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Original article

# Phenological Behaviors and Productivity of Different Pepper Genotypes in Depending on Environmental Conditions[1]

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**Abstract**

The main goal of the present study was to evaluate the phenological development of pepper genotypes with different origin depending on environmental factors under the Bulgarian conditions with a view to proposing the most suitable ones for inclusion in the breading programs. The experiments were carried out in 2015-2017 years under the South Bulgarian conditions, in Agricultural University-Plovdiv region, with seventh different pepper genotype and breeding lines. The plants were grown by the conventional for middle yearly field production technology. The phenophases of beginning and mass: sprouting, flower bud, flowering, fruit set and fruiting were recorded. Four harvests were done and productivity was determined. The average daily temperature, total active temperature sum, maximal and minimal temperature, rainfall and the hydrothermal coefficient of vegetation period were calculated. Between phenological behaviors on one hand and productivity on the other hand and elements of climatic conditions, high relations were determinated. High regression coefficients between average daily temperature, total active temperature sum and rainfall and periods between different stage of development and productivity were established. The highest productivity and earlier occurrence of some phenophases of 42-2013 and 42-2010 makes them most suitable to be proposed for inclusion in future breeding programs.

**Keywords:** Phenophases, Breeding, Development, Climate conditions, Temperature.

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## INTRODUCTION

The species *Capsicum annum* L. is known for its very wide diversity of subspecies and variants. Over the world, the numbers of cultivars and local populations are extremely high. Many local populations which are characterized by exceedingly good and valuable economic qualities are present (Cholakov, 2009). Genetic diversity is considered as one of the criteria for the pepper selection and for the reaching of the opportunities of the breeding programs (Geleta et al, 2004). Cholakov et al. (2002) reported that heat requirements for the development of the biological potential of different pepper varieties are a good basis for properly identifying the most appropriate micro-region for their cultivation and appearance of their genotypic features. Todorova (2000) underlined the importance of the active temperature sum for the good and harmonious development of the pepper plants, as well as for achieving maximum productivity. The temperature changes mostly affect on the flowering, abortion, and fruiting in the pepper. Garruna-Hernandez et al. (2012) establish that at a 5°C increase in temperature to $35^0$C, the flowering of the pepper is accelerated by 6 days, but fruiting is delayed by 27 days. Park et al. (2014) determinate $25^0$C as an optimal temperature for the development of peppers in Korea. Reducing by $5^0$C causes weaker vegetative growth, increases abortion and greatly reduces yields by 11%. Leon-Chan et al. (2017) suggests, that lower temperatures than optimal are one of the major abiotic factors that cause stress in pepper plants and limit their productivity due to the presence of harmful effects on photosynthetic components.

Temperature data in the form of non-linear and linear models can be used to predict the behavior of plants under field conditions (Judd et al., 1991). Observations on phenology can be very useful for monitoring the environment, especially climate change and development of plant diseases and pests as well as the presence of pollen, causing allergies (Sparks et al., 2000). A similar concept that the results of temperature and phenophases can serve to predict the development of pepper plants and also for the attack of diseases and pests suggested by Weintraub et al. (2007). The relationship between temperature and phenophases is significant.

According to AfifHedhly et al. (2009), the sexual reproduction phase in plants may be particularly vulnerable to the effects of global warming and the direct effect of temperature changes strongly this stages. Chmielewski et al. (2004) also reported that changes in temperature are more pronounced during the very early spring phases, i. e. when the plants are younger, whereas later in spring and summer there are changes due to an increase in temperature but lower.

The main goal of the present study was to evaluate the phenological development of pepper genotypes with different origin depending on environmental factors under the Bulgarian condition with a view to proposing the most suitable ones for inclusion in the breading programs.

