Effect of Air Temperature on Growth, Yield and Active Ingredients of Fenugreek (*Trigonella foenum-graecum*)

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Abstract: This study was carried out at the experimental farm of Environment and Bio-Agricultural Department, Faculty of Agriculture, Al-Azhar University, Nasr City, Cairo, Egypt during two successive winter seasons of 2012/ 2013 to study the effect of temperature under three different sowing dates (Oct. 1st, Oct. 20th and Nov. 10th) on growth, yield, chemical compositions and active ingredients of fenugreek plant. In addition, study the effect of GDD on developing of growth stages and active substances. In this study, a program of observations and measurements was developed, concerning: morphological, productivity elements and chemical composition of seeds. Results indicated that vegetation growth, yield components and chemical composition of fenugreek seeds showed on different dates differed in both seasons, and the early sowing date (Oct. 1st) resulted in considerably higher values compared to sowing at the end of October and during November. Also, developing growth stages of fenugreek was differed according to changing of sowing date and the total average of heat unit's accumulation (GDD) during all stages was 977.0, 951.3 and 931.3 GDD for the first, second and the third sowing dates, respectively. Finally we can projected that increase of air temperature under futuristic climate change according to IPCC could be impact on the growth, yield and chemical composition of fenugreek seeds as a result to accumulation of heat units (GDD).
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1. Introduction

Fenugreek (*Trigonella foenum-graecum* L., Fam. Fabaceae) is one of the oldest medicinal plants and spice. Fenugreek is believed to be native to the Mediterranean region (**Petropoulos, 2002**), but now is grown as a spice in most parts of the world. It is reported as a cultivated crop in regions of Europe, northern Africa, west and south Asia, Argentina, Canada, United States of America and Australia **(Petropoulos, 2002)**. Recent research has identified fenugreek as a valuable medicinal plant with potential for multipurpose uses and also as a source for preparing raw materials of pharmaceutical industry, especially steroidal hormones, **(Mehrafarin *et al.*, 2011)**.

The total cultivated area of medicinal and aromatic plants in Egypt about 73.0 thousand acres, and the cultivated area of fenugreek plant represented about 9560.0 acres **(Agricultural Economics, 2012)**. Applications of fenugreek were documented in ancient Egypt, where it was used in incense and to embalm mummies. In modern Egypt, fenugreek is still used as a supplement in wheat and maize flour for bread-making (**Ionescu and Roman**, **2013)**. Fenugreek seed contains 45-60% carbohydrates, mainly mucilaginous fiber (galactomannans), 20-30% proteins, 5-10% fixed oils (lipids), pyridine alkaloids, mainly trigonelline (0.2-0.38%), choline (0.5%), free amino acids, such as 4-hydroxyisoleucine (0.09%), arginine, histidine and lysine, calcium and iron, saponins (0.6-1.7%), vitamins A, B_1, C and nicotinic acid and 0.015% volatile oils **(Mehrafarin *et al.*, 2011).**

The use of medicinal plants is limited by the quality of active substances they contain. This quality depends on many ecological factors that affect the all plant organs (**Lombini *et al.*, 1999)**. The distribution and the degree of presence of medicinal plants are directly correlated with the ecosystem conditions, especially the soil quality and the environmental conditions which effect on the qualitative and quantitative characteristics of active substances. (**Yanive and Palevitch, 1982)**.

Yield of fenugreek seed showed on different dates differed in both seasons, sowing in the first two weeks of April resulted in considerably higher yield compared to sowing at the end of April and during May, **(Radojka and Jevdjovic, 2007)**. Plants require a specific amount of heat to develop from one point in their lifecycle to another, such as from seeding to the four-leaf stage. It's tough to predict plant growth based on the calendar because temperatures can vary greatly from year to year. Instead, Growing Degree Days (GDD), which is based on actual temperatures, is a simple and accurate way to predict when a certain plant stage will occur. Also, **(Ionescu and Roman**, **2013)** indicated that the maturity was in the third decade of July, after 95 days of vegetation growth and the heat units accumulation was 922.2 GDD (St>10°C).

The objectives of this investigation are to study the effect of air temperature under different

sowing dates, on growth, yield components and active ingredients of fenugreek plant, also study the impact of GDD on developing of growth stages.

