ΓΕΩΠΟΝΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ
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ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

«Η επίδραση της εφαρμογής καρποδετικών ορμονών στο στάδιο της άνθησης στα μορφολογικά και φυσιολογικά χαρακτηριστικά του καρπού της μελιτζάνας (*Solanum melongena* L.) κατά την ανάπτυξη, ωρίμανση και αποθήκευση»

"The effect of fruit-setting hormones applied at the stage of flowering on the morphological and physiological characteristics of eggplant (*Solanum melongena* L.) fruit during growth, maturation and storage"

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ΑΘΗΝΑ
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Abstract

During the cool season within the Mediterranean region, vegetable growers frequently use growth regulators to set eggplant fruit. Although this is a generally accepted technique to permit eggplant production at a time when pollen formation and fertility is low, the effect of growth regulator application on fruit quality and storage life has not been previously documented. Therefore, between 2008 and 2011 four experiments were carried out with the aim of defining in detail the effects of fruit-setting hormones not only on fruit set, but also on the morphological and physiological characteristics of eggplant fruit during growth, maturation and storage.

In the first experiment (2008-2009), four cultivars of eggplant, Tsakoniki and Black Boy (elongate fruit), Black Beauty and Emi (flask-type fruit) were grown both in greenhouse and open field during two consecutive cropping seasons: spring and autumn. Plant growth regulators (PGR), viz. β-NOA (60 ppm), NOA (60 ppm) + BA (30 ppm), and BA (30 ppm), were applied to emasculated flowers at anthesis to set fruit parthenocarpically, while in the control treatment fruit set was achieved by natural pollination. The morphological and physiological changes during growth and maturation of the parthenocarpic (seedless) and seed-containing fruit were compared. NOA effectively promoted fruit-set and improved all morpho-physicochemical characteristics of fruits irrespective of seasons and growing conditions. The application of BA in combination with NOA did not confer any particular benefit on fruit set and development, while the application of BA alone was ineffective in setting parthenocarpic eggplant, irrespective of cultivar, growing method (greenhouse or open field) and season (spring or autumn). Fruits set by NOA or NOA + BA had a higher mean weight than seed-containing fruit due to increased fruit length and diameter, but in most cases the dry matter content of parthenocarpic fruit was lower than that of seed-containing fruit. No significant differences were observed in the development of pericarp colour (L, C* and Hº) between parthenocarpic and seed-containing fruit at different days after anthesis. Other morpho-physiological traits (e.g. peduncle and calyx length) were not affected by PGR application. Measurements of pollen production, *in vitro* germination and pollen tube growth revealed significant differences in heat/cold susceptibility of the cultivars and so confirmed the need for PGR application during times of very high or low temperatures.

In the second experiment (2008-2009) the physico-chemical characteristics of parthenocarpic and seed-containing fruit were compared. From the results, it was found that the application of PGR (NOA or NOA + BA) did not affect the external or internal firmness of the fruit. Both the ascorbic acid (except in autumn grown Tsakoniki and Black Beauty) and the protein content of parthenocarpic fruit was similar to that of seed-containing fruit. A high variability in the anthocyanin content of the pericarp was detected and was independent of PGR application. It was also observed that the central region of the fruit (i.e. in or near the placenta) contained higher levels of phenolics than the proximal end of the fruit (tissue near the calyx) and that in general fruit set by PGR had a lower content of phenolics in both regions of the fruit than seed-containing fruit. However, no significant differences in the level of browning of the flesh (due to phenolics oxidation) were detected between parthenocarpic and seed-containing. PGR application for fruit set caused an increase in the concentrations of glucose and fructose in the fruit, whereas sucrose, maltose and starch were unaffected. Irrespective of PGR application, fruits set in spring tended to have higher sugar and starch levels than fruit set in autumn.

In experiment 3 (carried out in 2009 and 2011), the storage behaviour of fruit of cvs. Tsakoniki and Black Beauty grown in the greenhouse or open field was recorded at 10 and 20ºC for a period of up to 14 to 20 days. In all cases, fruits that were stored in air rapidly lost weight and became unmarketable within 7 days due to shriveling. In contrast, film-wrapped fruit lost weight at a greatly reduced rate and fruit firmness and colour were retained during storage. Film-wrapping also reduced the rate of loss of ascorbic acid during storage, while the phenolics content of wrapped fruit was lower than that of unwrapped fruit. Overall, parthenocarpic fruit showed a similar storage behaviour to that of seed-containing fruit, while storage at 10ºC maintained fruit quality better than 20ºC.

In experiment 4 (2011), fruit of cvs. Tsakoniki and Black Beauty were stored in controlled atmospheres, viz. CA_1 (3% O_2 + 3% CO_2), CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 + 0.035% CO_2), at 10ºC for 20 days. Early during storage (by day 7), decay symptoms were observed in CA_1 and this treatment was therefore discontinue. No decay was observed in the other two storage atmospheres. Both controlled atmospheres (CA_2 and CA_3) maintained better calyx and pericarp colour of the fruit. Within the controlled atmospheres, the external firmness of parthenocarpic fruit of cv. Tsakoniki remained higher than that of the seed-containing fruit, but internal firmness did not differ. Controlled atmosphere storage effectively reduced weight loss and it was observed that water loss through the calyx was 3-fold higher than via the pericarp; this accounted for the higher

water loss in Tsakoniki than in Black Beauty because of the higher calyx : pericarp ratio in the former. No detectable ethylene was found in the storage atmosphere, but a significant reduction in ascorbic acid content was detected in the parthenocarpic fruit of both cultivars. The protein and anthocyanin content of both parthenocarpic and seed-containing fruit was relatively stable during controlled atmosphere storage. Moreover, the total phenolics content was not affected by the storage environment, or by the presence or absence of seeds in the fruit. Higher atmospheric O_2 and lower CO_2 enhanced the degradation of starch with a concomitant increase in the concentrations of glucose, fructose and sucrose, but not maltose.

In conclusion, the application of NOA (or NOA + BA) proved a satisfactory method of obtaining fruit set in the eggplant cultivars examined in the present study. Overall, the quality of prthenocarpic fruit was similar to that of seed-containing fruit produced by natural pollination irrespective of cultivation method (greenhouse or open field) and season. Parthenocarpic fruit stored equally as well as seed-containing fruit, provided that fruit were enclosed in polyethylene film. Controlled atmospheres storage did not confer any additional benefit on the storage life or quality of parthenocarpic or seed-containing fruit beyond that obtained by fruit wrapping in polyethylene.

Περίληψη

Τα πειράματα που περιγράφονται στην παρούσα εργασία πραγματοποιήθηκαν με σκοπό να μελετηθεί η πορεία της ανάπτυξης, τα ποιοτικά χαρακτηριστικά και η μετασυλλεκτική συμπεριφορά των παρθενοκαρπικών (άσπερμων) καρπών της μελιτζάνας που προήλθαν από την εφαρμογή ρυθμιστών ανάπτυξης σε σχέση με των ένσπερμων καρπών που προέρχονται από φυσιολογική επικονίαση.

Στο πρώτο πείραμα, δύο ελληνικές ποικιλίες μελιτζάνας (Τσακώνικη και Emi) και δύο εισαγόμενες ποικιλίες (Black Beauty και Black Boy) καλλιεργήθηκαν στο θερμοκήπιο και στον αγρό σε δύο εποχές, την άνοιξη (2009) και το φθινόπωρο (2008). Η πορεία της ανάπτυξης και το εξωτερικό χρώμα των καρπών καταγράφηκαν από την καρπόδεση έως και τη συγκομιδή και οι συγκομισθέντες καρποί αναλύθηκαν ως προς το περιεχόμενό τους σε ξηρά ουσία. Παράλληλα με την ανάπτυξη των καρπών, καταγράφηκε η παραγωγή της γύρης ανά άνθος και προσδιορίστηκαν η βιωσιμότητα και η ζωτικότητα της γύρης με τη χρήση *in vitro* δοκιμών βλάστησης. Τα αποτελέσματα έδειξαν ότι το *β*-naphthoxyacetic acid (NOA) προώθησε αποτελεσματικά την καρπόδεση τόσο στο θερμοκήπιο, όσο και στον αγρό, ανεξάρτητα από την εποχή καλλιέργειας, ενώ η εφαρμογή μόνο βενζυλαδενίνης (BA) απέτυχε την επαγωγή της καρπόδεσης σε καμιά ποικιλία και η συνδυασμένη εφαρμογή NOA με BA είχε παρόμοια επίδραση με την εφαρμογή μόνο NOA. Το μήκος και η διάμετρος των παρθενοκαρπικών καρπών που έδεσαν με την εφαρμογή NOA ήταν μεγαλύτερα από τις αντίστοιχες τιμές στους ένσπερμους που παρήχθησαν με φυσιολογική γονιμοποίηση, ως εκ τούτου, οι παρθενοκαρπικοί καρποί ήταν μεγαλύτεροι σε μέγεθος και βαρύτεροι, γεγονός που με τη σειρά του αύξησε την απόδοση και την εμπορευσιμότητα των καρπών. Όμως, οι ρυθμιστές ανάπτυξης μείωσαν τη συσσώρευση του ξηρού βάρους στους καρπούς. Αν και δεν παρατηρήθηκαν σημαντικές διαφορές στις παραμέτρους του χρώματος L, C* και Hº μεταξύ των παρθενοκαρπικών και των ένσπερμων καρπών όλων των ποικιλιών κατά την ανάπτυξή τους, οπτικά, κατά τη συγκομιδή τους οι παρθενοκαρπικοί καρποί ήταν φωτεινοί σε εμφάνιση, με εφάμιλλη αν όχι καλύτερη ανάπτυξη χρώματος σε σχέση με τους ένσπερμους. Την άνοιξη οι καρποί όλων των ποικιλιών απέκτησαν το χαρακτηριστικό τους χρώμα 21 ημέρες μετά την άνθηση (ΗΜΑ), όταν το φθινόπωρο χρειάστηκαν 28 ΗΜΑ, υποδηλώνοντας ότι την άνοιξη η συγκομιδή μπορεί να πραγματοποιηθεί 7 ημέρες νωρίτερα σε σχέση με το φθινόπωρο,

ανεξάρτητα από την παρουσία ή απουσία των σπερμάτων στους καρπούς. Παρατηρήθηκε επίσης ότι οι ρυθμιστές ανάπτυξης δεν επηρέασαν το μήκος του κάλυκα ή του μίσχου.

Η καρπόδεση υπό κανονικές συνθήκες για την καλλιέργεια εξαρτάται σε μεγάλο βαθμό από την επιτυχία της επικονίασης και της γονιμοποίησης. Τα αποτελέσματα της παρούσας μελέτης έδειξαν ότι η βλαστικότητα και η βιωσιμότητα της γύρης καθώς και η επιμήκυνση των γυρεοσωλήνων διέφεραν μεταξύ των ποικιλιών όπως και μεταξύ των εποχών. Η Τσακώνικη εμφανίστηκε ιδιαίτερα θερμοευαίσθητη και δεν παρατηρήθηκε βλάστηση της γύρης όταν επικράτησαν πολύ υψηλές (Ιούλιος) ή χαμηλές (Ιανουάριος) θερμοκρασίες. Αντίθετα, η Black Boy επέδειξε ανθεκτικότητα στις υψηλές και χαμηλές θερμοκρασίες, ενώ στην Emi μολονότι η βιωσιμότητα της γύρης επηρεάστηκε αρνητικά από τις υψηλές ή χαμηλές θερμοκρασίες (όπως και στην Τσακώνικη), παρατηρήθηκε καρπόδεση λόγω της φυσικής ικανότητας της ποικιλίας αυτής να παράγει καρπούς παρθενοκαρπικά. Συνολικά, η παραγωγή γύρης ανά άνθος, η βλαστικότητα και η ζωτικότητα της γύρης ήταν υψηλότερες σε όλες τις ποικιλίες κατά το Μάιο, εξαιτίας των ευνοϊκών θερμοκρασιών (και πιθανά του φωτισμού). Όμως, για την πληρέστερη εξακρίβωση της επίδρασης του περιβάλλοντος στην παραγωγή και βιωσιμότητα της γύρης, απαιτείται περαιτέρω έρευνα, με έμφαση στις διαφορετικές εποχές καλλιέργειας.

Αν και οι ρυθμιστές ανάπτυξης έχουν ήδη προταθεί ως ένα μέσο για καρπόδεση υπό μη ευνοϊκές κλιματικές συνθήκες, εξ όσων γνωρίζουμε, στην παρούσα εργασία για πρώτη φορά περιγράφονται τα ποιοτικά χαρακτηριστικά των παρθενοκαρπικών καρπών της μελιτζάνας. Επομένως, στο δεύτερο πείραμα επιλεγμένες ποιοτικές παράμετροι των καρπών τεσσάρων ποικιλιών μελιτζάνας που παρήχθησαν παρθενοκαρπικά στο θερμοκήπιο ή στον αγρό κατά την άνοιξη (2009) ή το φθινόπωρο (2008) με την εφαρμογή μόνο NOA ή του συνδυασμού NOA+BA, μελετήθηκαν στο εργαστήριο μετά την συγκομιδή τους και συγκρίθηκαν με αυτές των ένσπερμων καρπών που προήλθαν από φυσιολογική επικονίαση. Από τα αποτελέσματα, φάνηκε ότι η εφαρμογή των ρυθμιστών ανάπτυξης δεν επηρέασε ούτε την εξωτερική ούτε την εσωτερική συνεκτικότητα των καρπών της μελιτζάνας, ανεξάρτητα από την ποικιλία, την εποχή και την μέθοδο της καλλιέργειας (θερμοκήπιο ή αγρός). Όμοια, το περιεχόμενο των καρπών σε ασκορβικό οξύ δεν επηρεάστηκε από την εφαρμογή των ρυθμιστών ανάπτυξης, εκτός από την Τσακώνικη και την Black Beauty στην φθινοπωρινή καλλιέργεια όπου τα επίπεδα του ασκορβικού οξέος ήταν χαμηλότερα στους παρθενοκαρπικούς καρπούς που παρήχθησαν στο θερμοκήπιο σε σχέση με τους αντίστοιχους ένσπερμους καρπούς. Το περιεχόμενο σε πρωτεΐνες σε όλες τις ποικιλίες δεν επηρεάστηκε από τη μέθοδο καρπόδεσης, ανεξάρτητα

από την ποικιλία, την περίοδο και τη μέθοδο καλλιέργειας (στο θερμοκήπιο ή στον αγρό). Αντίστοιχα, αν και παρατηρήθηκαν έντονες διαφοροποιήσεις μεταξύ των ποικιλιών ως προς τις τιμές του περιεχομένου του περικαρπίου των καρπών σε ανθοκυάνες, η εφαρμογή ρυθμιστών ανάπτυξης δεν φάνηκε να επηρεάζει το επίπεδο των ανθοκυανών. Τα φαινολικά, μια άλλη σημαντική ομάδα αντιοξειδωτικών συστατικών των καρπών της μελιτζάνας, έδειξαν διαφορές μεταξύ των ποικιλιών και ήταν σχετικά υψηλότερα στη κεντρική περιοχή των ένσπερμων καρπών σε σχέση με τους παρθενοκαρπικούς καρπούς. Τα αποτελέσματα έδειξαν ότι η εφαρμογή των ρυθμιστών ανάπτυξης μείωσε τα ολικά φαινολικά και στην περιοχή του κάλυκα και στην κεντρική περιοχή των καρπών, γεγονός που αύξησε και τη φωτεινότητα (L) της σάρκας των καρπών αυτών. Αυτό με τη σειρά του, οδήγησε σε μία πιθανά θετική επίδραση των ρυθμιστών ανάπτυξης στην ποιότητα των καρπών, μέσω της μείωσης της έντασης του μαυρίσματος τόσο στους ιστούς του πλακούντα όσο και σε ιστούς μακριά από τον πλακούντα, αν και σε όχι στατιστικά σημαντικό επίπεδο. Η φρουκτόζη, η γλυκόζη, η σακχαρόζη και η μαλτόζη προσδιορίστηκαν ως τα κυριότερα σάκχαρα στους καρπούς της μελιτζάνας και η εφαρμογή ρυθμιστών ανάπτυξης για καρπόδεση αύξησε σημαντικά το επίπεδο των αναγωγικών σακχάρων, γλυκόζης και φρουκτόζης. Όμως, οι ρυθμιστές ανάπτυξης δεν επηρέασαν το περιεχόμενο σε άμυλο των καρπών της μελιτζάνας.

Στις περισσότερες περιπτώσεις, οι ποιοτικές παράμετροι των καρπών της μελιτζάνας που μελετήθηκαν στην παρούσα εργασία δεν επηρεάστηκαν σε στατιστικά σημαντικό επίπεδο από την εποχή καλλιέργειας. Όμως, η υψηλότερη ένταση του φωτισμού και η αυξημένη φωτοπερίοδος κατά την άνοιξη φάνηκε γενικά πως βελτίωσαν μερικά από τα ποιοτικά χαρακτηριστικά, ιδιαίτερα το ασκορβικό οξύ και τα σάκχαρα (φρουκτόζη και γλυκόζη) και στους ένσπερμους και στους παρθενοκαρπικούς καρπούς. Αντίθετα με άλλα είδη της οικογένειας των Σολανωδών (τομάτα και πιπεριά) όπου η αυξίνη βελτίωσε την καρπόδεση υπό μη ευνοϊκές συνθήκες ανάπτυξης αλλά σε βάρος της ποιότητας των καρπών, στη μελιτζάνα είναι ξεκάθαρο ότι η εφαρμογή NOA ή NOA+BA όχι μόνο οδηγεί στην παραγωγή καρπών, αλλά επίσης βελτιώνει (ή τουλάχιστον δεν επηρεάζει) την ποιότητα των καρπών. Επομένως, η μέθοδος αυτή για να παράγονται καρποί υπό μη ευνοϊκές περιβαλλοντικές συνθήκες μπορεί να συστήνεται ανεπιφύλακτα.

Λόγω της έλλειψης διαθέσιμων πληροφοριών στη βιβλιογραφία σχετικά με την αποθηκευσιμότητα των παρθενοκαρπικών καρπών μελιτζάνας, στο τρίτο πείραμα οι καρποί δύο ποικιλιών (Τσακώνικη και Black Beauty) που προήλθαν από δύο ανοιξιάτικες καλλιέργειες στο θερμοκήπιο (2009 και 2011) και από μία στον αγρό (2009)

αποθηκεύτηκαν στους 10 και 20°C για 7, 14 και 20 ημέρες με ή χωρίς την κάλυψή τους με πλαστική μεμβράνη.

Τα αποτελέσματα έδειξαν ότι το χρώμα του περικαρπίου (L, C* και Hº) και στις δύο ποικιλίες δεν επηρεάστηκε από την επέμβαση αποθήκευσης (κάλυψη ή μη κάλυψη), τη θερμοκρασία και τη διάρκεια της αποθήκευσης. Παρατηρήθηκε ότι στις περισσότερες περιπτώσεις και οι ένσπερμοι και οι παρθενοκαρπικοί καρποί που καλύφθηκαν με μεμβράνη διατήρησαν καλύτερα τη συνεκτικότητά τους (εξωτερική και εσωτερική) σε σχέση με τους μη καλυμμένους καρπούς, ανεξάρτητα από τη θερμοκρασία και τη διάρκεια της αποθήκευσης. Η κάλυψη με μεμβράνη μείωσε αποτελεσματικά την απώλεια βάρους καθ' όλη τη διάρκεια της αποθήκευσης (7-20 ημέρες), ενώ οι μη καλυμμένοι καρποί έγιναν μη εμπορεύσιμοι μετά από αποθήκευση για 7 ημέρες στους 10 ή 20°C, ανεξάρτητα από την παρουσία ή απουσία των σπερμάτων. Οι καρποί της ποικιλίας Τσακώνικη (που είναι επιμήκεις σε σχήμα) ήταν περισσότερο ευάλωτοι στην απώλεια νερού σε σχέση με αυτούς της Black Beauty (που έχουν σχήμα φλάσκας), λόγω της υψηλότερης αναλογίας της επιφάνειας προς τον όγκο του καρπού. Οι καρποί που καλύφθηκαν με μεμβράνη είχαν ξεκάθαρα υψηλότερο ρυθμό αναπνοής σε σχέση με τους μη καλυμμένους καρπούς, αλλά αυτό πιθανά οφείλεται στην σταδιακή απελευθέρωση CO_2 που είχε συσσωρευτεί στους καλυμμένους καρπούς πριν τη μέτρηση, παρά σε αυτή καθ' αυτή την αναπνοή του καρπού. Γενικά, το περιεχόμενο σε ασκορβικό οξύ τόσο στους ένσπερμους όσο και στους παρθενοκαρπικούς καρπούς προοδευτικά μειωνόταν με την αύξηση του χρόνου αποθήκευσης, αλλά κυρίως σε στατιστικά σημαντικό επίπεδο μόνο στους 20°C. Η κάλυψη με μεμβράνη παρουσίασε τάση μείωσης της απώλειας του ασκορβικού οξέος πιθανά περιορίζοντας την οξείδωσή του, αλλά σε γενικές γραμμές όχι σε στατιστικά σημαντικό επίπεδο. Το περιεχόμενο των καρπών σε πρωτεΐνες και ανθοκυάνες ήταν γενικότερα σταθερό κατά την αποθήκευση και η κάλυψη με μεμβράνη καθυστέρησε την απώλεια αυτών των συστατικών. Σχετικά με τα ολικά φαινολικά της σάρκας των καρπών, παρατηρήθηκε ότι η κάλυψη με μεμβράνη μείωσε αποτελεσματικά τη συγκέντρωσή τους και στους ένσπερμους και στους παρθενοκαρπικούς καρπούς στους 10ºC, ενώ συσσώρευση φαινολικών παρατηρήθηκε στους μη καλυμμένους καρπούς. Σε όλες τις περιπτώσεις, η αποθήκευση στους 10ºC διατήρησε τη ποιότητα των καρπών καλύτερα από ότι οι 20°C. Συνολικά, τα αποτελέσματα του πειράματος έδειξαν ότι η κάλυψη με μεμβράνες βελτίωσε αποτελεσματικά την αποθηκευσιμότητα των καρπών της μελιτζάνας σε σχέση με τους μη καλυμμένους καρπούς, λόγω μείωσης στο ρυθμό απώλειας του νερού. Μετά από 20 ημέρες αποθήκευση στους 10°C οι καλυμμένοι με μεμβράνη καρποί

είχαν γενικότερα άριστη εμφάνιση, ενώ έγινε επίσης φανερό ότι οι παρθενοκαρπικοί (άσπερμοι) καρποί είχαν όμοια συμπεριφορά κατά την αποθήκευση σε σχέση με τους ένσπερμους καρπούς που παρήχθησαν με φυσιολογική επικονίαση.

Με σκοπό να αποκτηθούν περισσότερες πληροφορίες σχετικά με την ποιότητα των παρθενοκαρπικών και ένσπερμων καρπών της μελιτζάνας κατά την αποθήκευση, περαιτέρω πειραματισμός πραγματοποιήθηκε, με καρπούς των ποικιλιών Τσακώνικη και Black Beauty που αναπτύχθηκαν στο θερμοκήπιο κατά την άνοιξη του 2011 και αποθηκεύτηκαν υπό ελεγχόμενες ατμόσφαιρες [CA_1: 3% O_2 + 3% CO_2, CA_2: 10% O_2 + 3% CO_2 and CA_3: 20% O_2 + 0.035% CO_2] στους 10^oC έως και 20 ημέρες. Λόγω της ανάπτυξης αναερόβιων συνθηκών στην επέμβαση CA_1 (3% O_2 + 3% CO_2) και στην Τσακώνικη και στην Black Beauty μετά 8 ημέρες από την έναρξη της αποθήκευσης και των επακόλουθων συμπτωμάτων σήψης στους καρπούς, η επέμβαση αυτή διακόπηκε. Όμως, στις επεμβάσεις CA_2 (10% O_2 + 3% CO_2) και CA_3 (20% O_2 + 0.035% CO_2) καρποί και των δύο ποικιλιών αποθηκεύτηκαν έως και 20 ημέρες στους 10ºC. Και η «φρεσκάδα» του κάλυκα και το χρώμα του περικαρπίου που αποτελούν σημαντικές παραμέτρους ποιότητας για την μελιτζάνα ελέγχθηκαν αποτελεσματικά από τις επεμβάσεις CA_2 και CA_3. Η συνεκτικότητα, μία άλλη σημαντική φυσική παράμετρος ποιότητας, παρέμεινε σε μεγάλο βαθμό ανεπηρέαστη από τις ελεγχόμενες ατμόσφαιρες, αν και στη περίπτωση των παρθενοκαρπικών καρπών της Τσακώνικης το εξωτερικό περικάρπιο ήταν πιο συνεκτικό σε σχέση με αυτό των ένσπερμων καρπών, ενώ η εσωτερική συνεκτικότητα δεν επηρεάστηκε. Παρατηρήθηκε επίσης ότι η απώλεια νερού μέσω του κάλυκα ήταν 3 φορές υψηλότερη σε σύγκριση με την απώλεια μέσω του περικαρπίου και λόγω της υψηλότερης αναλογίας του κάλυκα ως προς το περικάρπιο οι καρποί της Τσακώνικης έχασαν περισσότερο νερό κατά την αποθήκευσή τους σε σχέση με αυτούς της Black Beauty. Όμως, η κάλυψη με μεμβράνες, όπως αποδείχθηκε στο προηγούμενο πείραμα, μείωσε αποτελεσματικά την απώλεια νερού μέσω του κάλυκα και κατά συνέπεια περιόρισε την απώλεια βάρους κατά την αποθήκευση. Σημαντική απώλεια ασκορβικού οξέος παρατηρήθηκε κατά την αποθήκευση στους παρθενοκαρπικούς καρπούς, ενώ δεν βρέθηκαν διαφορές στους ένσπερμους καρπούς που αποθηκεύτηκαν και στις δύο ελεγχόμενες ατμόσφαιρες. Όμοια με την κάλυψη με μεμβράνη στο προηγούμενο πείραμα, η αποθήκευση σε ελεγχόμενες ατμόσφαιρες επίσης παρεμπόδισε την αποδόμηση των πρωτεϊνών και των ανθοκυανών και στους ένσπερμους και στους παρθενοκαρπικούς καρπούς. Η αποθήκευση σε ελεγχόμενες ατμόσφαιρες παρεμπόδισε την απώλεια των φαινολικών της σάρκας και ενώ η μειωμένη συγκέντρωση O_2 στη CA_2 παρεμπόδισε την

αποδόμηση του αμύλου, η υψηλότερη συγκέντρωση O_2 της CA_3 προώθησε την αποδόμηση του αμύλου, οδηγώντας σε αυξημένη συγκέντρωση σακχάρων (κυρίως γλυκόζης, φρουκτόζης και σακχαρόζης) στους καρπούς με το πέρας της αποθήκευσης. Από τα παραπάνω αποτελέσματα συνάγεται ότι η κυριότερη θετική επίδραση της αποθήκευσης σε ελεγχόμενες ατμόσφαιρες φαίνεται να είναι η διατήρηση της φυσικής εμφάνισης (κάλυκας και χρώμα περικαρπίου) των καρπών, όταν όλες οι υπόλοιπες ποιοτικές παράμετροι δεν επηρεάστηκαν θετικά. Επομένως, η αποθήκευση σε ελεγχόμενες ατμόσφαιρες δεν φαίνεται να προσφέρει ένα σημαντικό πλεονέκτημα στην αποθήκευση των καρπών της μελιτζάνας πέρα από αυτό που προσφέρει η κάλυψη των καρπών με μεμβράνες πολυαιθυλενίου, ενώ συνολικά η αποθηκευτική συμπεριφορά των παρθενοκαρπικών καρπών που παράγονται με την εφαρμογή NOA ή NOA+BA για καρπόδεση, είναι παρόμοια με την αντίστοιχη των ένσπερμων καρπών που παράγονται από φυσιολογική επικονίαση.

Acknowledgement

All the praises are due to Almighty Allah for His ever-ending blessing for the success accomplishment of this work.

The author express his gratitude, profound respect and immense indebtedness to his research supervisor, Professor Harold Christopher Passam, Laboratory of Vegetable Production, Department of Crop Science, Agricultural University of Athens, Greece for his scholastic guidance, valuable suggestion and encouragement during the entire period of the research work and preparation of this thesis. I could have never completed this project without his help.

The author thanks his co-supervisor Dr. Constantinos Akoumianakis, Associate Professor and Dr. Dimitrios Savvas, Associate Professor, Laboratory of Vegetable Production, Department of Crop Science, Agricultural University of Athens, Greece for their valuable comments and co-operation during the experimental period and completion of this thesis.

The author also express his special thanks to Dr. Yannis Karapanos for his kind support and assistance for chemical and data analysis. The kind assistance from Andreas Ropokis is gratefully appreciated. I have been blessed with a friendly, helpful, and cheerful group of Vegetable Production fellow students; Dimitra Tsamaidi, Olympia Kyriakopoulou, Georgia Ntatsi, Despoina Makrogianni, Theodora Karanisa and Charitini Kontopoulou.

The completion of the degree has become possible by the support of State Scholarship Foundation (IKY), which is gratefully acknowledged.

Finally, his sincere and heartiest gratitude to his family members for their blessings, inspiration and support during entire period of the study.

The Author

To My Parents

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List of Abbreviations

2,4-D	Dicholorophenoxyacetic acid
ACC	1-aminocyclopropane-1-carboxylic acid
ANOVA	Analysis of variance
BA	6-benzylaminopurine
CA	Controlled atmosphere
Cloxyfonac	4-chloro-α-hydroxy-o- tolyloxyacetate
CPA	*4*-chlorophenoxyacetic acid
CPPU	N-(2-chloro-4-pyridyl)-*N*-phenylurea
cv.	Cultivar
DAA	Days after anthesis
DF	Dilution factor
dw	Dry weight
Folsystein	3-acetyl-1,3-thiazolidine-4-carboxylic acid;(2S)-2-[[4-[(2-amino-4-oxo-1H-pteridin-6-yl)methylamino]benzoyl]amino]pentanedioic acid
fw	Fresh weight
GA_3	Gibberelic Acid
GAE	Gallic acid equivalent
GAL	β-galactosidase
GC	Gas chromatograph
HDPE	High density polyethylene
HPLC	High performance liquid chromatography
IAA	Indole acetic acid
Iprodion	3-(3,5-dichlorophenyl)-N-isopropyl-2,4-dioxoimidazolidine-1-carboxamide
LDPE	Low density polyethylene
LSD	Least significant difference
MACC	1-malonylaminocyclopropane-1-carboxylic acid
MAP	Modified atmosphere packaging
MCP	1-Methylcyclopropen
NAA	Napthalene acetic acid
Nasunin	Delphinidin-3-p-coumarylrhamnosylglucoside-5-glucoside
NOA	β-naphthoxyacetic anid
PAL	Phenylalanine ammonia-lyase
PE	Polyethylene
PGR	Plant growth regulator
POD	Pyrogallol peroxidase
PPO	Polyphenoloxidase
PME	Pectin methylesterase
RH	Relative humidity
TAL	Tyrosine ammonia-lyase
Vinchlozolin	3-(3,5-dichlorophenyl)-5-methyl-vinyl-1,3-oxazolidine-2,4-dione

CHAPTER 1

1 Introduction

1.1 Research Background

Eggplant (*Solanum melongena* L.), also known as aubergine and brinjal (Lester and Hasan, 1991; Lawande and Chavan, 1998), is one of the most widely distributed and cultivated species of the *Solanaceae* family. Eggplant is believed to have originated in the Indo-Burma region but has a secondary center of diversity in China (Vavilov, 1931; Boswell, 1949). Although eggplant originated in subtropical regions, today it is commercially cultivated worldwide and with a growing reputation (Doganlar *et al.,* 2002). Different cultivars of eggplant are now globally available and characterized on the basis of plant morphology, fruit size, shape and color and a variety of growth characteristics. The global area under eggplant cultivation is estimated to be 1.66 million ha with a production of 41.84 million tons, and about 93% of world production comes from Asian countries (FAOSTAT, 2011). Greece is the fifth largest producer of eggplant in the Mediterranean region and contributes about 8.79% to total EU production (FAOSTAT, 2011).

Eggplant is a popular vegetable crop in the tropics and sub-tropic regions, where it is cultivated for its physiologically mature but unripe fruits, which can be cooked or fried whole, dried or pickled. Eggplant fruits have a great nutritive potential due to the presence of ascorbic acid and phenolics, both of which are powerful antioxidants (Vinson *et al.,* 1998). During the last decades intense interest has been aroused on the activity of antioxidants in eggplant, which enhance its total nutritional value in comparison with other vegetables. As a common vegetable in traditional Mediterranean cuisine, eggplant is widely consumed by the Greek people. In Greece, it took 6th place in the top-10 list in terms of vegetable production in 2010 (Greek Ministry of Agriculture, 2011). In Greece, most eggplants (90.23%) are grown in the spring and summer, mainly in the open field, whilst the remainder (9.77%) are grown under cover during autumn and winter (Greek Ministry of Agriculture, 2011).

Eggplant is considered to be a vegetable of hot climates (Romano and Leonardi, 1994; Lawande and Chavan 1998) requiring relatively higher temperatures during growth and development compared with other *Solanaceous* crops, eg. tomato (*Solanum lycopersicon* L.) and pepper (*Capsicum annum* L.). Low night air temperature and

insufficient light are detrimental to eggplant fruit-set (Sato and Ito, 1973; Wang *et al.,* 1980; Sun *et al.,* 1990; Abeny and Russo, 1997). During winter in the Mediterranean region, low minimum night temperature (≤8°C) hamper fruit-set and development, probably as a result of reduced pollen germinability (Nothmann and Koller, 1975). However, the use of heating in greenhouses increases the cost of production; therefore, fruit set is generally induced by applying plant growth regulators during the winter production of eggplant in unheated greenhouses in the Mediterranean area (Nothmann and Koller, 1975; Olympios, 1976; Donzella *et al.,* 2000; Acciarri *et al.,* 2002). Gustafson (1936) first demonstrated the application of auxin to tomato to set parthenopcarpic fruit. Exogenous application of auxins, gibberellins and cytokinins, or mixtures of these hormones, has been reported to increase fruit set in eggplant (Nothmann and Koller, 1975; Olympios, 1976), tomato (Kojima *et al.,* 2003), pepper (Heuvelink and Korner, 2001) and pepino (Ercan and Akilli, 1996). In contrast to tomato, where hormone reduces fruit quality (Olympios, 2001), hormone-set, parthenocarpic eggplant fruits are appreciated by consumers because they have no seeds, which harden during maturation impart a bitter taste and interact with other constituents during cooking. In fact, parthenocarpy in eggplant increases the commercial value of the fruit because they are easy to consume, they have a minimal-waste, and they possess a relatively long shelf-life (Gillaspy *et al.,* 1993; Gonzalez *et al.,* 2004; Habashy *et al.,* 2004). However, to date no studies have been conducted to evaluate the complete profile of fruit quality in response to growth regulator application to eggplant fruit.