## Materials and Methods

The experiments were carried out in the Experimental Fields and the laboratories of the Department of Horticulture and of the Department of Botany and Agro-meteorology at the Agricultural University-Plovdiv, Bulgaria in the period of 2015-2017. The following pepper patterns with conic shape, which originate from Bulgaria, Hungary, Greece, and Poland were investigated:

- 26-2003 - Selection line in local population from Thessaloniki, Greece;
- 42-2013 – Selection line in local population from region Brestovica, Plovdiv, Bulgaria;
- 43-2010 - Selection line in local population from region Saedinenie, Plovdiv, Bulgaria;
- 106-2-2008 - Selection line in local population from Szeged, Hungary;
- 110-12-2008 - Selection line in local population from Budapest, Hungary;
- 114-2012 - Selection line in local population from Krakow, Poland;
- Kurtovska kapia 1619 – control variety, Bulgaria

The plants were grown by the conventional for Bulgaria technology for middle-early field production through not pricked out seedlings. The autumn deep plowing was preceded by the fertilization with 320 kg/ha$^{-1}$ triple superphosphate and 250 kg/ha$^{-1}$ potassium sulfate. The soil preparing in the spring consisted of cultivation, fertilization with ammonium nitrate at a dose of 200 kg/ha$^{-1}$ and formation of the furrows. The sowing of the seeds for seedlings growing was performed in an unheated plastic greenhouse with a sowing rate of 1800 g/ha$^{-1}$, as 8 g seeds were sown on a square meter. The sowings were realized on 26.03.2015, 24.3.2016 and 22. 03.2017. The planting was carried out during the period 20 to 22 May, under the scheme 60 x 15 cm. During the vegetation all the agro-technological practices included in the technology were applied and regular care was taken for the normal development of the plants. There were three hoeing. The plants were fertilized twice in the phases of mass flowering and the beginning of fruiting, with ammonium nitrate at a dose of 180 kg.ha$^{-1}$. The experiments were carried out in four replicates with 7 m$^2$ size of the experimental plots.

Phenological observations of beginning (B) and for mass (M) manifestation of the following phonological phases: sprouting (by date and in days after sowing), flower buds, flowering, fruit sets and fruiting (by date and in days after sprouting) were accounted. The beginning of the appearance of the respective phase was reported at its onset in 10% of the plants and mass - in 70% (Dimova and Marinkov, 1999). The productivity was determined, as by gathering one harvest of not ripe fruits and three harvests of ripening fruits having done.

The daily climatic information about 3 year's period (2015-2017) from Meteorological station - Plovdiv in the Experimental fields of Agricultural University, Plovdiv used. The changes in the main meteorological factors during the vegetation period were determinated. The basic climatic factors were mean air temperature, the sum of precipitations (about periods between different stages of development and per day of the period) and Hydrothermal Coefficient (HTC). The agro-climatically parameters by the periods between separate stages and for all vegetation period were established. The Hydrothermal coefficient as a complex character for air temperatures and humidity were applied for characterization of the moisture condition (Selianinov, by Kouzmova, 2003). Due to the large volume of regressions between the different phenophases and the studied climatic factors as figures are presented the regression and correlation dependences between the rate of the plant development and the main climatic factors by periods between the phases, where the greatest significance was established, but only for genotypes with the highest productivity and the fastest rate of development, which are interesting for pepper breeding programs.

Data of the study were subjected to analysis of variance, and the least significant differences between means were calculated by the Fisher test at $p = 0.05$. A method for ANOVA and a method for establishing the regression coefficient are described by Fowel and Cohen (1992). Statistical analysis for agrometeorological conditions was done through Excel with Visual Basic.

**Results**

In most of the studied genotypes, the sprouting had begun at the latest in 2016, but at the earliest one was in 2017. First, genotype 42-2013, had sprouted on 31.03.2017 or 9 days after sowing, followed by 43-2010 – on 10 days (Table 1). Of all studied patterns, for the three years, at the latest, the start of sprouting was recorded at 26-2003 (originating in Greece) at 18.04.2016 or 25 days after sowing. Mass sprouting follows a similar trend, and the difference from the beginning is with 3 days for most genotypes up to 8 days later in 2015 for 114-2012, that originates from Poland. Differences from the standard Kurtovska kapia 1619 variety are little, but in many of the tested variants, this phase has occurred earlier. On average, for the three years of the study, the period from sowing to the sprouting of the studied genotypes was between 14 and 20 days.