2. Materials and Methods

This study was carried out at the experimental farm of Environment and Bio-Agricultural Department, Faculty of Agriculture, Al-Azhar University, Nasr City, Cairo, Egypt during two successive winter seasons of 2012/ 2013 to study the effect of air temperature under different sowing dates (Oct. 1st, Oct. 20th and Nov. 10th) on growth, yield and active ingredients of fenugreek plant. In addition, study the effect of GDD on developing of growth stages and active substances.

In this research seed material of the plant species fenugreek *(Trigonella foenum graecum L.),* Domestic cultivar was used. Plot sizes of the experiment were 1.5 × 3.0 m = 4.5 m^2 and the seeds were sown by hand in continuous rows with the distance of 30 cm between rows. The cultural practices performed during the vegetation period concerned the manual weeding works, carried out as often as necessary. In this experiment a program of observations and measurements was developed, concerning morphological parameters (Plant height, branches and leaves number, shoot fresh and dry weight). Harvesting was carried out in full maturation stage and the treatments of drying fenugreek shoot and seed was under shade and sun, then samples taken for investigation of productivity elements and seed yields (number of pods/ plant, number of seeds/ pods and 100 seeds weight), also chemical composition of fenugreek seeds was done like (protein, carbohydrates, fibers, lipids and Ash), finally the active ingredients trigonellin and saponins were detected in fenugreek seeds according to **(Gorham, 1986 and Hiai *et al.*, 1976)**, respectively.

Also average minimum and maximum air temperature (Table 1) was measured to study the relationship between different sowing dates and heat unit's (GDD) during growth stages of fenugreek. GDD for a particular crop is defined in the simplest form by the equation:

$$GDD = T_{mean} - T_{base}$$

Where T_{mean} is the daily mean air temperature and T_{base} is the minimum daily mean air temperature required for plant growth (T_{base} = **10** ^{o}**C**). The GDD concept was found to be very accurately in predicting the phenological development for the studied crop, (**Ionescu and Roman**, **2013)**.

Table (1): Monthly average air temperature during years of 2012 and 2013 on Cairo, Egypt*

Year	Temp. (°C)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2012	Min.	8.9	9.5	11.2	16.3	19.9	22.8	24.7	24.9	22.3	20.6	17.0	12.3
	Max.	17.4	18.9	21.4	29.5	32.6	35.2	35.9	35.6	32.8	30.7	25.9	20.6
2013	Min.	10.4	11.5	13.9	15.4	20.3	22.4	22.8	23.9	22.2	17.6	16.9	10.9
	Max.	19.5	21.7	26.5	27.2	33.7	34.3	33.3	35.1	32.8	28.0	25.9	19.3

(*) http://www.tutiempo.net/en/Climate/Egypt/EG.html

Mathematical-statistical producers were used to process the obtained experimental data. Testing of the significance of determined differences between calculated means values was done using "SPSS software ver. 18" for windows 7 following the methods of **(Steel and Torrie, 1980)**. All evaluations of significance were carried out based on F-test and Duncan-test for threshold of significance of 5%.

3. Results and Discussion

3.1 Vegetation growth parameters

Data presented in Table (2) showed that there is the relationship between different sowing dates and vegetation growth of fenugreek, and the results indicated that significant differences between the three sowing dates on plant height, number of branches, number of leaves, shoot fresh and dry weight in both seasons. Data of first winter season showed that the early sowing date (Oct. 1st) was recorded the highest values for all measured parameters with the means of 35.3, 3.7, 21.0, 14.2 and 3.6 for plant height, number of branches, number of leaves, shoot fresh and dry weight, respectively, flowed by the second sowing date and the third one, and the second winter season recoded the same trend. These results could be attributed to the impact of air temperatures and heat units (GDD) on developing growth of fenugreek according to different of sowing date, and different climate conditions. These results are in agreement with that obtained by **Nandre *et al.*, (2011)** who indicated that, the vegetative growth in terms of plant height, number of branches and number of leaves, were increased due to an early sowing date (1st November).

