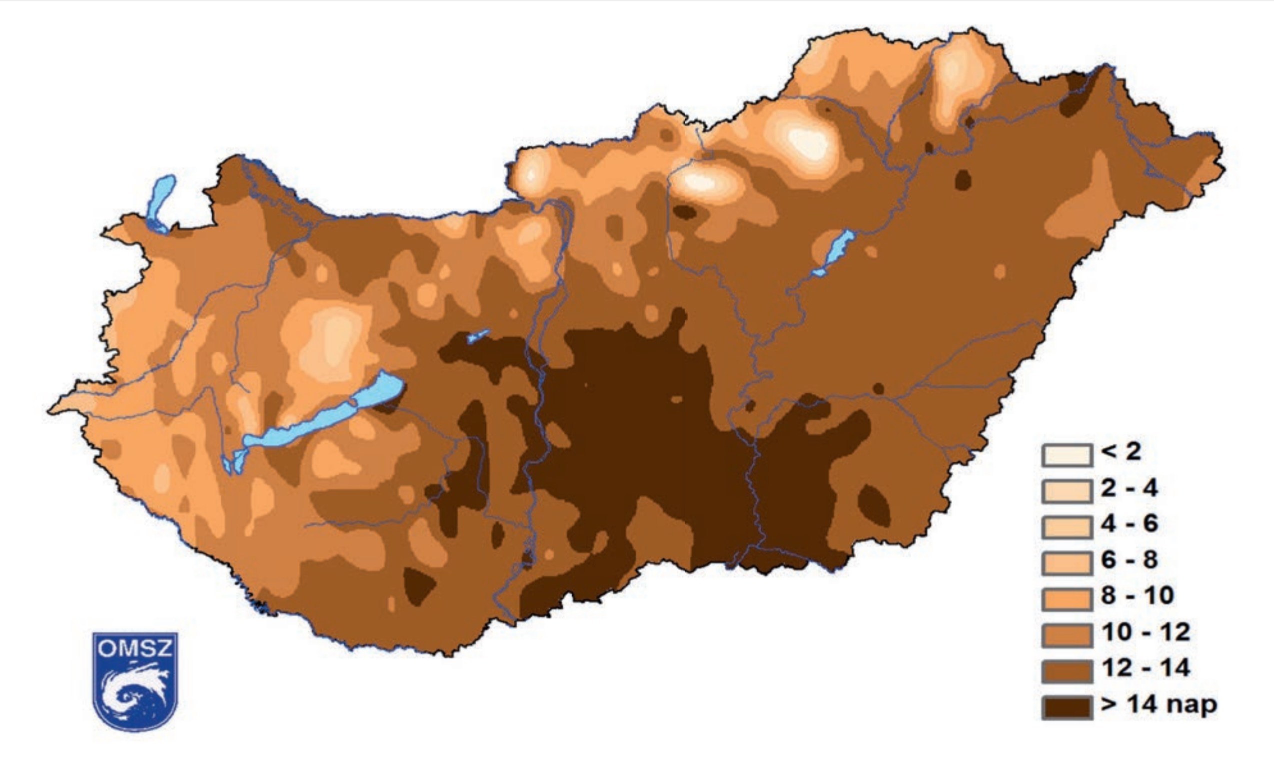


**Figure 1. Number of heat days 1981-2016**

## TEMPERATURE EXTREMES

Not only the temperature values themselves, but also the tendencies in the intensity and frequency of the extreme values are signs of a changing climate. Both a decrease in the number of frosty days (daily minimum temperature <0 ° C) and an increase in the number of heat days (maximum daily temperature ≥ 30 ° C) indicate a warming trend (Figure 1). The cooler and warmer periods are also reflected in the values of the extreme indices, but extreme warm weather situations have become more frequent since the 1980s.