The earliest occurrence of flower buds was reported at 114-2012 on 26.05.2017 or 49 days post-emergence. Next is genotype 43-2010 - on 29.05.2015 and 2017 or 45 and 55 days post-emergence respectively, followed by 26-2003 (31.05.2017, 51 days post-emergence). In the last genotype, however, the differences in years are more significant and in 2016 the last appearance of the flower buds was observed - on 14.06. The mass occurrence of the flower buds phase was from 10 days later than the beginning at number 26-2013, in 2015 to 16 days in the same year for 106-2-2008 (originating in Hungary). For most genotypes, this period between phases is approximately 12 days. It is relatively longer in 2015 for 43-2010 and for 42-2013, and in 2016 this happens at 110-12-2008 and 114-2012. Triennial data show that for a mass occurrence of the flower buds phase was needed between 62 days (Kurtovska kapia 1619) and 70 days (42-2013) from sprouting.

An essential phenophase is flowering. Its onset occurs on average for about 16 days after the beginning of a flower bud. This period is the shortest in 2015 at 106-2-2008, 14 days. With the longest duration from the beginning of a flower bud to the beginning of flowering are characterized, in the same year, the breading numbers 114-2012, 26-2013, 110-12-2008, as well as the standard variety Kurtovska kapia 1619, 26 and 19 days, respectively. The occurrence of mass flowering, on average for the studied genotypes, was 13 days later. However, for the plants of number 26-2003, which originate in Greece was needed only 10 days in 2015 to begin the mass event of this phase, whereas on 106-2-2008 (from Hungary) for it was 17 days. From the sprouting to the mass occurrence of this phase, an average of three years the necessary period was approximate of 83 days.

At the earliest at 1.07, a fruit sets phase began at Kurtovska kapia 169 in 2017, with a difference from the beginning of a flowering of 5 days. This difference is also little for number 26-2003 - 6 days. For the remaining variants the period between phase from the beginning of flowering to the beginning of the fruit set is from 8 to 11 days. The mass formation, an average for all genotypes and vegetations is 13 days. It starts 6 days earlier in 2016 for 43-2010 and later in 2017 for 110-12-2008. Between sprouting to the mass formation of fruit set for three years of experiments were needed 88 days (106-2-2008) to 100 days (42-2013).