3.2 Yield and yield components

Results in Table (3) indicated that the temperature has great impacts on productivity elements of fenugreek in both seasons, and the obtained experimental data in the first winter season showed that the first sowing date (Oct. 1st) was recorded the highest values for all yield components in terms of number of pods, number of leaves and 100 seeds weight with means of 10.0, 15.0 and 1.5, respectively, while the third sowing date (Nov. 10th) was detected the lowest values for all measured parameters with the means of

6.0, 12.0 and 1.2, respectively, and the second winter season has the same trend, and there is no significant difference between the two seasons in all measured parameters. These results could be attributed to change of air temperature and accumulation of heat units (GDD) according to different sowing date, and different climate conditions. These results are in a harmony with those obtained by **Radojka and Jevdjovic, (2007)** who reported that yield of fenugreek seeds showed on different dates differed in both seasons, sowing in the first two weeks of April resulted in considerably higher yield compared to sowing at the end of April and during May, also **Ionescu and Roman**, **(2013)** indicated that maturity in the third decade of July, after 95 days of vegetation and the accumulation of 922.24 GDD (St>10°C). Finally; **Nandre *et al.*, (2011)** indicated that, the productivity elements in terms of number of pods, number of seeds/ pod, weight of seeds/ pod, seed yield/ plot and seed yield per hectare were found to be the maximum with an early sowing date (1st November), whereas harvested fenugreek plants were characterized by following productivity elements: 20.1 pods/plant, 11.4 seeds/pod and 3.9 g seeds/plant.

Table (2) Effect of sowing dates on vegetation growth of fenugreek

Frist season (Winter 2012)					
Sowing dates	**Plant height (cm)**	**No. of branches**	**No. of leaves**	**Shoot fresh weight (g)**	**Shoot dry weight (g)**
Oct. 1st	35.3^{a} ±7.0	3.7^{a} ±1.4	21.0^{a} ±7.3	14.2^{a} ±3.0	3.6^{a} ±1.1
Oct. 20th	31.3^{b} ±7.0	3.0^{b} ±1.4	18.7^{b} ±7.3	13.8^{a} ±3.0	2.0^{b} ±1.1
Nov. 10th	21.7^{c} ±7.0	1.0^{c} ±1.4	7.3^{c} ±7.3	8.8^{b} ±3.0	1.5^{b} ±1.1
Mean	**29.4**	**2.6**	**15.7**	**12.3**	**2.4**
Second season (Winter 2013)					
Oct. 1st	34.0^{a} ±7.0	3.3^{a} ±1.1	19.7^{a} ±6.5	13.9^{a} ±2.8	3.6^{a} ±1.1
Oct. 20th	30.0^{b} ±7.0	2.7^{b} ±1.1	17.3^{b} ±6.5	12.8^{b} ±2.8	1.9^{b} ±1.1
Nov. 10th	20.3^{c} ±7.0	1.1^{c} ±1.1	7.4^{a} ±6.5	8.6^{c} ±2.8	1.5^{b} ±1.1
Mean	**28.1**	**2.4**	**14.8**	**11.8**	**2.3**

Table (3) Effect of sowing dates on yield component of fenugreek

Frist season (Winter 2012)			
Sowing dates	**Number of Pods/ plant**	**Number of seeds/ pod**	**100 seeds weight (g)**
Oct. 1st	10.0^{a} ±2.1	15.3^{a} ±1.7	1.5^{a} ±0.2
Oct. 20th	9.0^{a} ±2.1	13.0^{ab} ±1.7	1.3^{ab} ±0.2
Nov. 10th	6.0^{b} ±2.1	12.0^{b} ±1.7	1.2^{b} ±0.2
Mean	**8.3**	**13.4**	**1.3**
Second season (Winter 2013)			
Oct. 1st	9.7^{a} ±2.1	14.0^{a} ±1.7	1.4^{a} ±0.2
Oct. 20th	8.7^{a} ±2.1	13.7^{a} ±1.7	1.3^{a} ±0.2
Nov. 10th	5.7^{b} ±2.1	11.0^{b} ±1.7	1.1^{b} ±0.2
Mean	**8.0** ±	**12.9**	**1.3**