## ABIOTIC AND BIOTIC STRESS FACTORS

Stress effects on plants (eg strong light intensity, extreme temperatures, drought, salt or heavy metal contamination, damage, insect bites or sucking, viral, bacterial or fungal infections) result in significant metabolic changes. Some of them represent a series of alternative biochemical processes following the modification of existing metabolic pathways, by canging of connections and regulations, while others represent the activation of new genes. For almost all types of stress (both biotic and abiotic), one of the most characteristic responses is the formation of reactive oxygen species (ROFs) and the formation of an oxidative microenvironment within the cell.
In general, conditions affecting all organisms with a similar mechanism, such as light, temperature, air, atmosphere, water, wind, and environmental conditions affecting specific species and ecosystems, such as soil, salinity, topography and natural disasters. Together with biotic factors (evolution, symbiosis, competition, etc.) they form the natural environment.
The abiotic environment affects the stability (or instability) of an ecosystem from two directions: on the one hand, it provides the conditions necessary for life to survive (e.g., temperature, water), and on the other hand, the population must adapt to the conditions it provides (e.g., extreme temperatures, water scarcity). Even the slightest permanent (eg soil erosion) or intermittent (eg flood) changes in abiotic factors can make the individual of the given ecosystem unstable and cause adaptation and acclimatization problem.

## EFFECTS OF CLIMATCHANGE TO THE ZKI BRED SPECIES

### *Sweet peppers*

The key biological need of field peppers in Hungary is the unmet heat demand for most of its growing time. Therefore, other biological needs, in particular water replenishment by cooling the environment, must be met by taking this primary need into account.
*Water demand:* Sweetpepper is a water-intensive plant at the level of optimal satisfaction of its other biological needs. This is evidenced by the following indicators. The transpiration coefficient of the peppers (water evaporated to produce a unit of dry matter) is around 300. An

indicator that can also be used from a cultivation point of view is the water consumption coefficient (water evaporated by the plant and the soil together to produce a unit of raw fruit weight), which is around 100 for peppers. We can only talk about the water demand of peppers depending on their heat demand. The correlation between the heat demand and water consumption from several years of observation is that an average of 6 °C of heat induces 1 mm of evapotranspiration water consumption in the field pepper field.

*Light demand:* Sweet peppers are a light-requiring plant, but it can also be concluded from several experimental observations that the lighting required for fruit kitting, which is stronger than the variety-specific threshold, is unnecessary for the plant. Beyond a certain limit, it is harmful to cultivation. Instead of experimental data on harmful luminosity and light spectrum, which are still incomplete today, we note the simplest ways to eliminate the harmful effects of excessive luminosity:

- field transplanting must be completed by 25 May;
- late or summer sown seedlings grown outdoors (eg for autumn shoots) should be shaded.

*Heat request.*:The heat demand of peppers is 25 ± 5 °C, depending on their different stages of development. The average requirement of 25 °C increases by 5–7 °C during germination. Peppers do not kit fruits above 35 °C.

## THE EFFECT OF DROUGHT ON PEPPER CULTIVATION

*Atmospheric drought:*

- poor fertilization
- low yield
- Distorted fruits

*Lack of soil precipitation:*

- Low yield
- Distorted fruits

*Strong UV radiation:*

- Sunburn of the fruits

Breeding responses

- Atmospheric drought:

Solution primarily for cultivation technology (sprinkler irrigation)
Selection of lines in the target environment

- Lack of soil precipitation:

Selection of lines in the target environment
Selection of hybrids in the target environment, performance test, root selection.

One of the most effective selection is the root selection: Root architecture is the most promising characteristic for drought avoidance to be used in breeding. Such characteristics can greatly improve drought-resistance of crops. (Figure 2.) Based on the consistent results from a series of analyses and experimental validation, we can conclude that the ATP synthesis should be a key factor to influence the root architecture.

Effective breeding for development and identification of drought tolerant pepper, good selection criteria are needed to distinguish the drought tolerant genotypes. Numerous selection indices based on mathematical relationship between stress and non-stress conditions has been established.

These indices are based on vulnerability and tolerance of genotype to drought. Drought tolerance is defined as the ability of plants to grow and reproduce optimally and then provide satisfactory yields when water availability is limited. Drought vulnerability genotype is often measured as a function of yield reduction under drought pressure, suggested the stress susceptibility index (SSI) for measurement of yield stability that understands the changes in both potential and actual yields in variable environments. We can defined stress tolerance as the differences in yield between stress and normal conditions and mean productivity as the average yield of genotypes under stress and non-stress conditions.

**Figure 2. In some cases, the root can be examined at an early stage.**

*Strong UV radiation:*
The trong UV radiation can cause big yield loss, and damage on the fruits (Figure 3.) Appearance of secondary pathogens on the affected part can also be a very dandgerous effect. Only one solution for this problem is the selection for good foliage coverage, and also selectoin of high decease resistant varieties.

