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ACHIEVING LARGER 'ETTINGER' FRUITS IN WESTERN GALILEE, ISRAEL

G. Ish-Am[1], H. Cohen[2], E. Eidelman[3], I. Regev[4], L. Winer[5] and E. Lahav[6]
[1] Agricultural R&D Western Galilee, Agricultural Experimental Farm, D.N. Oshrat 25212, Israel; and Ohalo College, P.O.B. 222, Katzrin 12900, Israel. ishamgad@macam.ac.il
[2] Extension Service, Israel Ministry of Agriculture, Yad Natan, D.N Oshrat 25212, Israel. hadco@shaham.moag.gov.il
[3] Ein-Hamifratz, D.N Oshrat 25210, Israel. eid_mata@netvision.net.il
[4] Extension Service, Israel Ministry of Agriculture, Yad Natan, D.N Oshrat 25212, Israel. itsreg@shaham.moag.gov.il
[5] Extension Service, Israel Ministry of Agriculture, 35 David Shimoni St. Hedera 38364, Israel. leowin@shaham.moag.gov.il
[6] Agricultural R&D Western Galilee, Agricultural Experimental Farm, D.N. Oshrat 25212, Israel. emilahav@gmail.com

'Ettinger' is the second most important avocado cultivar in Israel, constituting 25% of the avocado planted area. Due to local favorable climatic conditions in the Western Galilee, the fruits there reach maturity and marketing size in mid-September, two weeks earlier than in most other Israeli growing regions. The early fruits achieve a much higher price than the in-season ones, but only 285 g fruits and those heavier fit the early marketing limitations. Therefore, the growers try to get a higher percentage of fruits of this size. Avocado fruit growth is a combined effect of fruit-cell division and cell enlargement, in which the former is predominant during the early fruit growth stages and the latter becomes more important later.
This research aimed at developing a technology which would increase the 'Ettinger' large-fruit yield.
Throghout five seasons (2001 to 2006) we studied application of auxin spray at the start of blooming; cytokinin and auxin during the early fruit-set; spray of auxin and gibberellin-inhibitor, as well as girdling during the summer. Only the early fruit-set cytokinin spray showed a consistent positive effect. It increased the large-fruit yield in 9 out of 12 experiments, by an average of 16% (max 39%, min 5%). In two experiments it showed no effect, and in one experiment it had a negative one. The most effective cytokinin (benzyl adenine) concentration was between 30 and 50 ppm. The best timing found was one spray application about four weeks after the blooming peak.

Key words. *Persea americana*, fruit set, cytokinin, auxin, Benzyladenine

INCREMENTO DEL TAMAÑO DEL 'ETTINGER' EN EL NORESTE DE ISRAEL (GALILEA)

G. Ish-Am[1], H. Cohen[2], E. Eidelman[3], I. Regev[4], L. Winer[5] y E. Lahav[6]

[1] Agricultural R&D Western Galilee, Agricultural Experimental Farm, D.N. Oshrat 25212, Israel; and Ohalo College, P.O.B. 222, Katzrin 12900, Israel. ishamgad@macam.ac.il

[2] Extension Service, Israel Ministry of Agriculture, Yad Natan, D.N Oshrat 25212, Israel. hadco@shaham.moag.gov.il

[3] Ein-Hamifratz, D.N Oshrat 25210, Israel. eid_mata@netvision.net.il

[4] Extension Service, Israel Ministry of Agriculture, Yad Natan, D.N Oshrat 25212, Israel. itsreg@shaham.moag.gov.il

[5] Extension Service, Israel Ministry of Agriculture, 35 David Shimoni St. Hedera 38364, Israel. leowin@shaham.moag.gov.il

[6] Agricultural R&D Western Galilee, Agricultural Experimental Farm, D.N. Oshrat 25212, Israel. emilahav@gmail.com