**Table 1.** Phenological observations (date)

| Genotypes | year | Sprouting | | Flower buds | | Flowering | | Fruit sets | | Fruiting | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **B** | **M** | **B** | **M** | **B** | **M** | **B** | **M** | **B** | **M** |
| 26-2003 | 2015 | 6.4 | 9.4 | 11.6 | 21.6 | 30.6 | 10.7 | 6.7 | 18.7 | 27.7 | 13.8 |
| | 2016 | 18.4 | 24.4 | 14.6 | 26.6 | 30.6 | 11.7 | 9.7 | 21.7 | 26. 7 | 15.8 |
| | 2017 | 4.4 | 10.4 | 31.5 | 12.6 | 16.6 | 29.6 | 26.6 | 10.7 | 8.7 | 2.8 |
| 42-2013 | 2015 | 6.4 | 9.4 | 4.6 | 18.6 | 22.6 | 5.7 | 3.7 | 17.7 | 13.7 | 2.8 |
| | 2016 | 8.4 | 13.4 | 6.6 | 18.6 | 22.6 | 5.7 | 2.7 | 15.7. | 19.7 | 9.8 |
| | 2017 | 31.3 | 4.4 | 5.6 | 15.6 | 21.6 | 2.7 | 2.7 | 16.7 | 20.7 | 11.8 |
| 43-2010 | 2015 | 9.4 | 14.4 | 29.5 | 13.6 | 16.6 | 1.7 | 26.6 | 11.7 | 11.7 | 2.8 |
| | 2016 | 4.4 | 11.4 | 2.6 | 14.6 | 18.6 | 1.7 | 28.6 | 5.7 | 18.7 | 7.8 |
| | 2017 | 1.4 | 4.4 | 29.5 | 10.6 | 14.6 | 25.6 | 23.6 | 5.7 | 6.7 | 29.7 |
| 106-2-2008 | 2015 | 9.4 | 14.4 | 4.6 | 20.6 | 18.6 | 30.6 | 28.6 | 9. 7 | 18.7 | 12.8 |
| | 2016 | 13.4 | 19.4 | 13.6 | 26.6 | 30.6 | 13.7 | 8.7 | 21.7 | 28.7 | 14.8 |
| | 2017 | 5.4 | 10.4 | 5.6 | 17.6 | 22.6 | 5.7 | 2.7 | 15.7 | 23.7 | 13.8 |
| 110-12-2008 | 2015 | 9.4 | 14.4 | 16.6 | 29.6 | 5.7 | 16.7 | 17.7 | 29.7 | 30.7 | 21.8 |
| | 2016 | 8.4 | 11.4 | 6.6 | 20.6 | 23.6 | 6.7 | 2.7 | 17.7 | 22.7 | 12.8 |
| | 2017 | 1.4 | 4.4 | 31.5 | 12.6 | 15.6 | 27.6 | 25.6 | 14.7 | 15.7 | 7.8 |
| 114-2012 | 2015 | 6.4 | 14.4 | 4.6 | 16.6 | 30.6 | 13.7 | 9.7 | 25.7 | 30.7 | 19.8 |
| | 2016 | 8.4 | 11.4 | 2.6 | 16.6 | 19.6 | 2.7 | 29.6 | 13.7 | 12.7 | 7.8 |
| | 2017 | 4.4 | 7.4 | 26.5 | 8.6 | 12.6 | 23.6 | 22.6 | 5.7 | 11.7 | 3.8 |
| Kurtovska kaipa1619 | 2015 | 9.4 | 14.4 | 4.6 | 16.6 | 23.6 | 6.7 | 4.7 | 15.7 | 24.7 | 8.8 |
| | 2016 | 8.4 | 12.4 | 9.6 | 21.6 | 25.6 | 6.7 | 4.7 | 15.7 | 22.7 | 12.8 |
| | 2017 | 4.4 | 7.4 | 9.6 | 21.6 | 26.6 | 9.7 | 1.7 | 13.7 | 19.7 | 10.8 |

B-begging, M-mass,

The most important phase from an agronomic and economic point of view is fruiting. Its beginnings begin during the period 6-30.07, respectively in 2017 for Bulgarian population 43-2010 and in 2015 on 110-12-2008 and 114-2012. The period from the beginning of fruit sets to the beginning of fruiting averages was about 18-21 days. It was shorter in 2016 at 43-2010 and 114-2012, and in 2015 for 42-2013 and for 110-12-2008. For the occurrence of mass fruiting are needed more between 14 and 25 days, in 2015 for 26-2003 and for 106-2-2008, respectively. The earliest date when the mass formation of fruits was reported was 29.07.2017 for genotype 43-2010, followed by 2.08.2015 at 42-2013 and 43-2010 and in 2017 for 26-2003. It can be said that on average for the three years, the period from sprouting to mass fruiting of the tested genotypes is between 117 to 125 days, respectively for 43-2010 and 42-2013 and 106-2-2008.

To the fullest assessment of the pepper genotype behaviors can be achieved by the establishment of their productivity (Table 2). The highest yield was recorded over the three years for genotype 42-2013, with an average of 37.096 $t/ha^{-1}$ over the study period, exceeding Kurtovska kapia 1619 by 14.55%, followed by number 43-2010 by 8.92% over the control. This both genotypes are originating from Bulgaria. The weakest productivity was recorded in Poland genotype 114-2012 – 29.564 t/ha$^{-1}$, 8.71% lower than the control variety. It can be summarized that with the highest yield is characterized vegetation season of 2016, followed by this one of 2017. The obtained differences for productivity between investigated pepper genotypes are with statistical significance. The above mentioned high productivity as well as the relatively earlier periods of observation of some phenophases in genotypes 42-2013 and 43-2010, identified them as most suitable for use in future selection programs with pepper.

During the sowing to sprouting period, the meteorological conditions have a significant impact on the rate of development of all the studied pepper genotypes. In the genotypes 26-2003, 42-2013 and 106-2-2008, the determining climatic factor is the average daily air temperature, while for the genotypes 43-2010, 110-12-2008, 114-2012 and Kurtovska kapia 1619 the factor determining the rate of development is the amount of the rainfall.