Although eggplant is a common vegetable in our retail outlets, it has a very limited fresh shelf life for freshness (Mohammed and Sealy, 1986; Jha and Matsuoka, 2001). In the majority of perishable fruits and vegetables, shelf life can be extended by storage at low temperature from harvest until consumption and this is normally an effective means of maintaining quality and nutritional value. However, most of the fruits and vegetables originating from tropical regions, like eggplant, are sensitive to chilling, below about 10ºC. Chilling injury in eggplant is manifested mainly by the appearance of surface injuries, such as discoloration of the calyx, darkening of the seeds and pulp tissue, in severe case pitting and browning of the skin or surface scald, pitting and scald (Cantwell and Suslow, 1999; Concellon *et al.,* 2000, 2007; Prohens *et al.,* 2007). These symptoms do not normally appear during low temperature storage, but rapidly develop on the return of fruit to room temperature. The susceptibility to chilling injury depends on the temperature and time of exposure to low temperature, the cultivar and the period of harvest (Fallik *et al.,* 1995). It

has been reported that wrapping eggplant fruits in film can satisfactory reduce the symptoms of chilling injury as well as water loss (Mohamed and Sealy, 1986; Fallik *et al.,* 1995; Rodriguez *et al.,* 2001; Pahlevi *et al.,* 2009).

Apart from storage temperature and duration, the storage atmosphere can also affect the physiological processes of fresh, stored produce such as eggplant. Storing fruits or vegetables in controlled atmosphere (CA) enriched with high CO_2 and/or utilizing low O_2 levels can be a very beneficial tool in maintaining product quality and extending shelf life (Kader *et al.,* 1989). Although several studies have documented the effect of CA storage on eggplant (Kaynas *et al.,* 1995; Arvanitoyannis *et al.,* 2005; Catalano *et al.,* 2007), the CA storage of parthenocarpic eggplant fruits has not previously been described.

1.2 Origin and distribution of eggplant

Although differences of opinion exist about the origin of *Solanum melongena*, there is a general consensus that the Indo-Burma region is the primary centre of origin (Vavilov, 1931; Lester and Hasan, 1991). Strong support for this view point was provided by Isshiki *et al.* (1994) based on the isozyme and morphological variation detected in a large germplasm collection from India. There is wide genetic diversity among the species within this genus, which comprises about 1500 species (D'Arcy, 1991), and it is believed that the domestication of non-bitter, fruiting types of eggplant spread from the Indo-Burma region into China, where small-fruiting types developed that were distinctly different from those of Indian origin (Boswell, 1949; Nonnecke, 1989). The introduction of eggplant to the west was primarily via the Mediterranean region by Arab traders and this is considered to be a region of secondary domestication (Daunay *et al.,* 2001). Historical records indicate that Portuguese colonists took eggplant to Brazil before 1650 (Boswell, 1949). It was introduced into North American gardens in 1806 where the purple and white varieties were primarily an ornamental curiosity until the early 1900's (Boswell, 1949). It is now widely cultivated in the tropical, subtropical and warm temperate zones of the world, and as a heated greenhouses crop in more northerly cooler climates.

1.3 World production of eggplant

Eggplant is the third most important crop in the *Solanaceae*, after potato (*Solanum tuberosum* L.) and tomato (FAOSTAT, 2011). In 2010, the global production of eggplant was 41.84 million tonnes, of which 39.17 million tonnes came from Asia (mainly from

China and India), 1.55 million tonnes from Africa and 0.91 million tonnes from Europe (FAOSTAT, 2011). China is the largest producer of eggplant in the world followed by India, Egypt, Iran and Turkey (Table 1). European production of eggplant is concentrated in the Mediterranean region (Table 1). In 2010, eggplant production in Europe amounted to 806 thousand tonnes which was less than the production of Turkey (FAOSTAT, 2011).

Table 1. Major eggplant producing countries of the world (FAOSTAT, 2011).

World region	Country	Area (ha)	Production (ton)
Asia	China	731547	24501936
	India	612400	10563000
	Iran	29300	888500
Mediterranean	Egypt	25017	1229790
	Turkey	28000	846998
	Italy	10741	302551
	Spain	3450	190200
	Greece	2400	70900
North Europe	Netherlands	100	46000
	France	645	19928

Greece is the fifth largest producer of eggplant in the Mediterranean region and contributes about 8.79% to EU production. (FAOSTAT, 2011). The production of eggplant in Greece increased from 68.130 tonnes in 2005 to 70.900 tonnes in 2011, but the total production area showed a decreasing trend (Table 2) (FAOSTAT, 2011). In the Mediterranean region, eggplant is usually grown in the open field during summer and under cover during winter. In Greece, the area under open field cultivation was 2876 ha whereas under cover was only 311 ha during 2006.

Table 2. Area and production trend of eggplant in Greece during 2005-2010 (FAOSTAT, 2011).

Year	Area (ha)	Production (ton)
2005	3186	68134
2006	3188	69341
2007	3121	67928
2008	2900	85300
2009	2800	82000
2010	2400	70900

1.4 Flowering and fruit-set of eggplant

1.4.1 Flower morphology

Eggplant flowers are large, violet-coloured, and consist of the calyx: sepals 5**,** united, persistent; corolla: petals 5**,** united, usually cup shaped; androecium: stamens 5**,** alternate with the corolla; gynoecium: carpels united, ovary superior (Rashid and Singh, 2000). Flowers are extra-axillary (Shah and Patel, 1970) and are borne either solitary or in clusters, only one flower of which is potent (Kakizaki, 1924). Anthesis starts from about 7.30 am and continues up to 11 am; the peak time for anthesis is 8.30 to 10.30 am (Rashid and Singh, 2000). The stigma appears shiny and sticky when it is fully receptive. Prasad and Prakash (1968) found maximum receptivity to occur on the day of anthesis, followed by a gradual decrease with age, until on the fifth day after anthesis receptivity is almost negligible. Kakizaki (1924), Tatebe (1938) and Pal and Singh (1943) noted similar periodicity in the receptivity of the stigma in eggplant, and reported maximum receptivity on the day of flower opening.

1.4.2 Types of flower

Heterostyly reduces the yield potential of eggplant (Kowalska, 2006). Four types of flowers, *viz.* true short, pseudo-short, medium and long-styled, have been recognized in eggplant by Prasad and Prakash (1968) and Chadha and Saimbhi (1977). However, Nothmann *et al*. (1983a) divided eggplant flowers into two distinct morphological functional types only: namely, long- and short-styled based both on style length and on flower position in the cluster, instead of the commonly used descriptive methods, such as reference to style length only. Style length in eggplant is a varietal characteristic (Chadha and Saimbhi, 1977), but it is also influenced by external factors such as fruit load and plant age (Lenz 1970) and the cultivation environment (Wang *et al***.** 1980; Nothmann *et al.,* 1983a). In their experiment, Passam and Khah (1992) concluded that genotype is an important factor in the regulation of flowering and fruit-set in eggplant, with concomitant implications for fruit and seed production. Kabir (1981) noted that only long-styled and medium-styled flowers can set fruits, whereas short-styled flowers do not set fruit (Quagliotti, 1962; Prasad and Prakash, 1968; Siddique and Husain, 1974; Kowalska, 2003; Kowalska, 2006). It has been reported by Smith (1931) and Muthukrishnan and Srinivasan (1963) that under natural conditions and even with growth regulator sprays no short-style flowers could be induced to set fruit. Therefore, high fruit set is attributed to the production

of large numbers of long-styled flowers, which are characterized by their plump ovary and thick pedicel (Mohideen *et al.,* 1977). Passam and Bolmatis (1997) found maximum fruit weight and seed formation in those flowers in which the stigmata at maturity were situated close to the anther pores. Kowalska (2006) recorded most intensive fruiting during July and August in Poland, whereas Passam and Bolmatis (1997) reported under Greek conditions, eggplants produced the greatest number of flowers about one month earlier i.e. in June and July.

1.4.3 Effect of fruit load on flowering

Developing fruits reduce the growth of leaves, stems and roots in eggplant (Mochizuki, 1959). This may be due to competition for assimilates and nutrients, or alternatively, growth may be inhibited by hormones produced in the fruits, as suggested by Fulford (1962). This latter explanation is supported by Lenz (1970), who showed that developing fruits of eggplant inhibit pistil growth in flowers formed later on the same plants, and this retardation lasted longer in plants with four fruits than in those with two fruits. In contrast, male flower organs were not affected. Passam *et al.* (2001) showed that not only style length, but also flower and pistil (but not anther) mass are reduced during fruit development, whereas auxin influences the number of flowers. They indicated that even under climatic conditions that are favourable for fruit set, the fruit load of the plant may impose a restriction on pollination through its effect on style length. Khah *et al*. (2002) reported that during fruit growth, flower formation was reduced, style length and flower mass declined, but the length of the anther cone was not affected. According to Claussen (1986), fruit are strong sinks and partly hamper vegetative growth and the fruit set of new flowers by withdrawing leaf carbohydrates, which otherwise might have been available for nitrate assimilation.

1.4.4 Effect of climatic factors on fruit set

The eggplant is a warm-season vegetable and during the summer it is normally grown under field conditions. Many factors were found to be associated with the change in fruit set and flower-shedding, these included pollination and fertilization, previous fruiting (Wang *et al.,* 1980), climatic conditions (Qian, 1985; Sun *et al*., 1990) and field management (Carter and Johnson, 1988). During the long, hot season, plant growth, flowering and fruit development of eggplants are normal, but during the cool season many

abnormalities occur, including decreasing flower fertility, the production of seedless fruits (Nothmann and Koller, 1975a) and abnormal colour development (Nothmann *et al*., 1978). During winter and spring months in the Mediterranean region, the temperature regime affects the growth of greenhouse crops (Romano and Leonardi, 1994; Uzun, 2006) and hampers fruit-set and development, probably as a result of reduced pollen germinability (Nothmann and Koller, 1975a). According to the findings of Hazra *et al.* (2003), fruit set and fruit yield of eggplant were reduced by 14.3-71.0% and 66.3–83.5%, respectively, under protected and unprotected cultivation. In the hot summer months, less than 10% of the flowers of a sensitive cultivar (Long Negro) set fruit in comparison with over 40% in a tolerant cultivar (Emi) (Passam and Khah, 1992). Passam and Bolmatis (1997) noted that low humidity coinciding with high daytime temperatures may reduce stigma respectively and/or pollen germination. In heated plastic-covered greenhouses, Suzuki *et al.* (2005) recorded a lower marketable yield at 14^0C than at 16^0C or 18^0C. They also reported that the fruit shape at 16^0C was slightly more slender and the mesocarp of the fruit was less firm than that at 18^0C, but fruit colour and yield were similar at both temperatures. Studies under glasshouse conditions by Saito and Ito (1973) showed that higher night temperatures and/or low light intensity retarded the development of flowers, and smaller flowers with smaller sepals, petals, anthers and especially smaller ovaries with shorter styles were produced, and heavy flower drop ensued. Sometimes in summer, ovary growth ceased at an early stage but the calyx continues to grow resulting in an enlarged ovary enclosed in a hypertrophic calyx (Nothmann, 1983). During the warm season in Israel almost all the 'additional' flowers (i.e. the 2^{nd}, 3^{rd} or more flowers within a cluster) drop, but during the cool season some of them set fruit (Prasad and Prakash, 1968; Nothmann *et al.,* 1979). Nothmann *et al.* (1983a) showed that low temperatures may adversely affect fruit-set through a reduction in style length and can cause slow fruit development in eggplant (Nothmann, 1986). On the other hand, Bakker (1990) reported that the average fruit maturation period of eggplant in Holland in the autumn was 4 weeks, a week less than during spring because of higher temperatures.

Wang *et al.* (1980) reported that rainfall, high relative humidity and insufficient light intensity were detrimental to fruit set in eggplants. According to the findings of Sun *et al*. (1990) fruit setting ability was affected neither by natural light duration nor by relative humidity, but mainly by the average maximum temperature and precipitation during the first 5 days after the flowers had opened. It was reported that under limited light conditions, bud initiation in eggplant is poor and high flower abortion results, as well as

reduced flower bud occurrence due to the low availability of assimilates (Nothmann, 1986; Passam and Khah, 1992; Mohamed and Amer, 2001; Nkanash, 2001; Khah *et al.,* 2002). Olympios (1976) stated that temperature alone may not be the only limiting factor affecting fruit-set; light energy and photoperiod may also be involved. Uzun (2006) noted that the leaf number subtending the first fruit in eggplant declined linearly with decreasing temperature, particularly at the lowest daily mean light integral (1.9 MJ m^{-2} d^{-1}). In another study, Uzun (2007) reported that the highest number of flower buds (35) and fruit (12) per plant were obtained at the highest light intensity at 17^0C whereas the lowest number of flower buds (9) and fruit (4) per plant occurred at the lowest light intensity.

1.4.5 Pollen morphology and fertility

The anthers of eggplant dehiscence through apical pores within 15-30 minutes of the first opening of the flower (Prasad and Prakash, 1968), thus favouring self-pollination (Kakizaki, 1924; Rashid and Singh, 2000). The duration of dehiscence is very irregular and is affected by the time of day, temperature and humidity (Pal and Singh, 1943; Prasad and Prakash, 1968). In general, pollen release starts from 9.30 to 10 am. (Rashid and Singh 2000) or between 34 and 110 minutes after anthesis (Hazra *et al.,* 2003). The pollen grains appear as a fine, yellowish, powdery mass, which accumulates at the pore of the anther till they are mechanically distributed, e.g. shaken by wind or similar agencies (Kakizaki, 1924). Normal pollen appears turgid, whereas non-viable or sterile pollen grains are shriveled and elliptical (Prasad and Prakash, 1968). Depending on the variety, the maximum size of pollen is 20.65 × 19.94 micron and minimum 17.23 × 16.59 micron (Prasad and Prakash, 1968). Similar results for pollen size were also reported by Mishra (1962).

Low temperatures affect the germinability of pollen in Japanese varieties of eggplant (Hirose, 1965; Fujishita, 1965), for which the minimum temperature for normal germination of pollen on the stigma is 20^0C (Fujishita, 1965). In the Mediterranean region, the protected cultivation of eggplant is conducted under non-heated cover and the night temperatures during winter and early spring frequently fall below the biological limit and then pollen viability becomes a problem for fruit set (Abak and Guler, 1994). As reported by Abak and Guler (1994), the existence of 30-35% pollen viability is sufficient for the normal production of eggplant and these authors found 35% pollen viability and 12% pollen germination in a greenhouse in which the minimum temperature was set at 5^0C. According to the findings of another experiment, pollen viability and pollen germination

were respectively 52% and 13% inside a plastic-covered greenhouse heated only against the risk of frost (Abak *et al.,* 1995). As reported by Nothmann and Koller (1975a), low temperature stress in eggplant during the cool season caused a gradual loss of pollen fertility which led to the development of seedless fruit, but female fertility was not affected. Temperature-induced male sterility is transient, and full pollen fertility is regained with normal seed development, as temperature conditions improve. Passam and Bolmatis (1997) emphasized the need for vibration or some other form of assistance for pollen transfer when eggplants are grown under cover because air movement and insect activity for pollen transfer may be insufficient even for the small differences in proximity of the stigma and the anther pores. In Mediterranean countries, bumble bees are often introduced into greenhouses to improve pollination, but these insects are more efficient if the greenhouses are heated to a temperature of over 12ºC at night during the most critical period (between December 15 and February 15) (Abak *et al.,* 2000).

1.4.6 *In vitro* germination of pollen

Different experiments have been carried out to determine a suitable method, medium and incubation time for *in vitro* pollen germination of eggplant. This is important because staining of pollen as a test for its viability is not reliable (Vasil, 1958). Prasad and Prakash (1968) used a medium containing 5% sucrose with 0.01% H_3BO_3 for their pollen viability tests. Guler *et al.* (1995) reported that the 'agar in petri' method is better than 'hanging drop' and 'saturated petri' methods. They found 1% agar, 12% sucrose, 300 ppm H_3BO_3 and 300 ppm $Ca(NO_3)_2$ the best medium for pollen germination. However, although the percent germination was high in this medium, bursting of pollen grains and tubes was very frequent. Khan and Perveen (2006) used the 'hanging drop' technique with different concentrations of sucrose and boric acid (10% - 100%) for pollen germination. In another experiment, Hirose *et al*. (1968) used 17% sucrose and 1% agar, and observed that the addition of most inorganic salts inhibited both pollen germination and tube growth. To the contrary, boron promoted germination markedly at all concentrations and in the medium containing 57.13 ppm boric acid (10 ppm boron) the pollen tube grew at a rate of 375 microns an hour. Calcium and magnesium ions both inhibit pollen germination and tube growth, but when either calcium or magnesium are used to supplement boron then pollen germination and pollen tube growth are promoted (Hirose *et al*., 1968). The germination rate of eggplant pollen can be slightly increased by the addition of α-naphthalenacetic acid, β-indoleacetic acid, 2-chloroethyltrimethylammonium chloride and N-dimethyl amino

succinamic acid (Hirose *et al.,* 1968). According to Guler *et al*. (1995), 2-3 hours at 25ºC is the most suitable time for counting the germinated pollen grains without bursting. Pollen of eggplant can be stored for up to 48 weeks at low temperature (-3ºC) and in 30% benzene solution (Khan and Perveen, 2006). Rylski *et al*. (1984) used a 10% sucrose solution containing 0.01% H_3BO_4 at 27ºC for *in vitro* pollen germination and after 4 hours pollen germination was observed under fluorescent illumination (2500 lux). Furthermore, these authors tested pollen germination *in vivo* using cut styles (24 hours after pollination) and fixing them in 2:1 ethanol and 96% glacial acetic acid, followed by florescence microscopy (Martin, 1959).

1.4.7 Use of plant growth regulators for fruit-set in eggplant

Under field conditions in the Mediterranean region during summer, natural pollination takes place and fruit invariably contain seeds (Olympios, 1976). However, during winter and spring, ruit set under plastic cover is frequently poor and fruit development restricted, probably as a result of reduced pollen germinability (Nothmann and Koller, 1975b). It has been reported that the application of various growth regulators improves fruit-set in eggplants both during the normal growing season (Krishnamurthi and Subramanian, 1954; Muhukrishnan and Srinavasan, 1963; Sharma, 2006) and during the cool season (Nothmann *et al.,* 1974; Olympios, 1976; Nothmann, 1983; Nothmann *et al.,* 1983b; Lee *et al.,* 2004). Selection of effective growth regulators, optimal concentrations and spray intervals is very important to induce fruit set and development of eggplant during unfavorable winter conditions, such as low light intensity and low temperature (Lee *et al*., 2004). Handique and Sarma (1995) proved that hormones can modify heterostyly in eggplant flowers through their impact on the flower's anatomical structure and the transition of nutrients within the pistil's canals. Kowalska (2006) noted that naphthalene acetic acid (NAA) reduced the occurrence of remarkably short-styled flowers, but increased the number of long-styled flowers. Pessarakli and Dris (2003) reported that the optimum and proper use of growth regulators and genetic engineering substantially increase eggplant yield and improve fruit quality.

Plant growth regulators can be used to stimulate parthenocarpic fruit development in eggplant, e.g. foliar sprays of 2,4-D at 0.00025% applied to freshly opened flower clusters induced parthenocarpy (Sharma, 2006). Patel *et al.,* (1997) reported that the application of 2,4-D at 4 ppm to eggplant cv. Surati Ravaiya produced a higher yield (54.11 t ha^{-1}) than the control (33.07 t ha^{-1}). Sharma (2006) sprayed the whole plant with

several different types of plant growth regulator at different concentrations starting from flowering, and others at 20 days intervals after first flowering. He found that plant growth regulators had no significant effect on plant height and stem diameter but gave higher fruit yield (17.76 t ha^{-1}) at 40 ppm NAA. Krishnamurthi and Subramanian (1954) reported that 2,4-D was not able to set fruit in the true short-styled flowers, but pseudo-short-styled flowers could be induced to set fruits with 2,4-D with a maximum of 60% fruit set obtained by the application of 0.01% 2,4-D compared with 27% in the untreated control.

According to Olympios (1976) the synthetic auxin β-naphthoxyacetic acid (NOA) at 60 ppm alone, as well as in combination with 30 ppm 6-benzyl-aminopurine (BA) applied to open flowers during winter and early spring, had a positive effect on fruit-set and fruit development in eggplants, whereas early yield was induced by the application of n-meta-tolyl-phthalamic acid at 250 and 500 ppm to the whole plant. It was noted that BA alone benefited neither early yield nor total yield, but in fact reduced both, whereas auxin application was apparently able to exert its maximum effect only when both auxin and cytokinin levels were optimum (Olympios, 1976). According to Lee *et al.* (2004), cloxyfonac (4-chloro-α-hydroxy-o- tolyloxyacetate) application at 490 mg l^{-1} produced higher marketable yield than 4-CPA (*4*-chlorophenoxyacetic acid) and CPPU [*N*-(2-chloro-4-pyridyl)-*N*-phenylurea], but fruit set and development were similar in cloxyfonac and 4-CPA. Application of 2,4-D (2.5 ppm) reduced flower drop and increased fruit number per plant, which ultimately increased the yield per plant (Nothmann, 1983). During cool months, plants produced undersized fruits with many ovaries, but Nothmann (1983) and Nothmann *et al.* (1983b) observed that the occurrence of enlarged ovaries was limited and fruit-set and fruit growth were much improved by the application of 2,4-D at 2.5 ppm, especially in cultivars whose development was more affected by the unfavourable growing conditions of the cool seasons. These results are in contrast to other reports on the effect of 2,4-D treatments (under hot conditions), such as the formation of 'enlarged ovaries' and the restriction of the weight or size of the individual fruit (Muthukrishnan and Srinavasan, 1963; Matsumaru and Udagawa 1975). Van Ravestijn (1983) applied a spray mixture consisting of 20 mg l^{-1} 4-CPA and 500 mg l^{-1} iprodion [3-(3,5-dichlorophenyl)-N-isopropyl-2,4-dioxoimidazolidine-1-carboxamide] or 500 mg l^{-1} vinchlozolin [3-(3,5-dichlorophenyl)-5-methyl-vinyl-1,3-oxazolidine-2,4-dione] weekly to the flowers, and found earlier and higher yields through an increased number of fruit and higher mean fruit weight.

Nothmann *et al.* (1983b) found that treatments with 2,4-D improved the fruit set of basal and additional long-styled flowers which accounted for more than 90% of all fruit set but fruit-set in short-styled flowers was very low (8%); this indicated that fruit-set was more affected by style length than by flower position. Ramanandan *et al.* (1991) recorded the highest number of long-styled flowers by the application of growth regulator 1-triacontanol (5 ppm). It has been reported that different varieties react positively to plant growth regulators, but not to the same degree (Van Ravestijn, 1983; Nothmann *et al.,* 1983b; Sharma 2006). Nothmann *et al.,* (1983b) found no difference in fruit-set among the three varieties, Black Oval, Pusa Purple Long and Pusa Purple Cluster, following treatments with 2,4-D at 2.5 mg l^{-1}, but final yield differed.

Gibberellins are not preservable in solution, moreover they increase plant elongation and reduce the rate of fruit ripening; for these reasons most experiments on fruit set have been conducted using auxins (Van Ravestijn, 1983). Nothmann and Koller (1973) stated that gibberellins caused irregularly developed (split) ovaries in eggplant flowers, even during the warm season when the autonomous occurrence of 'splitting' is rare; degeneration of corollas during the cool season was also enhanced by gibberellin application. Split ovaries develop into deformed fruits. Nothmann and Koller (1975) showed that the application of gibberellins during summer produced a malformation of the ovary similar to that which occurs naturally during the cool season. Later on, Nothmann and Koller (1975b) reported that the production of entirely seedless fruits in late winter probably results from an increased level of gibberellins, with or without the auxins derived from non-germinable pollen; exogenous gibberellin was also capable of inducing fruit-set during summer in emasculated flowers. The results of a field study in the Dominican Republic indicated that the yield of 'Jira' eggplants could be enhanced by treatments with either folsystein [3-acetyl-1,3-thiazolidine-4-carboxylic acid;(2S)-2-[[4-[(2-amino-4-oxo-1H-pteridin-6-yl)methylamino]benzoyl]amino]pentanedioic acid], NAA or gibberellic acid (Morales-Payan, 2000). Seedless fruit developed after the application of gibberellin or auxin-like substances (Krishnamurthi and Subramanian, 1954; Choudhury and George, 1962; Muthukrishnan and Srinavasan, 1963), but fruit size and shape were frequently adversely affected (Krishnamurthi and Subramanian, 1954; Muthukrishnan and Srinavasan, 1963). Nothmann and Koller (1975b) showed that gibberellin (GA_3) induced the development of completely seedless fruits during all seasons. They also noted that the auxin-like substances, 2,4-D, NAA and NOA induced the development of degenerated

seeds, both in the period of normal seed development (summer) and in the period of climate-induced seedlessness (winter).

1.5 Nutritive value and quality of eggplant

1.5.1 Nutritive value

Eggplant has constituted an important vegetable for our diet for many centuries. Due to its nutrient composition, eggplant fruits rank among the most popular edible vegetables of the world. The composition the edible portion of eggplant fruit is given in Table 3.

Table 3. The nutrient composition of eggplant fruit (Chen and Li, 1997); values are derived from 100 g of edible portion.

Calories	24.0	Sodium (mg)	3.0
Moisture content (%)	92.7	Copper (mg)	0.17
Carbohydrates (%)	4.0	Potassium (mg)	2.0
Protein (g)	1.4	Sulphur (mg)	44.0
Fat (g)	0.3	Chlorine (mg)	52.0
Fiber (g)	1.3	Vitamin A(I.U.)	124.0
Oxalic acid (mg)	18.0	Vitamin B (mg)	
Calcium (mg)	18.0	Thiamine (B_1)	0.04
Magnesium (mg)	16.0	Riboflavin (B_2)	0.11
Phosphorus (mg)	47.0	B-carotene (μg)	0.74
Iron (mg)	0.9	Vitamin C (mg)	12.0

Since the 90's the nutritional value of eggplant has received attention by many authors due to its valuable source of anthocyanins, phenols, ascorbic acid, sugars, proteins etc.

1.5.2 Anthocyanin

The fruit colour of eggplant derives from two groups of pigments and their several distribution patterns (Daunay *et al.,* 2004b). The first group of pigments, anthocyanins, are located in the cell vacuoles of the fruit epidermis. The second group of pigments, chlorophylls A and B, are mostly located in the fruit sub-epidermal cell layers and are responsible for the green colour of the flesh, as well as the epidermis. The green colour can be masked by anthocyanins, if they are present, whereas in green and white eggplant accessions there may be no anthocyanin (Daunay *et al*., 2004; Azuma *et al*., 2008). The combination of the presence of anthocyanins and/or chlorophylls, with various combinations of their distribution patterns, is responsible for the great color diversity found

in eggplant fruits (Nothmann *et al.,* 1976; Daunay, 2008). Eggplant is ranked among the top ten vegetables in terms of oxygen radical scavenging activity (Stommel and Whitaker, 2003) due to its anthocyanins, which are major phenolics in eggplant and among the most important antioxidants, with a variety of physiological functions implicated in the prevention of mutagenesis, cancer and cardiovascular diseases as well as vision improvement (Todaro *et al*., 2009). Nasunin (delphinidin-3-p-coumarylrhamnosyl glucoside-5-glucoside) is the major anthocyanin isolated from the skin of most eggplant cultivars, it is a phenolic compound implicated in both the inhibition of hydroxyl radical generation and superoxide scavenging (ROS) (Kaneyuki et al. 1999; Matsuzoe *et al.,* 1999; Noda *et al.,* 2000). Huang *et al.* (2004) reported that the total phenolics content of eggplant skin is about two times greater than that of eggplant pulp. The fruit color of eggplant is affected by environmental factors (e.g. light and temperature) and cultivation conditions (Nothmann *et al*., 1978; Matsuzoe *et al*., 1999). In the hot season, fruit quickly develop a dark color, which remains unchanged until marketable size (Nothmann *et al.,* 1976); however, during the cool season, poor-colored fruits are produced (Nothmann *et al.,* 1978). Successful commercial cultivars should have intense color with a low value of L, a and b color coordinates (Munoz-Falcon *et al.,* 2009).

1.5.3 Phenols

Phenolic compounds present in the flesh of eggplant have anti-oxidant properties and can effectively scavenge free radicals (Hanson *et al.,* 2006). Studies have shown that eggplant extracts suppress the development of metastasis (Matsubara, 2005), and inhibit radical-mediated pathogenesis, carcinogenesis and atherosclerosis (Stommel and Whitaker, 2003). Phenolic phytochemicals from eggplant also have a hypo-lipidemic and anti-microbial action (Sudheesh *et al.,* 1997). The first report on the extraction and identification of chlorogenic acid and on browning in eggplant was published by Kozukue *et al.* (1979), while Whitaker and Stommel (2003) confirmed the predominant compound of chlorogenic acid (5-o-caffeoylquinic acid). The total content of chlorogenic acid accounts for 70–95% of total phenolics in eggplant fruit flesh (Whitaker and Stommel, 2003; Singh *et al.,* 2009). It is well documented that the quantity and quality of phenolics present in eggplant fruits largely depends on the cultivar (Stommel and Whitaker, 2003; Hassimoto *et al.,* 2005; Hanson *et al.,* 2006; Prohens *et al.,* 2007; Singh *et al.,* 2009; Luthrie *et al.,* 2010; Bhattacharya *et al.,* 2009; Akanitapichat *et al.,* 2010) and growing season (Hanson *et al.,* 2006). Luthrie *et al.* (2010) reported a higher total phenolic content in cv. Blackbell grown

conventionally as compared to that grown in an organic environment, but eggplant cv. Millionaire showed the opposite result with organically-grown fruit having a marginally higher total phenolics content than conventionally grown eggplant. Like other Solanaceous vegetables, glycoalkaloids present in eggplant fruits, at high concentrations (>20 mg 100 g^{-1} FW), may cause bitterness (Lawande and Chavan, 1998).

1.5.4 Ascorbic acid

Eggplant fruit contains ascorbic acid and phenolics, both of which are powerful antioxidants (Vinson *et al.,* 1998). Although most of the ascorbic acid is lost during the cooking process, it has been shown to prevent fruit flesh browning and therefore, high ascorbate content is desirable in eggplant cultivars (Jose *et al.,* 2010). The concentration of ascorbic acid present in eggplant flesh depends on the cultivars (Hanson *et al.,* 2006; Rodrigues-Burruezo *et al.,* 2008). Jose *et al.* (2008) found four times higher concentrations of ascorbic acid in eggplant grown in greenhouses than in the open air.

1.5.5 Sugars

Large eggplant fruit and high sugar content are important quality factors for some consumers (Hanson *et al.,* 2006). Kozukue *et al.* (1978) identified fructose, glucose, maltose and another unknown sugar in eggplant fruits; these accounted for more than 96% of the total sugars. Recently, Boo *et al.* (2010) reported that sucrose is another important sugar present in eggplant fruit, but the concentration is lower than that of fructose and glucose. During cultivation, low light and temperature are detrimental for the quality of eggplant fruit (Sezgin, 2007). Light intensity plays an important role in sugar metabolism during fruit growth, and can be increased by mulching treatments (Singh, 1992; Boo *et al.,* 2010). Eggplant contains a medium level of starch (95.34 mg 100 g^{-1}) (Kaynas *et al.,* 1995). Raigon *et al*. (2008, 2010) reported a lower level of protein (0.41-0.68 g 100 g^{-1}) in eggplant fruit landraces, whereas Nisha *et al.* (2009) found protein within the range of 0.69-1.66 g 100 g^{-1} in different commercial eggplant cultivars in the market. Esteban *et al.* (1992) observed a steady accumulation of protein until 42 days after fruit set, after which protein synthesis ceased.

1.5.6 Quality

The quality of vegetables is a complex matter and difficult to define. At purchase, vegetable consumers do not judge the nutritional quality, but they may be able to assess sensory aspects, such as shape, size, colour, freshness, firmness etc. The minimum European requirements for the quality of eggplants are the following: fresh, undamaged, firm, clean (without any visible extraneous material/water), with the calyx and some portion of the peduncle attached to the fruit, sufficiently mature, and without any inappropriate flavor or odours. Grading of fruit is either by diameter or weight, and all fruits within a particular package should be at the same maturity stage, as well as uniform in size and colour (Passam and Karapanos, 2008).

1.6 Postharvest quality and physiology

1.6.1 Freshness

The surface gloss and mean fruit weight are two important parameters to judge the freshness of eggplant fruits. These parameters decreased quadratically with the length of storage at 20ºC and 80-84 % relative humidity (RH) for up to 96 hours, with major changes being detected even within 48 hours (Jha *et al.,* 2002). Another important parameter, surface electrical resistance increased quadratically with the increase in storage period, while the reverse trend was observed in both weight and surface gloss during storage at 20ºC for 96 hours (Jha and Matsuoka, 2004). In a further experiment, surface gloss, firmness, volume and fruit mass decreased linearly with the length of storage at 25 ± 2ºC and 90 ± 5% RH (Jha and Matsuoka, 2002).

1.6.2 Rate of ethylene production and respiratory activity

Eggplant is a non-climacteric fruit, and the internal concentration of ethylene is very low, or even below the level of detection. According to Rodriguez *et al.* (1999), the rate of endogenous ethylene synthesis falls from 14 µl kg^{-1} h^{-1} at the stage of petal drop to 2 µl kg^{-1} h^{-1} on day 7, and subsequently remains at a low value (1.4 µl kg^{-1} h^{-1}) until commercial maturity. Cantwell and Suslow (1999) reported that the average ethylene production of eggplant fruit ranges from 0.1 to 0.7 µl kg^{-1} h^{-1} at 12.5ºC. Therefore, ethylene is not considered crucial for ripening control, but there is wide evidence that different stress-inducing factors, such as chilling, freezing, pathogen attack, salt stress and wounding, induce ethylene production (Kacperska, 1997). Concellon *et al.* (2005) observed that

chilling stress (0ºC) stimulated the level of ACC (1-aminocyclopropane-1-carboxylic acid) and MACC (1-malonylaminocyclopropane-1-carboxylic acid) and their levels remained high until chilling symptoms became severe. Rodriguez *et al.* (2001) observed a gradual increase in ethylene production from undetectable values to about 85 µl kg^{-1} h^{-1} after storage at 3ºC for 8 days. When the refrigerated were transferred to 20ºC, ethylene production rapidly increased, reaching 100 to 300 times higher than that measured at the cold storage outlet.