'Ettinger' es el segundo cultivo de aguacate más importante en Israel y constituye 25% del área de huertos plantados con aguacate. Debido a las buenas condiciones climáticas en la zona noreste de Israel (Galilea), 'Ettinger' madura y llega al tamaño adecuado al mercado a mediados de septiembre, dos semanas antes que el resto del país. Este fruto obtiene un precio más alto que el fruto de temporada, aunque sólo el fruto que llega al tamaño promedio de 285 gr. es cosechado, por lo tanto, es importante para los agricultores obtener un mayor porcentaje de frutos de este tamaño. El crecimiento del fruto de aguacate depende de un efecto conjunto de la división de las células y de su crecimiento. La división celular ocurre predominantemente durante la primera fase de evolución del fruto, mientras que su crecimiento se considera más importante en forma posterior. El objetivo de esta investigación fue el desarrollo de una tecnología que permita obtener un 'Ettinger' de mayor tamaño. Durante 5 temporadas (2001-2006) se examinaron los siguientes tratamientos: aplicación de auxina durante el principio de la floración, aplicación con citoquinina y auxina durante la primera etapa de cuaja; aplicación con auxina y un inhibidor de giberelina y anillado durante el verano. Un efecto positivo fue logrado sólo con el tratamiento de citoquinina, elevando en un promedio de 16% (máx. 39%-min.5%) el tamaño del fruto en 9 de 12 experimentos. En dos experimentos no hubo efecto alguno y en uno se logró un efecto contrario. La concentración más efectiva de citoquinina (adenina bencílica) estuvo entre 30 a 50 ppm. Se determinó que el momento más adecuado para su aplicación era luego de cuatro semanas posteriores al punto más alto de floración.

INTRODUCTION

'Ettinger' is the second most important avocado cultivar in Israel, constituting about 25% of the avocado orchards' area. Since the 80's, when the 'Ettinger' had been proved to be the best pollinizer, under Israel conditions, of the main A flowering-type cultivars (Gazit, 1977; Degani and Gazit, 1984; Guil et al., 1986; Degani et al., 1989), its proportion has been increasing. Moreover, the 'Ettinger' has a high market value, both in the local market and for export. This green skin and high fat-containing flesh avocado matures early, during October, which promotes its acceptance by the comparatively empty market of that season. Due to favorable local climatic conditions the 'Ettinger' fruits of the north-western region of the country (the Western Galilee) mature early, in mid September, about two weeks before most of the other Israeli growing regions. The early fruits achieve a higher market price, and therefore the Western Gelilee growers try at that season to maximize the marketable fruit rate, which need to reach, or exceed the size of 286 g.

As with other fruits, the avocado fruit growth results from a combined effect of cell division and cell growth. However, not as in many other fruits, the avocado fruit-cell division is not limited to the early fruit-growth stages, but continues throughout its development, being predominant mainly during the early fruit-growth stages (Schroeder, 1958; Nitsch, 1965). One may distinguishe three stages of avocado fruit growth: the first stage: slow growth, resulting mainly from cell division; the second stage: fast growth, resulting from fast cell growth and a moderate rate of cell division; and the third stage: slower growth rate, due to a slower rate of both cell division and cell growth, or even cell growth cessation and only cell division continuation (Bower and Cutting, 1988).

The course of fruit growth is controlled by a complex array of plant growth regulators (PGRs), mainly auxines (IAA), cytokinins (CKs), gibberellines and ABA. The PGRs originate from various plant organs, including roots, active buds, the fruit embryo and other fruit parts. These PGRs control both fruit cell division and cell growth, as well as resource supply to the growing fruit, and the fruit ripening progress (Martens et al., 1994). Similar cell sizes were observed in large, as well as in small 'Hass' fruits, while these fruits were found to differ in their cell quantity (Cowan et al., 1997). In other words, the limiting factor of 'Hass' avocado fruit size is not cell growth but cell division. Cytokinins are active in promoting cell division in various plant organs, including fruits. High levels of CKs in avocado fruits were reported by Gazit and Blumenfeld (1970), who found a positive correlation between CKs' level and fruit growth rate resulting from cell division. In later works it was further demonstrated that high levels of both CKs and IAA are necessary for the fruit's proper growth. However, fruit-growth rate may be restrained under a high level of ABA, which may play an antagonistic role to the CKs (Cowan et al., 1999; 2005).

Increasing fruit size, as well as yield, has been achieved in numerous fruit trees by applying exogenous PGRs during bloom and fruit growth (Elfving and Visser, 2006). In Israel a foliar application of gibberellin inhibitors during bloom is commercially used for that purpose (Adato, 1990, 1992). A foliar application, or application by

irrigation of CKs on avocados were also studied, with some positive results (Lovatt, 2005, Salazar-Garcia et al., 2006, Ish-Am et al., not published).

This research was aimed at developing a technology, which would increase the 'Ettinger' large-fruit yield by PGRs' implication during bloom, early fruit-set and fruit development.

