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Reproductive Growth of Tomato (*Lycopersicon esculentum* Mill.) in Qassim, Saudi Arabia, During Winter

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ABSTRACT. In this study the tomato cultivars Pearson Al-improved, Marmande and VFN-8 were grown at three planting dates, to identify the reproductive attributes and abnormalities implicated in the low yield of field-grown tomatoes, encountered in Qassim, Saudi Arabia, during the winter season. The planting dates started in September, 1987, with monthly intervals, and then repeated the following year. In all cvs, the number of flowers per plant decreased slightly, whereas fruit set percentage and average fruit weight decreased substantially, resulting in a significantly low yield, as planting date was delayed. The failure of fruit set and perhaps the reduction in average fruit weight could be ascribed to inefficient pollination during the first two plantings, in addition to lack of fertilization during the last planting. Inefficient pollination was due to poor pollen dehiscence and due to both poor pollen dehiscence and low pollen production during the first two and the last plantings, respectively, whereas the lack of fertilization was due to low pollen viability and female sterility. Cv Marmande outperformed the other cvs, followed by Pearson Al-improved, during late plantings.

Tomato is mainly produced in polyethylene-covered tunnels and air-heated greenhouses in Qassim, Saudi Arabia, during the winter season. The yield of field-grown tomato is very poor (Annual Report 1986), presumably due to the drop in temperature (Cholette and Lord 1989), light intensity (Boivin *et al. 1987*) and/or in day length (Gianquinto and Pimpini 1988). However, the reproductive factors implicated have not been specified, although such information is critical to any breeding program to improve the productivity of the field-grown tomato during this time of the year.

While the number of flowers per cluster and fruit size do not seem to be noticeably affected (Rylski 1979, McAvoy *et al.* 1989), fruit set is drastically reduced at low temperature (Went 1944, Dempsey 1970, Charles and Harris 1972, Rylski 1979, Nguyen 1983) and low light intensity (Kinet 1977, McAvoy *et al.* 1989). However, most of these findings were obtained from controlled environment studies where the plants were exposed to constant levels of climatic factors. In contrast, under the field conditions, the plants would be exposed to continuously changing levels of such factors, which could have a quite different effect on the reproductive performance of the plants (Curme 1962, Hussey 1963).

Irrespective of its magnitude, the lack of fruit set under low temperature and light intensity could be ascribed to one or more of the many reproductive abnormalities, depending on the interactive effects of relative humidity, day and night temperatures, and light conditions (Rylski 1979, Picken 1984).

The present research was conducted to identify the reproductive attributes and abnormalities associated with low yield of field-grown tomato in Qassim, Saudi Arabia, during the winter season.

Experimental

This study was conducted at the College of Agriculture and Veterinary Medicine, Buriedah, Qassim, Saudi Arabia during 1987-1989. Daily maximum and minimum air temperature and relative humidity were recorded from a thermograph and a hygrograph, respectively, located at the experimental site. Solar radiation data were obtained from Qassim metreological station, at Unayzah, about 30 km away.

Experiment I:

The tomato cultivars Pearson Al-improved, referred to hereafter as Pearson; Marmande and VFN-8 were grown at three dates starting September, 4th and 9th during 1987 and 1988, respectively, with monthly intervals. The seeds were sown in 30 × 40 cm plastic boxes filled with sterilized soil mixture of 1 peat: 2 sandy loam soil by volume, and watered as needed to keep the soil wet. Uniform seedlings were transplanted at the fourth true leaf stage, each to a 40-liters plastic pot filled with an alkaline sandy loam soil. Half strength Hoagland's solution was added alternately with tap water whenever the tensiometers inserted in the soil reached 20 kPa.

The pots were arranged in a split plot design with three replications. The planting dates were used as main treatments and the cultivars as subtreatments. Each cv per planting date per replicate was represented by one pot.

The plants were examined daily for the presence of open flowers. The date at which each plant had the first open flower was recorded, to determine the number of days from sowing to this stage. At anthesis, the open flowers of the first five clusters on each plant were tagged. These flowers, and the fruits developed from them, were counted and the percents fruit set were calculated (the percent fruit set = 100 × number of fruits/number of open flowers (Picken 1984)). A fruit was considered set when the ovary was at least five mm in diameter. When started to change red, each fruit was picked and weighed to determine the average and the total fruit weight.