Depending on the cultivar, the respiration of fresh eggplant fruit ranges from 30 to 69 ml CO_2 kg^{-1} h^{-1} at 12.5ºC (Cantwell and Suslow, 1999). During storage at 3ºC, CO_2 production decreased from 70 to 30 ml CO_2 kg^{-1} h^{-1} over the first 3 days after harvest and remained around that value up to day 11, but when the fruits were transferred from 3ºC to 20ºC the respiratory intensity increased markedly (Rodriguez *et al.,* 2001). Earlier Kozukue and Kozukue (1975) found that CO_2 production increased to a high level after transfer to room temperature and it was speculated that the degree of chilling-injury could be estimated from the production of CO_2. Ethanol vapour treatment effectively reduced the respiration rate of fresh-cut eggplant during storage for 8 days at 10ºC (Hu *et al.,* 2010).

1.6.3 Weight loss

Fruit and vegetables are living tissues and continue to lose water after harvest, which can become a serious problem because it causes shrinkage and weight loss. Most commodities become unsalable as fresh produce after losing >7-10% fresh weight. Transpiration through the stomata is considered the major cause of postharvest weight loss and poor quality in eggplant (Diaz-Perez, 1998). Transpiration is inversely proportional to fruit size and the surface area/mass. According to Diaz-Perez (1998), 60% of eggplant fruit transpiration occurs via the calyx. Therefore, in small fruit, where the calyx area ratio is higher, the proportion of water transpired through the calyx is greater than in large fruit. Decrease of firmness during storage is a consequence of weight loss. Decrease in firmness of eggplant was reported by Jha *et al.* (2002) and was attributed to fruit shrinkage and the loosening of the upper cell layer (epidermis) during storage. Similarly, the firmness of transgenic parthenocarpic eggplant pulp (both fresh and frozen) decreased rapidly at -20ºC (Maestrelli *et al.,* 2003). To minimize the weight loss of stored eggplant, various research has been carried out by different researchers. Hung *et al.* (2011) recommended a nano-size mist environment for reducing weight loss, as well as to control postharvest disease. The weight loss rate of eggplant samples were 5.3 and 8.5% when they were stored under nano-

mist (particle diameter <100 nm) and ultrasonic (particle diameter of 216 nm) humidifiers, respectively for 10 days. Ethanol vapour treatment also effectively reduced weight loss and maintained the integrity of cell membranes in fresh-cut eggplant, as indicated by the low value of electrolyte leakage (Hu *et al.*, 2010). 1-Methylcyclopropene (1-MCP) has also been used to reduce water loss and maintain better firmness in stored eggplant fruit (Massoloa *et al.,* 2011).

1.6.4 Storage conditions

The quality and shelf life of fresh produce are highly dependent upon the storage atmosphere. Vegetables of tropical and subtropical origin, like eggplant fruit, are susceptible to chilling injury at temperatures well above 0ºC (Nothmann, 1986; Concellon *et al.,* 2007), and the recommended storage temperature for eggplant fruits is >10ºC (Cantwell and Suslow, 1999). Ryall and Lipton (1979) recommended a storage temperature of 10-12°C and relative humidity of 90-95%. In addition, rapid cooling to 10°C immediately after harvest is beneficial to retard discoloration, weight loss, drying of the calyx and decay. According to Ganesan *et al.* (2004), the shelf life of eggplant (cv. Pattabiram) could be extended by up to 9 days in a cost-effective cool chamber with the addition of 100 l water per day. Disinfected eggplant fruits could be stored at 8°C in perforated polyethylene (PE) bags for more than three weeks without sustaining chilling injury (Fallik *et al.,* 1995). Massoloa *et al.* (2011) suggested that 1-MCP treatments delay senescence, prevent the increase in sugars and are beneficial to complement low temperature storage and maintain the quality of eggplant fruit.

1.6.5 Storage at low temperature

Eggplant is prone to chilling injury when exposed to temperatures below 10°C (Nothmann, 1986). Chilling injury of eggplant is characterized by darkening of the seeds and pulp tissue, and in severe cases pitting and browning of the skin or surface scald were observed (Cantwell and Suslow, 1999). Susceptibility to chilling injury depends on the cultivar as well as on the degree of ripeness and period of harvest. In Israel, eggplants harvested during winter (December- January) were more susceptible to chilling injury than those harvested during spring (March-April), which had been exposed to low temperature during fruit growth (Fallik *et al.,* 1995). Abe *et al.* (1976) recommended storage of eggplant harvested in the warm season (July) at above 10ºC, while for fruit harvested in the cool season (October) 10ºC or below may be preferable, since severe pitting was observed in

warm season-grown eggplant fruit stored at 6°C, but no pitting was found in cool season fruit stored at the same temperature.

Kozukue and Kozukue (1975) observed chilling injury in eggplant fruit after 4 days storage at 1°C. Concellon *et al.* (2000, 2007) observed chilling injury symptoms when fruits were stored at 0°C and 5°C, but not at 10°C. Chilling injury caused a decrease in L_0 (lightness) and DL (oxidation potential). At 5°C, chilling injury occurred within 6-8 days (Concellon *et al.,* 2007), whereas Rodrigez *et al.* (2000) observed chilling injury at 3°C. In contrast, Fallik *et al*. (1995) reported chilling injury at a comparatively higher temperature (12ºC), which was manifested mainly by the appearance of surface injuries such as pitting, seed browning and discoloration of the calyx. The symptoms of chilling injury become extremely severe when the fruit is transferred to 20ºC (Abe *et al.,* 1976; Kozukue and Kozukue, 1975). Concellon *et al.* (2007) reported that skin from the upper section of the fruit was lighter and redder in colour, and had a lower concentration of anthocyanins throughout the subsequent storage period at 1ºC. Chilling injury was less in the central section, where anthocyanins, which are known to have antioxidant properties, are more abundant and therefore exert a protective role.

The level of phenolics has been shown to correlate with browning in different eggplant varieties (Prohens *et al.,* 2007). Browning is the result of reactions between phenolic compounds and oxidative enzymes due to cellular disruption. Kozukue *et al.* (1979) investigated the mechanism of browning by determining the changes in phenolic substances, phenylalanine ammonia-lyase (PAL) and tyrosine ammonia-lyase (TAL), either during storage at 1°C or after exposing fruit to low temperature for various periods. They found a rapid turn-over of chlorogenic acid in the early stages of cold storage of eggplant fruit, and the development of browning was closely related to chlorogenic acid, PAL and TAL. Concellon *et al.* (2004) characterized the polyphenoloxidase (PPO) and catecholase activity of eggplant fruit during storage at 0ºC and 10ºC. During storage of fruits at 10ºC, the activities of the soluble and insoluble PPO fractions increased, whereas, at 0ºC, the PPO activity of both fractions decreased and remained at lower levels, during which browning of the pulp tissue was observed.

A number of techniques have been proposed to control chilling injury as well as to reduce browning in eggplant. The activity of the enzymes PPO and POD (pyrogallol peroxidase) involves the oxidation of phenolics compounds, and the application of 1-MCP to eggplant fruits reduced their activity as a consequence of which browning was prevented (Massoloa *et al.,* 2011). Catalano *et al.* (2007) found that higher levels of CO_2 (2% O_2 and

5% CO_2) in packaged fresh-cut eggplants reduced the activity of PPO, PME (pectin methylesterase) and β-GAL (β-galactosidase) which were involved in fresh-cut eggplant degradation during chilled storage. Ethanol vapour may also reduce enzymatic browning in fresh-cut eggplant (Hu *et al.,* 2010). Storing fruit in modified atmospheres reduced the level of polyamines, putrescine and spermidine, which are found at higher levels (except spermidine) in chilling-injured eggplant fruit at 3ºC (Rodriguez *et al.,* 2001). Temkin-Gorodeiski *et al.* (1993) reported that dipping the eggplant calyx in a solution of fungicide and plant growth regulators retarded calyx senescence and controlled decay for more than two weeks of storage at 12°C.

1.6.6 Film-wrapping storage

Satisfactory lengthening of the shelf life of eggplants was achieved by enclosing fruit in polyethylene film, and storing under controlled temperature and relative humidity conditions. Mohamed and Sealy (1986) observed that, depending upon the cultivar, the fruit of eggplants can be stored at an ambient temperature of 8-9°C for 17 days, preserving perfect commercial quality, as long as the fruits are packed in shrinkable films of low density polyethylene (LDPE) or high density polyethylene (HDPE). Similarly, Fallik *et al.* (1995) and Rodriguez *et al.* (2001) reported that the refrigerated storage of eggplants can be extended by enclosing the fruits in polyethylene (PE) bags, thereby reducing or retarding chilling injury. In addition, eggplant fruit wrapped in HDPE maintained fresher flavor, firmness and quality for a longer period (Ben-Yehoshua, 1985). Another report showed that polyethylene film efficiently preserved the external appearance and reduced the weight loss of fruits of eggplant cv. Embú, whereas a coating with cassava starch (3%) was not so efficient in maintaining the shelf life of eggplant fruits stored for 15 days under environmental conditions (26-29ºC and 50-75% RH) (Pahlevi *et al.,* 2009). Gajewski *et al.* (2009) found an increased level of phenolics in the fruit skin when greenhouse-grown eggplants were wrapped with stretch film and stored at 16ºC. Although different sealed plastic films (heat-shrinkable copolymer and, polyvinyl chloride stretchable film) successfully reduced weight loss and maintained firmness, increased decay occurred compared with tissue-wrapped eggplants or eggplants wrapped in perforated film during storage at 7.2ºC for 1,2 and 3 weeks (Risse and Miller, 1983). Significant decay was observed even when the fruit were treated with chlorine and stored in different sealed plastic films.

1.6.7 Controlled atmosphere storage

To reduce respiration and maintain fruit quality, research has been carried out to find the optimum conditions to preserve the freshness of eggplant fruits. Controlled atmosphere (3% O_2 + 3% CO_2) prolonged the shelf-life of eggplant fruit cv. Pala-49 for up to 6 weeks and fruits had a better appearance, with little change in reducing and total sugars, starch and ascorbic acid (Kaynas *et al.,* 1995). In the same study, fruit injury occurred at a high level of CO_2 (5%O_2 + 10% CO_2). Catalano *et al.* (2007) reported that modified atmospheres increased the shelf-life and quality parameters of fresh-cut eggplants. These authors packed fresh-cut eggplant under a high CO_2 concentration (2% O_2 and 5% CO_2) and found decreased activity of PPO, PME and β-GAL. Modified atmosphere packaging (MAP) resulted in better maintenance of vitamin C, firmness and prolonged the shelf life of grafted eggplant cv. Tsakoniki in comparison with storage at 10ºC (Arvanitoyannis *et al.,* 2005). However, overall, controlled or modified atmospheres do not show great benefits to eggplant. Reducing the level of O_2 (3–5%) could delay deterioration just for a few days (Cantwell and Suslow, 1999).

1.7 Research objectives

To our knowledge, there is no accessible published information regarding the effect of fruit-setting plant growth regulators (PGR) on the morphological and physiological characteristics of eggplant fruits during growth, maturation and storage. This constitutes a major research gap since fruit setting PGR are commonly used to obtain eggplant fruits in the Mediterranean region during autumn and winter. Therefore, an attempt has been made to evaluate the impact of fruit-setting PGR on fruit growth and development as well as on physiological and quality parameters of eggplant. It is also of the utmost importance to determine the physiological and biochemical profile of parthenocarpic eggplant fruit under different storage conditions, and determine an appropriate storage protocol for quality conservation and better shelf-life. With this background, the present investigation was undertaken with the following objectives;

1. To study the effect of fruit-setting PGR on the growth and development of eggplant fruit in the greenhouse and the field during two cultivation seasons,
2. To study the effect of fruit-setting PGR on the quality attributes of eggplant fruit,
3. To investigate the physiological and biochemical changes in parthenocarpic eggplants as affected by different storage conditions.

1.8 Outline of the chapters

There are seven chapters in this thesis. Chapter 1 reviewed the available literature on eggplant relating to origin and distribution, world production, flower and fruit-set. Following this, recent progress in postharvest physiology in relation to the quality of harvested eggplant is detailed. Chapter 2 describes the general materials and methods for all experiments. This chapter also describes the details of different biometric parameters, storage conditions, physiological and biochemical measurements. Chapter 3 describes the effect of fruit-setting hormones on the morphological and physiological characteristics of eggplant. Chapter 4 details the effect of fruit-setting hormone on the physico-chemical characteristics of eggplant, while the effects of temperature, film-wrapping and controlled atmosphere storage on the postharvest quality of eggplant are described in chapters 5 and 6, respectively. Chapter 7 discusses the results of all the experiments and presents the conclusions of the study. The references are presented in the bibliography.

CHAPTER 2

2 General Materials and Methods

The investigation consisted of 4 experimental phases to achieve the research objectives. This chapter describes the general materials and methods that were used in all the experiments. Specific materials and methods for particular experiments will be discussed in the relevant chapters.

2.1 Experimental site

All the experiments were carried out in the greenhouse and open field of the Laboratory of Vegetable Production, Agricultural University of Athens, Athens, Greece. The experimental site is situated at 37º58' North latitude, 23º32' East longitude and at an altitude of 30 m above mean sea level. The area of the unheated plastic greenhouse was 300 m^2 and ventilation was by means of side windows.

2.2 Climate and weather

The climate is predominantly Mediterranean. The weekly meteorological data on rainfall, temperature and global radiation during the experimentation period were obtained from the Department of Meteorology, Agricultural University of Athens. By using a data logger (Hobo Weather Station data logger, Onset Computer Corp., Pocasset, MA, USA), the indoor air temperature and light intensity within the plastic greenhouse were recorded. Inside the greenhouse, maximum and minimum monthly air temperatures of 50.66ºC and 2.89ºC was recorded during July and December, 2008 while in the open field maximum and minimum air temperatures of 35.9ºC and 4.3ºC were observed during July and December, 2008. The highest value for total monthly rainfall in 2009 was recorded in January with 81.6 mm. In comparison with the first two years (2008-2009), 2011 was a moderate year with a maximum air temperature of 47.9ºC within the greenhouse during July. The meteorological data are presented in Appendices 1, 2 and 3.

2.3 Design of experiment

In the first and second experiment, each trial (open field and greenhouse) was arranged as a completely randomized design with four replications. For the storage experiments, 40 plants were grown for each treatment. For all measurements of fruit quality and storage, 4 replicates of 3 randomly selected fruit each were used.

2.4 Plant material

At the beginning of the research program four cultivars of eggplant were chosen namely, Tsakoniki, Black Beauty, Emi and Black Boy. Tsakoniki and Emi are grown commercially in Greece, while Black Beauty is a popular cultivar around the world, known for its fruit color and shape. One Asian cultivar, namely Black Boy, was tested in the first and second experiment. The fruit of Tsakoniki is long and cylindrical with an attractive red-white striped color, whereas, both Emi and Black Beauty produce large, flask-shaped or oblong, purple fruit. Black Boy produced dark, long, cylindrical fruits and the seeds were obtained from Phuja Seeds Pvt. Ltd., India. The seeds of Tsakoniki and Black Beauty were obtained from Geniki Fytotechniki, Athens, Greece, while those of Emi were produced at the Agricultural University of Athens.

2.5 Cultural practices

2.5.1 Seed sowing

Seeds of all eggplant cultivars were sown in seed trays containing 54 cells (4 cm × 4 cm) filled with commercial peat-based compost (TS-2, Klasmann-Deilmann GmbH, Geeste, Germany). The seed trays were kept in a glasshouse maintained at a temperature of 20±1ºC and seed germinated within 11 days. To maintain soil moisture during germination, hand-watering was provided when necessary.

2.5.2 First transplantation

At 11 days after emergence in the spring, and 16 days after emergence in the autumn, the seedlings were transplanted to 1 l (12cm diameter) individual plastic pots containing the same commercial peat-based compost and placed on a bench in the glasshouse. Irrigation was provided by hand approximately twice a week until final repotting.

2.5.3 Second (final) transplantation

Seedlings reached the four leaf stage by 23 days after emergence in the spring and 29 days in the autumn, respectively. At this time, only uniform and healthy young seedlings were transplanted to larger 11 l (30 cm diameter) pots containing a 1:1 (v/v) mixture of commercial peat-based compost (TS-2) and agricultural grade perlite (P4 Perloflor, Isocon, Greece). Light irrigation was given immediately after planting to get quick and uniform plant establishment. Both in the open field and greenhouse, plants were spaced at 75 cm between rows and 45 cm apart within the row, giving a plant density of 3 plants m^{-2}.

2.5.4 Pruning

Pruning was carried out from 20 days after repotting and continued until the final harvest of fruits. During pruning no side shoot was allowed to grow on the plants. The first flower of each plant was removed to encourage plant development and avoid the chance of parthenocarpic fruit set, a phenomenon commonly observed in the first-set fruit.

2.5.5 Training

In order to avoid lodging, the stems of the plants were trained on vertical cordons tied to transverse wires 2.5 m above the ground.

2.5.6 Irrigation

Drip irrigation was used both in the open field and in the greenhouse. In the greenhouse, the frequency of irrigation varied from 2 times per day in autumn to 3 times per day in summer with 3 minutes irrigation for each cycle. In the open field experiment, irrigation frequency varied depending upon soil moisture and climate.

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2.5.7 Application of plant nutrient

Fertilizer was applied with drip irrigation throughout the cropping season and the nutrient solution was prepared according to the recipe in Table 4 (Sonneveld, 2002). The electric conductivity and pH of the nutrient solution was 2.1 dS m^{-1} and 5.6, respectively

Table 4. Composition of the nutrient solution.

Nutrient	Nutrient solution
NO_3^-	16.00*
$H_2PO_4^-$	1.25*
NH_4^+	0.80*
K^+	7.75*
Ca^{2+}	7.00*
Mg^{2+}	4.00*
Fe	15.00
Mn	10.00
Zn	4.00
B	25.00
Cu	0.75
Mo	0.50

The concentrations of macronutrients(*) and micronutrients are given in mM and μM, respectively.

2.5.8 Application of plant growth regulators

Individual flowers were tagged on the day of anthesis (opening of the corolla) and in the absence of hormone application the fruits were considered to be formed from natural pollination. During autumn, insufficient amount of viable pollen caused lack of fruit set; therefore, hand pollination was carried out to obtain seed-containing fruit. To obtain parthenocarpic fruits, anthers were emasculated approximately 24 h before anthesis to prevent self-pollination, and flowers were then sprayed with plant growth regulator (PGR) to ensure fruit set. A hand sprayer was used to apply PGR and the flowers were tagged to show the date of application and the PGR. Both hand-pollination (autumn crop) and application of PGR was performed in the morning between 8 and 9 am. At the beginning of the research program, two plant growth regulators, namely 6-benzylaminopurine (BA, Sigma Chemicals) and β-naphthoxyacetic acid (NOA, Spyrou AEBE, Greece) were used alone or in combination, but because BA alone did not effectively set fruit this treatment was discontinued. Details of the treatments of each experiment are presented in the relevant chapters.

2.5.9 Application of pesticides

To control mites (*Tetranychus evansi*), plants were sprayed with Vertimec 1.8 EC (Syngenta) at 0.50 ml l^{-1} 2 times in the spring crops. Confidor 200 SC (Bayer Crop Science) was also used at 0.50 ml l^{-1} in the spring crops to control white fly (*Trialeurodes vaporariorum*).

2.5 Collection of pollen and *in vitro* pollen germination test

Flowers of eggplant cultivars (Tsakoniki, Black Beauty, Emi and Black Boy) were collected both from the plastic greenhouse and from the open field during the months of May-July, 2008 and November, 2008-January, 2009. Only long-styled flowers at the anthesis stage were collected early in the morning (between 8 to 9 am) to investigate pollen production (weight of pollen per flower) and pollen viability. Pollen was extracted from 15-20 flowers of each cultivar, combined and weighed to determine the pollen productivity per flower.

In order to evaluate the viability of eggplant pollen, germination tests were carried out using the culture medium of Karapanos *et al.* (2006), which consisted of KNO_3 (100 g l^{-1}), $MgSO_4.7H_2O$ (200 g l^{-1}), H_3BO_3 (100 g l^{-1}), $Ca(NO_3)_2.4H_2O$ (300 g l^{-1}), agar (10 g l^{-1}) and 15% of sucrose. The pH of the medium was adjusted to 6.5. Germination tests were carried out in 8 cm glass Petri dishes containing 15 ml agar-based medium. Pollen was smeared over the surface of medium with a soft brush and the dishes (three replicates per treatment) were sealed and placed in the dark at 20±0.5°C for 6 h. After incubation, germination was stopped by spraying the surface of the medium with 0.5% acetocarmine (Merck, Germany) in 45% acetic acid (Heslop-Harrison and Heslop-Harrison, 1992). Photographs were taken at five positions on each Petri dish (i.e., 15 photographs per treatment) with a digital camera (resolution of 1024×768 pixels) fitted to an optical microscope (Olympus BX 40; Tokyo, Japan). Germination was measured optically using the computer image analysis programme Image Pro Plus 2.0 (Media Cybernetics Inc., Silver Spring, MD, USA) to pinpoint the pollen grains. Germination was defined as pollen grains in which the length of the pollen tube was equal to, or longer than the diameter of the pollen grain. Randomly, 3-5 pollen tubes were selected from each photograph and their length measured by tracing and converting the pixels value to μm.

2.6 Harvest

The fruits were harvested when they attained marketable size and a shiny, bright color. In spring, fruits were harvested at 28 days after anthesis, starting from mid June and continuing until mid July. During autumn, fruits were harvested at 30 days after anthesis, starting from mid December until to mid January.

2.8 Biometric observations

2.8.1 Weight of fruits

Individual fruit weight was measured at harvest using an electronic balance (Mettler, Model PE-3600) and recorded in grams.

2.8.2 Length of fruit

The length of fruit was recorded individually from the proximal end of the fruit (site of the calyx) to the distal end (point of abscission of the style) using a meter rule and recorded in centimeters. Length was measured at 7, 14, 21 days after anthesis and at harvest.

2.8.3 Fruit diameter

After anthesis, the diameter of individual fruit was recorded using an electrical digital caliper (ROHS, Germany) at weekly intervals and expressed in cm. Measurements of fruit diameter were made across the widest part of the fruit.

2.8.4 Calyx length

At harvest, the length of the calyx was measured in centimeters from the end of peduncle to the point where indentation is initiated.

2.8.5 Peduncle length

The peduncle length of the harvested fruits was measured individually from the base of the calyx, which adheres to the fruit, to the point of attachment of the peduncle of the stem using an electrical digital caliper (ROHS, Germany).

2.9 Fruit quality attributes

2.9.1 Pericarp colour

Eggplant fruit colour was recorded using a Chromameter (Minolta CR 300, Japan) calibrated against a standard white plate. Chromatic analysis was carried out following the CIE (Commission International de l'Eclairage) system of 1976. Values of L*, a* and b* were measured to describe a three dimensional colour space and interpreted as follows: L* indicates lightness, read from 0 (completely opaque or ''black'') to 100 (completely transparent or ''white''). A positive a* value indicates redness (negative a* indicates greenness) and a positive b* value yellowness (negative b* indicates blueness) on the hue-

circle (Hutchings, 1994; Voss, 1992). It was decided to express the pericarp colour in terms of L, Chroma (C*) and Hue angle (H^o) because the purple colour development of the fruit was better described using C* and H^o than a* and b*. The hue angle (H^o), hue = arctangent (b*/a*), represented red-purple (0^o), yellow (90^o), bluish-green (180^o) and blue (270^o) (McGuire, 1992). The chroma (C*), obtained from $(a^{*2} + b^{*2})^{1/2}$, corresponded to the intensity or colour saturation, in which low values represent dull colour while high values represent vivid colour. In addition, the changes in fruit colour during storage were measured using the following equations

$\Delta L = L_s - L$

$\Delta H^o = H_s - H$

$\Delta C = C_s - C$

Here L_s, H_s and C_s represented the value of lightness, hue angle and chroma, respectively after storage. In the first and second experiments, skin colour was measured only at the central section of each fruit at 7, 14 and 21 days after anthesis and also at the harvest stage. During the storage experiment, skin colour was measured at the proximal end (near to the calyx) and in the central region of individual fruits from the beginning until the end of storage. The data of each measurement are the average of duplicate measurements at two opposite points on the equator of each fruit (all experiments) plus the proximal part (storage experiments).

2.9.2 Firmness

The firmness (kg) of fruits was expressed as the force required to penetrate the fruit by a 6.3 mm-diameter conical needle penetrating to a depth of 0.6 cm at a constant speed of 200 mm min^{-1} using a penetrometer (Chatillon DFIS-10, USA) mounted on a Chatillon TCM 201-M support. For external firmness, four measurements were made on each fruit, two in the proximal pericarp and two in the pericarp of the central region of the fruit. Fruits were transversely cut into halves in the central portion of each fruit and measurement of internal flesh firmness was determined on two opposite positions in the cortical tissue.

2.9.3 Sample preparation

All eggplant fruits were peeled, and the skin (rind) and the flesh of the fruits were separated. The flesh of the fruits was chopped immediately so as to prevent oxidation into small pieces (1-2 cm) and stored in air-tight plastic bags. In the first and second experiment, flesh was stored at –80ºC (Kaltis, Taiwan) until chemical analysis or before

being freeze-dried (Heto, Lyolab 3000, Denmark) at -60^{o}C for 3 days. For determination of anthocyanin content, freeze-dried skins were used in all experiments. The freeze-dried eggplant samples were ground to a fine powder in a pestle and mortar.

2.9.4 Analysis of ascorbic acid

During the storage experiment, ascorbic acid content (mg 100 g^{-1} fresh weight) was determined by the spectrophotometric procedure of Bajaj and Kaur (1981). Five grams of fresh tissue were homogenized in 100 ml oxalic acid-EDTA cold solution. The homogenate was centrifuged at 3000 rpm for 10 min at 4^{o}C and the supernatant was subsequently filtered with filter paper (MN 617, Macherey Nagel, Germany). A 5 ml aliquot was then transferred to a 25-ml volumetric flask to which 0.5 ml metaphosphoric acid-acetic acid solution, 1 ml sulphuric acid solution (5%), and 2 ml of ammonium molybdate (5%) reagent were added. The mixture was adjusted to a volume of 25 ml with distilled water and allowed to stand for 15 min, after which the absorbance at 760 nm was measured with a UV/VIS spectrophotometer (Perkin-Elmer Lambda 1A, Waltham, Massachusetts, USA). Ascorbic acid concentration was quantified using a standard curve of L-ascorbic acid and expressed as mg 100 g^{-1} fresh weight.

In the second experiment, ascorbic acid was measured with a RQflex reflectometer method (Merck RQflex 2, Germany) and expressed as mg 100 g^{-1} fresh weight. Five gram of fresh sample was homogenized with cold 0.4% oxalic acid solution using a home-blender, the homogenate was then filtered with filter paper (MN 617, Macherey Nagel, Germany) and the ascorbate concentration was measured in the filtrate using the appropriate Merck stick indicator.

2.9.5 Protein analysis

Protein concentrations were determined following the method of Bearden (1978). The protein reagent used in the assay consisted of 0.04 mg ml^{-1} Coomassie Brilliant Blue G-250 (Serva 17524), and 85% ortho-phosphoric acid. Extraction was performed according to McCown *et al.* (1968) using 1 g fresh sample. The eggplant flesh tissue was extracted with 5 ml of 100mM Tris-HCl (pH 7.5) using a homogenizer (CAT Unidrive X1000, Germany), the mixture was vortexed vigorously and kept in the refrigerator at 4-5ºC for 1 hr. The homogenate was centrifuged at 5300 rpm for 15 min at 4ºC. One hundred microliter (100 µl) of supernatant was diluted with 1400 µl distilled water to which 1.5 ml Bearden solution was added. After vortexing, absorbance was measured at 595 nm using a

UV/VIS spectrophotometer (Perkin-Elmer Lambda 1A, Waltham, Massachusetts, USA). The protein concentration was calculated using bovine serum albumin (BSA; Sigma Chemical) as a standard and expressed as mg protein g^{-1} fresh weight.

2.9.6 Evaluation of browning potential

Browning of mesocarp tissue was evaluated using a chromameter (Minolta CR 300, Japan) as described by Concellón *et al.* (2005). To determine the colour parameter L* (lightness), fruits were cut transversely at the midpoint between the blossom and stem ends (slice thickness 1.0 cm). A sharp knife with a straight edge was used to produce clean cuts. Two measurements in the central part of each slice of fruit were made: (1) near the placenta and (2) at a distance from the placenta, immediately after being cut (L_0) and 30 min later (L_{30}). During the storage experiment, measurements were taken only near the placenta tissue. All measurements were made on five fruits from each treatment, and in duplicate. The differences between L_{30} and L_0 ($\Delta L = L_{30} - L_0$) were used as a measure of the degree of browning.

2.9.7 Analysis of total phenol

Total phenolic compounds were quantified using the Folin–Ciocalteu reagent (FC) and the colorimetric method of Singleton and Rossi (1965). Extraction was performed according to Velioglu *et al.* (1998) using 100 mg freeze-dried (experiment 2) or 1 g fresh flesh (storage experiment). In the case of fresh samples, tissues were disrupted into the extraction medium using a homogenizer. The eggplant flesh tissue was extracted with 4 ml 80% aqueous methanol containing 2.7% HCl (37%), shaken for 2 h on an orbital shaker (200 rpm) at room temperature and centrifuged at 5300 rpm for 15 min at 4ºC. The extraction procedure was repeated twice and the supernatants were combined for the total phenolics assay. Three hundred microliter (300 µl) of extract was added to 2.25 ml of Folin–Ciocalteu reagent, followed by 2.25 ml of sodium carbonate solution (60g l^{-1}). The samples were vortexed and left to stand for 90 min at room temperature. After incubation, absorbance was measured at 765 nm using a UV/VIS spectrophotometer (Perkin-Elmer Lambda 1A, Waltham, Massachusetts, USA). Phenol content was estimated from a standard curve of gallic acid and results were expressed as mg of gallic acid equivalents (GAE) 100 g^{-1} fresh fruit.

2.9.8 Anthocyanin analysis

Anthocyanin was extracted from the skin of each eggplant fruit (proximal and central part separately) and measured using the pH-differential method according to Lee *et al.* (2005) and Todaro *et al.* (2008). Eggplant skin (100 mg freeze-dried sample) was extracted with 2 ml 70% ethanol containing 1.35 ml HCl (37%). The solution was incubated in a water bath at 40^{o}C for 1 hr, and then centrifuged at 5300 rpm for 10 min. The supernatant was removed and the extraction procedure was repeated with another 2 ml of extraction medium, and the supernatants were combined. Two dilutions of each sample were prepared, one for pH 1.0 using potassium chloride buffer (0.025 M) and another for pH 4.5 using sodium acetate buffer (0.4 M). The supernatant (1.5 ml) was diluted with each buffer (3 ml) and after 20 min its absorbance was measured at 520 and 700 nm using a UV/VIS spectrophotometer (Perkin-Elmer Lambda 1A, Waltham, Massachusetts, USA). The concentration of anthocyanin (mg l^{-1}) in the extract was calculated according to the following formula and expressed as delphinidin-3-glucoside equivalent:

Concentration of anthocyanin in the extract (delphinidin-3-glucoside equivalent, mg l^{-1}) = (A×MW×DF×1000)/ ε × l

where A is the absorbance = ($A_{520nm} - A_{700nm}$) at pH 1.0 – ($A_{520nm} - A_{700nm}$) at pH 4.5, MW is the molecular weight (g mol^{-1}) = 500.8 g mol^{-1} for Del-3-glc, DF is the dilution factor (1.5 ml sample is diluted to 3 ml, DF = 2), ε is the molar extinction coefficient (L mol^{-1} cm^{-1}) = 23,700 for Del-3-glc, L (path length in cm) = 1.

The anthocyanin content of eggplant skin was then expressed as mg anthocyanin 100 g^{-1} fresh sample.

2.9.9 Sugar analysis

Soluble sugar concentration was determined using a high performance liquid chromatography (HPLC) system equipped with an isocratic pump (Varian 9010, Inc., USA), a refractive index detector (Erma ERC-7511, Tokyo, Japan), and a Supelco Supelcosil LC-NH_2 (5µm, 25cm x 4,6mm) column (Sigma-Aldrich, St. Louis, MO, USA) maintained at 30°C, with 80% acetonitrile + 20% H_2O (HPLC grade, Fisher Scientific, Hampton, New Hampshire, USA) as eluent, at a flow rate of 1 ml min^{-1}. Sugars were measured in ethanolic extracts of eggplant flesh, following the method of Piccaglia and Galleti (1988), with few modifications. Five hundred milligrams of homogenized fresh tissues were extracted in 2 ml 80% ethanol at 65^{o}C for 25 min. The suspension was centrifuged (5500 rpm, 15 min) and the supernatant was kept for sugar analysis. The

procedure was repeated twice and all the supernatants were combined and evaporated to dryness at 65^{o}C with the aid of continuous ventilation (N_2). The residue was re-dissolved in 3 ml of HPLC grade water and filtered using 0.20 μm polyester membrane filters (Macherey-Nagel Chromafil PET 20/15). The solution was injected in a Rheodyne injector with a 20 μl loop. The areas under the curves were computed by a software package (LC Solution, Shimadzu Crop., Japan) and the concentration of fructose, glucose, sucrose and maltose, which are the major sugars in eggplant fruit (Kozukue *et al.,* 1978; Boo *et al.,* 2010), were identified by the retention times and their concentrations were calculated using standards of known concentration for each sugar, and expressed as mg 100 g^{-1} fresh weight.

2.9.10 Starch analysis

Starch content was determined by using the ethanol-insoluble residues of the soluble sugar analysis, as described by the method of Dekker and Richards (1971). Starch was digested by adding amyloglycosidase (A7420 from *Aspergillus niger*, Sigma-Aldrich, St. Louis, MO, USA) at approximately 1 mg enzyme g^{-1} fresh tissue. The glucose content was subsequently determined colorimetrically following the method of Barham and Trinder (1972), using a GOD-POD (glucose oxidase/peroxidase) kit for glucose determination (Biosis Ltd., Athens, Greece), in a spectrophotometer at 510 nm (Perkin-Elmer Lambda 1A, Waltham, Massachusetts, USA). Starch content was estimated from a standard curve of starch and results were expressed as mg 100 g^{-1} fresh fruit.