In the period from sprouting to flower buds, differences between genotypes are also observed. In 43-2010 and Kurtovska kapia1619 determining climate factor is the average daily temperature of the air, in pattern 114-2012 determining is the quantity of the rainfall, in the variants 42-2013 and 110-12-2008 the rate of development depends on both - the temperature of the air and the amount of precipitation. In the other two genotypes 26-2003 and 106-2-2008, the development is not dependent on the climatic conditions, but mainly on the biological features of these two genotypes.

For the period of flower buds to flowering, differences between the separate variants are observed. Air temperature is a determinant climatic factor on the rate of development at 26-2003, the amount of rainfall is determining the rate of development at 43-2010. In the genotypes 106-2-2008, 114-2012 and Kurtovska kapia 1619 the influence on the rate of development was caused both of the air temperature and the amount of precipitated rainfall. In genotype 110-12-2008, the rate of development does not depend on the weather conditions, but mainly on the biological genotype features.

The period from flowering to the fruit sets is also characterized by differences between the variants. For genotype 106-2-2008, the rate of development is not dependent on the climatic conditions, but on the biological features. The rainfall amount determines the development at 42-2013 and 43-2010, the air temperature - at Kurtovska kapia 1619. In the other variants, the rate of development depends on both the average daily air temperature and the amount of precipitated rainfall.

During the period from the fruit sets to fruiting, differences between the tested genotypes have also been established. For genotype 43-2010, the development is not dependent on weather conditions but on biological features. Precipitation is a determining factor in the rate of development in genotypes 106-2-2008 and 110-12-2008, while in the other variants the precipitation and the air temperature are determined.

On the figures № 1, 2 and 3 are presented only the highest dependencies between the rate of development and the main climatic factors only for the genotypes with the highest economic importance. In these figures, some common effects in other genotypes are also reflect be.

**Discussion**

Different varieties sometimes have specific requirements, related to the cultivation technology and to the environmental conditions during the growing season, which makes it necessary to test them in outside of the area of their origin. Geleta et al. (2005), investigating the morphological indexes of a large number of pepper genotypes, emphasized the importance of origin in relation to their manifestations under different conditions. One of the most important elements for identifying the real potential of individual genotypes according to Meneses-Lazo et al. (2018) is phenological and physiological studies.

**Table 2.** Productivity of different pepper genotypes (t/ha-[1])

| Genotypes | 2015 | 2016 | 2017 | Average | % |
|---|---|---|---|---|---|
| 26-2003 | 32.185 | 34.086 | 33.129 | 33.133 | 102.31 |
| 42-2013 | 35.184 | 39.123 | 36.982 | 37.096 | 114.55 |
| 43-2010 | 33.111 | 37.152 | 35.552 | 35.272 | 108.92 |
| 106-2-2008 | 29.884 | 31.156 | 34.128 | 31.723 | 96.56 |
| 110-12-2008 | 32.293 | 32.151 | 30.998 | 31.814 | 97.03 |
| 114-2012 | 27.459 | 30.213 | 31.111 | 29.564 | 91.29 |
| Kurtovska kaipa 1619 | 30.122 | 32.589 | 34.435 | 32.382 | 100.0 |
| LSD (p=0.05%) | 0.864 | 0.926 | 1.002 | 2.300 | |

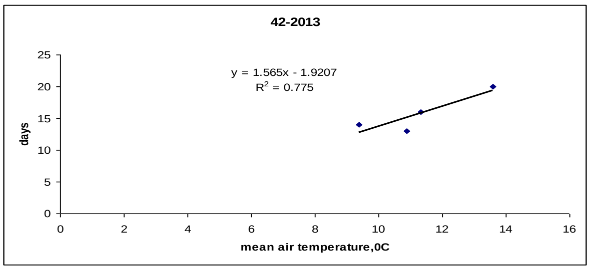
Some differences between the tested in this studied genotypes as well as vegetation seasons in the phenological development of plants were observed. The earliest beginning of sprouting that was observed was between 9-10 days. This coincides with the conclusion that was made by another scientist. Mundarain et al. (2005) indicate that the onset of pepper emergence occurs approximately 6 days after sowing. However, in most of the variants, the mass expressing of this phenophase was between 14 and 20 days. Moreno-Pérez et al. (2011), establishing that for the sprouting of the pepper seed, but under conditions of Mexico, an average of about 16 days are necessary. This is once again proof that the environmental conditions play a significant role in pepper plant development.