Experiment 2:

This experiment was conducted to investigate any reproductive abnormalities associated with the low fruit set encountered in Experiment 1. The layout and the cultural specifications were as described in Experiment 1, except that each cv per planting date per replicate was represented by two plants. One plant was used for destructive, and the other for non-destructive, analysis. In addition, two more plants of each cv were grown at each planting date during 1987, and at the last planting date during 1988, to be used as pollen sources. These plants were covered with perforated polyethylene bags during the day, in addition to cartoons at night to keep them at 20-30°C and 10-20°C day/night air temperatures, as indicated by maximum and minimum thermometers.

Using the plants reserved for destructive analysis, 20 open flowers were collected from the first five clusters of each plant, at midday, and examined for the presence of exserted stigmas. Then, each pistil was put on a glass slide in a few drops of aniline blue. A cover slip was put on each slide and pressed gently to crush the tissues. Then the slides were examined with a light microscope to determine the percents flowers with pollen-free stigmas. Furthermore, the staminal cones of these flowers were examined under a dissecting microscope to determine the percentages of the flowers with abnormal anthers. To estimate the level of pollen production, the weight of pollen grains per flower were determined by weighing six staminal cones with and without pollen grains, one day prior to anthesis. Pollen viability was estimated by putting some pollen grains, from each plant, on a glass slide in a few drops of acetocarmine. Ten minutes later, the slides were covered with slips and four microscopic fields were examined with a light microscope. The viable pollen grains would stain red, whereas, the non-viable ones would not stain.

Using the plants reserved for non-destructive analysis, 20 open flowers per plant were tagged and hand-pollinated, at about 10-12 AM, with pollen grains, of which above 60% were viable. These pollen grains were collected from the plants kept under the covers with the exception of the first two 1988 plantings, in which every plant was hand-pollinated by its pollen grains. The fruits developed from the tagged flowers were counted to calculate the percents fruit set. A fruit was considered set when the ovary was at least 5 mm in diameter. This fruit set was used as an estimate of the female fertility.

All percentages were transformed to arc sine, and these, along with the rest of the data, were subjected to analysis of variance (Gomez and Gomez 1984).

Results and Discussion

Average daily air temperatures, solar radiation and average relative humidity are presented in Fig. 1. For both experimental periods the temperatures and solar radiation decreased gradually with the delay in planting and they were minimal in January and December respectively, whereas the relative humidity displayed an opposite trend. The day length, although not presented here, decreased gradually from September to March. It was 10.6 and 8.2 hours for September and March, 1988/1989, respectively.

The length of the period from sowing to anthesis increased with delayed planting (Table 1), apparently due to the drop in temperature (Cholette and Lord 1989) and light intensity (McAvoy *et al.* 1989), with cv Marmande starting to flower before the others by more than a week. Fewer flowers, which reached anthesis, were produced, as planting was delayed (Table 1). This reduction in flower number could be ascribed to carbohydrate deficiency (Hussey 1963, Calvert 1969) resulting from low irradiance and short photoperiods during January and February (Howlett 1936). Of these flowers which reached anthesis, more than 55%, on the average, developed into fruits, in the first planting (Table 1), then the level of fruit set decreased significantly to be less than 15% in the last one. The highest and the lowest fruit set percentages were exhibited by cvs Marmande and VFN-8, respectively. Significant reductions in fruit set were also reported with other tomato cvs grown under low temperature (Went 1944, Charles and Harris 1972, Rylski 1979, Nguyen 1983) and/or low light intensity (Kinet 1977, McAvoy *et al.* 1989).