2.9.11 Respiration rate

For respiration measurements, individual fruits were weighed and placed in a 3850 ml glass jar closed with an airtight glass lid for 3 min. The outflows from the glass jar were connected via a manifold to an infra-red CO_2 analyzer (LI-COR model LI 6262, Lincoln, Nebraska, USA). The respiration rate of the fruit was calculated based on the increase in concentration of CO_2 within the glass jar and expressed as ml CO_2 kg^{-1} h^{-1}.

2.9.12 Rate of ethylene production

Individual fruits were placed in a 530 ml impermeable plastic bag and sealed for 2 h and kept at the fruit's initial storage temperature. Previous experiments showed that ethylene is not absorbed by this type of plastic bags. After this incubation period, gas samples were taken with the aid of a 0.5 ml air tight syringe. The gas sample was immediately injected

into a gas chromatograph (Perkin Elmer Sigma-300, Norwalk, USA) equipped with a flame ionization detector and a column (120 cm × 0.2 cm i.d. column of 80-100 mesh activated alumina). The detector and oven were operated at 150^{o}C and 100°C, respectively. The detection limit of the instrument was 0.42 nmol. Ethylene production (µl kg^{-1} h^{-1}) was calculated based on the ethylene concentration of a series of standard samples (0.1-20 µl ethylene l^{-1}).

2.9.13 Percentage dry weight

Fruits were cut into small pieces with a stainless steel knife. A known weight of the fresh cortical tissue was placed in an oven at 85ºC, until no further loss of weight was observed in the samples. The dry tissue was weighed and the % dry matter calculated from the reduction in the initial weight.

2.9.14 Percentage weight loss

Fruits from the storage experiments were individually weighed before the storage treatment and also recorded after the storage period. Fruit weight loss was calculated as the percent reduction in weight.

2.15 Statistical analysis

One factor analysis of variance (ANOVA) was conducted for all variables using the Statgraphics Plus Version 2.1 statistical program (STSC, Inc., 1987). The means were compared using Fisher's Least Significant Difference (LSD), while the Student t-test was used to compare pairs of means. All analyses were regarded as significant at $P \leq 0.05$.

CHAPTER 3

Effect of fruit-setting hormones on the morphological and physiological characteristics of eggplant.

3.1 Introduction

Successful completion of pollination and fertilization is essential to trigger fruit set in most flowering plants (Gillaspy *et al.*, 1993). In Solanaceous vegetables, such as eggplant, flowers are self-pollinating and during the summer in the Mediterranean region, fruit-set occurs normally under field conditions, but during the cool season fruit-set and development is hampered, notably as a result of reduced style length as well as low pollen germinability (Nothmann and Koller, 1975). Rainfall, high relative humidity and insufficient light may also be detrimental to fruit set in eggplants during the cool season in the Mediterranean region (Olympios, 1976; Wang *et al.,* 1980). In winter, therefore, plant growth regulators (PGR) can be used to stimulate parthenocarpic fruit development (Olympios, 1976; Lee *et al*., 2004; Kowalska, 2006) and in Greece, as in other Mediterranean regions, the commercial production of eggplants during winter is frequently achieved in greenhouses by means of PGR application. So far, information on the role of fruit-setting PGR on the morphological and physiological characteristics of eggplant fruit during growth and development is meager. Therefore, the aim of this work was to compare morphological and physiological changes during the growth and maturation of eggplant fruits set by PGR application with those set by natural pollination.

3.2 Materials and methods

The present investigation was carried out during two consecutive seasons of autumn (2008) and spring (2009) to study the effect of fruit-setting hormone on the morphological characteristics of eggplant fruit during growth and maturation. In both trials, four eggplant cultivars, Tsakoniki, Black Beauty, Emi and Black Boy, were cultivated in an unheated greenhouse and in the open field. Detailed information on crop husbandry methods is presented in Chapter 2. Seasonal variation in pollen productivity and viability were also studied under both greenhouse and open field conditions (methods detailed in Chapter 2). Plant growth regulators (PGR), viz. β-NOA (60 ppm), NOA (60 ppm) plus BA (30 ppm), and BA (30 ppm) were applied to set parthenocarpic eggplant fruits, while naturally

pollinated fruits formed the control. Each trial was arranged in a completely randomized design with 4 replications and 16 plants for each cultivar. After fruit-set, the diameter, length and skin colour of the individual fruit were recorded at 7, 14 and 21 days after anthesis (DAA), and also at harvest. To avoid competition among fruits on the same plants only 1 to 2 fruits were allowed to set per plant. Fruits were harvested at 28 and 30 DAA during spring and autumn, respectively, and the mean fruit weight, length of peduncle and length of calyx were recorded (details described in Chapter 2).

3.3 Results

In the present investigation, the application of BA (30 ppm) alone failed to set eggplant fruit in either season. Therefore, the results discussed here refer only to treatments with NOA (60 ppm), NOA (60 ppm) in combination with BA (30 ppm), and the control.

3.3.1 Fruit color

Fruit colour is an important quality characteristic that affects the consumer's decision to purchase or not (Sloulin, 1990). In this study, color values of eggplant fruit were measured on different DAA up to harvest and presented as chroma (C*), hue angle (Hº) and L values. In Tsakoniki, the value L for the fruit skin was minimum at 7DAA and afterwards increased throughout the growing season, indicating that the fruit became increasingly lighter in color as they approached maturity (Fig 1). The pattern of changes in L values followed a similar trend in all cases and there were no significant differences ($P \leq 0.05$) in L value between parthenocarpic and seed-containing fruit at different DAA up to harvest, irrespective of the season and whether the plants were cultivated in the field or under cover (Fig 1).

The chroma value (C*) of Tsakoniki fruit increased gradually from 7DAA and reached its highest value at 21DAA, except in open field grown fruit during autumn, indicating that the fruit became more red-purple in color at 21DAA than at 7DAA (Fig 2). A decrease in C* value was then observed between 21DAA and harvest, except in open field-grown fruit in autumn. In all crops, the C* value was higher in the fruit set with PGR than in the naturally-set fruit. This result indicates that hormone-set fruit (especially those set by NOA) have a more intense red-purple colour than those set by natural pollination, but usually not to a statistically significant level (Fig. 2). The C* value for fruit from the spring greenhouse and open field crop was higher than that of the corresponding autumn

crop until 21DAA, indicating that the spring fruit were darker red-purple in color than those of the autumn. Afterwards a sharp decrease in C* value was recorded in the spring grown fruit between 21DAA and harvest, indicating that spring-grown fruits lost their intense colour more rapidly than those of autumn-grown fruit. At harvest, fruit grown in the open field tended to have a higher C* value (darker red-purple colour) than the corresponding greenhouse-grown fruit, but the differences were not statistically significant (Fig.2).

The Hue angle (Hº) of Tsakoniki fruit calculated at different DAA up to harvest increased with maturation (changing from negative to positive), indicating that fruit colour changed from red-purple to whitish-purple (Fig 3). The value of Hº did not differ between parthenocarpic and seed-containing fruit ($P \leq 0.05$) and no major differences were observed between greenhouse and open field-grown fruits. At harvest, however, considerable differences were noted between spring and autumn grown fruit, with Hº being higher in the fruit grown in spring than in the autumn. Additionally, the Hº value tended to be higher in fruit that were formed parthenocarpically by treatment with NOA + BA than by natural pollination, whereas the Hº value of the NOA treatment was intermediate between the two (Fig. 3), but these differences were not statistically significant. In comparing the colour of Tsakoniki with the stage of maturity, it is also important to note that the fruit of this cultivar is bi-coloured: red-purple and white. The change in C* and Hº, therefore, may not only indicate a change in the intensity of red-purple colour, but also a change in the white striping of the fruit (hence the abrupt change in C* between 21DAA and harvest in the spring crop).

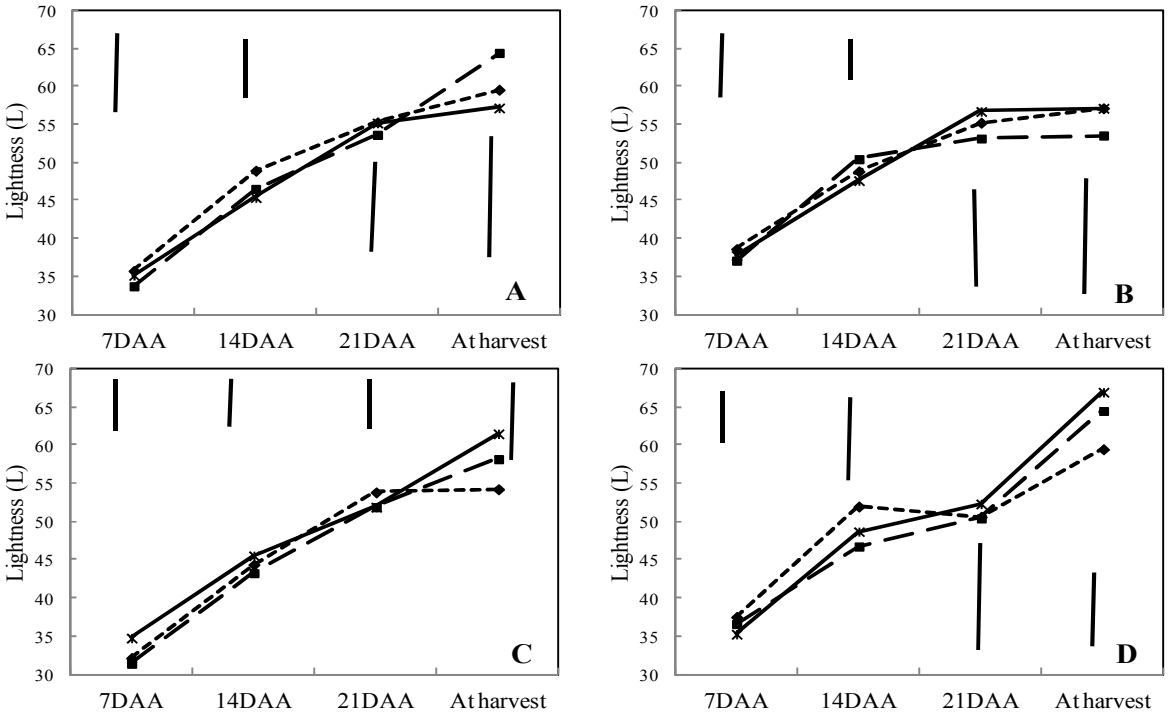

Fig. 1. Lightness (L) of fruit of eggplant cv. Tsakoniki at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

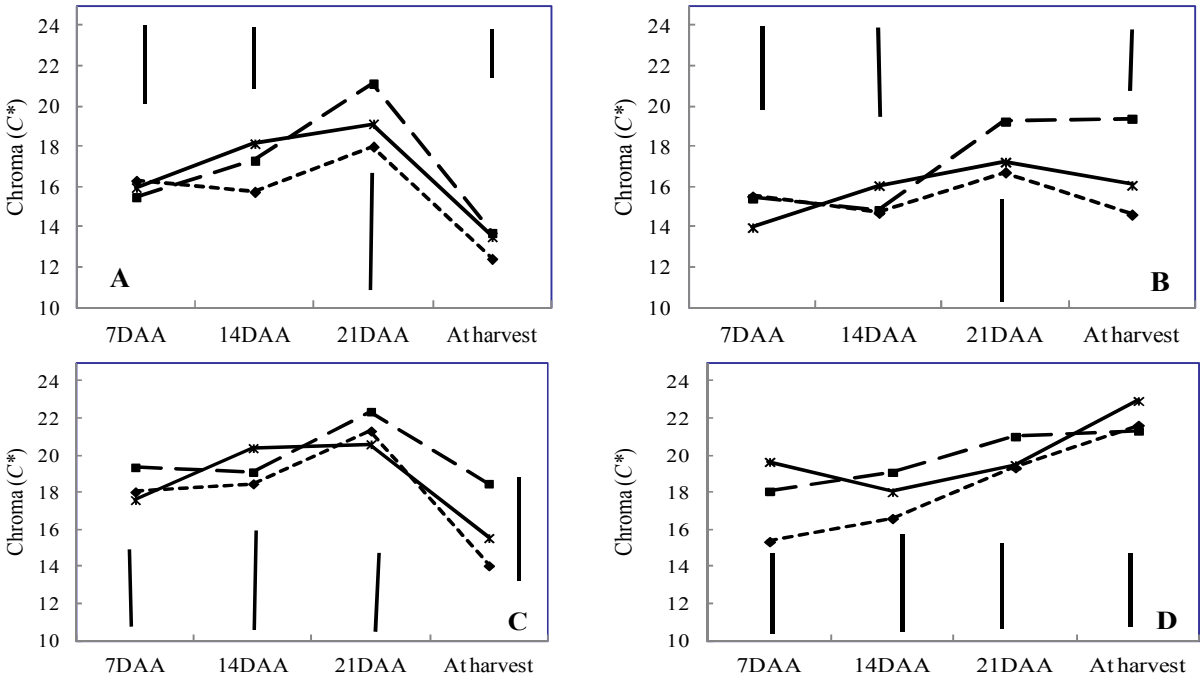

Fig 2. Chroma (C*) of fruit of eggplant cv. Tsakoniki at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

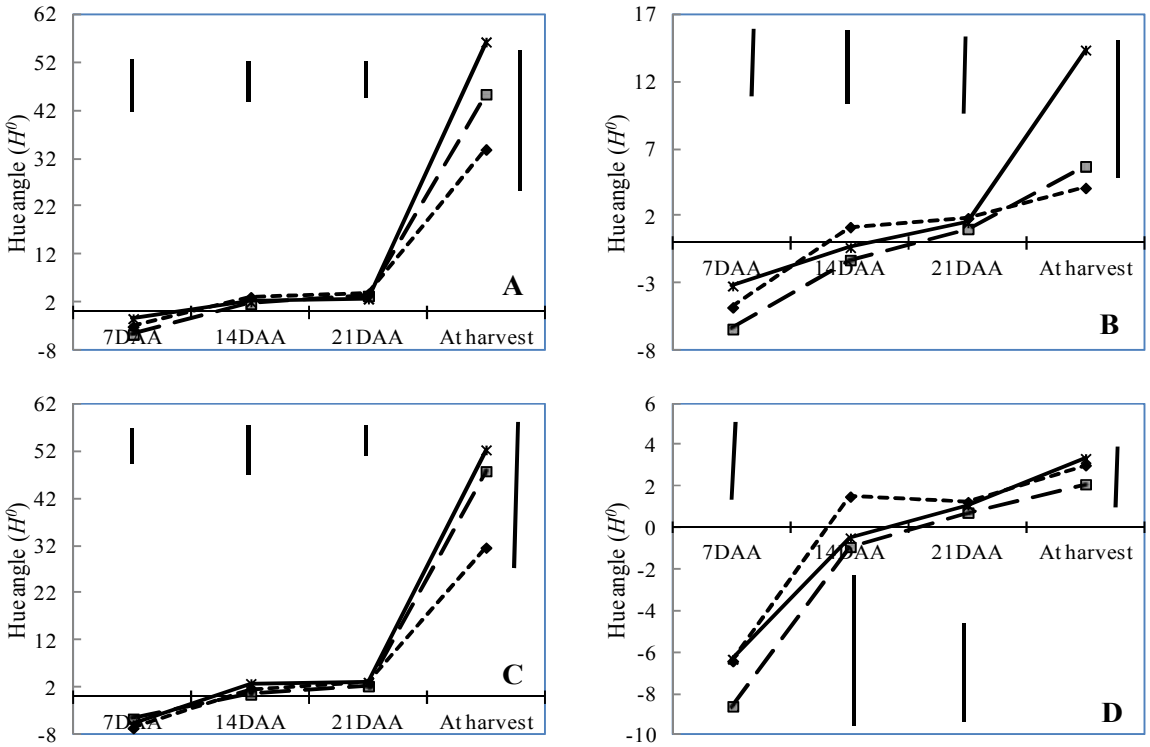

Fig 3. Hue angle (Hº) of fruit of eggplant cv. Tsakoniki at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

In general, the fruit color of Black Beauty is uniformly dark purple and there were no significant differences in the color coordinates L, C* and Hº between parthenocarpic and seed-containing fruit of this cultivar at different DAA until harvest (Fig 4, 5 and 6). Figure 4 indicates that the changes in L value of both seed-containing and parthenocarpic fruit were minimum from 7 DAA to 21 DAA, i.e., there was little change in lightness. Between 21 DAA and harvest, however, the L value increased sharply, indicating a lightening of fruit colour during maturation (Fig. 4). Moreover, the mean value of L tended to be higher in the greenhouse-grown fruit of Black Beauty than in those grown in the open field, irrespective of treatment and season, but not to a statistically significant level.

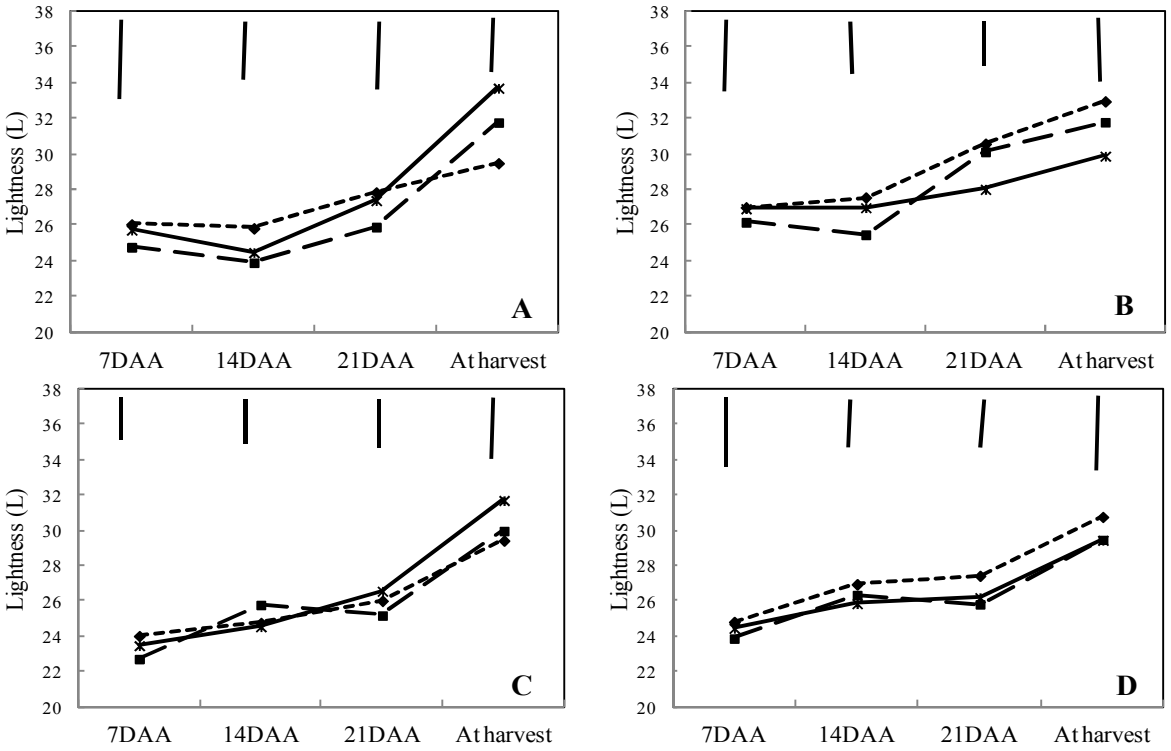

Fig 4. Lightness (L) of fruit of eggplant cv. Black Beauty at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

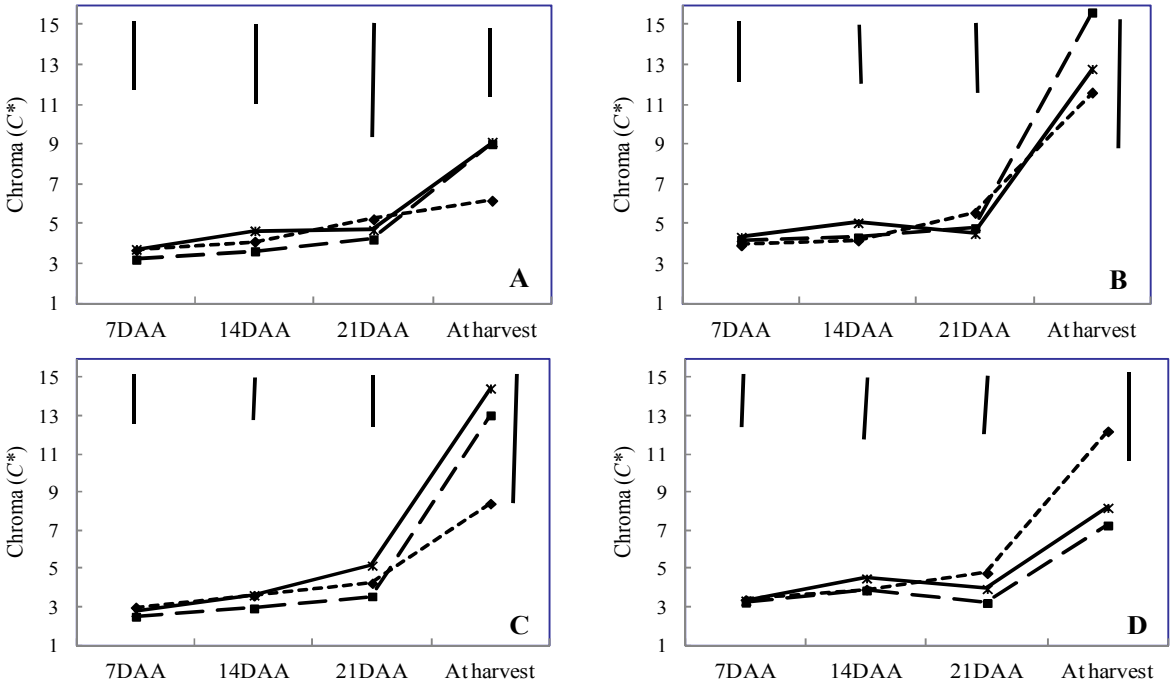

Fig 5. Chroma (C*) of fruit of eggplant cv. Black Beauty at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

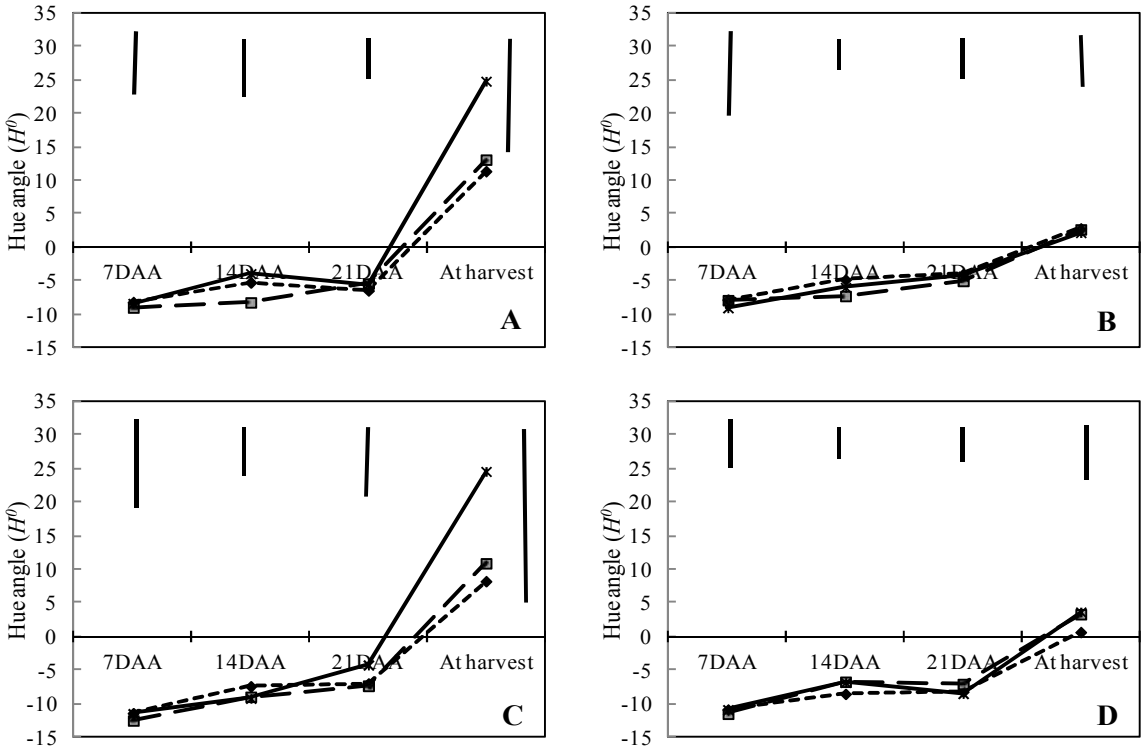

Fig 6. Hue angle (Hº) of fruit of eggplant cv. Black Beauty at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

It was observed that at an early growth stage (7 DAA) C* was minimum in both parthenocarpic and seed-containing fruit of Black Beauty and the fruit were dark purple in color (Fig 5). No major changes were observed from 7 DAA to 21 DAA, irrespective of season or growing conditions (greenhouse or open field), but thereafter C* increased abruptly, reaching a maximum value at harvest, at which stage the fruit attained a lighter purple color (Fig 5). C* value did not vary in fruits between spring and autumn or between the greenhouse and open field.

The changes of Hº in parthenocarpic fruit of Black Beauty followed the same pattern as that of seed-containing fruit at different DAA until harvest (Fig 6). At 7 DAA, Hº was negative, indicating a purple color of the fruit. During maturation, the Hº value changed from negative to positive, indicating that fruit color changed from purple to red-purple. This change occurred for both parthenocarpic and seed-containing fruit between 21 DAA and harvest. No major differences were observed between fruit grown in the greenhouse and those grown in the open field, but fruit grown in spring had a higher Hº value at harvest than those grown in autumn irrespective of growing conditions (Fig. 6).

In Emi, the value of L decreased between 7 and 14DAA, then increased during the course of fruit maturation, reaching a maximum value at harvest (Fig 7). Increasing values of L indicated that the eggplant fruit became lighter in colour towards harvest maturity. Although the L value was usually lower in seed-containing fruit at harvest than in parthenocarpic fruit, the difference was not significant ($P \leq 0.05$). Between seasons and growing conditions (greenhouse and open field) no significant differences were recorded, although, exceptionally, in the spring greenhouse crop the L value of the seed-containing fruit was higher than that of NOA-induced fruit.

The chroma value of fruit of Emi decreased between 7 and 14 DAA but then increased up to harvest, which coincided with the fading of fruit color during the process of fruit maturation (Fig 8). However, the C* value did not differ ($P \leq 0.05$) between parthenocarpic and seed-containing fruit at different DAA until harvest, when in the open field crop in the spring the C* value of the parthenocarpic fruit was higher than that of the seed-containing fruit. The autumn grown fruit were observed to have a more intense purple colour than the spring grown fruit, although this was not reflected in the C* values except at harvest.

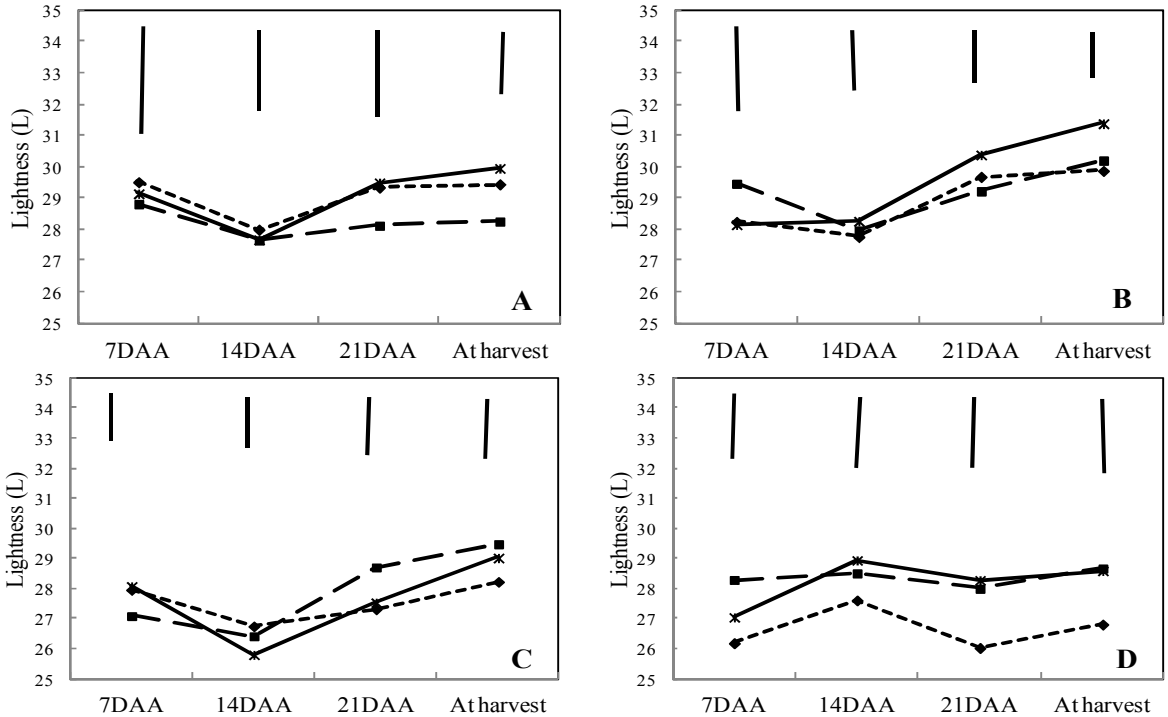

Fig 7. Lightness (L) of fruit of eggplant cv. Emi at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—✳—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

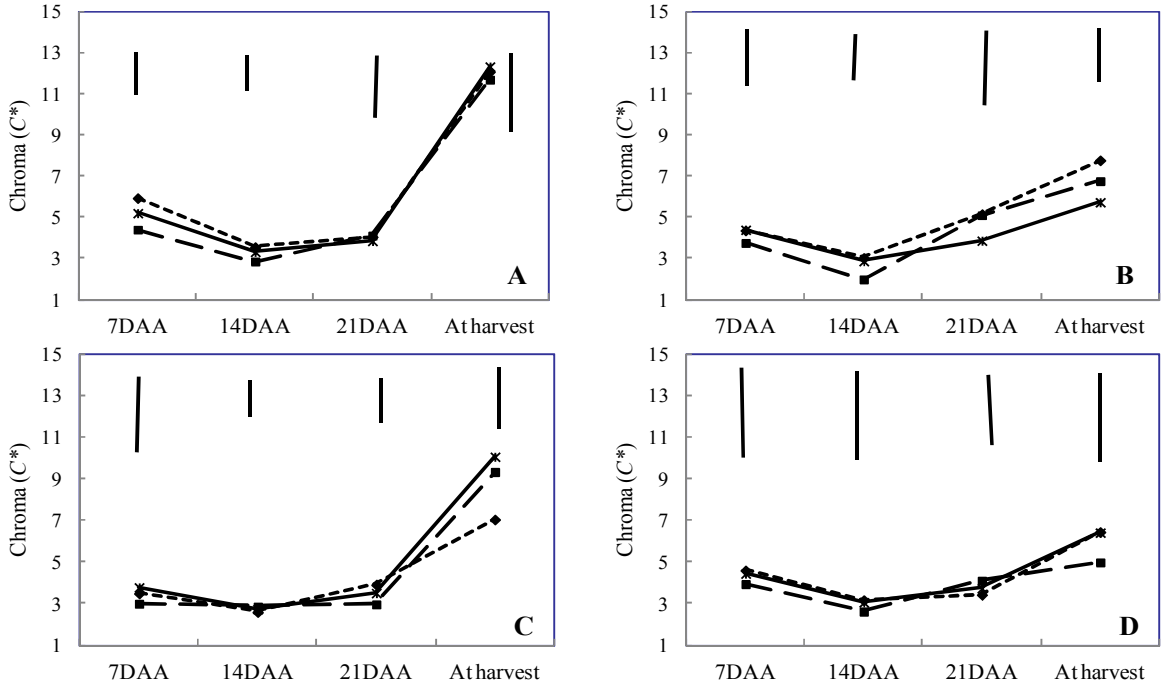

Fig 8. Chroma (C*) of fruit of eggplant cv. Emi at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

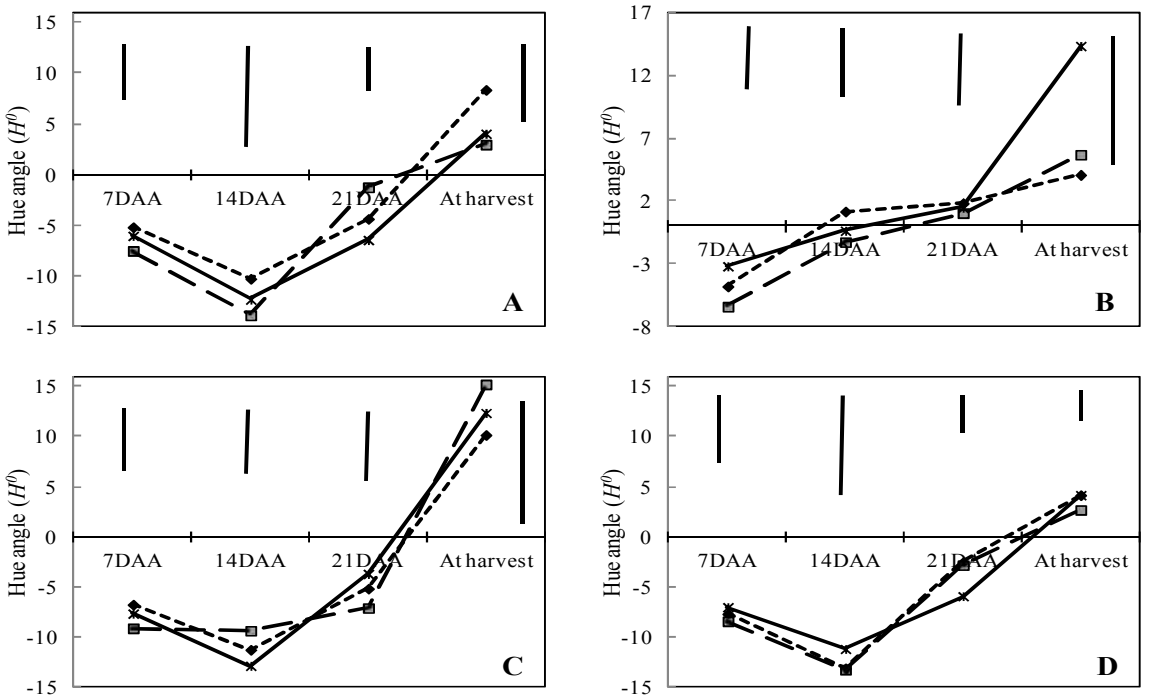

Fig 9. Hue angle (Hº) of fruit of eggplant cv. Emi at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

It was observed that the Hº value of Emi decreased from 7 to 14DAA, but increased sharply thereafter, reflecting the color changed from dark purple to light purple (Fig 9). In all cases, however, the Hº value remained negative from 7 to 21DAA, but between 21DAA and harvest changed from negative to positive. As in the case of C*, the Hº value did not differ ($P \leq 0.05$) between parthenocarpic and seed-containing fruit of Emi at different DAA until harvest. No difference in Hº value was observed between fruit for the greenhouse and that from the open field, except at harvest when the open field-grown spring fruit were observed to be lighter purple in colour than the greenhouse crop.