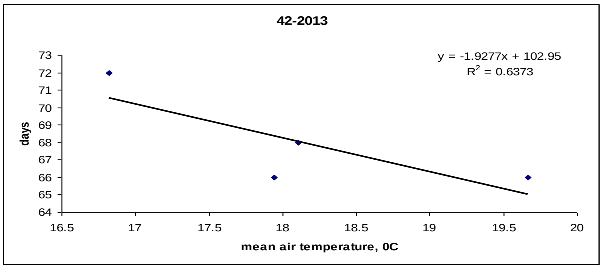
The importance of the climate-specific are revealed very well in the development of generative phases. The most sensitivity to the conditions of the different year was established for the beginning and for the mass of flowering and fruit sets The differences in the first stage between the included in this experiment patterns were between 9 and 7 days, respectively. While in fruit sets it was much bigger, around 12 days between first and last genotype. Very important is the duration of full vegetation period, from sprouting to mass fruiting. Average for the three years of investigation it was between 117 to 125 days. It must be pointed out that the shortest one it was for 43-2010 and 42-2013 – 117 days. A similar length, of 117 days of vegetation period for different pepper genotype, reported also Moreno Pérez et al. (2011).

The term of the setting of the different stage of development of pepper is particularly important because it gives the idea for the normal development of the plants as well as for the period of earliest fruiting and entry of the mass production. Sbiriciog (2010) also highlights that for the evaluation of pepper genotype is very important the duration of the separate phenological phases. The significance of phenological stages was emphasized by Geleta et al. (2004) too, and they have made this conclusion on the base of establishment of the strong correlation between flowering and fruit maturity.

Complete evaluation of the individual genotypes necessarily involves their economic qualities and suitability to the appropriate growing conditions. Genotypic differentiation, the importance of the productivity from an agronomic point of view and the interaction with the phenological development of plants and climatic features in their cultivation underlined Todorova et al. (2004), Moreno Pérez et al (2011) and Costa et al. (2014). In our investigation also some difference between the three years of study were observed. With the highest productivity are characterized the vegetation season of 2016, followed by this one of 2017. With the most productive, among the experimented pepper patterns, are selection numbers 42-2013 and 43-2010, both originated from the region of Plovdiv, Bulgaria. It once again confirms the standpoint that the development of the full potential of the plant is possible to be the best in the local condition of the origin as well as that the environmental behaviors are determined factors for productivity.

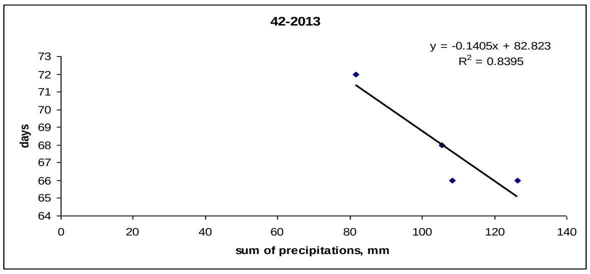
In the research carried out by us indicates the strong dependence between the developments of individual pepper genotypes with the main climatic factors was established. For most of the patterns, the higher dependence is determined by the average daily air temperature and rainfall.