MATERIALS AND METHODS

Experiments were carried out during five consecutive seasons (2001 to 2005), in 'Ettinger' plots of commercial orchards in the costal plain of the Western Galilee, Israel, Longitude 35º10' E, Latitude 33º00' N.

Treatments included the following foliar-applied PGRs: The cytokinin Benzyladenine (BA, 6-Benzylaminopurine, Bongrow®), the auxin Maxim® (3,5,6–TPA), the auxin Hadranol® (2,4-D) and the gibberellin inhibitor Magic® (Paclobutrazol).

Each experiment included several treatments and a non-treated control. Each treatment included four replications, each of which consisted of a single row of 15 to 20 trees (about 0.05 ha). The fruits of each replication were harvested, weighed and sorted as one group. Timing of application and PGR concentrations are presented in Tables 1 and 2. The timing of application is indicated by the number of days (d) that passed between full bloom date (FB) and the application date.

RESULTS

No effect had been observed in the auxin experiments (Table 2, Exp 13, 14, 16), nor in the gibberellin–inhibitor one (Table 2, Exp 15). Therefore these experiments discontinued. However, significant results had been demonstrated in the BA experiments (Table 3).

BA concentration effect, which has been studied during the 2001, 2002 and 2005 seasons, was maximal within the range of 20 to 50 ppm (Table 3, Exp 1, 2, 3, 4, 12, and Fig 1). Therefore BA concentration of 30 (or 40) ppm was selected for the following seasons' experiments. Three BA applications of each concentration were employed during the first two seasons (Table 1, Exp 1 to 4), while the preferred number of applications was studied during the 2003 season (Table 3, Exp 5, 6, 7). Only one application was used throughout the last two seasons (Table 1, Exp 8 to 12), since two or three applications were found to only moderately increase yield parameters, or not affect them at all, while one application was more effective (Table 3, Exp 8 to 12). The optimal timing for the single application was not very clear (Table 3, Exp 8 to 11). A single application achieved the maximal effect at different timings, from FB–7d to FB+28d, and in most experiments exhibited yield improvement at all timings (Table 3, details are not reported here).

Table 1: Five seasons' experiments with foliar applied Benzyladenine (BA)
All experiments included an untreated control
Tabla n° 1: Resumen de experimentos realizados durante cinco temporadas con aplicación foliar de Benzyladenine (BA)
Todos los experimentos incluyen un no tratado - control
FB = time of full bloom, d = days.

Exp No	Experiment site	Variable studied	BA concentrations (ppm)	Number of applications	Timing of application
	2001 season				
1	Gesher Haziv	BA concentration	0, 5, 10, 20, 50, 100	3	FB+14d FB+28d FB+42d
2	Matzuva	BA concentration	0, 20, 50	3	FB+14d FB+28d FB+42d
	2002 season				
3	Lohamey Hageta'ot	BA concentration	0, 20, 40, 60	3	FB+14d FB+28d FB+42d
4	Matzuva	BA concentration	0, 20, 50	3	FB+14d FB+28d FB+42d
	2003 season				
5	Shomrat	Number of applications	0, 30	1, 2, 3	FB FB+21d FB+42d
6	Matzuva	Number of applications	0, 30	1, 2	FB FB+21d
7	Lohamey Hageta'ot	Additional replication	0, 30	1	FB
	2004 season				
8	Shomrat	Timing of application	0, 30	1	FB-7d FB FB+10d
9	Bet Ha'emek	Timing of application	0, 30	1	FB-7d FB FB+10d
10	Matzuva	Timing of application	0, 30	1	FB-7d FB
	2005 season				
11	Shomrat	Timing of application	0, 40	1	FB FB+14d

					FB+28d
12	Lohamey Hageta'ot	BA concentration	0, 20, 40, 60	1	FB+14d

Table 2: Three seasons' experiments with foliar applied PGRs, other than BA
All experiments included an untreated control
Tabla nº 2: Resumen de experimentos realizados durante tres temporadas con aplicación foliar de varios PGRs
Todos los experimentos incluyen un no tratado - control
FB = time of full bloom, FFO = time of first flower opening, d = days, w = weeks.