As planting date was delayed, smaller and fewer fruits per plant were produced, resulting in a significant decline in total fruit yield per plant (Table 2). Cv pearson outyielded both other cvs initially, but it was replaced by cv Marmande

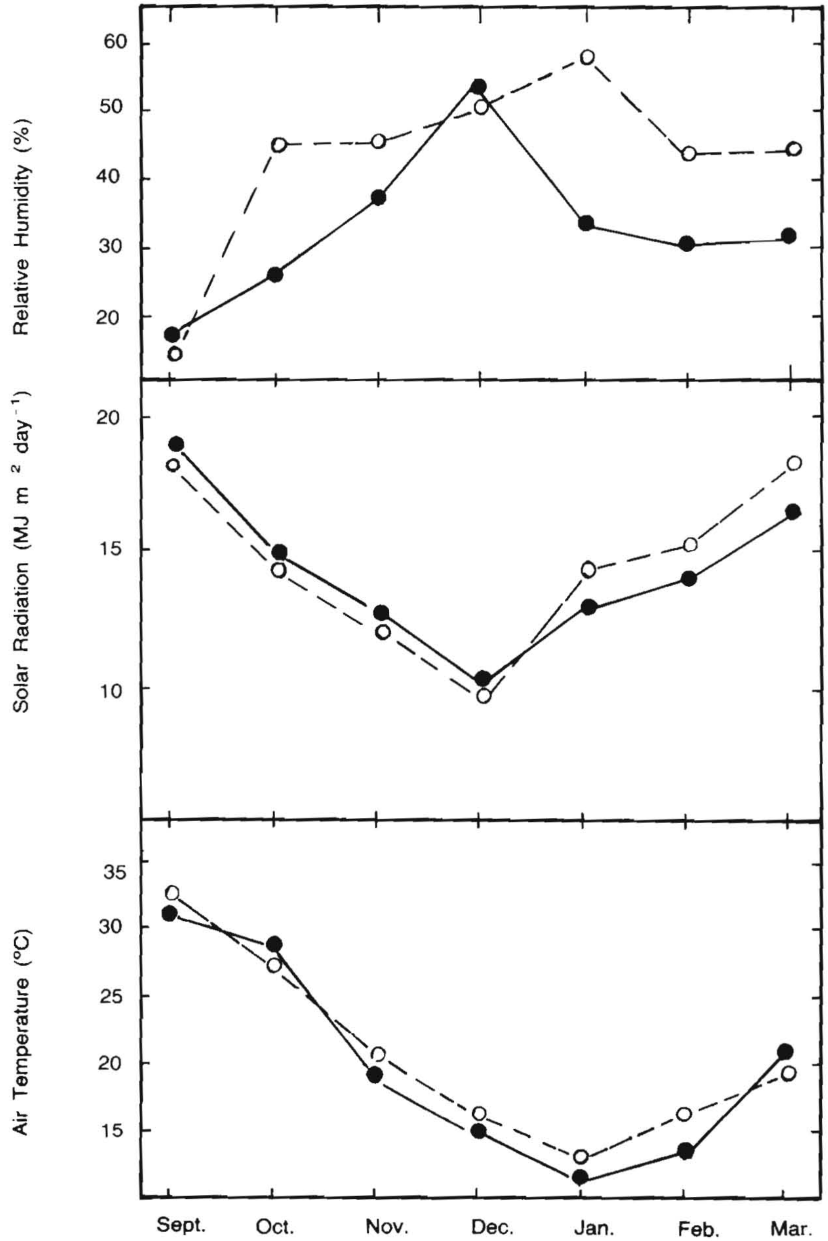

Fig. 1. Average daily air temperature, solar radiation and average relative humidity during the 1987-1988 (o- - - -o) and the 1988-1989 (●——●) experimental periods.

Table 1. Days to anthesis, number of flowers per plant and fruit set percentage of three tomato cvs grown at three planting dates

Planting date	Days to anthesis			No. of flowers per plant			Fruit set (%)		
	Pearson	Marmande	VFN-8	Pearson	Marmande	VFN-8	Pearson	Marmande	VFN-8
1987									
Sept	68 Ab*	62 Ba	69 Ab	28 Aa	25 Aa	28 Aa	61.2 ABa	64.6 Aa	48.3 Ba
Oct	73 Aab	64 Ba	74 Aab	25 Aab	23 Ba	25 Aab	37.0 ABb	46.2 Ab	28.4 Bb
Nov	76 Aa	67 Ba	78 Aa	22 Ab	21 Aa	22 Ab	16.5 Ac	25.8 Ac	5.5 Bc
1988									
Sept	68 Aa	60 Bb	72 Aa	29 Aa	24 Bab	28 Aa	59.3 Aa	65.7 Aa	43.6 Ba
Oct	70 Aa	63 Bab	73 Aa	28 Aa	27 Aa	27 Aa	41.0 Ab	44.2 Ab	23.2 Bb
Nov	73 Aa	65 Ba	76 Aa	18 ABb	20 Ab	15 Bb	6.9 Bc	18.2 Ac	0.0 Cc