In Black Boy, no significant difference ($P \leq 0.05$) was observed between parthenocarpic and seed-containing fruit in relation to L, C* and Hº values at different DAA up to harvest (Fig 10, 11 and 12). The L values of both parthenocarpic and seed-containing fruit initially decreased (between 7 and 14DAA), but then increased, indicating that the fruit became lighter in colour during maturation (Fig 10). The L values for the field-grown crops (both spring and autumn) were initially lower (between 7 and 14DAA) than those of the corresponding greenhouse crops, but by harvest these differences had disappeared, except in the spring-grown open field NOA-induced fruit, which had a higher L value at harvest.

In Black Boy, the C* value did not change significantly at the early stage of development (from 7 to 14 DAA), but subsequently increased up to harvest, indicating that fruit color changed from purple to orange-purple (Fig 11). In general, no major differences in C* value were found between the spring and autumn crops but the open field-grown fruit had higher C* values than those of the corresponding greenhouse-grown fruit at harvest.

The fruit color of Black Boy changed from purple to orange-purple color during maturation, Figure 12 showed that the Hº value decreased between 7 and 14DAA then increased up to harvest, although a decrease in Hº value was observed in the seed-containing and NOA-induced fruit of the autumn-grown open field crop at harvest. Except for this, a similar pattern of Hº value change was observed in both the spring and autumn crops. No differences were detected between greenhouse and open field-grown fruits irrespective of seasons.

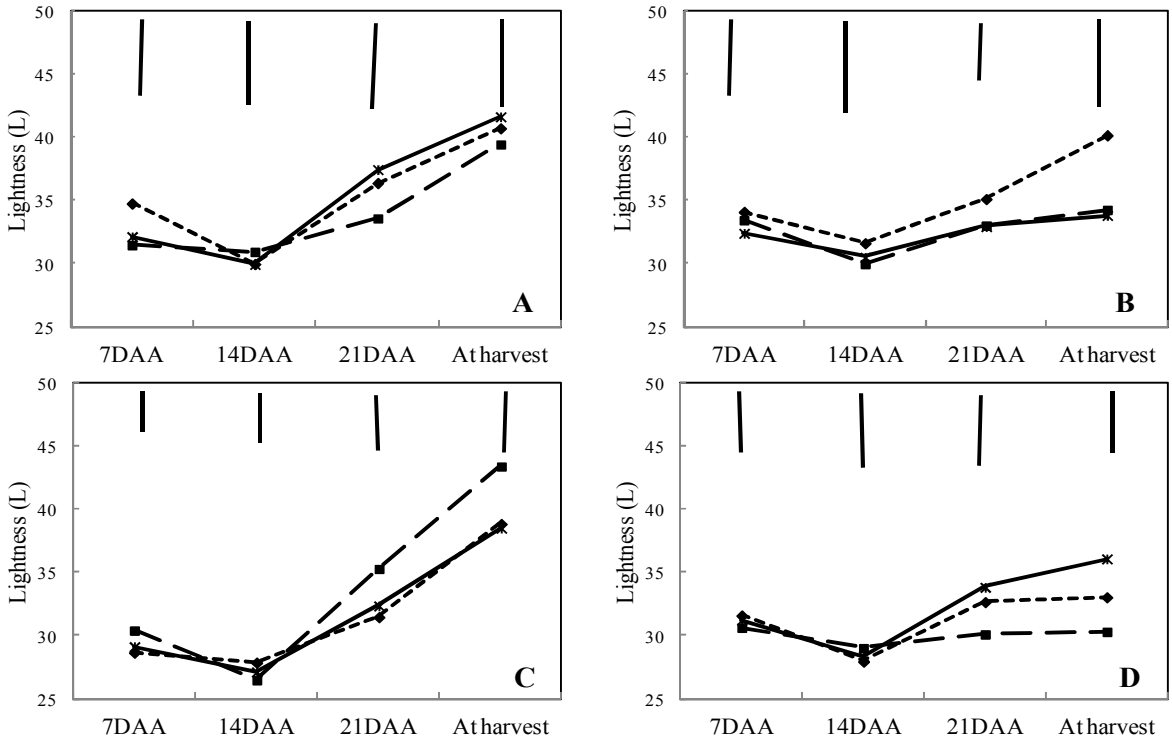

Fig 10. Lightness (L) of fruit of eggplant cv. Black Boy at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—✳—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

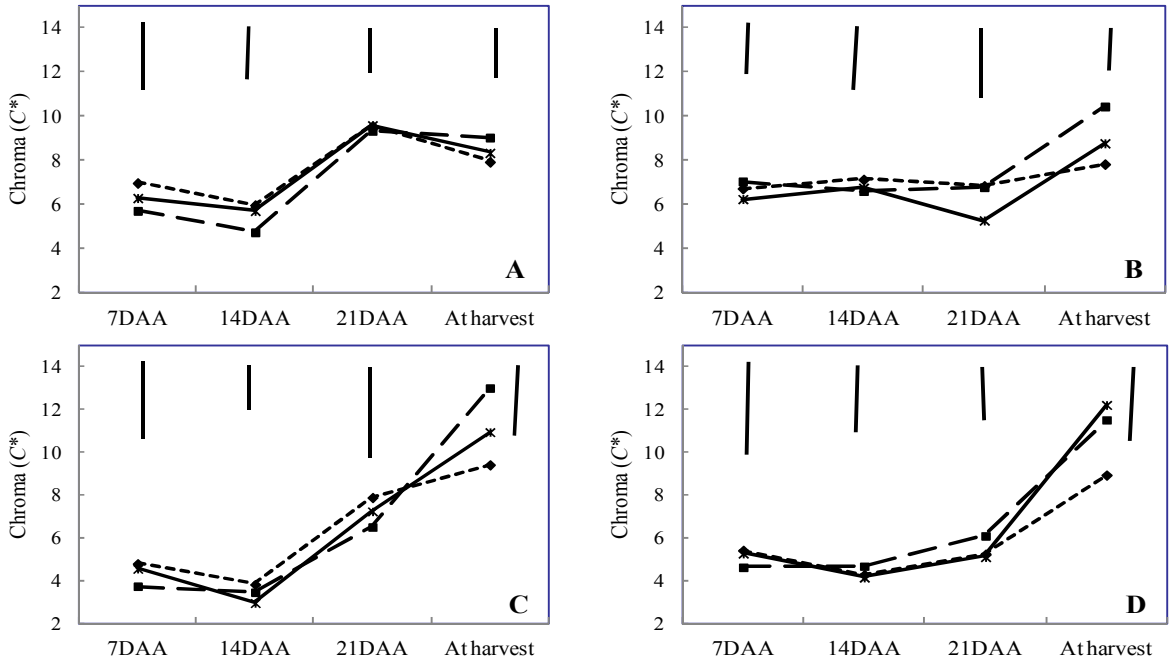

Fig 11. Chroma (C*) of fruit of eggplant cv. Black Boy at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—✳—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

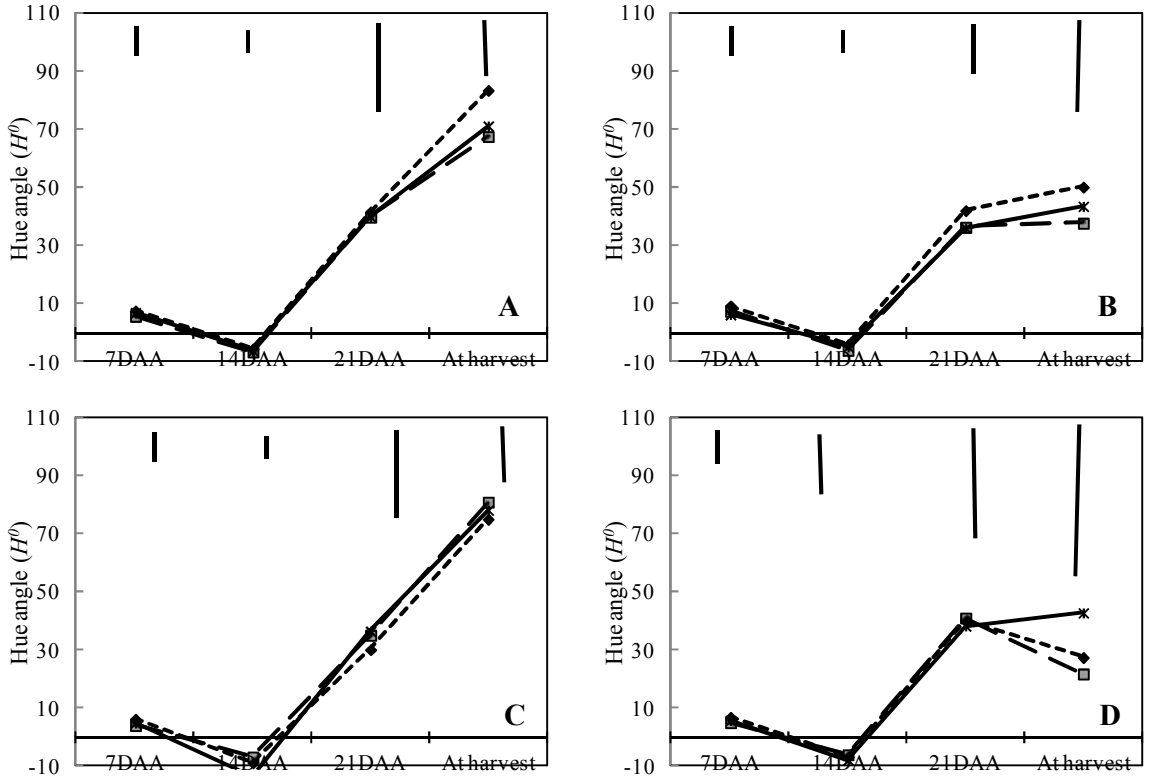

Fig 12. Hue angle (Hº) of fruit of eggplant cv. Black Boy at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

3.3.2 Length of fruit

The length of greenhouse and open field-grown eggplant fruit was recorded at different DAA until harvest during spring and autumn. In the spring, the fruit of all eggplant cultivars grew quickly and frequently the length of the fruit was higher than that of corresponding fruits grown in the autumn.

In Tsakoniki, fruit length increased faster than diameter, the fruit being elongate in shape. The data on fruit length indicated a significant difference ($P \leq 0.05$) between parthenocarpic and seed-containing fruit at different DAA during spring and autumn with the hormone-set fruit (especially those set by NOA) being significantly longer than the naturally pollinated fruit (Fig 13). In most cases, however, the differences in fruit length between NOA and NOA + BA-treated fruits were insignificant ($P \leq 0.05$).

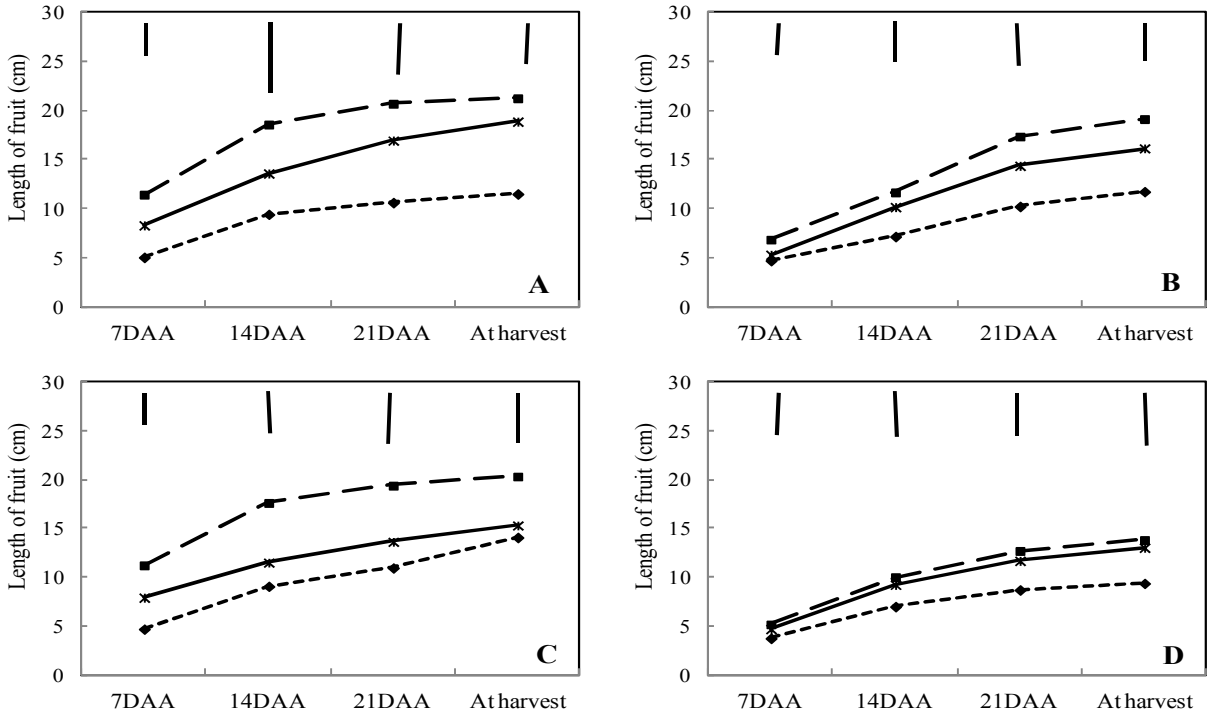

Fig. 13. Length (cm) of fruit of eggplant cv. Tsakoniki at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

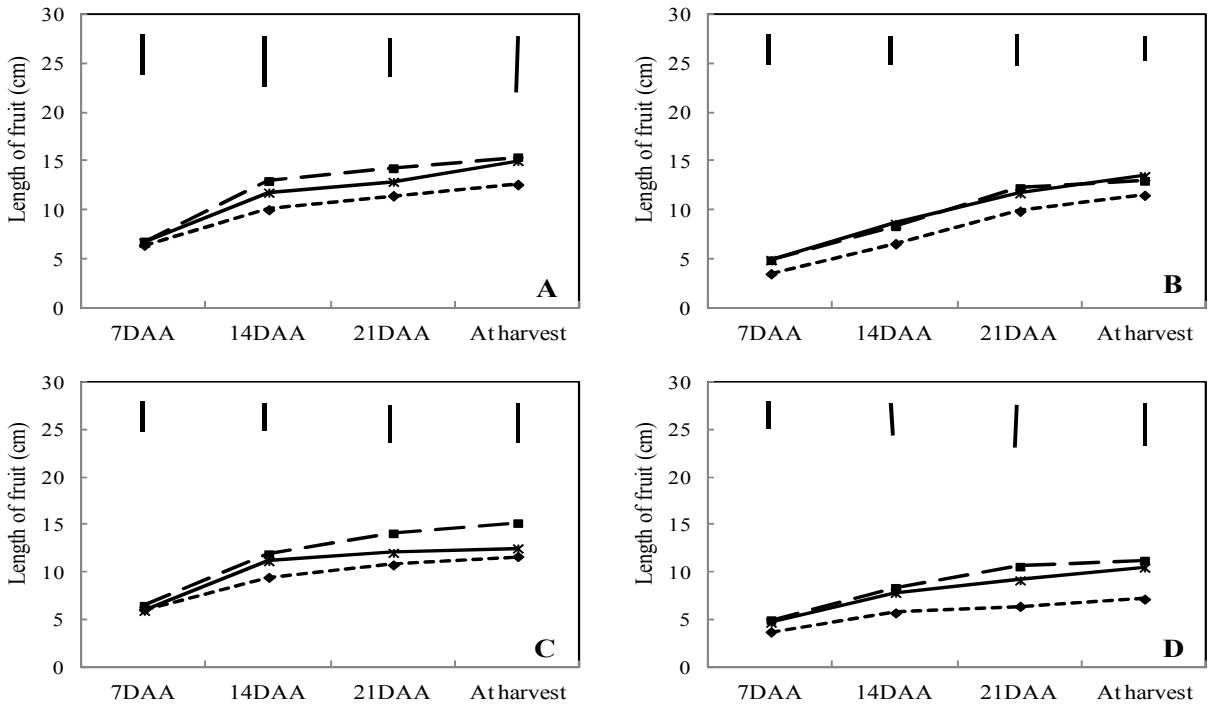

Fig. 14. Length (cm) of fruit of eggplant cv. Black Beauty at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

Fruit length increased continuously from 7 DAA to harvest in both seasons and almost 75% of the final fruit length was achieved in parthenocarpic fruits between 7 DAA and 14 DAA, while during the same period the seed-containing fruit reached about 60% of their final length. Between fruits produced in the greenhouse and those produced in the open field, the former tended to have a consistently greater length, although not to a statistically significant level.

The data on the length of fruit of Black Beauty is presented in Fig. 14. Although some differences in fruit length between parthenocarpic and seed-containing fruit were observed at different DAA these were only significant in the open field crop between 14 DAA and at harvest during autumn (Fig. 14). The length of the greenhouse-grown parthenocarpic fruit almost doubled between 7 and 14 DAA and increased progressively thereafter, whereas seed-containing fruit reached 65% of their final length within the same duration. At harvest, the maximum length of fruit (15.43 cm) was recorded in greenhouse-grown NOA-treated fruit in the spring, which was higher than that of NOA + BA-treated (15.03 cm) and seed-containing fruit (12.63 cm) in the same cultivation. Overall, the length of fruit grown in the greenhouse tended to be higher than that of the corresponding fruit grown in the field.

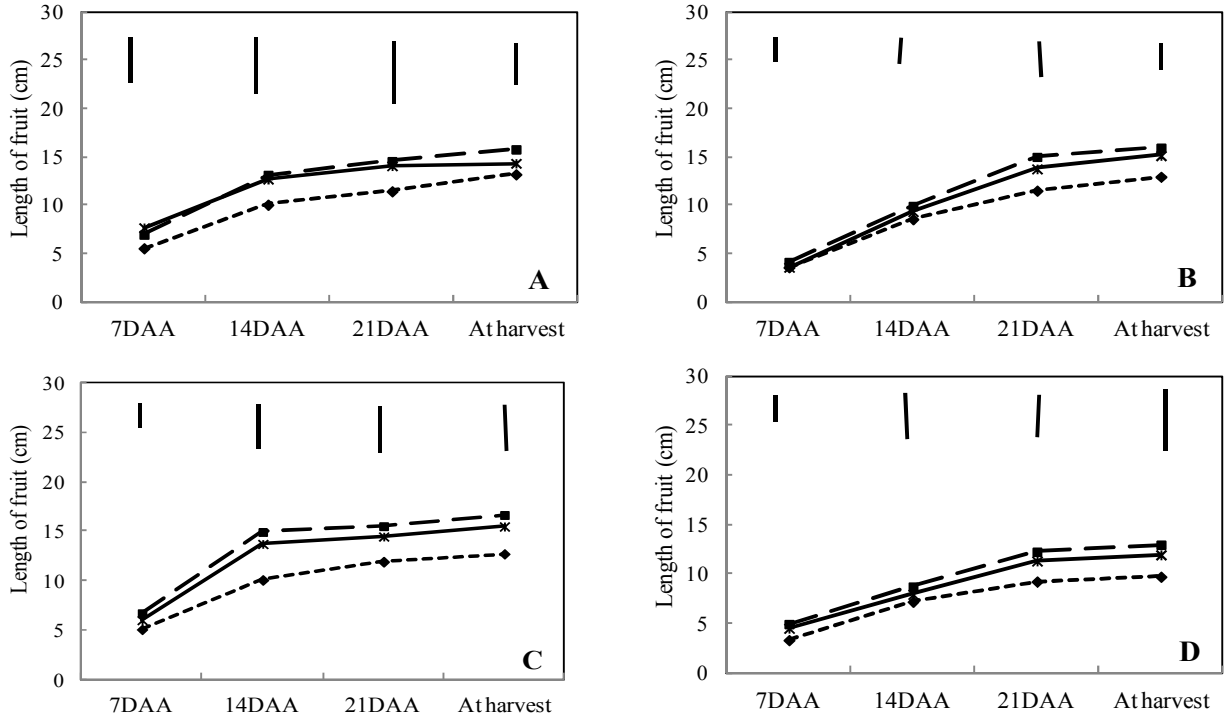

Fig. 15 Length (cm) of fruit of eggplant cv. Emi at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—✳—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

No significant differences ($P \leq 0.05$) were observed in the length of parthenocarpic and seed-containing fruit of Emi at different DAA. However, the parthenocarpic fruit (NOA-treated) grew more rapidly and tended to attain their maximum length earlier than the corresponding seed-containing fruit. At harvest, parthenocarpic (NOA and NOA + BA-treated) fruits were longer than seed-containing fruits, but no significant difference ($P \leq 0.05$) was found between NOA and NOA + BA-treated fruits or between parthenocarpic and seed-containing fruit. Final fruit length was lower in the open field crop than in the greenhouse crop in the autumn, but there was virtually no difference in the length of open field and greenhouse fruit in the spring.

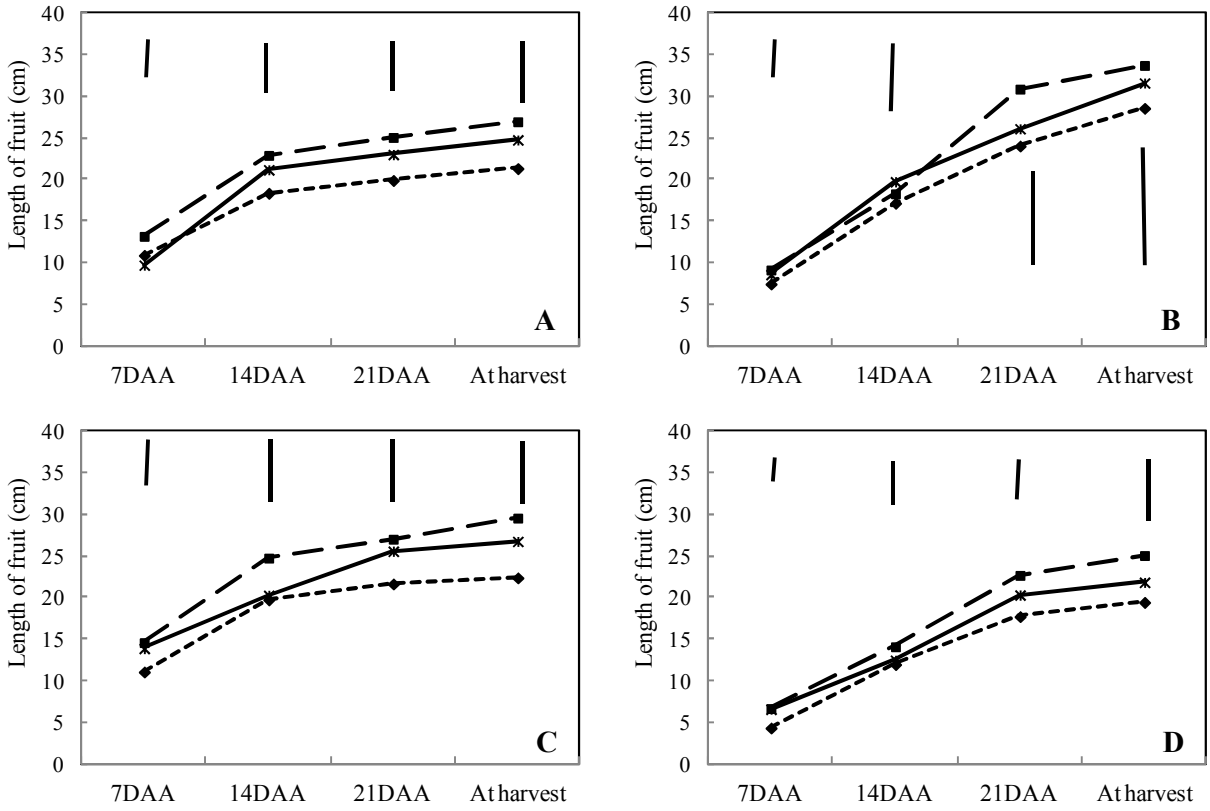

Fig. 16. Length (cm) of fruit of eggplant cv. Black Boy at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—✳—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

The length of fruit of eggplant cv. Black Boy increased with time. Both in the greenhouse and in the open field, the treatments did not differ significantly ($P \leq 0.05$) at different DAA, however at 7 DAA the NOA-induced fruits were already longer than those of NOA + BA and seed-containing fruit and this difference persisted until harvest (Fig.

16). By 21 DAA, the NOA-induced fruits had attained almost 95% of their final length; they then continued growing at a slower rate until harvest. Between the autumn and spring crops there was no significant difference in fruit length at harvest for each corresponding treatment, although fruit in the open field in autumn tended to elongate at a slower rate than those in the spring (7 and 14 DAA).

3.3.3 Diameter of fruit

The diameter of fruits of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy was measured from 7 DAA up to harvest. In all the cultivars, fruit diameter showed a similar trend to that observed for fruit length. The fruit diameter of greenhouse-grown eggplants tended to be higher than that in the open field, particularly in the autumn. Similarly, eggplant fruit grown in spring had a relatively higher fruit diameter compared with the autumn crops.

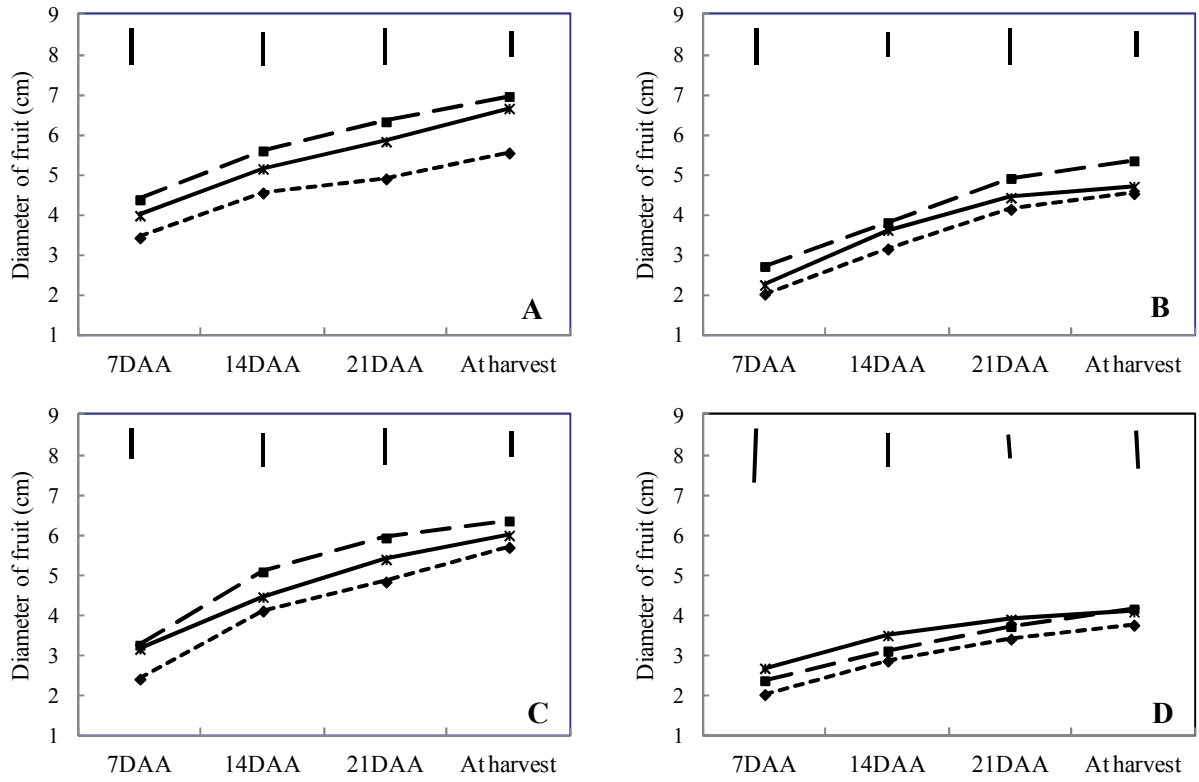

Fig. 17. Diameter (cm) of fruit of eggplant cv. Tsakoniki at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

The mean fruit diameter of Tsakoniki was higher in parthenocarpic fruit than in seed-containing fruit from 7 DAA until harvest; however, significant differences ($P \leq 0.05$) were only detected in the greenhouse crop during spring. It was observed that the diameter of parthenocarpic fruit increased faster than that of the seed-containing fruit from 7DAA until harvest. The increase in diameter of NOA-induced fruit was similar to that of fruit induced by NOA + BA. During spring, at harvest, the mean diameter attained by the greenhouse-grown NOA-induced fruit, NOA + BA-induced and seed-containing fruit was 6.96, 6.66 and 5.55 cm, respectively.

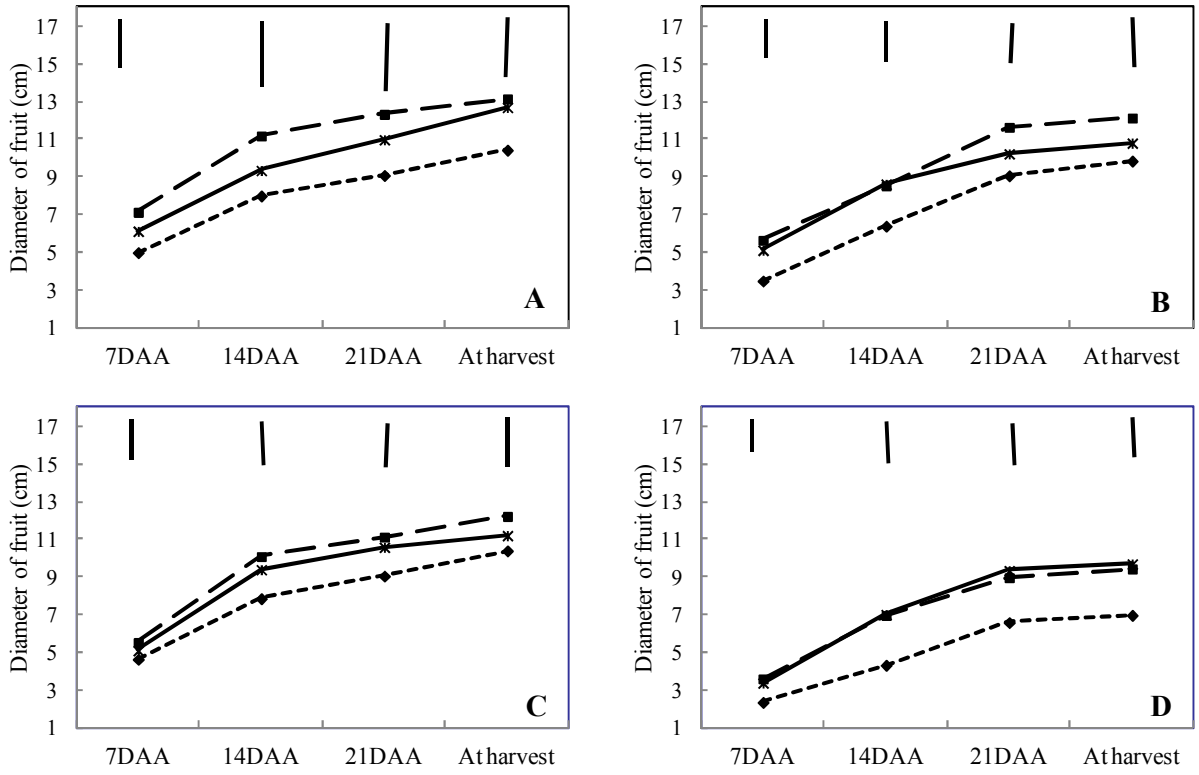

Fig. 18. Diameter (cm) of fruit of eggplant cv. Black Beauty at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—✳—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

The diameter of both seed-containing and parthenocarpic fruits of Black Beauty showed an initial phase of rapid growth between 7 and 21 DAA followed by a slower increase (21 DAA to harvest) (Fig. 18). The fruit diameter of parthenocarpic fruit tended to be higher than that of seed-containing fruit at different DAA, but the differences were only significant ($P \leq 0.05$) in the greenhouse crop during autumn. Although NOA-induced fruit had a higher diameter than NOA + BA-induced fruit, this difference was generally

insignificant ($P \leq 0.05$). The diameter of greenhouse-grown fruits was invariably higher than that of fruit grown in the field in the autumn, but not in the spring. The NOA-induced fruit with the largest diameter (13.15 cm) were obtained in the greenhouse during spring and the lowest diameter was observed in seed-containing fruit (6.98 cm) in the open field crop during autumn.