Exp No	Experiment site	PGR studied	PGR concentration	Number of applications	Timing of application
	2001 season				
13	Gesher Haziv	Maxim	3 ppm	3	FB+14d FB+28d FB+42d
	2002 season				
14	Bet Ha'emek	Hadranol	0.015%	1	FB+15w (August 1st week)
15	Bet Ha'emek	Magic	0.3%	1	FB+15w (August 1st week)
	2003 season				
16	Lohamey Hageta'ot	Hadranol	0.015%	1	FFO

Fig 1: Effect of BA concentration, and Maxim addition, on 'Ettinger' yield (Exp 1, Gesher Haziv 2001)
Figura 1: Efecto de BA, y Maxim sobre el rendimiento total de 'Ettinger' (Gesher-Haziv 2001)

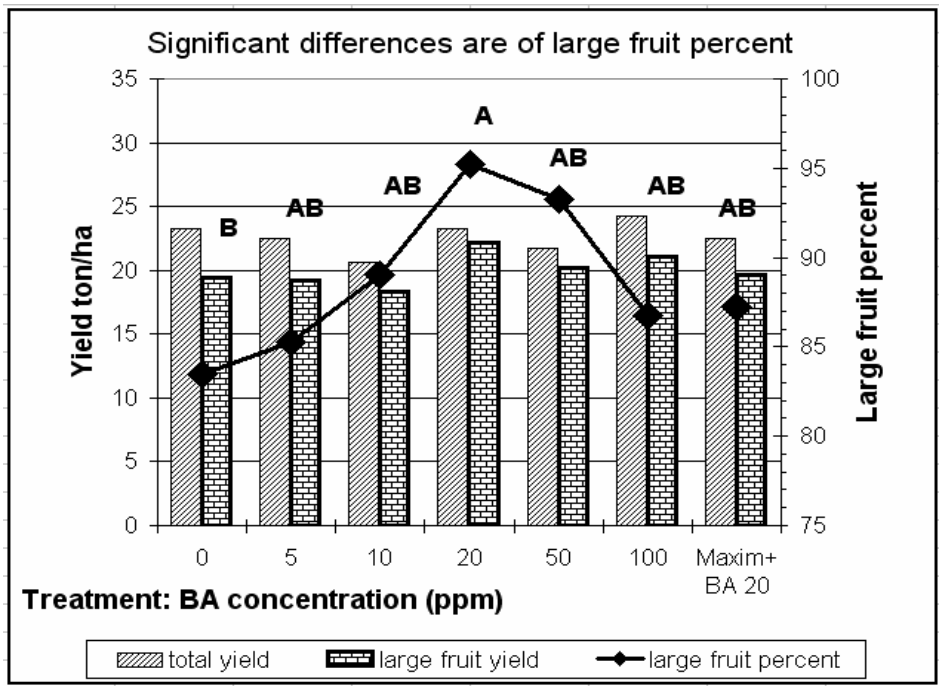

Table 3: Results of five seasons' experiments with foliar applied BA
Tabla n° 3: Resultados de experimentos realizados durante cinco temporadas con aplicación foliar de Benzyladenine (BA)
FB = time of full bloom, d = days.

Exp No	Variable studied	Control yield		Best treatment	Best treatment to control ratio (%)			Comments
		Total yield (tons^{x}ha^{-1})	Large fruit percent		Large fruit yield	Large fruit percent	Total yield	
	2001 season							
1	BA concentration	23.3	83.5	20 ppm	114	114 *	100	**
2	BA concentration	20.9	90.9	50 ppm	99	102	97	young trees
	2002 season							
3	BA concentration	32.4	46.0	40 ppm	108	94	115	
4	BA concentration	25.5	84.4	50 ppm	106	120 *	96	young trees
	2003 season							
5	Number of applications	8.87	81.6	one and two applications	109	107 *	103	

6	Number of applications	16.6	88.6	control and one application	91	98	94	young trees
7	Additional replication	7.09	86.1	one application	118	105	112	***
	2004 season							
8	Timing of application	19.6	78.6	FB–7d	133	103	128	**
9	Timing of application	28.3	78.7	FB+10d	114	97	118	** ***
10	Timing of application	29.3	76.2	FB	105	99	108	
	2005 season							
11	Timing of application	14.6	70.1	FB+28d	139 *	106	127 *	**
12	BA concentration	18.5	77.4	40 ppm	100	102	98	
Average of all Exp		**20.41**	**78.51**		**111.3**	**103.9**	**108.0**	

* Differ significantly from the control ($p<0.05$)

** Large fruit yield increased in all treatments

*** Significance couldn't be tested since repetitions' yields were not separated

DISCUSSION

The objective of this research was to increase 'Ettinger' large-fruit yield, and hence this parameter will be primarily discussed. However, total yield, as well as large fruit percentage will be elaborated as well.