* Mean separation by Duncan's multiple range test, 5% level, using transformed values (arc sine) for the percentages. Lower case letters for the columns and upper case letters for the raws.

during the last two plantings, reflecting a significant interaction at the 5% level. Probably this is why cv Marmande is widely grown elsewhere, during winter (Hassan 1988).

Stigmatic examination revealed that less than 10% of the flowers produced from September planting had pollen-free stigmas (Table 3). The percentage of such flowers increased significantly with the delay in planting, so that the majority of the flowers in November planting were of this type. Such flowers would not set, due to the lack of pollination (Rylski 1979), which is a common problem in many other locations during winter (Verkerk 1957, Kepcka 1966).

The lack of pollination, in general, is brought about by stigma exsertion (Rick and Dempsey 1969), failure of pollen adherence to the stigmatic surface, pollen indehiscence (Van Koot and Van Ravestijn 1963) and/or poor pollen production (Charles and Harris 1972).

Stigma exsertion, which was reported with some other tomato cvs grown under low temperature (Charles and Harris 1972) and low light intensity (Howlett 1936), was not observed in this study. Likewize, the failure of pollen adherence to the stigmas might not occur, since the level of relative humidity was not very low (Fig. 1) to induce such a problem (Van Koot and Van Ravestijn 1963, Bakker 1988).

While none of the flowers from September planting had abnormal anthers, above 35% and most of the flowers of October and November plantings, respectively, had such anthers (Table 4). Abnormal anthers were shrivelled and had very narrow longitudinal slits, apparently resulting in poor pollen dehiscence during the last two plantings. Irrespective of the antheridial condition, pollen production, as indicated by weight of pollen grains per flower, decreased with the delay in planting (Table 4). This decline which seems to be primarily induced by the low temperature (Charles and Harris 1972) was slight in October, while it was substantial to be statistically significant, at the 5% level, for all cvs and experimental periods, in November planting.

Under these conditions, other possible abnormalities which might occur with the flowers with pollen free stigmas were pollen inviability (Charles and Harris 1972) and perhaps female sterility (Picken 1984). This and the drop of some pollinated flowers, as indicated by the higher percentage of the flowers with pollen grains on their stigmas in comparison with that of fruit set (Tables 1 and 3), made it worthwhile to investigate these abnormalities.

As expected, pollen viability was significantly reduced in late plantings (Table 4). But, still above 60% of the pollen grains produced by October planting were

Table 2. The fruit yield and its components of three tomato cvs grown at three planting dates

Planting date	No. of fruits per plant			Ave fruit weight (g)			Total fruit weight per plant (kg)		
	Pearson	Marmande	VFN-8	Pearson	Marmande	VFN-8	Pearson	Marmande	VFN-8
1987									
Sept	17 Aa*	16 Aa	13 Ba	88	73	86	1.525 Aa	1.165 Ba	1.145 Ba
Oct	10 Ab	11 Ab	7 Bb	55	51	48	0.532 Ab	0.545 Ab	0.336 Bb
Nov	4 ABc	5 Ac	1 Bc	19	29	17	0.068 Ac	0.151 Ac	0.025 Ac
1988									
Sept	17 Aa	16 Aa	12 Ba	92	68	80	1.557 Aa	1.091 Ba	0.982 Ba
Oct	11 Ab	12 Ab	6 Bb	48	51	43	0.540 Ab	0.610 Ab	0.271 Bb
Nov	1 Bc	4 Ac	0 Bc	13	18	–	0.018 Ac	0.064 Ac	0.000 Ac

* As in Table 1.