**Figure 3. Strong UV radiation on pepper**

ZKI have already one solution for this problem, it is the CMV and Xv Resistant Tomato Peppers called: TEMES F1
ZKI Zrt is the market leader in the tomato-shaped pepper market in terms of commercial turnover, thanks to a hybrid called Bihar F1. Based on this and the needs of the market, the pepper breeding group has set itself the goal of developing a new tomato-shaped pepper, which can be considered a novelty on the world markets. With regard to the modern, high-demand, resistant tomato pepper hybrid, it is important to know that in terms of its use, tomato peppers are one of the most important raw materials in the processing industry, despite the fact that fresh market demand for them is also significant. The processing industry is placing ever higher demands on the raw material supplied: the product must be pesticide-free and of high quality.
The majority of tomato-shaped pepper cultivation takes place outdoors. The shed is perfect to protect from high UV raadiation. Among the pathogens, both cucumber mosaic virus (CMV) and Xanthomonas cause significant crop loss. It is very difficult to protect against CMV because viral vectors are aphids that can cause large infections even in relatively small numbers.

## CUCUMBER: *IMPORTANT TRAITS IN CUCUMBER PRODUCTIONS*

### *Soil salinization*

It has long been known in vegetable production that each vegetable species reacts differently to soil salinization. Some show an acceptable level of development even on slightly saline soils, while others stop their development quickly on such soils or due to poor quality - salinating - irrigation water. In the last ten years, with the advancement of nutrient solution (simultaneous application of water and nutrients), the role of this plant property has come to the fore, it has become an important part of cultivation technology.
Among the plants, salt tolerance (halophytes), moderately salt-tolerant, and salt-sensitive (glycophytic) plants can be distinguished on the basis of salt stress, i.e. sensitivity to soil salinization. The latter group includes most of the vegetables grown and known in Hungary. In the case of vegetables, the category "salt tolerant" can only be considered relative, which means that the plants belonging to this group are less sensitive to soil salinisation or high concentrations of nutrient solution, only the so-

**Figure 4. Temes F1**

called they are "salt tolerant" compared to a sensitive group, but they are sensitive compared to saline plants.

*Drought Resistance*
Drought during the production of cucurbit crops can lead to shorter vines, cause delayed flowering, and shift the plant towards maleness (with more staminate, fewer pistillate flowers), and reduce fruit yield and quality.
*Flooding Resistance*
In most cases, cucurbit crops are extremely sensitive to flooding, which is why they are often grown on well-drained soils, or in arid regions. Raised beds are useful in areas with rain during the production season, unless the soils are sandy.
*Heat Resistance*
Heat tolerance is an important trait for cucumber production, considering that many countries in the tropics struggle with food security issues.

## BREEDING RESPONSE:

At ZKI we have established several selection criterias for the above mentioned stress factors, to decrease the adverse effect the plants.

*Drought:*
Selecton for strong root system
Foliage with low transpiration coefficient
*High temperature:*
Intensely functioning root system despite high heat
Row Selection
*Increased radiation (Figure 5.)*
Strong foliage covering the crop
Fruit-shelled genotypes less sensitive to sunburn
*Wind damages:*
Thick-textured leaf plate
Strong flexible petiole
Strong stem

**Figure 5. The effect of high UV in cucumber cultivation**

## PEAS:

Green peas (Pisum sativum L.), a typical temperate vegetable plant with some frost tolerance, is one of the earliest to be eaten fresh. According to producer experience, it is a plant of "warm spring, cool summer".
Among vegetables, the second largest crop in Hungary (after sweet corn) accounts for 20% of the domestic vegetable production area. More than 90% of the surface is machine-cleaned, and the canned canned or frozen goods are made. Its production area in Hungary - according to CSO data - has been 14-17 thousand hectares in recent years.
Reqirements:
It requires intense lighting and long day conditions. At low brightness, the growing season is extended and the flowers become less fertile. There are two critical periods in terms of water demand, the time of germination and the time of flowering. When peas germinate, they absorb 105-110% of the seed weight. Its water demand is usually provided from the stored autumn-winter precipitation. To produce one ton of crop, you need 18.9 kg of nitrogen, 5.6 kg of phosphorus, and 15.2 kg of potassium pure active ingredient.
The last two years have not been favorable for green pea cultivation in terms of weather. The year 2018 brought the worst yields of the last 15 to 20 years, with an average yield of 3.9 to 4 tons instead of the planned and expected 5.5 to 6 tons. This has had and still has an effect on the spirit of cultivation. By 2019, there was a significant reduction in production area, in 2019 the sown area was only 19,200 hectares, which means a decrease of approximately 10 percent. As the year 2019 did not do well either, the decline will continue in 2020 as well.
The cultivation of peas in the domestic processing industry is still 30-40% under non-irrigated conditions.