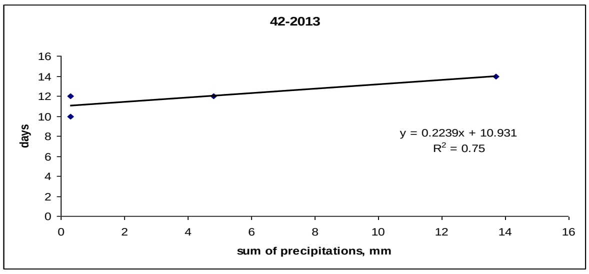



A) sowing – mass sprouting

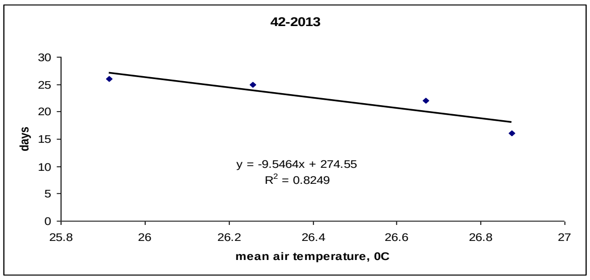
B) mass sprouting – mass flower buds

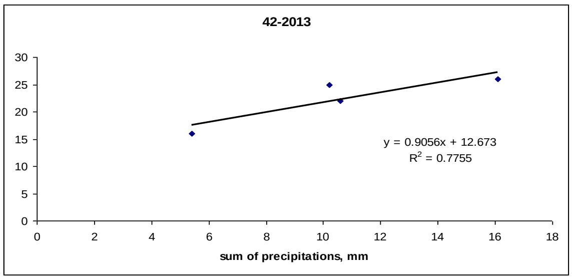



C) mass sprouting – mass flower buds

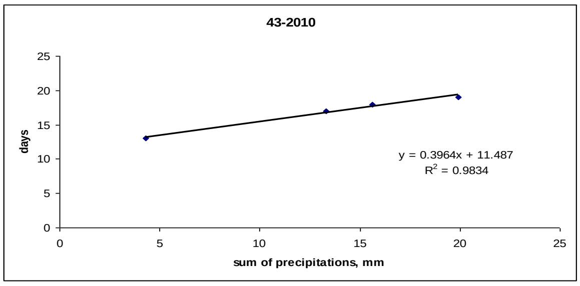
D) mass flowering-mass fruit sets



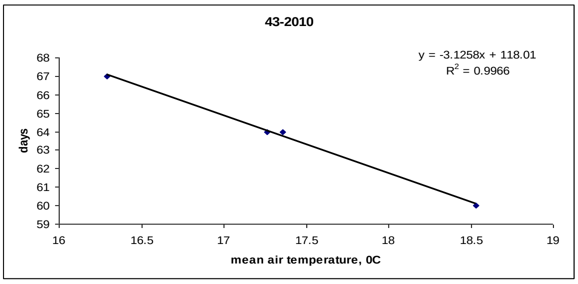




E) mass fruit sets- mass fruiting

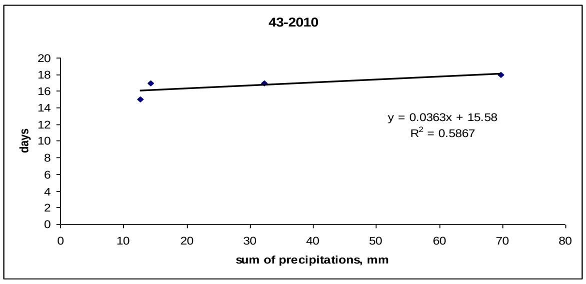
**Figure 1.** Regression analysis between the climatic factors and rate of development of separate phenophases with the highest dependencies on genotype 42-2013