3.3 Heat unit's accumulation (GDD)

Resulted presented in Table (4) showed that the effect of sowing dates on heat unit's accumulation (GDD) during fenugreek growth stages and the results indicated that there is significant differences between numbers of days for each growth stage and GDD according to different sowing dates in both seasons, whereas the first sowing date (Oct. 1st) was recorded the highest day number during vegetation and maturity stages followed by the second sowing date (Oct. 20th) and the third one (Nov. 10th), while the third and second sowing dates were recorded the highest day number in the germination and flowering stages, respectively, also the first sowing date was detected the highest heat units accumulation (GDD) at all growth stages followed by the second sowing date and the third one. In the total at the maturity stage the results indicated that there are significant differences between sowing dates on season length and accumulation of GDD, in both seasons the first sowing date was detected the highest day number from sowing date until maturity stage followed by the second sowing date and the third one by the means of 134.0, 123.0 and 112.0 days, respectively. Also, the first sowing date was recorded the highest GDD from sowing date until maturity stage followed by the second sowing date and the third one by the means of 980.6, 942.8 and 914.7 GDD in the first season and 973.3, 959.8 and 948.0 GDD in the second season, respectively. These results could be attributed to the different of air temperatures

according to different of sowing dates, whereas the plant development depends on temperature. These results in agreement with those obtained by **Radojka and Jevdjovic, (2007)** who reported that plants require a specific amount of heat to develop from one point in their lifecycle to another, such as from seeding to the four-leaf stage. It's tough to predict plant growth based on the calendar because temperatures can vary greatly from year to year. Also**, Ionescu and Roman**, **(2013)** indicated that the maturity was in the third decade of July, after 95 days of vegetation growth and the heat units accumulation was 922.2 GDD (St>10°C).

Table (4) Effect of sowing dates on heat unit's accumulation (GDD) during of fenugreek growth stages

Frist season (Winter 2012)										
Sowing dates	**Germination stage**		**Vegetation stage**		**Flowering stage**		**Maturity stage**		**Total**	
	No. of days	**GDD**	**No. of days**	**GDD**	**No. of days**	**GDD**	**No. of days**	**GDD**	**No. of days**	**GDD**
Oct. 1st	6.0^{b} ±2.1	90.8^{a} ±4.9	34.0^{a} ±2.3	346.3^{a} ±10.4	24.0^{b} ±3.0	254.3^{a} ±14.7	70.0^{a} ±12.5	289.2^{a} ±9.9	134.0^{a} ±11.0	980.6^{a} ±33.1
Oct. 20th	7.0^{b} ±2.1	81.2^{b} ±4.9	30.0^{b} ±2.3	334.4^{ab} ±10.4	30.0^{a} ±3.0	256.7^{a} ±14.7	56.0^{b} ±12.5	270.5^{b} ±9.9	123.0^{b} ±11.0	942.8^{b} ±33.1
Nov. 10th	10.0^{a} ±2.1	84.7^{b} ±4.9	30.0^{b} ±2.3	325.6^{b} ±10.4	27.0^{ab} ±3.0	230.2^{b} ±14.7	45.0^{c} ±12.5	274.2^{b} ±9.9	112.0^{c} ±11.0	914.7^{c} ±33.1
Mean	**7.7**	**85.6**	**31.3**	**335.4**	**27.0**	**247.1**	**57.0**	**278.0**	**123.0**	**946.0**
Second season (Winter 2013)										
Oct. 1st	6.0^{b} ±2.1	97.1^{a} ±5.7	34.0^{a} ±2.1	334.0^{b} ±18.1	24.0^{b} ±3.0	236.8^{a} ±15.6	70.0^{a} ±12.5	305.4^{a} ±7.8	134.0^{a} ±11.0	973.3^{a} ±12.7
Oct. 20th	7.0^{b} ±2.1	88.7^{b} ±5.7	31.0^{b} ±2.1	369.0^{a} ±18.1	30.0^{a} ±3.0	206.5^{b} ±15.6	56.0^{b} ±12.5	295.6^{b} ±7.8	124.0^{b} ±11.0	959.8^{ab} ±12.7
Nov. 10th	10.0^{a} ±2.1	99.5^{a} ±5.7	30.0^{b} ±2.1	343.6^{b} ±18.1	27.0^{ab} ±3.0	214.9^{b} ±15.6	45.0^{c} ±12.5	290.0^{b} ±7.8	112.0^{c} ±11.0	948.0^{b} ±12.7
Mean	**7.7**	**95.1**	**31.7**	**348.9**	**27.0**	**219.4**	**57.0**	**297.1**	**123.0**	**960.4**