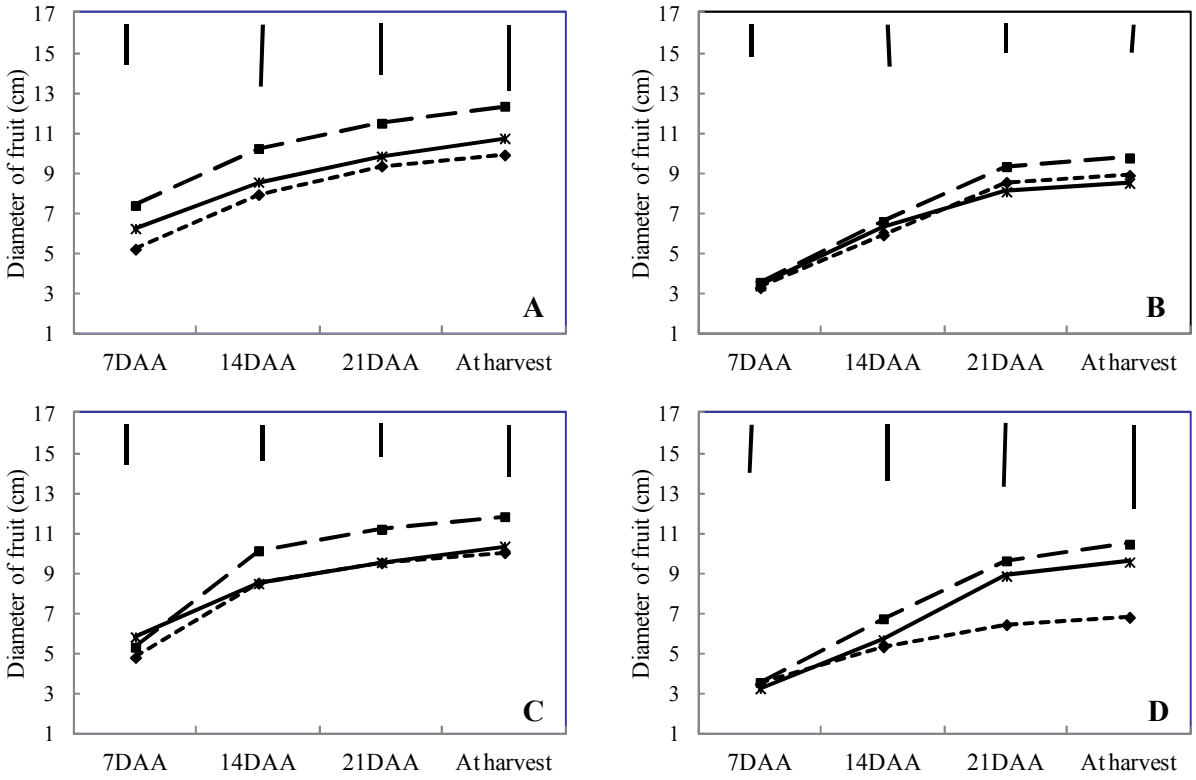

Fig. 19. Diameter (cm) of fruit of eggplant cv. Emi at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—✳—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

The fruit diameter of Emi from 7 DAA to harvest is shown in Fig. 19. No noticeable differences in diameter were observed between parthenocarpic and seed-containing fruit at 7 DAA in either season ($P \leq 0.05$). Afterwards, a rapid increase in the fruit diameter of parthenocarpic fruit was observed, which continued until 21 DAA, following which growth continued at a slower rate until harvest. On the other hand, the diameter of seed-containing fruit increased gradually until harvest. Thus the diameter of parthenocarpic fruit at harvest (both NOA and NOA+BA-induced fruit) was higher than that of the seed-containing fruit, but not to a statistically significant level, irrespective of season and the method of cultivation (greenhouse and open field). Fruit diameter in the

spring tended to be higher than that of fruit in the autumn both in the greenhouse and in the open field.

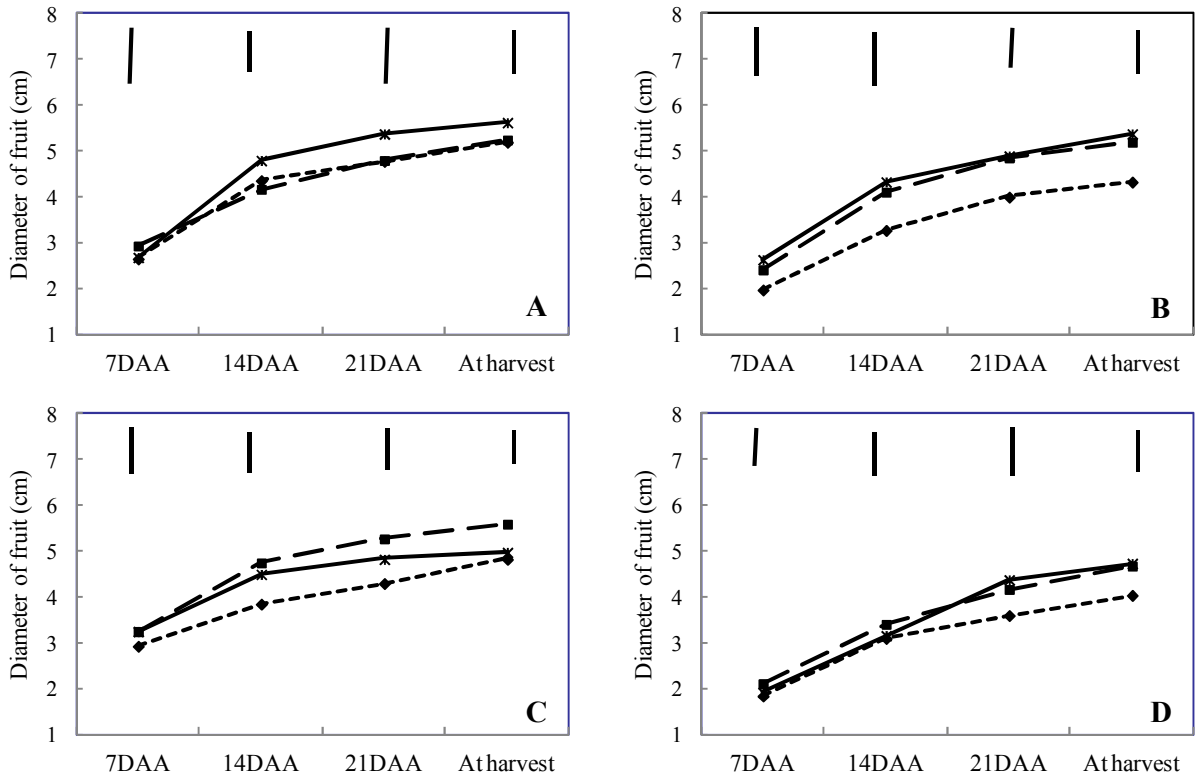

Fig. 20. Diameter (cm) of fruit of eggplant cv. Black Boy at 7, 14, 21 DAA and at harvest as influenced by natural pollination (···♦···), 60 ppm NOA (--■--) and 60 ppm NOA + 30 ppm BA (—∗—). The cultivar was grown both in the greenhouse (A, B) and in the open field (C, D) during spring (A, C) and autumn (B, D). Vertical bars indicate LSD value according to Fisher's least significant difference test ($P \leq 0.05$).

The data on fruit diameter of cv. Black Boy are presented in Fig 20. The diameter of parthenocarpic fruit increased progressively with the advancement in growth up to harvest. In spite of its initially similar growth rate (7DAA), the diameter of seed-containing fruit was lower than that of parthenocarpic fruit from 14 DAA up to harvest, but not to a statistically significant level ($P \leq 0.05$). At harvest, the maximum diameter of fruit was recorded in the greenhouse in spring from the NOA + BA treatment (5.63 cm) followed by NOA-induced fruit (5.25 cm) and seed-containing fruit (5.20 cm); however, the differences were not significant ($P \leq 0.05$). The diameter of the greenhouse and open field-grown fruit did not differ at harvest in either season, but fruit from the autumn crop tended to have a smaller diameter than that of fruit from the corresponding spring crop, even it not to a significant level.

3.3.4 Mean fruit weight

The mean weight of individual eggplant fruit was measured at harvest and growth regulators were found to have a significant effect on fruit weight both in the greenhouse and in the open field crops, except in greenhouse-grown Emi.

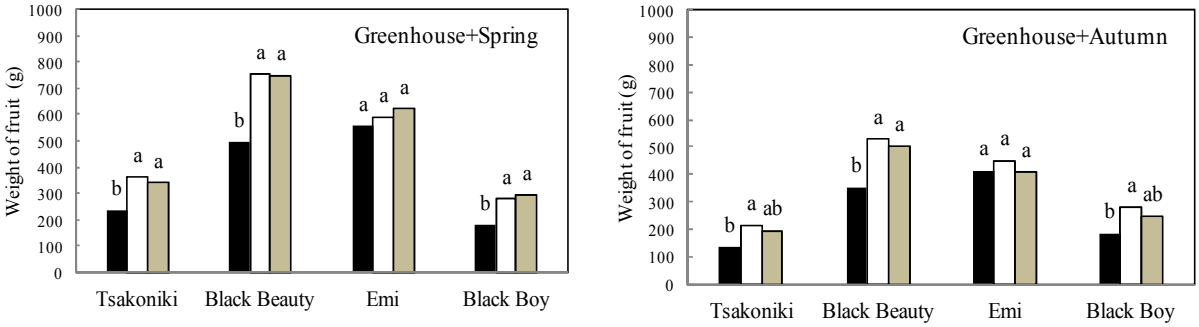

Fig. 21. Mean fruit weight (g) of greenhouse-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

In spring, the highest mean fruit weight of Black Beauty and Tsakoniki was 802.31 and 360.84 g respectively in NOA-induced fruit, whereas the highest mean fruit weight of Emi and Black Boy was 620.72 and 320.34g respectively in NOA + BA-induced fruit.(Fig. 21). However, the difference between NOA alone or NOA in combination with BA was not statistically significant ($P \leq 0.05$). In autumn, the same pattern was observed, but mean fruit weight was lower than in the spring. The lowest fruit weight in all cultivars was found in naturally pollinated fruit during spring and autumn, while growth regulator stimulation of fruit development was higher in spring than in autumn.

The mean fruit weight of Tsakoniki, Black Beauty, Emi and Black Boy grown in the open field is shown in Fig. 22. As in the greenhouse crop, the mean weight of Black Beauty and Emi was larger than that Black Boy and Tsakoniki in both seasons (Fig. 22).

Similar to the greenhouse experiment, the application of growth regulators had a beneficial effect on the mean fruit weight of open field-grown eggplant fruits. Statistical analysis showed significant differences ($P \leq 0.05$) between the parthenocarpic and seed-containing fruits of all cultivars.

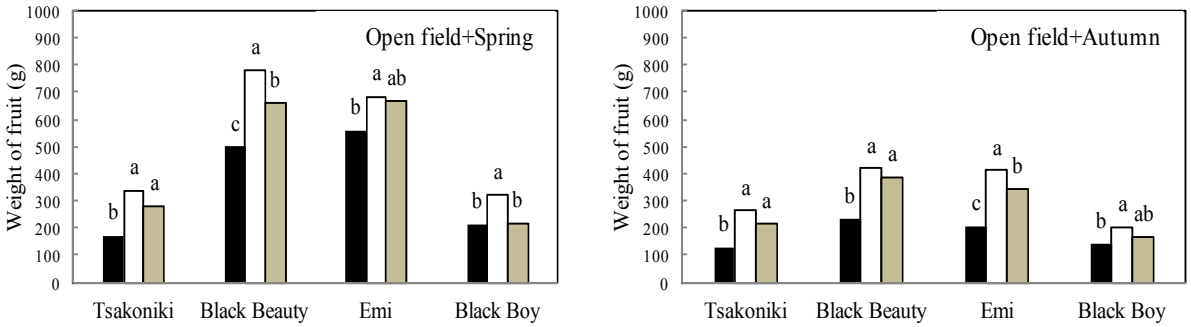

Fig. 22. Mean fruit weight (g) of field-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

Overall, NOA iincreased the fruit weight of field-grown eggplant cultivars more than the same hormone applied in combination with BA, but only to a statistically significant level in Black Beauty and Black Boy during spring. In all cases the lowest fruit weight was recorded in the fruit of all cultivars derived from natural pollination, although in Emi during spring and in Black Boy in both seasons the mean fruit weight of fruit set by natural pollination did not differ significantly from that of the NOA + BA treatment. The individual fruit weight of spring grown eggplants was higher in all cultivars than in the autumn crops.

3.3.5 Length of peduncle

The peduncle length of greenhouse and field-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy was recorded during spring and autumn.

The results showed that despite differences between cultivars the growth substances did not influence ($P \leq 0.05$) the length of the peduncle of greenhouse-grown eggplant fruits (Fig. 23). In general, the peduncle length was shorter in Black Beauty than in the other cultivars (Fig. 23). Between seasons there were no differences in the peduncle length of corresponding cultivars and treatments.

Similarly, the peduncle length of field-grown fruit of all eggplant cultivars did not vary significantly between natural pollination and hormone treatments ($P \leq 0.05$) (Fig. 24). The peduncle length of Black Beauty was shorter than in the other cultivars and no differences were detected between seasons.

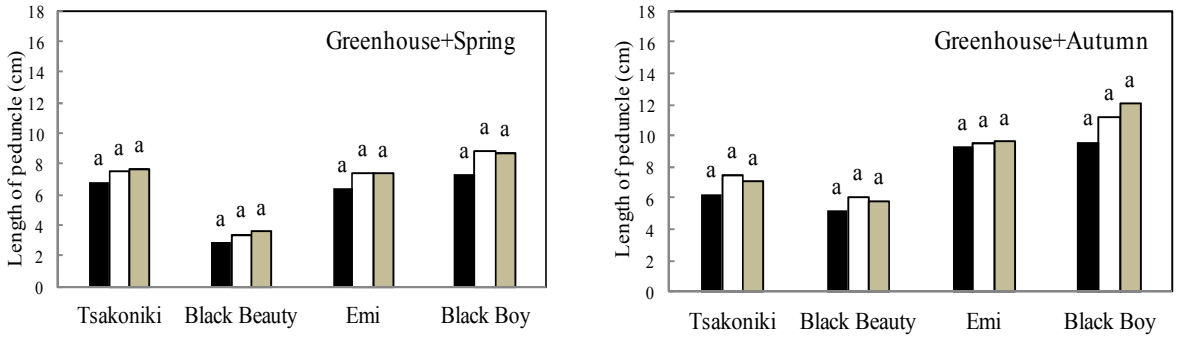

Fig. 23 Length of peduncle (cm) of greenhouse-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

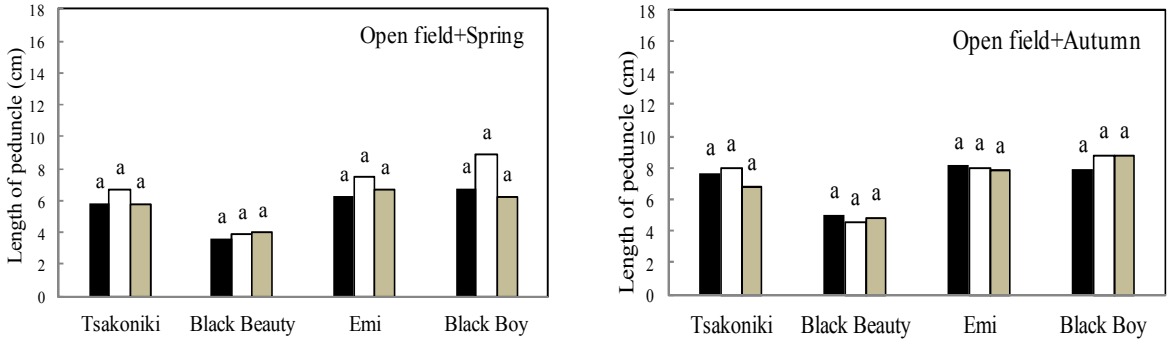

Fig. 24. Length of peduncle (cm) of open field-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

3.3.6 Length of calyx

The length of the calyx of fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy was measured at harvest during two consecutive seasons: spring and autumn.

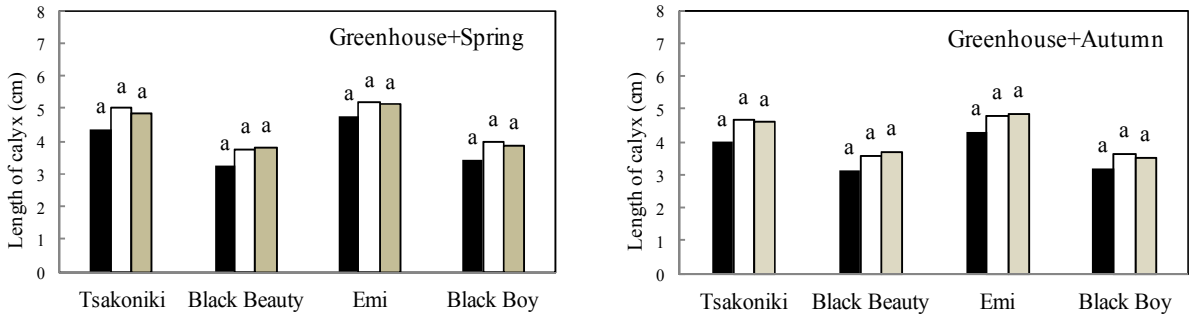

Fig. 25. Length of calyx (cm) of greenhouse-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

There was no effect of hormone application on the calyx length of greenhouse-grown eggplant fruit of any cultivar (Fig. 25). Additionally, calyx length was not affected by season, but varied with cultivars, e.g. the calyx length of Black Beauty and Black Boy was less than that of Tsakoniki and Emi in both seasons. The calyx length of greenhouse-grown Tsakoniki varied from 4.38 to 4.99 cm, Black Beauty from 3.23 to 3.79 cm, Emi from 4.77 to 5.17 cm and Black Boy from 3.42 to 3.99 cm, respectively, during spring.

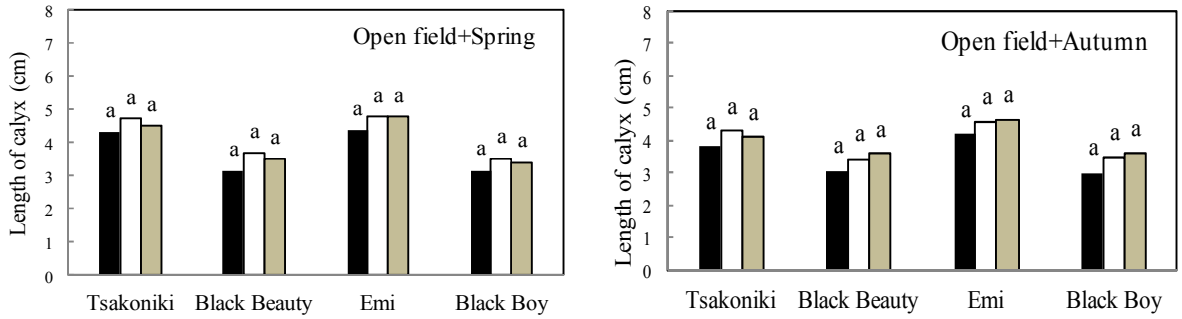

Fig. 26. Length of calyx (cm) of field-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

From Fig 26, it is observed that the length of the calyx was not affected by the application of growth substances (NOA and a mixture of NOA with BA) in the field-grown fruit of any cultivar during spring and autumn. As in the greenhouse crop, the calyx length was dependent on cultivar (Black Beauty and Black Boy having a shorter calyx than Emi and Tsakoniki) irrespective of season.

3.3.7 Percentage (%) dry matter

The dry matter content of fruits of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy was evaluated at harvest. The results revealed that the percentage dry matter in all cultivars in both seasons was highest in the fruit from natural pollination, and to a statistically significant degree in cvs. Tsakoniki and Emi (Fig. 27 and 28). Between the two hormone treatments, no difference in the percentage dry matter accumulation was observed, irrespective of cultivar.

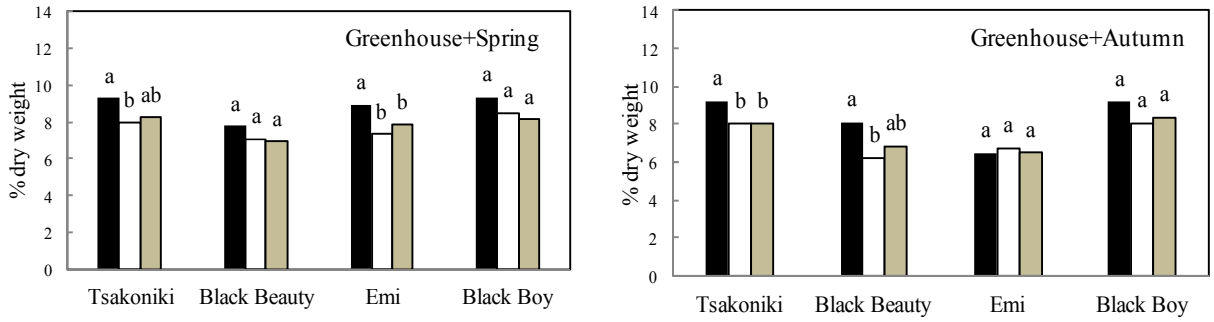

Fig. 27. Percentage dry matter accumulation of greenhouse-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

The percentage dry matter content of field-grown eggplant cultivars during spring and autumn is shown in Fig. 28. Similar to the greenhouse cultivation, in spring seed-containing eggplant fruit accumulated significantly higher dry matter ($P \leq 0.05$) than parthenocarpic fruit, except in cv. Black Beauty. Although dry matter accumulation tended to be higher in seed-containing fruit in the open field crop during autumn, the differences between hormone-induced and naturally pollinated fruit were not significant ($P \leq 0.05$). Similarly, between the two hormone treatments no differences in dry matter content were observed irrespective of season.

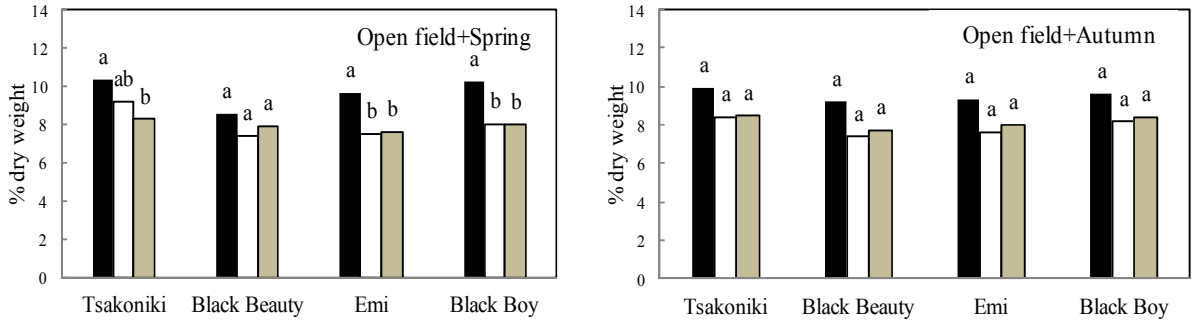

Fig. 28 Percentage dry matter accumulation of field-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy as influenced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivars accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

3.3.8 Pollen production

Results regarding the pollen production per flower of greenhouse and open field-grown crops of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy during spring and autumn are summarized in Fig 29. All the cultivars produced a higher amount of pollen per flower under greenhouse conditions, except during the month of July when extremely high

temperatures (maximum 50.7°C during flowering and mean 34.1ºC) prevailed inside the greenhouse (Fig 29).

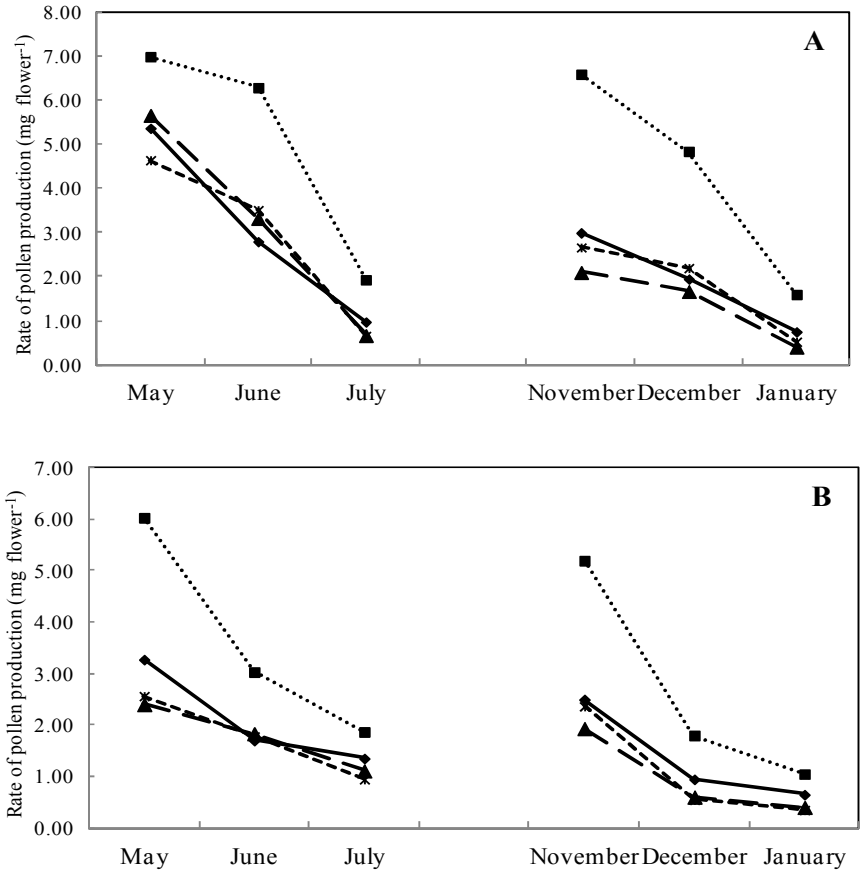

Fig. 29. Seasonal variation in pollen production of fruit of eggplant cvs. Tsakoniki (—♦—), Black Beauty (···■···), Emi (--▲--) and Black Boy (--✳--) cultivated in the greenhouse (A) or the open field (B) during spring and autumn.

In both greenhouse and open field cultivation, pollen production per flower in Black Beauty was relatively higher, followed by Emi, Black Boy and Tsakoniki, respectively (Fig. 29). Pollen production in all the eggplant cultivars followed the same pattern. In the spring crop, the highest pollen production per flower was recorded in May in the greenhouse: Black Beauty (7.00 mg), Emi (5.67 mg), Tsakoniki (5.38 mg) and Black Boy (4.65 mg), respectively, whereas in the autumn the lowest pollen yield was recorded in January in the field grown crop: Black Beauty (1.05 mg), Tsakoniki (0.65 mg), Emi (0.40 mg), and Black Boy (0.35 mg). It was observed that changes in solar radiation, maximum and minimum temperature were associated with the seasonal variation of pollen production of eggplant cultivars (Appendix 1 and 2). Comparatively high solar radiation and temperature enhanced pollen production of the eggplant cultivars but excessively high

temperatures during July and low temperatures during January significantly reduced pollen production.

3.3.9 *In vitro* pollen germination

The percentage of pollen germination in relation to the growing season and cultivars is presented in Table 5.

All the cultivars showed a higher percentage of pollen germination in the open field-grown crop than in the greenhouse crop in the spring (i.e. under favourable temperatures, except the hot month of July), whereas during the autumn, when the outdoor temperatures were low, pollen germination was higher in the greenhouse crop (Table 5).

Table 5. Mean germination (%) of pollen collected from the flowers of greenhouse and field-grown eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy during the course of the spring (May-July) and autumn (November-January) crops.

Month	*In vitro* germination of pollen (%)			
	Tsakoniki	Black Beauty	Emi	Black Boy
Greenhouse				
May	21.02 ± 3.84	38.16 ± 6.42	10.55 ± 4.05	41.67 ± 14.43
June	8.39 ± 4.51	14.74 ± 4.50	3.50 ± 0.71	30.00 ± 4.07
July	*	6.28 ± 2.26	*	28.99 ± 2.83
November	18.71 ± 2.55	18.25 ± 4.39	5.00 ± 1.41	40.36 ± 5.65
December	6.91 ± 2.47	11.20 ± 3.30	2.55 ± 0.36	30.24 ± 3.06
January	*	5.35 ± 1.47	*	8.19 ± 0.98
Open field				
May	29.22 ± 3.27	52.12 ± 5.54	17.36 ± 4.64	72.06 ± 7.89
June	22.14 ± 7.66	22.80 ± 5.89	9.21 ± 1.70	32.46 ± 4.31
July	*	7.57 ± 2.36	*	29.36 ± 3.19
November	15.48 ± 2.26	14.68 ± 2.40	4.50 ± 0.71	21.47 ± 11.86
December	6.00 ± 1.45	7.91 ± 1.42	3.02 ± 0.22	13.27 ± 1.74
January	*	2.51 ± 1.07	*	6.14 ± 1.01

** Pollen was not viable, i.e. germination was 0%.*

In all cultivars, the highest pollen germination was recorded in May, irrespective of whether the plants were grown in the greenhouse or outdoors. Subsequently, pollen germination fell with increasing air temperature and the lowest pollen germination in all cultivars during the spring crop was observed in July (Table 5). In autumn, maximum pollen germination in all cultivars was recorded in the greenhouse-grown crop during November whereas the lowest germination was observed in the field crop during January, when the mean air temperature was low with wide fluctuations. Differences in pollen germination were observed between cultivars. Black Boy showed the highest pollen germination percentage both at high and low temperatures. Although Tsakoniki and Emi

produced pollen during the months of July and January the pollen failed to germinate, due to sterility, presumably as a result of the prevailing high (July) or low (January) air temperatures both in the greenhouse and in the field.

3.3.10 Pollen tube length

Mean pollen tube length was recorded during pollen germination of the different eggplant cultivars grown in the greenhouse and open field during spring and autumn (Table 6).

Table 6. Length of the pollen tube of pollen collected from flowers of greenhouse and field-grown plants of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy during the course of the spring (May-July) and autumn (November-January) crops and measured after 6 h incubation at 20±0.5°C.

Month	Length of pollen tube (mm)			
	Tsakoniki	Black Beauty	Emi	Black Boy
Greenhouse				
May	0.75 ± 0.34	1.01 ± 0.33	0.22 ± 0.12	0.86 ± 0.26
June	0.26 ± 0.11	0.43 ± 0.15	0.06 ± 0.02	0.55 ± 0.12
July	*	0.21 ± 0.08	*	0.27 ± 0.11
November	0.56 ± 0.27	0.62 ± 0.13	0.17 ± 0.04	0.66 ± 0.17
December	0.24 ± 0.10	0.21 ± 0.05	0.07 ± 0.01	0.23 ± 0.13
January	*	0.15 ± 0.04	*	0.21 ± 0.14
Out field				
May	0.77 ± 0.31	1.53 ± 0.32	0.38 ± 0.18	1.02 ± 0.36
June	0.37 ± 0.17	0.75 ± 0.16	0.14 ± 0.08	0.59 ± 0.26
July	*	0.28 ± 0.14	*	0.22 ± 0.07
November	0.11 ± 0.04	0.42 ± 0.16	0.16 ± 0.05	0.58 ± 0.13
December	0.06 ± 0.01	0.06 ± 0.02	0.04 ± 0.01	0..25 ± 0.07
January	*	0.05 ± 0.01	*	0.05 ± 0.02

** Pollen was not viable.*

Pollen tube length ranged from 1.53 (Black Beauty) to 0.04 mm (Emi) at the time of measurement (6 h incubation) and, similar to the percentage pollen germination, the length of pollen tube was higher when the cultivars were grown in the open field in spring and in the greenhouse in autumn. The length of pollen tubes generally decreased with temperatures that were higher or lower than the 22.54ºC optimum during flowering, and the responses of the cultivars were different. All cultivars attained their maximum pollen tube length in the germination test when pollen was collected from the flowers of plants grown in the field during May, with mean values for Tsakoniki, Black Beauty, Emi and Black Boy 0.77, 1.53, 0.38 and 1.02 mm, respectively after 6 h incubation at 20±0.5°C. High temperatures in the greenhouse in July reduced the length of the pollen tube during the germination test in Black Beauty and Black Boy, while minimum pollen tube length

was recorded for pollen from the open field-grown plants of Black Beauty and Black Boy during January (Table 6). At times of very low (January) or high (July) temperature the pollen of Emi and Tsakoniki (as noted above) failed to germinate.

3.4 Discussion

The results of the present experiment not only confirm earlier reports of the positive effect of auxin on fruit-set in out of season eggplant (Olympios, 1978; Nothmann *et al.,* 1983) but also show that auxin application positively affects fruit size and colour, both in greenhouse and open field crops, irrespective of cultivar.

Fruit color is an important maturation indicator for fruit harvest and differs considerably among cultivars. Fruits of Tsakoniki are bi-coloured with purple/red and white stripes at maturity, while those of Black Beauty and Emi are predominantly purple, but with a varying intensity of colour, and fruits of Black Boy are orange-purple. These cultivar specific differences were present during the entire fruit development until harvest. The color changes during fruit maturation were reflected by changes in the values of L, C* and Hº. In all cultivars, an increase in L value was observed during fruit development corresponding to a lightening of fruit colour during maturation; however, the rate was more pronounced in Tsakoniki, indicating a higher change in lightness in this cultivar towards maturity. During early development of the fruit, a minimum change in C* value was detected in all cultivars, but between 21DAA and harvest the C* value of Tsakoniki decreased while that of the other cultivars increased. During fruit development, Hº changed from negative to positive in all cultivars. This change occurred earlier in Tsakoniki and Black Boy than Black Beauty and Emi.

Fruit colour is a major indicator of fruit quality; therefore, it is important to harvest fruit when colour development is optimal (Passam and Karapanos, 2008). In the present experiment, minimum changes of colour coordinates L, C* and Hº were observed in all cultivars until 21DAA during spring whereas, in most cases in autumn the changes in colour coordinates were minimum until harvest, indicating that during spring all the cultivars reached marketable quality in terms of colour at 21 DAA, whereas in the autumn fruits should preferably be harvested at 28 DAA. In our experiment, in most cases we did not observe significant differences ($P \leq 0.05$) in L, C* and Hº value between parthenocarpic and seed-containing eggplant fruit of any cultivar, but overall visual colour

formation in parthenocarpic fruit was as good or better than that of seed-containing fruit in all cultivars.

With respect to seasonal variation, it was observed that color development in the fruit of all cultivars was sensitive to temperature and probably light. Changes in the colour coordinates of fruit of all cultivars were more rapid in spring than in autumn. Additionally, in spring colour development of the fruit skin was uniform whereas, in the autumn some green areas were observed on the fruit skin of Black Beauty, Emi and Black Boy. According to Nothmann *et al.* (1978) cool season grown eggplant fruits usually show poor colouration. It was also visually observed that open field-grown fruits of all cultivars were darker in color than those of greenhouse-grown fruits, which might result from differences in solar radiation in the two crops. In other Solanaceous crops, e.g. tomato (Cox *et al.,* 2003), the amount of light affects fruit colour by altering the lycopene content of the fruit.