Auxin application at the beginning of- and during bloom, as well as during advanced stages of fruit evolution (Table 2, Exp 13, 14, 16), did not contribute to the yield. This may be understood from the conclusion that large and small avocado fruits differ not by their cell size but by their cell number, as was found for 'Hass' (Cowan et al., 1997). In other words, the avocado growth limiting factor is the continuing cell-division process, which is mainly controlled by the cytokinins and less so by the auxins.

Gibberellin inhibitor application during full bloom is commercially accepted as an effective tool for increasing both fruit growth and fruit retention on the tree (Adato, 1990, 1992). This effect had been explained as a result of shoot-growth inhibition, which increases resource supply to the young fruits and, in turn, strengthens their embryo and promotes cell division. However, in this work gibberellin inhibitor, which was applied much later in the course of fruit development (Table 2, Exp 15), had no effect on both fruit growth and fruit retention. It may be assumed that the already retained fruits at that stage are strong enough to compete with the shoot growth for resource supply.

BA concentration effect on 'Ettinger' large-fruit percent, and to a lesser extent on large-fruit yield, exhibited a typical maximum curve (Fig 1, Exp 1). Both 5 ppm, and 100 ppm BA were found to have no effect, while 20 to 50 ppm BA showed a maximum effect. In other words, too low BA concentration is not enough for promoting avocado fruit cell division, while too high concentration is again ineffective.

A possible explanation for the advantage of a single BA application over two and three applications may be an overdose effect, which was revealed in Exp 1 (Fig 1). It may be further suggested that an exogenous application of an optimal BA concentration promotes endogenous cytokinin production, which later reacts as an overdose with the additional exogenous application (see also later).

The 'Ettinger' bloom in Israel lasts about 8 weeks. New flowers open daily throughout this period, and may set fruits. Therefore, the tree may carry fruits of different ages throughout blooming, as well as later on. Moreover, the best period for pollination and fruit set changes between seasons and locations, depending on the weather and on the blooming time of the local species that compete for pollination with the avocado bloom (Ish Am and Eisikowitch, 1998). Assuming there is a preferred stage of fruit development for an exogenous cytokinin application, the best timing for BA application may also change between seasons and locations. Since this best timing is not known in advance, and was found to be within the range of FB–7d to FB+28d, we recommend using the FB+14d timing for the BA application.

No correlation has been found between treatment effectiveness and the control total yield (Table 3). That is to say, a meaningful increase in large-fruit yield (and somewhat less so in total yield) was achieved under low yield conditions (Table 3, Exp 5, 7), medium yield conditions (Table 3, Exp 8, 11) and even under very high yield conditions (Table 3, Exp 1, 3, 9). However, some connection has been noticed between treatment effectiveness and the control large-fruit percent (Table 3, $p=0.097$ for the correlation between total yield increase and the control large-fruit percent). Most effective total-yield increase, and also (but somewhat less so) large-fruit yield increase, has been achieved in experiments of low, or medium large-fruit percent of the control, while in the cases of a very high large-fruit percent of the control (about 90%) the total-yield increase was nil, or even negative (see in Table 3, Exp 2, 6, which were performed in a young orchard). This effect may be explained by the assumption that large 'Ettinger' avocado fruits carry a higher rate of active endogenous CK than the small ones, and therefore addition of an exogenous CK may be more effective (enhancing growth) for the latter fruits than for the former.

Large-fruit yield has increased in 9 out of 12 experiments (Table 3), while out of the other three experiments in two the control large-fruit rate was very high (about 90%). The average increase of large-fruit yield was 11.3% in all 12 experiments and 14.6% in the 10 experiments where the large-fruit rate was not very high. Total-yield average increase was 8.0% and 10.5%, and large-fruit rate increase was 3.9% and 4.7% in all 12 experiments, and in the 10 experiments where the large-fruit rate was not very high, respectively.

In conclusion, an Israeli farmer who does not have a high enough 'Ettinger' large-fruit rate, and applies BA using the above recommended method (a foliar application of BA concentration of 30-40 ppm; one application on FB+14d), may expect an increase of about 15% in the large-fruit yield, which may be mainly significant during the early-season harvest (mid to end of September).

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