Table 3. Percents pollen - free stigmas of three tomato cvs grown at three planting dates

Planting date	Cultivars			Mean
	Pearson	Marmande	VFN-8	
1987				
Sept	0.0 Ac*	5.0 Ac	6.7 Ac	3.89 c
Oct	41.7 ABb	33.3 Bb	48.3 Ab	41.11 b
Nov	75.0 ABa	70.0 Ba	81.7 Aa	75.56 a
Mean	38.89 AB	36.11 B	45.56 A	
1988				
Sept	5.0 Ac	5.0 Ac	10.0 Ac	6.67 c
Oct	45.0 Ab	28.3 Bb	48.3 Ab	40.55 b
Nov	86.7 ABa	78.3 Ba	93.3 Aa	86.11 a
Mean	45.56 A	37.22 B	50.55 A	

* As in Table 1

viable, whereas most of these produced later were inviable, with cv Marmande being less affected, followed by cv Pearson. The artificial pollination, using viable pollen grains, resulted in more than 90% and less than 20% fruit, set for all cvs, in the first two and the last plantings, respectively (Table 5). Comparing these values with those of the natural pollination (Table 1) indicates that the artificial pollination improved fruit set substantially for the first two plantings, while it had no significant effect during the last one. Thus, it may be deduced that both low pollen viability and female sterility were limiting factors for fertilization and fruit set during November planting only. On the other hand, the drop of pollinated flowers during the first two plantings was probably due to poor pollen dehiscence resulting in too few pollen grains per stigma to induce the swelling and enlargement of the ovaries. In addition, the drop of some of these flowers, especially the distal ones, could be induced by the competition with others for assimilates (Picken 1984).

The reduction in average fruit weight with the delay in planting (Table 2) might be ascribed to the same abnormalities as with the failure of fruit set. It seems that these abnormalities had reduced the number of fertilized ovules and, subsequently, the number of seeds per fruit which, in turn, could have resulted in a progressively smaller fruits (Imanishi and Hiura 1977).

Therefore, the fruit yield of field-grown tomato in Qassim, during early winter could be increased by using some practices which improve the pollination

Table 4. Antheridial and pollen characteristics of three tomato cvs grown at three planting dates

Planting date	Flowers with abnormal anthers (%)			Pollen weight per flower (mg)			Viable pollen grains (%)		
	Pearson	Marmande	VFN-8	Pearson	Marmande	VFN-8	Pearson	Marmande	VFN-8
1987									
Sept	0.0 Ac*	0.0 Ac	0.0 Ac	7.5 Aa	7.1 Aa	7.4 Aa	92 Aa	96 Aa	89 Aa
Oct	42.0 Ab	36.7 Ab	45.0 Ab	5.7 ABb	6.2 Aa	5.0 Ab	66 Ab	70 Ab	55 Ab
Nov	83.3 Aa	65.0 Ba	86.7 Aa	1.0 ABc	2.1 Ab	0.3 Bc	14 ABc	22 Ac	8 Bc
1988									
Sept	0.0 Ac	0.0 Ac	0.0 Ac	7.4 Aa	6.8 Aa	7.1 Aa	90 Aa	93 Aa	96 Aa
Oct	38.3 Ab	35.0 Ab	46.7 Ab	5.5 Aa	5.6 Aa	5.0 Ab	61 Ab	68 Ab	59 Ab
Nov	96.7 Aa	86.7 Bb	100.0 Aa	0.7 Ab	1.6 Ab	0.1 Ac	12 ABc	18 Ac	5 Bc

* As in Table 1.

Table 5. Percents fruit set of artificially (hand) Pollinated flowers, using viable pollen, of three tomato cvs grown at three planting dates

Planting date	Cultivars			Mean
	Pearson	Marmande	VFN-8	
1987				
Sept	91.7 Aa*	95.0 Aa	91.7 Aa	92.78 a
Oct	95.0 Aa	96.7 Aa	90.0 Aa	93.89 a
Nov	6.7 ABb	20.0 Ab	5.0 Bb	10.56 b
Mean	64.45 B	70.56 A	62.22 B	
1988				
Sept	95.0 Aa	93.3 Aa	95.0 Aa	94.44 a
Oct	96.7 Aa	93.3 Aa	91.7 Aa	93.89 a
Nov	5.0 ABb	13.3 Ab	0.0 Bb	6.11 b
Mean	65.56 A	66.66 A	62.22 A	

* As in Table 1

efficiency, such as flower vibration (Verkerk 1957, Kepcka 1966). Alternatively tomato genotypes with high pollination efficiency should be searched for, so as to incorporate this character into genetic backgrounds suitable for Qassim region. However, for late winter, a group of genotypes with complementary characteristics is needed to develop a suitable cv.