The growth of eggplant fruit was assed in fruit length and diameter at different DAA as well as in terms of mean fruit weight at harvest. Length and diameter of developing seed-containing eggplant fruits were compared with those of fruit set parthenocarpically by NOA and NOA in combination with BA. In our experiment, the pattern of development of seed-containing and parthenocarpic fruit was similar in all cultivars, but the parthenocarpic fruits showed faster growth than the seed-containing fruit. The growth curve also showed that in most cases there was little or no difference in fruit size at 7DAA in any treatment, but between 7DAA and 21DAA parthenocarpic fruit were larger than seed-containing fruit. In summary, the growth curve might be described as follows: during the initial 7DAA, enlargement of the fruit is mediated through cell division. At this stage there are relatively small differences in growth between fruit developing parthenocarpically and those developing from natural pollination, and it is possible that the stimulus received by the ovary is the same in both cases. Afterwards (7-21DAA), fruit development in parthenocarpic fruits was largely a result of cell expansion as a result of the application of NOA or the mixture of NOA and BA. The application of auxin has been shown to increase fruit size in eggplant (Nakansha, 2000) and cherry (Stern *et al.,* 2008), whereas a negative effect on fruit size was reported in tomato (Ho, 1996) and pepper (Heuvelink and Korner, 2001). Fruit length and diameter on different DAA was generally higher within the greenhouse thanks to the warmer temperature compared with the open field. Moreover, fruit growth in spring was more rapid and resulted in early maturity, whereas in autumn the eggplant fruit of all cultivars grew at a slower rate, resulting in a longer period of fruit development and initially relatively smaller fruits.

It is currently accepted that exogenous auxins play a significant role in fruit-set and development in several crops, e.g. eggplant (Olympios, 1978; Nothmann *et al.,* 1983, 1975; Van Ravestijn, 1983; Sharma, 2006; Nkansha, 2000), tomato (Sjut and Bangerth, 1982), pepper (Silveira *et al.,* 1986; Thanopoulos 2012), strawberry (Thompson, 1969), mandarin (Guardiola and Azaro, 1987), pepino (Ercan and Akilli, 1996). The present results revealed that the application of growth regulators increased the mean individual fruit weight of all the eggplant cultivars of the present experiment, except Emi in the greenhouse. In most cases, the heaviest fruits were obtained with NOA followed by NOA in combination with BA and natural pollination, respectively. The highest fruit weight apparently results from the promotive effect of NOA on fruit growth and development by securing maximum length and diameter compared with the other treatments. Earlier reports also indicated that NOA increased the fruit weight in eggplant (Olympios, 1976), strawberry (Thompson, 1969) and pepino (Ercan and Akilli, 1996). However, because in previous experiments NOA and other plant growth regulators were applied to plants under commercial growing conditions (i.e. without the removal of the stamens) it is likely that the fruits contained seeds (Olympios, 1976), whereas in our experiments the hormone-induced fruit were all parthenocarpic, i.e. contained no seed.

It was also observed that the stimulatory effect of NOA on fruit growth depends on the growing conditions and season. Our results revealed that under decreasing light intensity and temperature in autumn, fruit-set and the rate of fruit development were limited, probably due to a lack of assimilate supply owing to the competition for available metabolites between vegetative growth and reproductive development, as observed in pepper (Thanopoulos, 2012). During autumn, however, it is clear that less favourable environmental conditions markedly decreased the individual fruit weight of all cultivars, more in the case of pollinated fruits than in those treated with NOA. This might suggest a difference in hormone levels between the two treatments. Why the addition of BA should reduce the effect of NOA is not clear. It is known that BA affects cell division rather than cell expansion and possibly the presence of BA reduced the effect of NOA on cell expansion. Olympios (1976) observed a beneficial effect of adding BA to NOA during hormone application to eggplant, since both fruit set and fruit yield increased; however, as indicated above, the fruits in this case probably contained seeds. In pepper, NOA induces fruit set, but fruit size is small in the absence of seeds; if seeds are present, however, NOA application increases fruit size beyond that of the seed-containing, untreated control (Thanopoulos, 2012).

Elongation of the peduncle in tomato was observed following the application of gibberellic acid (GA) (Owen and Aung, 1990). According to our results, peduncle length is primarily influenced by genotype and NOA alone or in combination with BA did not significantly increase the length of the peduncle of eggplant fruits in any of the cultivars examined, but the warmer environment of the greenhouse, especially during autumn, favoured the elongation of the peduncle compared with the open field crop, but not to a significant level.

The length of the calyx varied among the eggplant cultivars; Tsakoniki and Emi had the longest calyx followed by Black Boy and Black Beauty. Genotypic differences are primarily responsible for this variation in calyx length, since all the cultivars regardless of season and growing conditions (greenhouse and open field) showed a similar response to growth substances. Although the application of NOA and a mixture of NOA and BA tended to increase the length of the calyx, this effect was statistically insignificant.

Dry matter content is also used to measure the productivity of the plant. Our results showed that the application of NOA alone or in a mixture with BA caused a reduction in the percentage dry matter content of eggplant fruit; however, in some cases the differences in percent dry matter were not significant between parthenocarpic and naturally pollinated fruit. From a physiological stand point, the decrease in percentage dry matter of the fruit tissues may have resulted in part from an increased osmotic concentration of the cell sap of the tissues due to their response to growth regulator application, which ultimately increased the water absorbing capacity of the fruit. It has been reported earlier that application of exogenous auxin reduces the dry matter content of tomato (Picken and Grimmett, 1986) and strawberry (Al-Madhagi *et al.,* 2011). No significant effect of season or growing conditions on fruit dry matter was observed, although it might have been expected that eggplant fruit would accumulate a higher percentage dry matter in the field than in the greenhouse, especially in spring, because the light received by the plant for photosynthesis was relatively higher in the field.

Although the number of flowers per plant and the amount of pollen produced at certain times of the year was too low to permit satisfactory statistical analysis, it is apparent from the results that each genotype showed a specific response to temperature (and probably light) in respect of pollen production and germination. Black Beauty and Emi yielded higher amounts of pollen due to their large stamens in comparison with the small stamens of Black Boy and Tsakoniki. Genotypic differences in pollen production have also been reported in several crop species e.g., in eggplant (Boyaci *et al.,* 2009) and

tomato (Damidaux and Martinez, 1992). In the present study, the rate of pollen production per flower in all cultivars was severely reduced under both high and low temperatures as reported for tomato by Karapanos (2007). Formation of viable pollen with high germination capability is a prerequisite for fruit set. It is widely acknowledged that temperature influences the viability of pollen (Abak and Guler, 1994) more than that of the gynoecium (Karapanos, 2007). Tsakoniki and Emi were found to be more thermo-susceptible than Black Beauty and Black Boy as no pollen germination was observed in the former during the months when excessive high (July) or low (January) temperatures prevailed. Overall, Black Boy showed the greatest tolerance to high and low temperatures in terms of pollen germination and pollen tube growth. It was also observed that fruit set in Emi was not affected by pollen viability as measured by an *in vitro* germination test, because this cultivar has the natural ability to produce a parthenocarpic fruit (Passam and Khah, 1992). Although pollen germination is a good indicator of male fertility, is also important to know the rate of pollen tube growth because for fertilization it is necessary that the pollen tubes reach the ovules and penetrate them (Karapanos, 2007). In our experiment, pollen tube growth in relation to the season of pollen collection was similar to that of pollen germination. High temperatures during spring and low temperatures during autumn apparently exerted a negative effect not only on pollen viability (germination) but also on pollen vigour, i.e. pollen tube length, as observed in tomato (Karapanos, 2007). In eggplant, previous work has reported that under the Mediterranean climate better pollen production and viability was obtained during May when the average temperature ranged between 24 and 27ºC (Abak and Guler, 1994). In this work we found similar results. Under field conditions, lower temperatures, especially during autumn, reduced pollen production as well as pollen germination.

CHAPTER 4

The effect of fruit-setting hormone on the physico-chemical characteristics of eggplant.

4.1 Introduction

Eggplants are known to be good sources of natural antioxidants, such as ascorbic acid and phenolics, and in recent years have received considerable attention due to the presence of these substances, which are beneficial for human health, e.g., by suppressing the development of blood vessels required for tumor growth and metastasis (Matsubara *et al.,* 2005) and inhibiting inflammation that can lead to atherosclerosis (Han *et al.,* 2003). A number of studies have reported the use of plant growth regulators (PGR) to improve fruit-set in eggplant (Olympios, 1976; Lee *et al*., 2004; Kowalska, 2006); however, no studies have been conducted so far to evaluate the complete profile of fruit quality in response to growth regulator application. In view of the importance of fruit quality in eggplant and the role of plant PGR in improving fruit set, especially under low temperatures (Chapter 3), this study was designed to evaluate the effect of exogenous application of PGR on the physico-chemical characteristics of the fruit.

4.2 Materials and methods

The present investigation was carried out during autumn 2008 and spring 2009 to evaluate the fruit quality attributes of naturally pollinated (seed-containing) and parthenocarpic (seedless) eggplants. Eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy were grown both in the greenhouse and in the open field. Plant growth regulators (PGR) viz., β-NOA (60 ppm), β-NOA (60 ppm) in combination with BA (30 ppm), and BA (30 ppm) were applied to set parthenocarpic eggplant fruits while naturally pollinated fruits were produced as the control. Fruits were harvested at 28 (spring crop) and 30 (autumn crop) days after anthesis and quality was evaluated by determining the firmness, ascorbic acid content, protein content, total phenolic content, anthocyanin content, browning potential, sugar and starch contents by methods which are presented in Chapter 2. As noted in Chapter 3, because BA (30 ppm) alone failed to set fruit, the results of this treatment are not presented here.

Each trial was arranged in a completely randomized design with 4 replications. Results were analysed by ANOVA and differences between the means of treatments assessed by the LSD test ($P \leq 0.05$). For differences between seasons (autumn-spring) and indoor-outdoor crops, the student t-test was applied.

4.3 Results

4.3.1 Firmness

Both external firmness (measured proximally near to the calyx and midway between the two ends of the fruit) and flesh firmness (measured in the central region of the fruit) of fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy were measured at harvest. In most cases, the external firmness (proximal and centre) of eggplant fruit grown either in the greenhouse (Table 7) or in the open field (Table 8) tended to be higher in fruit set by NOA alone or in combination with BA than in the naturally pollinated control, but in most cases not to a statistically significant level. For example, the firmness of seed-containing fruit of Tsakoniki at the proximal end was significantly lower than that of parthenocarpic fruit derived from NOA treatment in both the greenhouse (Table 7) and field in the spring, as well as that from the NOA + BA treatment in the field (Table 8), while in the other cultivars no significant differences occurred. Similarly, in the autumn, significant differences were observed at the proximal end of fruit of Black Boy (in the greenhouse) and both the proximal and central regions of the fruit in Black Beauty and Emi (in the field). Internally, the flesh firmness of Tsakoniki and Black Beauty in the autumn (greenhouse crop) and Black Boy in the spring (field crop) was significantly lower in the seed-containing fruit (Tables 7 and 8).

In all cases, external firmness in the proximal region (near to the calyx) was less than in the central region of fruit and, in general, the firmness of the flesh was higher in fruit with high external firmness, but not to a statistically significant level. No significant differences were detected ($P \leq 0.05$) between autumn-grown fruits and spring-grown fruits, or between the external pericarp and the flesh firmness of open field and greenhouse-grown fruit (Tables 7 and 8).

Table 7. The firmness (kg) of greenhouse-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (T_1), 60 ppm NOA (T_2) and 60 ppm NOA + 30 ppm BA (T_3). Firmness was measured externally at two positions: proximally (near to the calyx) and in the centre of the fruit, and internally in the centre of the fruit.

Treatments	Spring			Autumn		
	Proximal	Centre	Internal	Proximal	Centre	Internal
Tsakoniki						
T_1	2.86 b	3.59 a	1.66 a	3.10 a	3.53 a	1.09 b
T_2	3.70 a	4.22 a	1.37 a	2.98 a	3.14 a	1.44 a
T_3	3.59 ab	3.99 a	1.39 a	2.45 b	2.79 b	1.39 ab
Lsd	0.75	0.87	0.67	0.49	0.38	0.31
Black Beauty						
T_1	3.31 a	3.63 a	1.25 a	2.79 a	2.64 a	0.83 b
T_2	3.91 a	4.24 a	1.46 a	2.90 a	2.76 a	1.13 a
T_3	3.78 a	4.00 a	1.26 a	2.77 a	2.71 a	1.09 ab
Lsd	0.91	0.69	0.58	0.52	0.69	0.30
Emi						
T_1	3.70 a	3.89 a	1.75 a	2.41 a	2.76 a	0.99 a
T_2	3.82 a	4.04 a	1.63 a	2.58 a	2.65 a	1.10 a
T_3	3.72 a	4.27 a	1.59 a	2.63 a	2.54 a	1.12 a
Lsd	0.68	0.68	0.64	0.24	0.23	0.18
Black Boy						
T_1	2.53 a	2.95 a	0.85 a	2.36 ab	2.63 a	0.97 a
T_2	2.99 a	3.38 a	1.03 a	3.02 a	2.91 a	1.02 a
T_3	2.77 a	3.16 a	1.07 a	2.21 b	2.51 a	0.94 a
Lsd	0.67	0.65	0.51	0.67	1.10	0.35

In each column, means followed by the same letters for each cultivar are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

4.3.2 Ascorbic acid content

Ascorbic acid is a powerful antioxidant and is considered to be an important quality parameter of eggplant fruit (Vinson *et al.,* 1998; Hanson *et al.,* 2006; Rodrigues-Burruezo *et al.,* 2008). The ascorbic acid content of eggplant fruit was measured at harvest during two consecutive seasons (spring and autumn) (Fig. 30). Among the cultivars, Tsakoniki tended to have a slightly higher concentration of ascorbic acid than the others, but the differences were not statistically significant ($P \leq 0.05$).

In most cases, parthenocarpic fruit produced in the greenhouse by the application of NOA alone or in combination with BA had a slightly lower ascorbic acid content than the seed-containing fruit, irrespective of season, but not usually to a statistically significant level ($P \leq 0.05$), with the exception of Tsakoniki and Black Beauty during the autumn (Fig. 30). Between seasons, a slightly higher concentration of ascorbic acid was observed in all treatments in the spring crop, except in seed-containing fruit of Black Boy.

Table 8. The firmness (kg) of open field-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (T_1), 60 ppm NOA (T_2) and 60 ppm NOA + 30 ppm BA (T_3). Firmness was measured externally at two positions: proximally (near to the calyx) and in the centre of the fruit, and internally in the centre of the fruit.

Treatments	Spring			Autumn		
	Proximal	Centre	Internal	Proximal	Centre	Internal
Tsakoniki						
T_1	2.76 b	3.82 a	1.47 a	3.77 a	3.55 a	1.16 a
T_2	4.45 a	4.65 a	1.50 a	2.97 a	2.94 a	1.53 a
T_3	3.95 a	4.02 a	1.64 a	3.22 a	3.43 a	1.29 a
Lsd	0.84	1.04	0.66	1.08	1.09	0.76
Black Beauty						
T_1	3.74 a	3.59 a	1.27 a	3.41 b	3.35 b	1.54 a
T_2	4.31 a	4.47 a	1.39 a	4.91 a	4.61 a	1.51 a
T_3	4.50 a	4.57 a	1.65 a	4.25 ab	4.73 a	1.46 a
Lsd	0.91	0.98	0.53	1.38	1.06	0.56
Emi						
T_1	3.71 a	3.91 a	1.31 a	2.95 b	2.89 b	1.80 a
T_2	4.23 a	4.33 a	1.44 a	5.07 a	4.77 a	1.43 a
T_3	4.16 a	4.12 a	1.50 a	4.41 ab	4.18 ab	1.50 a
Lsd	1.29	1.04	0.42	1.76	1.67	0.67
Black Boy						
T_1	3.02 a	3.21 a	0.94 b	3.51 a	3.08 a	1.20 a
T_2	3.19 a	3.58 a	1.73 a	2.69 a	2.63 a	1.35 a
T_3	3.24 a	3.39 a	2.08 a	3.95 a	3.32 a	1.43 a
Lsd	0.98	1.17	0.49	1.52	1.04	0.41

In each column, means followed by the same letters for each cultivar are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

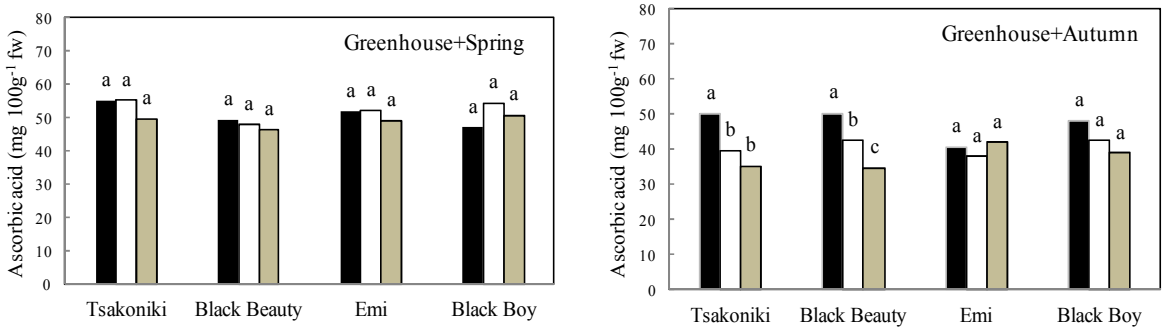

Fig. 30 The ascorbic acid content (mg 100 g^{-1}) of fruit of greenhouse-grown eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivar in each season separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Between seasons significant differences ($P \leq 0.05$) were detected by the t-test between T_2 and T_3 of Tsakoniki, T_3 of Black Beauty and T_2 of Emi.

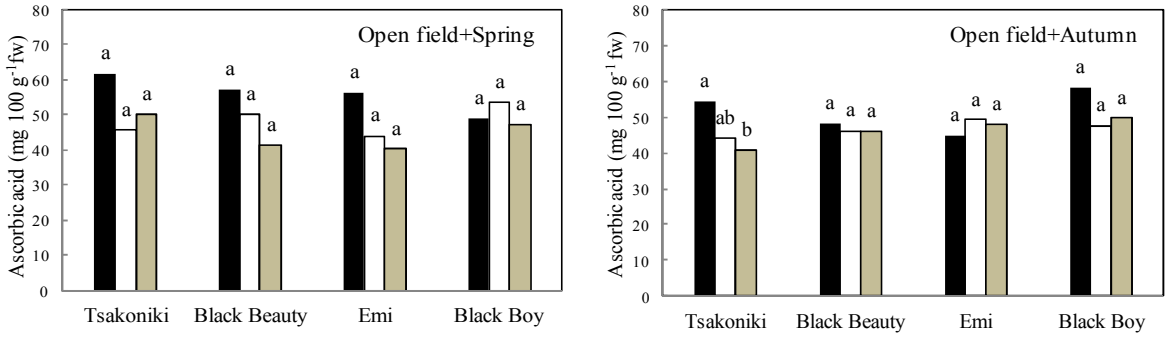

Fig. 31. The ascorbic acid content (mg 100 g^{-1}) of fruit of open field-grown eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivar in each season separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). According to t-test, no significant differences ($P \leq 0.05$) was detected between seasons.

As observed in Fig. 31, there was no significant difference ($P \leq 0.05$) in the ascorbic acid content of seed-containing and parthenocarpic fruit grown in the open field, nor were there any significant differences between the fruit treated with NOA and the mixture of NOA and BA. A significant variation in ascorbic acid content was detected only in the autumn, where seed-containing fruit had a higher ascorbic acid content than parthenocarpic fruit produced by NOA + BA in cv. Tsakoniki (Fig. 31). Autumn field-grown eggplant fruits had similar levels of ascorbic acid to those grown in the spring, whereas in both seasons open field-grown fruits (seed-containing and parthenocarpic) had a comparatively higher ascorbic acid concentration than greenhouse-grown fruit. But this difference was statistically significant only in parthenocarpic fruit of Black Beauty (T_3) and Emi (T_2) (Fig. 30 and 31).

4.3.3 Protein content

The application of PGR had no significant impact ($P \leq 0.05$) on the protein content of greenhouse-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy in either season (Fig. 32). In all cultivars, the seed-containing fruit appeared to have a slightly higher protein content than the parthenocarpic fruit, but not to a statistically significant level. Additionally, no significant differences were detected between the corresponding treatments of the spring and autumn crop of any cultivar.

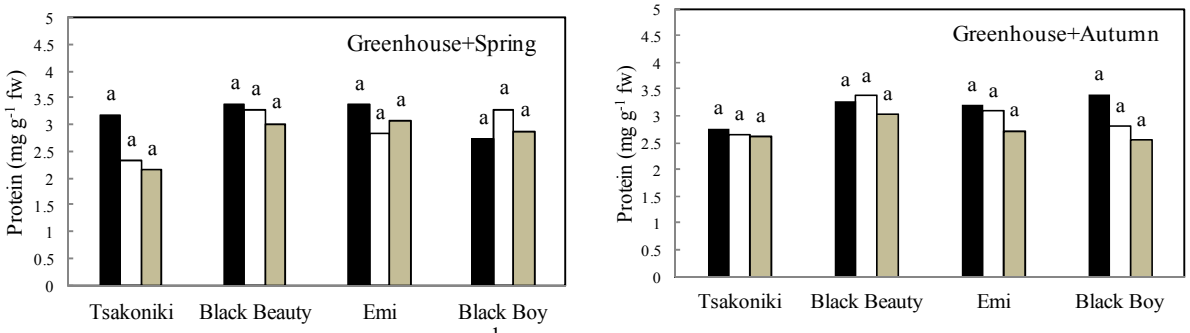

Fig. 32. The protein content (mg g^{-1} fw) of greenhouse-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivar in each season separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). According to the t-test, no significant differences between seasons ($P \leq 0.05$) were detected between the corresponding treatments of any cultivar.

Similarly, no significant variation ($P \leq 0.05$) in protein content was observed between open field-grown, seed-containing and parthenocarpic eggplant fruit (Fig. 33). Neither NOA alone or in combination with BA influenced the protein levels in the fruits of any eggplant cultivar. Additionally, no differences in protein content were observed between the two seasons. Although the protein content of open field-grown eggplant fruits appeared to be slightly higher than that of the corresponding greenhouse-grown fruit, this difference was statistically insignificant ($P \leq 0.05$) (Fig. 32 and 33).

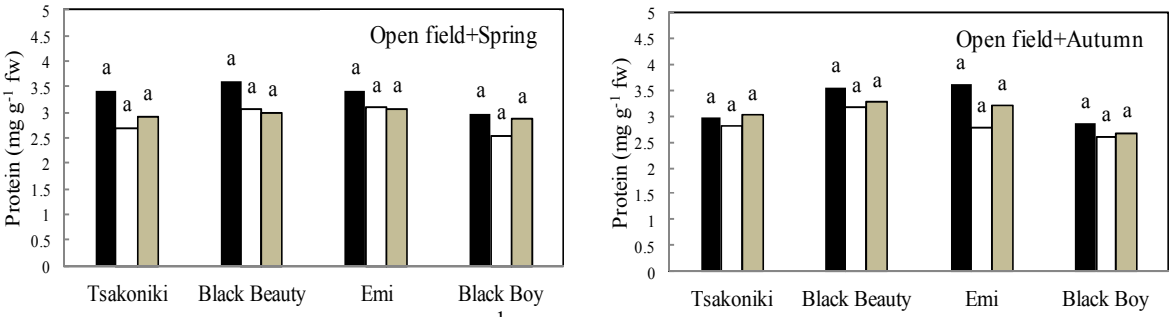

Fig. 33. The protein content (mg g^{-1} fw) of open field-grown fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (■), 60 ppm NOA (□) and 60 ppm NOA + 30 ppm BA (■). Means of each cultivar in each season separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). According to the t-test, no significant differences between seasons ($P \leq 0.05$) were detected between the corresponding treatments of any cultivar.

4.3.4 Phenolics content

The total phenol content of eggplant fruit was measured at two positions (proximal and central regions) after harvest during spring and autumn. Among the cultivars studied, the phenol content of fruits was higher in Tsakoniki, Black Beauty and Black Boy than in Emi, irrespective of the growing season and conditions (Table 9).

Table 9. The total phenol content (mg GAE 100 g^{-1} fw) in the proximal and central regions of fruit of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (T_1), 60 ppm NOA (T_2) and 60 ppm NOA + 30 ppm BA (T_3).

Treatment	Greenhouse				Open field			
	Spring		Autumn		Spring		Autumn	
	Proximal	Central	Proximal	Central	Proximal	Central	Proximal	Central
Tsakoniki								
T_1	69.47 a	103.84 a	74.98 a	85.92 a	70.34 a	93.40 a	77.87 a	77.03 a
T_2	72.83 a	96.38 a	68.61 a	79.59 a	71.63 a	75.98 a	61.74 a	62.59 a
T_3	73.46 a	86.15 a	63.07 a	70.75 a	73.24 a	75.20 a	67.08 a	70.57 a
Lsd	18.48	20.18	18.84	24.33	26.15	25.89	18.13	20.56
Black Beauty								
T_1	75.09 a	90.13 a	73.85 a	100.23 a	73.48 a	87.64 a	67.34 a	89.76 a
T_2	50.09 b	73.57 ab	75.24 a	67.30 b	51.65 b	71.82 ab	63.31 a	64.97 b
T_3	63.20 ab	59.82 b	66.98 a	71.86 b	57.46 ab	66.87 b	70.74 a	68.57 ab
Lsd	20.58	24.43	26.87	20.30	17.18	19.18	18.87	24.55
Emi								
T_1	60.44 a	78.83 a	61.07 a	84.47 a	72.38 a	89.56 a	73.45 a	88.26 a
T_2	62.95 a	72.23 a	57.36 a	77.73 a	64.66 a	68.61 a	69.56 a	68.89 ab
T_3	65.60 a	81.20 a	61.19 a	66.00 a	66.47 a	64.86 a	66.39 a	61.67 b
Lsd	14.27	29.88	14.35	26.45	13.58	25.80	18.59	19.74
Black Boy								
T_1	65.75 a	98.18 a*	64.75 a	78.32 a*	86.93 a	96.76 a	89.19 a	86.65 a
T_2	67.10 a	73.05 b	58.85 a	58.47 b	66.37 ab	69.29 b	71.62 b	69.40 a
T_3	70.19 a	84.01 ab*	61.38 a	64.81 ab*	60.36 b	80.59 ab	70.09 b	64.77 a
Lsd	18.47	19.99	18.02	16.34	25.88	19.56	16.13	25.66

In each column, means followed by the same letters for each cultivar separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Comparison of means by the t-test showed that only treatments T_1(naturally pollinated) and T_3 (NOA + BA) differed significantly between the two seasons (spring and autumn) in the greenhouse crop, while no significant differences between greenhouse and open field-grown fruit were detected by the t-test ($P \leq 0.05$).

The results showed no significant differences ($P \leq 0.05$) between seed-containing and parthenocarpic fruits with respect to the phenol content of the proximal region, although seed-containing fruit showed a comparatively higher phenol content than the parthenocarpic fruit, but the difference was significant only in greenhouse and open field-grown Black Beauty during the spring and open field-grown Black Boy in both seasons (Table 9). The results presented in Table 9 also show that in all cultivars, the proximal

region of the fruit contained comparatively lower levels of phenolics than the central region of the fruit regardless of PGR application, but significant differences were only evident in seed-containing fruits of Black Beauty and Black Boy, while the differences between fruit produced by NOA and the combination of NOA and BA were insignificant ($P \leq 0.05$). The concentration of total phenolics of all cultivars was generally higher in the open field-grown fruit than in the greenhouse-grown fruit in both seasons, but not to a statistically significant degree ($P \leq 0.05$). Between seasons, no significant differences in phenolics content in either the proximal or the central region of the fruit were detected, with the exception of Black Boy, in the central region of the greenhouse-grown seed-containing and parthenocarpic (NOA + BA) fruit (Table 9).

4.3.5 Degree of browning

The lightness (L) value of slices of eggplant fruit was recorded immediately after cutting and 30 min later. The change in L value (ΔL) of the eggplant slices was considered to indicate the degree of browning of the individual fruit and was evaluated at two positions on each fruit: near to the placental tissue and at a distance from the placental tissue (i.e. towards the proximal end of the fruit). A decrease in L value was evident in both positions after 30 min, but was more pronounced in the position near to the placental tissue (Table 10). Although in both seasons the L_0 value (lightness value immediately after cutting) for seed-containing fruit was comparatively lower than for parthenocarpic fruit, the differences were statistically significant ($P \leq 0.05$) only in greenhouse-grown Tsakoniki during spring. Moreover, although the degree of browning appeared to show an increasing trend with the advancement of time, the differences in values were in most cases not significant ($P \leq 0.05$), except in greenhouse grown Tsakoniki during autumn.

Table 11 presents the L_0 value and degree of browning of the flesh towards the proximal end of the fruit, i.e. at a distance from the placenta. The L_0 value of seed-containing fruit did not differ from that of parthenocarpic fruit, except in greenhouse-grown Emi and open field-grown Black Boy during autumn. In addition, there were no significant differences ($P \leq 0.05$) between seed-containing and parthenocarpic fruit with respect to the degree of browning.

Table 10. The lightness (L_0) and browning index (ΔL) of the fruit flesh of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (T_1), 60 ppm NOA (T_2) and 60 ppm NOA + 30 ppm BA (T_3). Measurements were made in the central part of each slice of the fruit near to the placenta.

Treatment	Greenhouse				Open field			
	Spring		Autumn		Spring		Autumn	
	L_0	ΔL	L_0	ΔL	L_0	ΔL	L_0	ΔL
Tsakoniki								
T_1	74.68 b	-9.02 a	74.08 a	-9.73 a	75.96 a	-5.27 a	71.48 a	-4.08 a
T_2	82.86 a	-2.98 b	76.70 a	-5.53 b	73.19 a	-3.37 a	74.76 a	-3.18 a
T_3	81.28 a	-4.67 a	74.07 a	-4.35 b	75.15 a	-6.28 a	78.63 a	-3.27 a
Lsd	4.29	3.07	5.16	3.99	6.83	3.98	4.71	3.27
Black Beauty								
T_1	70.65 a	-8.04 a	76.46 a	-8.60 a	68.35 a	-4.96 a	73.41 a	-5.81 a
T_2	75.30 a	-2.88 a	78.85 a	-7.54 a	75.26 a	-6.21 a	73.26 a	-5.58 a
T_3	77.59 a	-5.42 a	80.78 a	-6.45 a	77.62 a	-6.23 a	70.93 a	-6.62 a
Lsd	8.09	7.10	4.40	2.51	6.91	6.23	6.49	2.94
Emi								
T_1	72.66 a	-4.30 a	80.73 a	-3.62 a	74.62 a	-3.64 a	78.10 a	-5.29 a
T_2	78.17 a	-1.71 a	78.94 a	-4.30 a	77.73 a	-4.56 a	73.60 a	-4.22 a
T_3	78.07 a	-2.37 a	81.85 a	-5.11 a	76.16 a	-4.22 a	75.38 a	-4.65a
Lsd	5.52	2.68	3.17	3.53	3.79	6.00	11.38	3.24
Black Boy								
T_1	72.72 a	-5.35 a	70.18 a	-5.52 a	71.68 a	-2.67 a	74.39 a	-6.08 a
T_2	74.88 a	-2.99 a	75.47 a	-5.46 a	74.22 a	-3.08 a	71.57 a	-3.39 a
T_3	74.57 a	-2.61 a	72.34 a	-4.70 a	74.35 a	-2.65 a	73.79 a	-6.07 a
Lsd	10.53	3.51	7.30	4.84	2.98	5.22	6.32	4.99

In each column, means followed by the same letters for each cultivar separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Comparison of means by the t-test showed no significant differences between fruit produced in the greenhouse and the open field regardless of season, and no significant differences between the two seasons (spring and autumn) at $P \leq 0.05$.

The L_0 value near the placenta (Table 10) tended to be lower than that away from the placenta, indicating that the colour of the tissue near the placenta was darker. Additionally, a higher degree of browning was observed in the tissue near the placenta. All cultivars of eggplant followed a similar pattern of browning. No significant differences were detected between seasons or between greenhouse and open field-grown fruit.

Table 11. The lightness (L_0) and browning index (ΔL) of the fruit flesh of eggplant cvs. Tsakoniki, Black Beauty, Emi and Black Boy produced by natural pollination (T_1), 60 ppm NOA (T_2) and 60 ppm NOA + 30 ppm BA (T_3). Measurements were made in the central part of each slice of fruit towards the proximal end of the fruit, i.e. at a distance from the placenta.

Treatment	Greenhouse				Open field			
	Spring		Autumn		Spring		Autumn	
	L_0	ΔL	L_0	ΔL	L_0	ΔL	L_0	ΔL
Tsakoniki								
T_1	82.91 a	-3.13 a	82.28 a	-4.21 a	80.78 a	-2.18 a	78.98 a	-2.65 a
T_2	85.22 a	-2.20 a	80.83 a	-1.53 a	81.88 a	-1.79 a	79.22 a	-1.50 a
T_3	85.05 a	-2.51 a	80.97 a	-3.37 a	83.66 a	-3.38 a	79.57 a	-2.35 a
Lsd	2.91	3.46	3.04	3.16	3.25	4.43	4.54	2.83
Black Beauty								
T_1	81.15 a	-1.85 a	82.67 a	-1.93 a	77.07 a	-2.28 a	81.79 a	-2.78 a
T_2	85.67 a	-1.74 a	83.82 a	-2.16 a	81.68 a	-1.38 a	82.34 a	-3.72 a
T_3	83.70 a	-0.24 a	85.31 a	-2.43 a	83.45 a	-3.39 a	80.04 a	-3.51 a
Lsd	5.05	5.23	4.27	2.94	7.43	4.82	3.37	1.33
Emi								
T_1	79.26 a	-0.45 a	84.18 a	-1.19 a	80.62 a	-1.78 a	78.26 a	-3.03 a
T_2	83.41 a	-0.11 a	81.54 b	-2.20 a	83.81 a	-2.21 a	82.66 a	-3.19 a
T_3	83.67 a	-0.75 a	84.17 a	-1.51 a	84.36 a	-2.35 a	82.09 a	-2.19 a
Lsd	4.59	3.71	1.61	2.08	4.42	2.42	5.70	3.32
Black Boy								
T_1	81.81 a	-1.76 a	76.34 a	-3.67 a	77.96 a	-2.82 a	80.82 a	-2.88 a
T_2	81.04 a	-0.48 a	79.38 a	-1.80 a	79.65 a	-1.41 a	77.02 b	-1.69 a
T_3	83.65 a	-1.25 a	77.87 a	-1.75 a	82.32 a	-0.21 a	80.93 a	-3.79 a
Lsd	2.68	3.99	6.15	7.01	4.79	3.02	3.28	3.70

In each column, means followed by the same letters for each cultivar separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). The t-test revealed no significant differences ($P \leq 0.05$) between spring and autumn or between greenhouse and field-grown fruit.