Growing green peas seems simple, but it is becoming increasingly risky due to the effects of climate change. Despite its short growing season (3 to 3.5 months), it can no longer be produced reliably without irrigation and modern nutrient replenishment. In the last decade, research into cultivation technologies (use of varieties and types, tillage methods, nutrient replenishment experiments, etc.) has lagged behind, without which development is difficult.
A solution is needed to breed drought-tolerant varieties

## BREEDING RESPONSE:

The breeding of drought-tolerant varieties in Hungary began in the second half of the 19th century. It achieved its first successes in the first half of the 20th century. At that time, yield averages were still relatively low, and breeders often started from landscape varieties, primitive forms, and ecotypes adapted to the domestic drought in the production of varieties. However, due to the transition to intensive agricultural production, these varieties, due to their productivity and many other disadvantages, soon disappeared from public cultivation. In producing increasingly abundant varieties, breeders have sought to obtain and use other genetic resources — the best genotypes in the world. Classical selection was performed in two directions:

a / for higher root mass for a higher water uptake, and

b / for smaller leaf area and better waxiness for lower water release. However, traditional breeding has not been able to show substantial progress. The main reasons for

**Figure 6. Strong roots, and effect of that**

this are, on the one hand, the changing appearance and complex effect of drought.

*Genetic and methodological reasons for the lack of drought tolerant varieties:*

- drought-adapted varieties produce less, even in drought conditions, than intensive, high-yielding varieties and hybrids,
- drought tolerance and yield is negatively correlated,
- knowledge of the inheritance of drought tolerance traits is lacking or incomplete,
- drought tolerance is a complex property, therefore selection for a single stamp (gene) does not lead to results,
- the interactions of genes associated with drought tolerance are unknown, there are currently no morphological, phenological, physiological or biochemical, etc. a test that is in itself suitable for determining the drought tolerance of a genotype and could therefore be used for reliable selection of drought tolerant genotypes, selection on traditional stamps (eg root mass, leaf waxiness, hairiness, stoma count, cuticle thickness, senescence, etc.) did not lead to breakthrough, substantial progress, we cannot expect rapid successes from newer selection approaches - (eg infrared temperature measurement and photography, artificial drought stress, various physiological parameters, etc.), which are currently being tested or introduced.

However we have estblished some easy and well followed selection criteria such as:

- very strong roots (the stronger the roots, the more drought resistant) figure 6.
- good soil cover (the better the plant cover, the less soil evaporation)
- semi-afila types (due to varietal nature)
- double wrinkled types (due to varietal character)

**Figure 7. Double wrinkled peas**

- choosing varieties where the flower is covered with leaves (the less the pollen burns, the more it will not cause abortion)
- concentrated flowering
- 3 pods / floor

## WATERMELON: *THE EFFECT OF DROUGHT AND HIGH UV IN WATERMELON CULTIVATION*

Losses due to sunburn and heat shock during periods of intense summer sun exposure are a growing problem in outdoor cultivation. Sunburn alone can result in up to 10-15% loss of yield, depending on the degree of damage, which in the case of intensive growing conditions corresponds to a worthless yield of 8,000-12,000 kg / ha in watermelon. This loss may be further exacerbated by outages due to physiological processes that become unfavorable due to overheating.
In addition to the symptoms of sunburn necrosis on the crop, strong irradiation and high temperatures already inhibit photosynthesis beyond a certain point, leading to a loss of quality and quantity.
*High UV:*
Requires 12 hours of sunlight per day, responds sensitively to light intensity. Excessive UV radiation from the fruit symptoms of sunburn. This completely destroys the integrity and marketability of the crop. Therefore, as a result of climate change, it is primarily the high, increasingly extreme levels of UV that are taken into account during breeding.
It is therefore appropriate to limit the extent of intensive exposure to crops as much as possible. With the cultivation technology and the choice of variety, the aim should be to develop sufficient foliage to protect the crops in the shade, but this alone is often not enough to prevent problems.
*Drought:*
Water is increasingly becoming a limiting factor for agricultural production, especially in arid, semi-arid climates such as the Mediterranean region. The competition for water resources between agriculture, industry and the population requires the continuous irrigation technology