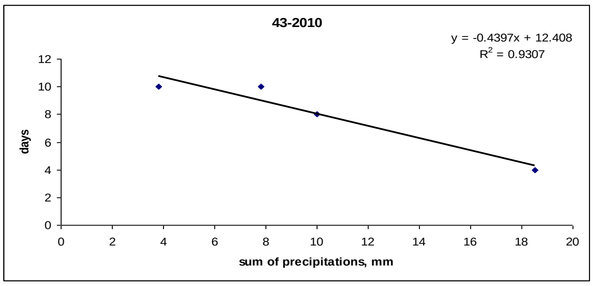

A) sowing –mass sprouting




B) mass sprouting-mass flower buds

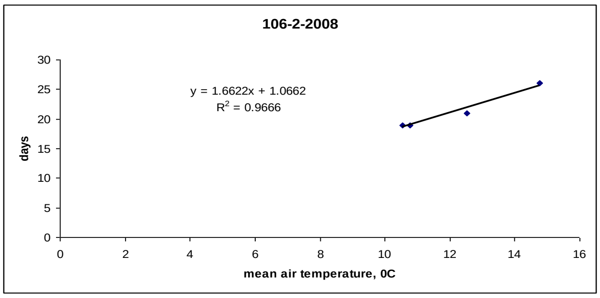



C) mass flower buds-mass flowering

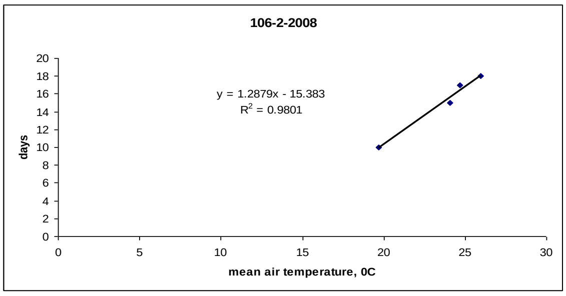



D) mass flowering – mass fruit sets

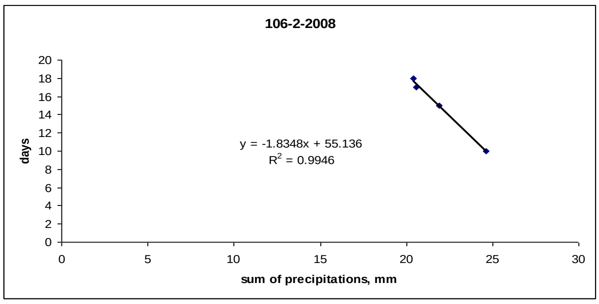
**Figure 2.** Regression analysis between the climatic factors and rate of development of separate phenophases with the highest dependencies on genotype 43-2010



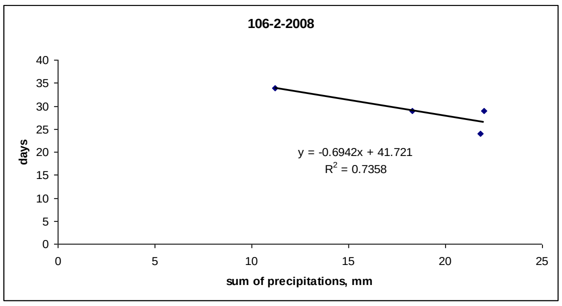

A) sowing – mass sprouting




B) mass flower buds- mass flowering




**C)** mass flower buds- mass flowering




D) mass fruit sets mass fruiting

**Figure 3.** Regression analysis between the climatic factors and rate of development of separate phenophases with the highest dependencies on genotype 106-2-2008

For some breeding numbers such as 106-2-2008, the highest resistance to environmental conditions was observed. No matter of the established dependence on some genotypes of the amount of rainfall, by the reason of pepper growing under irrigation conditions and providing it with an optimal amount of water, it could be pointed out that this climatic factor is of secondary importance. For genotype 42-2013, with the highest productivity, the influence of climatic factors is the weakest during the flowering period, whereas in the other high productive genotype 43-2010 this is observed during the ripening period. As above mentioned, these genotypes are also most appropriate to be proposed for the use in the selection of this crop.

**Conclusions**

The earlier occurrence of phenophases was observed in 2017. The sprouting is the earliest, for 11 days, for genotypes 42-2013 and 43-2010. The least days for flowering were required for the breeding numbers 43-10-2010 and 110-12-2008, respectively originating from Bulgaria and Hungary, while the fruiting began at the earliest in patterns with the same origin - 43-2010 and 42-2013. Productivity is highest for genotypes, which originates from Bulgaria, 42-2013 and 42-2010. This fact, as well as the earlier occurrence of some phenophases in this patterns, make them most suitable to be proposed for inclusion in future breeding programs. The highest resistance to the change in environmental parameters in the years of the study indicates the genotype 110-12-2008. Climatic conditions are of less significance in the periods from flower buds to flowering and for mass maturing for the most productive patterns such as 42-2013 and for 43-2010, respectively.

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