Conclusion

As temperatures and light intensity decreased with the delay in planting, more number of days were needed by all tomato cvs (Pearson Al-improvd, Marmande, VFN-8) to reach anthesis. Conversely, the number of flowers per plant, percent fruit set, average fruit weight and, consequently, total fruit weight decreased significantly. Flower examination indicates that the percentage of flowers with pollen-free stigma and with abnormal anthers as well as pollen viability and production had followed the same trend. However, the reduction in pollen viability and production was substantial only during the last (November) planting.

Using viable pollen grains, artificial pollination improved fruit set significantly during the first two (September and October) plantings, while it had no effect during the last one.

Thus, the failure of fruit set could be attributed to inefficient pollination during the first two plantings, in addition to lack of fertilization during the last planting. Inefficient pollination was apparently due to poor pollen dehiscence, in addition to poor pollen production during the first two and the last plantings, respectively, whereas the lack of fertilization could be ascribed to poor pollen viability and female sterility. The reduction in average fruit weight with the delay in planting, was, probably, induced by the abnormalities as the failure of fruit set.

Although cv Marmande outperformed the others at late plantings still its yield was very low. To increase the yield of field-grown tomato at early winter, some practices which improve pollination efficiency, such as flower vibration, may be employed. Nevertheless genetic improvement could be achieved by using genotypes with complementary strengths to develop suitable cvs for Qassim area.

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النمو الثمري للطماطم في منطقة القصيم بالمملكة العربية السعودية أثناء فصل الشتاء

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زرعت أصناف الطماطم بيرسون أ ١ - المحسن ومارماند و قي اف ان - ٨ في سبتمبر ثم في أكتوبر ثم في نوفمبر خلال عامي ١٩٨٧ و ١٩٨٨ م وذلك لدراسة مسببات إنخفاض إنتاجية الطماطم الحقلية في منطقة القصيم بالمملكة العربية السعودية أثناء فصل الشتاء.

أدى تأخير الزراعة إلى زيادة المدة من الزراعة حتى تفتح الأزهار بينما انخفض عدد الأزهار ونسبة الثمار العاقدة ومتوسط وزن الثمرة وبالتالي الوزن الكلي للثمار. كان الإنخفاض في عدد الأزهار طفيفاً بالمقارنة مع نسبة الثمار العاقدة ومتوسط وزن الثمرة.

أثبت فحص الأزهار أن هنالك إنخفاضاً ملموساً في نسبة الأزهار الملقحة وحيوية حبوب اللقاح بالإضافة إلى وزن حبوب اللقاح المنتجة كلما تأخرت الزراعة، كما أثبت التلقيح اليدوي حدوث انخفاضٍ شديدٍ في حيوية الجزء الأنثوي للأزهار عند الزراعة في نوفمبر.

من هذا يتضح أن فشل عقد الثمار يعزى إلى عدم حدوث التلقيح عند الزراعة في سبتمبر وأكتوبر وإلى عدم حدوث التلقيح والاخصاب عند الزراعة في

نـوفمبر. يـرجع عـدم حدوث التلقيـح إلى إنخفاض إنتشـار حبوب اللقـاح عنـد الزراعة في الميعادين الأول والثاني، بـالاضافـة إلى إنخفاض انتـاج حبوب اللقـاح عند الزراعة في الميعاد الأخير. أما عـدم حدوث الاخصـاب فيرجـع إلى انخفاض حيوية حبوب اللقاح والعقم **الانثـوي**. من المرجـح أن تكون هـذه العوامـل ذاتها هي المسؤولة عن انخفاض متوسط وزن الثمرة أيضاً.

كان الصنف مارماند هو الأحسن، يليه الصنف بيرسون أ ١ ـ المحسن، عند الزراعة المتأخرة.