**Figure 8.The effect of high UV in the Watermelon fruit**

development of vegetable production. As a long-established method for woody plants, one way to increase water use efficiency and avoid yield losses in vegetable crops is to graft greenery plants to drought stress-reducing rootstocks under water-scarce conditions.
- In order to grow the crop, it requires a very large amount of water in Hungary only by irrigation
- Evaporates very intensively due to summer heat, can lose up to 2 liters of water per day Intensive technologies
- Drip irrigation and nutrient replenishment

## BREEDING RESPONSE:

*Drought:*
- strong deep penetrating roots, leading to more efficient water uptake

Water stress is an important cause of reduced yield in watermelon. It may be that some genotypes are more efficient in water use than others, but it probably will be difficult to develop highly efficient varieties since watermelon fruit have very high water content. In Israel, deep-rooted varieties are used in unirrigated desert areas.
Pollination problems are responsible for improper fruit development. It is necessary for all three lobes of the stigma to be fully pollinated if the fruit is to develop fully, and without curvature. Proper fruit development requires adequate numbers of honeybees or bumblebees during flowering, along with weather that is conducive to pollination. Bumblebees can be more effective pollinators than honeybees. Cold, rainy weather leads to poor pollen shed, and hot weather often leads to reduced bee activity. In the case of triploid hybrids, it is necessary to have up to one third of the field planted to a diploid pollenizer to assure adequate fruit development in the triploids which are male sterile.
The melons, once planted, grow so rapidly, if temperatures are favorable, that relatively few cultivations can be given after the plants show aboveground. The strong development of the laterals in the several species of cultivated cucurbits becomes apparent early in the life of the plant.

- strong stems and foliage which provides better soil cover.

*High UV:*
- large area of foliage covering mainly the crop
- strong vigor,
- by selecting the peel less prone to sunburn.
- breeding resistance to leaf and stem diseases ( a new challenge) deceases:

*Fusarium Wilt*. Fusarium wilt is caused by Fusarium oxysporum f. sp. niveum. The disease was first reported in 1889 in Mississippi, and was widespread throughout the southern parts of the United States by 1900. Three types of pathogen spores are commonly observed: small, colorless, oval, non septate microconidia; large, sickle shaped,

**Figure 10. Healthy baby watermelon**

septate macroconidia; and thick walled circular chlamydospores. There are three races known: 0, 1, and 2. Most current varieties are resistant to race 0, and some also are resistant to race 1. Race 2 was discovered more recently, and occurs mainly in the south central production areas such as Texas and Oklahoma, but it also has been found in Florida.

*Anthracnose.* Anthracnose caused by Colletotrichum lagenarium is an important disease of watermelon in the United States. Symptoms caused by this pathogen may occur on leaves, stems, and fruit. Lesions on leaves are irregular shaped, limited by the leaf vein, and brown to black in color. Lesions on the stem are oval shaped and tan colored with a brown margin. Lesions similar to those found on stems and leaves also appear on the fruit. Older fruit show small water-soaked lesions with greasy, yellowish centers that are somewhat elevated. Seven races of the anthracnose pathogen have been reported. Races 4, 5, and 6 are virulent in watermelon, but races 1 and 3 are most important. Many varieties are resistant to races 1 and 3, and resistance to race 2 will be needed in the near future.

## CONCLUSIONS

The abiotic environment affects provides the conditions necessary for life to survive (e.g., temperature, water), and on the other hand, the population must adapt to the conditions it provides (e.g., extreme temperatures, water scarcity). All in all, we have good technics in breeding, to select varieties which are able to survive extreme climate conditions  and also good understanding what to do, which directions to go in senlecting new promising, and valuable varieties for the effects caused by the climate change.

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