3.4 Chemical compositions of fenugreek seeds

Data detected in Table (5) showed that there are significant differences of sowing dates on chemical composition and active ingredients of fenugreek seeds, in both season the first sowing date was recorded the highest values of chemical compositions (protein, carbohydrates, fiber, lipids and ash) and active ingredients (trigonellin and saponins) followed by the second sowing date and the third one. These results could be attributed to effect of air temperature during the maturity stage on chemical composition and active ingredients of fenugreek seeds, whereas the increase of air temperature led to decrease the accumulation of chemical components as a result to increase of respiration rate. These results are in a harmony with those obtained by **Hassanein *et al.*, (2012)** who indicated that the exposure of germinated fenugreek seeds to different temperatures induce reprogramming of gene expression in a coordinated fashion by changing the metabolism, protein and DNA profiles. These findings may suggest that fenugreek can be introduced in breeding programs to produce tolerant varieties and pave the way for cloning and characterization of underlying genetic factors which could be useful for engineering plants with improved heat tolerance.

Table (5) Effect of sowing dates on chemical composition and active ingredients of fenugreek seeds

Frist season (Winter 2012)							
Sowing dates	**Protein (%)**	**Carbohydrates (%)**	**Fiber (%)**	**Lipids (%)**	**Ash (%)**	**Trigonellin (%)**	**Saponins (%)**
Oct. 1st	26.4^{a} ±1.8	50.2^{a} ±1.9	8.7^{a} ±0.9	3.7^{a} ±0.4	6.9^{a} ±0.6	0.74^{a} ±0.1	1.3^{a} ±0.2
Oct. 20th	24.5^{b} ±1.8	49.3^{ab} ±1.9	7.4^{ab} 0.9	3.4^{a} ±0.4	6.1^{ab} ±0.6	0.51^{b} ±0.1	1.2^{ab} ±0.2
Nov. 10th	22.9^{c} ±1.8	46.6^{b} ±1.9	6.9^{b} ±0.9	3.0^{a} ±0.4	5.7^{b} ±0.6	0.49^{b} ±0.1	0.9^{b} ±0.2
Mean	**24.6**	**48.7**	**7.7**	**3.4**	**6.2**	**0.58**	**1.1**
Second season (Winter 2013)							
Oct. 1st	24.1^{a} ±1.2	49.7^{a} ±2.6	7.8^{a} ±0.6	3.5^{a} ±0.6	6.4^{a} ±0.8	0.72^{a} ±0.1	1.4^{a} ±0.3
Oct. 20th	23.7^{ab} ±1.2	46.5^{ab} ±2.6	7.0^{ab} ±0.6	2.8^{ab} ±0.6	5.8^{ab} ±0.8	0.52^{b} ±0.1	1.3^{ab} ±0.3
Nov. 10th	21.9^{b} ±1.2	44.6^{b} ±2.6	6.7^{b} ±0.6	2.3^{b} ±0.6	4.8^{b} ±0.8	0.45^{c} ±0.1	0.8^{b} ±0.3
Mean	**23.2**	**46.9**	**7.2**	**2.9**	**5.6**	**0.56**	**1.1**

Conclusion

It could be concluded from these obtained results that the air temperature under different sowing dates will have a great effects on vegetation growth, yield, chemical composition and active ingredients of fenugreek seeds, and the results showed on different dates differed in both seasons, and the early sowing date (Oct. 1st) resulted in considerably higher values compared to sowing at the end of October and during November. Also, developing growth stages of fenugreek was differed according to changing of sowing date and the total average of heat unit's accumulation (GDD) during all stages was 977.0, 951.3 and 931.3 GDD for the first, second and the third sowing dates, respectively. Finally we can projected that increase of air temperature under futuristic climate change according to IPCC could be impact on the growth, yield and chemical composition of fenugreek seeds as a result to accumulation of heat units (GDD).

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