4.3.6 Anthocyanin content

In a preliminary analysis, anthocyanin was measured from the pericarp of the central region of eggplant fruits at harvest. It was observed that the anthocyanin content varied considerably between the eggplant cultivars, with Black Beauty and Emi containing comparatively higher levels of anthocyanin than Black Boy and Tsakoniki. However, within each cultivar considerable variation in anthocyanin concentration was observed; for example, the anthocyanin concentration in Black Beauty and Emi ranged from 16.26-22.80 and 14.84-19.02 (mg l^{-1} delphinidin-3-glucoside equivalent) respectively, which was approximately 2-fold higher than in Black Boy (8.31-10.16 mg l^{-1}) and 4-fold higher than in Tsakoniki (4.07-4.88 mg l^{-1}). The application of PGR did not appear to affect the anthocyanin concentrations in the fruit pericarp of any cultivar, irrespective of growing season and growing conditions.

4.3.7 Sugar content

The concentration of sugars in seed-containing and parthenocarpic fruit of eggplant cvs. Tsakoniki and Black Beauty was measured at harvest during spring and autumn (Table 12). In the present study, we detected fructose, glucose, sucrose and maltose as the major sugars in both eggplant cultivars.

Table 12. The concentration of sugars (mg 100 g^{-1} fw) in greenhouse-grown Tsakoniki and Black Beauty produced by natural pollination (T_1) and 60 ppm NOA (T_2) during spring and autumn. Values are means ± standard deviation

	Spring			
Treatments	Fructose	Glucose	Sucrose	Maltose
Tsakoniki				
T_1	534.97 ± 35.39 †	632.85 ± 29.18	35.29 ± 9.95	85.70 ± 11.89
T_2	643.25 ± 44.44 †	739.96 ± 38.57 †	62.93 ± 22.03	101.90 ± 19.54
Significance	*	*	ns	ns
Black Beauty				
T_1	863.78 ± 62.86	780.54 ± 46.97	31.64 ± 7.29	124.14 ± 13.70
T_2	1024.14 ± 79.67	1025.20 ± 77.31	47.71 ± 19.01	133.12 ± 21.69
Significance	*	*	ns	ns
	Autumn			
Treatments	Fructose	Glucose	Sucrose	Maltose
Tsakoniki				
T_1	462.27 ± 23.83 †	569.92 ± 28.65	16.04 ± 5.63	63.67 ± 13.56
T_2	555.62 ± 35.73 †	658.24 ± 39.38 †	35.69 ± 6.76	78.25 ± 16.46
Significance	*	*	ns	ns
Black Beauty				
T_1	699.84 ± 52.51	772.53 ± 35.90	32.28 ± 5.81	91.54 ± 10.12
T_2	876.56 ± 36.00	904.37 ± 47.23	46.71 ± 9.86	106.26 ± 14.93
Significance	*	*	ns	ns

Significant differences between seed containing and parthenocarpic fruit of each cultivar during each season separately are indicated by asterisks (*) ($P \leq 0.05$); ns = not significant. Significant differences in glucose and fructose levels between the spring and autumn grown fruit, according to the t-test, are indicated by an arrow (†).

Table 12 shows that the fructose and glucose content of both cultivars was higher than that of sucrose and maltose, regardless of seasonal variation. The results reveal a significant difference ($P \leq 0.05$) between seed-containing and parthenocarpic eggplant fruit for fructose and glucose content; however, no significant differences were observed for sucrose and maltose. Therefore, it is evident that NOA enhanced the concentration of fructose and glucose in eggplant fruit. In Tsakoniki, higher fructose and glucose accumulation was observed in spring-grown seedless eggplant fruit than in the autumn-grown fruit (T_2), but in seed-containing fruit only fructose was significantly higher in the

spring than in the autumn (T1). No differences in non-reducing sugars (i.e. sucrose and maltose) were detected between seasons (Table 12).

4.3.8 Starch content

The starch content of fruits of eggplant cvs. Tsakoniki and Black Beauty cultivated in the greenhouse showed a significant ($P \leq 0.05$) increase in parthenocarpic fruit compared with seed-containing fruit during spring, but not in autumn (Fig. 35). In Tsakoniki, during spring, the concentration of starch in NOA-set fruit and fruit set by pollination was 93.65 and 70.84 mg 100 g^{-1} fw, respectively, while in Black Beauty, the corresponding values were 123.80 mg 100 g^{-1} fw and 93.07 mg 100 g^{-1} fw, respectively. Similar patterns of starch concentration were also observed in the autumn, but the concentrations were lower compared to the spring.

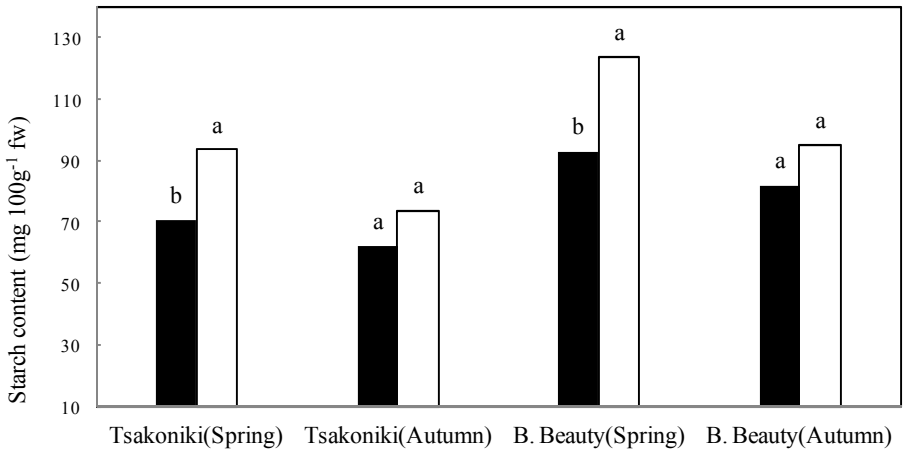

Fig. 34. The starch content (mg 100 g^{-1} fw) of greenhouse-grown eggplant cvs. Tsakoniki and Black Beauty produced by natural pollination (■) and 60 ppm NOA (□). The means for each cultivar in each season separately accompanied by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$).

4.4 Discussion

Based on the results of the present study it is apparent that overall most of the quality parameters were either not significantly affected by the application of auxin (NOA) for fruit set.

Fruit firmness is an important quality attribute and depends on the cultivar, maturity stage, growing season and cultural practices. The present study showed that neither NOA alone nor NOA in combination with BA significantly influenced the external

and internal firmness of eggplant fruits. This result agrees with previous reports where the application of different commercial auxins did not affect the firmness of pepper (Lopez-Elias *et al.,* 2005; Salas *et al.,* 2009), although in other species, e.g. apple (Guak *et al.,* 2002; Curry (2006) and kiwifruit (Bregoli *et al.,* 2006), hormones have been reported to increase fruit firmness. By contrast, in stone fruit species, e.g. pear, plum and apricot, exogenous application of auxin stimulates ethylene production which induces cell wall degradation, and thereby decreases fruit firmness (Kondo *et al.,* 2004; Forlani *et al.,* 2010). For good quality, eggplant fruits should have sufficient firmness to withstand transport and handling, but should be relatively soft for consumption. Although hormones have been used for many years to set eggplant fruit, especially during winter (Olympios, 1976; Van Ravestijn, 1983), this is the first time to our knowledge that a comparison of firmness between seedless (parthenocarpic) and seed-containing fruit has been made.

Ascorbic acid is a potent antioxidant, therefore a high ascorbic concentration in eggplant fruit is a desirable quality trait. The present study showed some variation in ascorbic acid content between cultivars but not to a statistically significant level. Several other studies have also reported variation in the ascorbic acid content of eggplant cultivars (Hanson *et al.,* 2006; Rodrigues-Burruezo *et al.*, 2008). The present results reveal that the exogenous application of NOA alone or in combination with BA did not affect the ascorbic acid content of the eggplant cultivars tested in this experiment, except in Tsakoniki and Black Beauty grown in the greenhouse during autumn and Tsakoniki grown in the field in autumn. In each case the ascorbic acid content was higher in seed-containing fruit than in parthenocarpic fruit. In tomato fruit set by auxin, the fruit ascorbic acid content was not affected by hormone application (Murneek *et al.,* 1954), while Rotino *et al.* (2005) did not find any difference in ascorbic acid levels between the commercial hybrid Allfresh 1000 and the transgenic parthenocarpic tomato cv. UG82. In other species, however, the ascorbic acid level in fruit was increased by hormone application, e.g. by foliar application of NAA in pepper (Sridhar *et al.,* 2009), or a commercial mixture of auxin (phenothiol) in strawberry (Roussos *et al.,* 2009), or 2,4-D in citrus (Saleem *et al.,* 2007, 2008). In our study, we found a generally higher ascorbic acid content in open field-grown eggplant fruit; this difference might result from the lower light intensity inside the greenhouse. In the greenhouse, plants have less exposure to low wavelength radiation than in the open field, and in tomato, several studies have reported that greenhouse-grown fruit had lower levels of ascorbic acid than fruit grown in the open field (Lopez-Andreu *et al.,* 1986; Stewart *et al.,* 2000; Dumas *et al.,* 2003). Due to the lower light intensity and shorter days

during fruit growth in autumn, eggplant fruit contained lower levels of ascorbic acid during this season compared with fruit grown in the spring. This finding is consistent with an earlier report by Venter (1977) who found increasing levels of ascorbic acid in tomato fruit from early summer to late summer.

The results of the present investigation showed that PGR did not significantly influence the protein content of eggplant fruits, and even though the protein content of seed-containing fruits tended to be slightly higher than that of parthenocarpic fruits, regardless of growing season and conditions, this difference was not statistically significant. Chrominski (1967) reported reduced protein content in wheat grain after treatment with Cycocel (4 to 12 kg ha^{-1}). On the contrary, Graham and Ballesteros (1980) found increased levels of protein in tomato leaves after foliar application of gibberellic acid. Evidently the type of PGR, as well as the method of application, affects the tissue protein level. However, insufficient literature relating to the effect of growth substances on fruit protein content is available to make a conclusive statement on eggplant fruit protein content in relation to growth regulator application.

Eggplant is ranked among the top ten vegetable species as a source of fruit phenolic constituents (Cao *et al.,* 1996). The results of the present study showed a variation in total phenolics among the eggplant cultivars. This confirms the findings of Stommel and Whitaker (2003), Whitaker and Stommel (2003), Prohens *et al.* (2005) and Hanson *et al.* (2006), all of whom found a wide variation in phenolics among eggplant cultivars. Significant differences in the content of phenolics (both in the proximal and central regions of the fruit) were observed between seed-containing and parthenocarpic fruits of Black Beauty and Black Boy, the total phenolics contents of the fruit decreasing after the application of PGR. The application of auxin has similarly been shown to decrease the total phenolic substances in strawberry (Given *et al.,* 1988; Roussos *et al.,* 2009) and the hypanthium of *Rosa canina* L. (Atalay and Kadioglu, 2001). On the other hand, the seeds present in naturally pollinated fruits are a good source of phenolic compounds as reported for different fruits (Bocco *et al.,* 1998; Shi *et al.,* 2003; Soong and Barlow, 2004), which could explain the presence of a higher phenolics content in the central part of seed-containing eggplant fruit than in parthenocarpic fruit. Both NOA and the combination of NOA and BA had a similar effect on the phenol content of eggplant fruits of all cultivars.

The oxidation of phenolics causes browning of the cut surfaces of fruit and reduces eggplant quality during cooking. The results showed that fruit with higher values for phenol content had lower L_0 values, which is logical as the L value of the flesh is

associated with the phenol content of the respective fruit. This meant that, despite a lack of statistical significance ($P \leq 0.05$), seed-containing fruit had a slightly darker coloured flesh (lower L value) than seedless fruit. The degree of browning near to the placenta of seed-containing eggplants tended to be higher than that of parthenocarpic fruit, but in most cases not to a statistically significant level. Presumably, this difference resulted from the relatively higher total phenolics in the flesh of seed-containing fruit compared with parthenocarpic fruit. In support of this finding, some authors reported a positive correlation between the concentration of phenolics and the degree of browning in eggplant (Prohens *et al.,* 2007) and apple (Coseteng and Lee, 1987). However in our experiment, differences in the degree of browning in the placental tissue of seed-containing and parthenocarpic fruit were statistically insignificant. Although the degree of browning of tissue measured at a distance from the placenta was less than that recorded in the placental tissue, there was no significant difference here between seed-containing and parthenocarpic fruit. The differences in phenolic contents between the proximal and central part of the fruit might explain the lower changes in browning index of the non-placental tissue in seed-containing and parthenocarpic fruit.

We found that fructose, glucose, sucrose and maltose are the major sugar constituents of eggplant fruit. This result supports the findings of Kozukue *et al.* (1978) and Esteban *et al.* (1992) that reducing sugars are the main sugars in eggplant. The results showed that the content of fructose and glucose was comparatively higher than that of sucrose and maltose in eggplant fruit, which is consistent with the results of Kozukue *et al.* (1978). It was observed that the application of PGR for fruit set did not affect the concentration of sucrose and maltose, but significantly increased the content of the reducing sugars fructose and glucose. This result is in full accordance with the findings of Wei-Ping *et al.* (2011) who found that 2,4-D reduced the activity of fructokinase in tomato, leading to an increase in the level of fructose and glucose. Similarly, it has been shown that the application of auxins increased the sugar levels in citrus fruits (Agusti *et al.,* 2002; Saleem *et al.,* 2007; Nawaz *et al.,* 2008) and grape (Bottcher *et al.,* 2011), but in pepper Belkbir *et al.* (1998) observed that NAA did not affect fructose, glucose or sucrose. In the present study, a higher level of fructose and glucose in Tsakoniki was observed during the spring compared to the autumn fruit. In tomato, Georgelis and Scott (2006) reported a higher sugar content during spring, whereas Gautier *et al.* (2008) did not find any variation in sugar content under different growing temperatures.

The effect of growth regulators on fruit starch content was not significant, although the application of NOA during spring slightly increased the level of starch in eggplant fruits of both Tsakoniki and Black Beauty. In kiwifruit, Famiani *et al.* (2007) observed a higher level of starch after applying 2,4-D. Regarding seasonal variation, starch in apple progressively increased at higher temperatures (Warrington *et al.,* 1999), and our results appear to be consistent with these findings since parthenocarpic eggplant fruit had a higher starch content in spring than in autumn. It is open to conjecture whether the slightly higher flesh firmness of parthenocarpic fruit (Table 7), albeit to a statistically insignificant degree, relates to the higher starch content of these fruits. From a nutritional point of view the fact that parthenocarpic fruit contain both more starch and more sugar than seed-containing fruit (whereas protein did not differ), indicates that the former may have a higher nutritive value.

CHAPTER 5

The effects of temperature and film-wrapping on the postharvest quality of eggplant.

5.1 Introduction

Refrigerated storage is one of the most popular methods used for extending the postharvest life of fresh horticultural commodities (Ryall and Lipton, 1979). Low temperatures slow down the rate of metabolism of the produce and can also reduce the rate of growth and spread of pathogens and decay. Eggplant is a warm season plant and the fruit are susceptible to chilling injury at temperatures lower than about 10^{o}C, depending on the growing season (Ryall and Lipton, 1979). Wrapping of eggplant fruit with film appeared to be a beneficial supplement to refrigeration (Mohamed and Sealy, 1986). Although film wrapping has been reported to prolong the shelf life of eggplant by reducing weight loss and decay (Fallik *et al.,* 1995; Rodriguez *et al.,* 2001; Gajewski *et al.,* 2009), the detailed effects of film wrapping on the physiological and biochemical changes of eggplant fruits during storage have not been fully defined, especially in parthenocarpic fruits. Thus, the aim of this study was to detail the specific physiological and biochemical changes in eggplant fruit as affected by different storage temperatures, with particular emphasis on PGR-induced parthenocarpic fruit.

5.2 Materials and methods

This experiment comprised two cultivations, the first was started on 5 March 2009 and the second on 7 February 2011, with a view to studying the storage behaviour of naturally pollinated and parthenocarpic eggplant fruit of cvs. Tsakoniki and Black Beauty. The first cultivation was carried out both in the greenhouse and in the open field, while the second cultivation was confined to the greenhouse. Forty plants of each cultivar were grown in each case and parthenocarpic (seedless) fruit were set by emasculation and spraying the flowers at anthesis with β-NOA (60 ppm). The details of crop husbandry are presented in Chapter 2. Both pollinated and parthenocarpic fruits of uniform size and shape were harvested at 25 days after anthesis and immediately transferred to the laboratory. Both types of fruit were either individually wrapped with film or unwrapped and stored at 10 or 20ºC and 80 ± 5% relative humidity (RH) in a storage cabinet (Lovibond, Germany) for 7 and 14 days (first cultivation) and 10 and 20 days (second cultivation). In all cases, 5 fruits

were employed per treatment and storage condition. The rate of oxygen and water vapour permeability of the flexible vinyl film (LMC-AT/8, AEP Industries Packaging, Spain) was 19000 $cm^3\ m^{-2}\ 24h^{-1}$ and 190 g $m^{-2}\ 24h^{-1}$ respectively. The methods for the measurement of weight loss (%) and the analysis of skin colour, ascorbic acid content, protein content, total phenolic content, anthocyanin content, browning potential, sugar and starch content, respiration and ethylene production are described in Chapter 2.

5 Results

5.3.1 Pericarp colour

Colour changes (L, C* and Hº) of unwrapped and film-wrapped seed-containing and parthenocarpic fruit of eggplant cvs. Tsakoniki and Black Beauty were monitored during postharvest storage for 7 and 14 days at 10 and 20ºC.

5.3.1.1 Pericarp colour of Tsakoniki

The L (lightness) value of film-wrapped and unwrapped eggplant fruit (seed-containing and parthenocarpic) changed during storage at both temperatures; however, in most cases the changes were insignificant ($P \leq 0.05$) (Tables 13-15). A significant increase in ΔL with storage time was detected only in film-wrapped, parthenocarpic fruit (greenhouse crop of the 2nd cultivation) stored at 10ºC for 20 days (Table 15). At the end of storage, a significant difference in ΔL was observed between unwrapped and film-wrapped, seed-containing fruit (open field crop and greenhouse crop of the 2nd cultivation) stored at 10ºC (Tables 14 and 15). Between seed-containing and parthenocarpic (seedless) fruit, it was observed that unwrapped seed-containing fruit exhibited a significantly higher change in L value (ΔL) than unwrapped parthenocarpic fruit (open field crop and greenhouse crop of the 2nd cultivation) at 10ºC (Tables 14 and 15). At 20ºC, no significant changes in L value (ΔL) were recorded with time, nor were any differences found between wrapped and unwrapped fruit, or between seed-containing and parthenocarpic fruit of any crop (Tables 13-15).

Changes in the C* value of both naturally pollinated and parthenocarpic fruit of cv. Tsakoniki during storage at 10 and 20ºC varied irrespective of treatment: in some cases ΔC* decreased (indicating a loss of red colour intensity) whereas in other cases ΔC* increased with storage time (Tables 13-15). Statistically significant differences in ΔC were noted for unwrapped seed-containing fruit stored at 10ºC (Tables 13 and 14) and 20ºC

(Tables 14 and 15) as well as wrapped, seed-containing fruit stored at 20°C (Table 14). Between wrapped and unwrapped fruit, significant changes in ΔC* were detected in seed-containing fruit of the 2nd greenhouse crops stored at 20ºC (Table 15), whereas between seed-containing and parthenocarpic fruit a significant difference in ΔC* was observed only in fruit from the open field stored at 10 and 20°C (Table 14) and the 2nd greenhouse crop stored at 20°C (Table 15).

The hue angle (Hº) of fruit of eggplant cv. Tsakoniki increased slightly during storage at both 10 and 20ºC; however, the difference was only significant in unwrapped naturally pollinated fruit from the open field crop stored at 10 and 20ºC (Table 14). Comparing storage treatments, ΔHº was higher in unwrapped naturally pollinated fruit (greenhouse crop of 2nd cultivation) than in film-wrapped fruit stored at 10ºC for 20 days (Table 15). Between seed-containing and parthenocarpic fruit, ΔH was significantly higher in film-wrapped, seed-containing fruit stored at 10°C (Tables 13 and 15).

Table 13. Changes in pericarp colour (L, C* and Hº) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Changes in colour attributes during storage at 10ºC								
	ΔL			ΔC			ΔH		
	7 day	14 day	Lsd	7 day	14 day	Lsd	7 day	14 day	Lsd
Seeded fruit									
Unwrapped	0.59 a	2.53 a	7.46	-0.53 a	-4.66 b	3.92	0.19 a	0.30 a†	0.20
Film	-1.14 a	3.94 a	6.79	-0.40 a	-4.87 a	5.87	0.18 a	0.46 a†	0.29
Parthenocarpic									
Unwrapped	-1.15 a	-1.06 a	9.05	-1.91 a	2.36 a	5.03	0.10 a	0.16 a	0.18
Film	1.40 a	-0.61 a	4.34	-0.49 a	-0.79 a	4.72	0.11 a	0.19 a	0.12
	Changes in colour attributes during storage at 20ºC								
Seeded fruit									
Unwrapped	-0.62 a	-1.08 a	3.68	-1.09 a	-2.41 a	9.36	0.22 a	0.25 a	0.23
Film	0.32 a	1.93 a	4.67	-0.91 a	-1.21 a	7.23	0.16 a	0.23 a	0.17
Parthenocarpic									
Unwrapped	1.87 a	2.09 a	4.59	1.47 a	2.32 a	4.78	0.15 a	0.20 a	0.21
Film	0.89 a	2.38 a	4.36	2.14 a	-0.12 a	4.03	0.10 a	0.21 a	0.14

In each row, means followed by the same letters for each colour attribute separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, no significant differences were detected between corresponding treatments of seed-containing and parthenocarpic fruit, while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

Table 14. Changes in pericarp colour (L, C* and Hº) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Changes of colour attributes during storage at 10ºC								
	ΔL			ΔC			ΔH		
	7 day	14 day	Lsd	7 day	14 day	Lsd	7 day	14 day	Lsd
Seeded fruit									
Unwrapped	-1.02 a	3.99 a*†	6.08	-0.12 b	2.66 a*	1.06	0.09 a	0.03 b	0.05
Film	-1.10 a	-2.34 a†	2.58	0.11 a	0.99 a	4.65	0.05 a	0.02 a	0.19
Parthenocarpic									
Unwrapped	1.07 a	-2.79 a*	7.32	-1.80 a	0.76 a*	3.01	0.10 a	0.15 a	0.08
Film	0.79 a	1.15 a	8.50	-0.37 a	-1.44 a	4.99	0.06 a	0.11 a	0.13
	Changes of colour attributes during storage at 20ºC								
Seeded fruit									
Unwrapped	1.15 a	3.79 a	6.29	-2.06 a	-3.47 b*	1.34	0.05 b	0.11 a	0.04
Film	-1.45 a	3.14 a	5.73	-0.75 a	-3.11 b	2.31	0.02 a	0.12 a	0.10
Parthenocarpic									
Unwrapped	0.98 a	1.00 a	7.34	-1.37 a	0.66 a*	2.59	0.06 b	0.11 a	0.04
Film	1.31 a	2.79 a	3.02	-1.83 a	-0.91 a	2.13	0.04 a	0.12 a	0.09

In each row, means followed by the same letters for each colour attribute separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

Table 15. Changes in pericarp colour (L, C* and Hº) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Changes of colour attributes during storage at 10ºC								
	ΔL			ΔC			ΔH		
	10 day	20 day	Lsd	10 day	20 day	Lsd	10 day	20 day	Lsd
Seeded fruit									
Unwrapped	3.30 a	2.08 a*†	2.40	-2.07 a	1.51a	4.52	0.12 a	0.21 a*†	0.12
Film	-0.25 a	-1.89 a†	5.89	-1.04 a	1.58 a	5.21	0.08 a	-0.04 a†	0.18
Parthenocarpic									
Unwrapped	-0.37 a	-0.80 a*	3.04	1.19 a	0.25 a	1.66	0.08 a	0.12* a	0.09
Film	-1.77 b	3.63 a	4.87	1.08 a	-1.26 a	2.75	0.16 a	0.25 a	0.21
	Changes of colour attributes during storage at 20ºC								
Seeded fruit									
Unwrapped	2.94 a	4.95 a	2.13	-1.24 a	-4.08 b*†	1.36	0.16 a	0.23 a	0.07
Film	2.04 a	4.14 a	3.77	-1.15 a	-0.62 a†	3.19	0.10 a	0.22 a	0.14
Parthenocarpic									
Unwrapped	-0.02 a	0.76 a	5.92	0.41 a	0.51* a	4.01	0.15 a	0.12 a	0.19
Film	-0.42 a	1.50 a	3.96	-0.63 a	-1.10 a	3.64	0.05 a	0.41 a	0.46

In each row, means followed by the same letters for each colour attribute separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

5.3.1.1 Pericarp colour of Black Beauty

The L value of Black Beauty changed during the storage period, but to a statistically significant level (P≤0.05) only at 10ºC in unwrapped, naturally pollinated fruit from the open field and 2nd greenhouse crop (Tables 17 and 18) and in film-wrapped, naturally pollinated fruit of the 2nd cultivation (Table 18). A significantly greater decrease in L value was recorded in unwrapped, naturally pollinated fruit than in the corresponding unwrapped parthenocarpic fruit stored at both 10 and 20°C for 14 days (open field crop, Table 17) and 20 days (2nd greenhouse crop, Table 18). Finally, film-wrapped fruit from the 2nd greenhouse crop showed a higher ΔL than unwrapped fruit after storage at 10ºC for 20 days (Table 18).

Table 16. Changes in pericarp colour (L, C* and Hº) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Changes of colour attributes during storage at 10ºC								
	ΔL			ΔC			ΔH		
	7 day	14 day	Lsd	7 day	14 day	Lsd	7 day	14 day	Lsd
Seeded fruit									
Unwrapped	0.10 a	-0.19 a	3.13	-0.23 a	0.04 a	2.10	0.13 a	0.12 a	0.12
Film	0.38 a	-0.51 a	1.84	0.54 a	0.37 a	1.69	0.16 a	0.09 a	0.08
Parthenocarpic									
Unwrapped	-1.40 a	-0.29 a	2.91	-0.95 a	-0.69 a	2.46	0.08 a	0.07 a	0.07
Film	-0.38 a	-0.09 a	2.36	-0.30 a	0.81 a	1.72	0.15 a	0.06 a	0.23
	Changes of colour attributes during storage at 20ºC								
Seeded fruit									
Unwrapped	1.15 a	0.44 a	2.14	0.76 a*†	0.52 a	1.00	0.03 a	0.06 a	0.08
Film	-0.46 a	0.78 a	2.61	-1.35 a†	-0.08 a	2.61	0.03 a	0.02 a	0.06
Parthenocarpic									
Unwrapped	0.53 a	0.25 a	1.58	-0.45 b*	0.82 a	0.78	0.07 b	0.11 a	0.03
Film	-0.40 a	1.14 a	2.38	0.47 a	0.78 a	1.86	0.05 a	0.08 a	0.10

In each row, means followed by the same letters for each colour attribute separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

No significant changes (P ≤ 0.05) in ΔC were observed in naturally pollinated and parthenocarpic fruit of Black Beauty in relation to the duration of storage at 10ºC, but at 20ºC a significant increase in ΔC was observed in unwrapped, seed-containing fruit from the 2nd greenhouse crop (Table 18) and in unwrapped, parthenocarpic fruit from the 1st greenhouse and open field crops (Tables 16 and 17), as well as in wrapped, parthenocarpic fruit from the 2nd greenhouse crop (Table 18). Between seed-containing and parthenocarpic

fruit, no significant differences in ΔC were found during storage at 10°C, irrespective of the treatment and duration of storage, but at 20°C a significant difference in ΔC was detected between wrapped and unwrapped seed-containing and parthenocarpic fruit on day 7 (Tables 16 and 17). A higher value for ΔC (low purple intensity) was recorded at 20°C in unwrapped seed-containing fruit than in film-wrapped, seed containing fruit stored for 7 days (1st greenhouse crop, Table 16), but to the contrary, film-wrapped, parthenocarpic fruit of the open field crop had a higher ΔC value than the corresponding unwrapped fruit at 20ºC after storage for 7 days (Table 17).

Table 17. Changes in pericarp colour (L, C* and Hº) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Changes of colour attributes during storage at 10ºC								
	ΔL			ΔC			ΔH		
	7 day	14 day	Lsd	7 day	14 day	Lsd	7 day	14 day	Lsd
Seeded fruit									
Unwrapped	-1.08 a	-2.68 b*	1.29	-0.28 a	0.18 a	0.51	0.09 a	0.10 a	0.06
Film	-0.10 a	-1.32 a	2.22	0.34 a	0.20 a	1.09	0.04 a	0.08 a	0.06
Parthenocarpic									
Unwrapped	0.31 a	-1.12 a*	2.15	0.67 a	-0.58 a	2.10	0.15 a†	0.08 a	0.07
Film	-0.18 a	-0.27 a	1.18	0.97 a	-0.50 a	1.53	0.05 a†	0.04 a	0.05
	Changes of colour attributes during storage at 20ºC								
Seeded fruit									
Unwrapped	0.81 a	-0.07 a*	1.15	-0.30 a	-0.29 a	1.20	0.04 a*	0.07 a	0.04
Film	1.36 a	0.34 a	2.69	-0.23 a*	0.02a*	0.67	0.03 a*	0.05 a	0.07
Parthenocarpic									
Unwrapped	0.95 a	1.41 a*	2.23	-0.40 b†	0.29 a	0.66	0.52 a*	0.12 b	0.13
Film	-0.12 a	0.13 a	1.66	0.42 a*†	0.98a*	0.58	0.58 a*	0.09 b	0.08

In each row, means followed by the same letters for each colour attribute separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

It was observed that Hº increased slightly during storage at 10 and 20ºC, but with the exception of parthenocarpic fruit (wrapped and unwrapped) from the open field stored at 20°C (Table 17), the differences were not statistically significant (P ≤ 0.05). Between seed-containing and parthenocarpic fruit, a significant difference in ΔH was observed after storage at 20ºC for 7 days irrespective of wrapping (Table 17) and after 20 days in wrapped fruit only (Table 18). It was also observed that at 20°C unwrapped parthenocarpic fruit had a significantly higher ΔH value on day 20 than the corresponding film-wrapped fruit (2nd greenhouse crop, Table 18).

Table 18. Changes in pericarp colour (L, C* and Hº) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Changes of colour attributes during storage at 10ºC								
	ΔL			ΔC			ΔH		
	10 day	20 day	Lsd	10 day	20 day	Lsd	10 day	20 day	Lsd
Seeded fruit									
Unwrapped	0.09 a	-3.86 b*†	3.90	-0.04 a	-0.43 a	2.29	0.10 a	0.04 a	0.07
Film	-0.84 b	2.31 a†	0.98	-0.36 a	2.88 a	3.76	0.02 a	0.01 a	0.07
Parthenocarpic									
Unwrapped	-0.14 a	0.08 a*	3.34	0.84 a	0.88 a	3.28	0.04 a	0.11 a	0.19
Film	-1.59 b	0.84 a	1.68	1.15 a	2.13 a	1.45	0.03 a	0.05 a	0.04
	Changes of colour attributes during storage at 20ºC								
Seeded fruit									
Unwrapped	-0.54 a	-0.85 a*	1.24	-1.32 b	0.67 a	0.60	0.03 a	0.07 a*	0.10
Film	1.56 a	-0.30 a	3.18	0.35 a	1.86 a	5.72	0.01 a	0.02 a	0.15
Parthenocarpic									
Unwrapped	0.43 a	2.10 a*	2.87	0.93 a	-0.33 a	5.60	0.07 a	0.31 a*†	0.28
Film	-0.08 a	2.23 a	2.60	1.71 b	2.96 a	0.79	0.03 a	-0.02 a†	0.09

In each row, means followed by the same letters for each colour attribute separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

5.3.2 Firmness

5.3.2.1 External firmness

The firmness of fruit of eggplant cvs. Tsakoniki and Black Beauty was measured externally in the central region of the fruit and presented in Tables 19-22. The study revealed that at harvest there were no significant (P ≤ 0.05) differences in external firmness between naturally pollinated and parthenocarpic fruit of either cultivar, although parthenocarpic fruit showed a tendency to be slightly firmer than naturally pollinated fruit.

At 10ºC, significant changes in the external firmness of both unwrapped and film-wrapped fruit of Tsakoniki with storage time (both seed-containing and parthenocarpic) were recorded in the 1st greenhouse crop (Table 19), whereas in the 2nd greenhouse crop a significant decrease in firmness of film-wrapped seed-containing and parthenocarpic fruit was observed (Table 20). At 20ºC, significant changes in firmness in relation to storage time were observed in unwrapped, seed-containing fruit from the open field crop on day 14, unwrapped parthenocarpic fruit from the 1st greenhouse crop on day 7 and film-wrapped parthenocarpic fruit on days 7 and 14 (Table 19). The results also indicate that

unwrapped, seed containing fruit from the 1st greenhouse cultivation were firmer than the corresponding unwrapped parthenocarpic fruit when stored at 10ºC for 14 days (Table 19).

Table 19. Changes in external firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 day	14 day	Lsd	7 day	14 day	Lsd
Greenhouse (1st cultivation)							
Seeded fruit							
Unwrapped	2.99 ab	2.56 b	3.13 a*	0.54	2.77 a	3.16 a	0.61
Film	2.99 a	2.98 a	2.54 b	0.30	2.64 a	2.67 a	0.36
Parthenocarpic							
Unwrapped	3.54 a	2.67 b	2.61 b*	0.38	2.55 b	2.64 ab	0.94
Film	3.54 a	3.21 a	2.45 b	0.56	2.72 b	2.60 b	0.58
Open filed cultivation							
Seeded fruit							
Unwrapped	2.90 b	3.11 b	3.08 b	0.56	3.43 ab	3.87 a	0.78
Film	2.90 a	3.14 a	3.10 a	0.39	3.34 a	3.39 a	0.62
Parthenocarpic							
Unwrapped	3.25 a	3.58 a	3.32 a	1.09	3.32 a	3.45 a	0.74
Film	3.25 a	3.42 a	2.84 a	0.81	3.50 a	3.21 a	0.34

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*), while no significant differences between unwrapped and wrapped fruit were detected by the Student t-test (P ≤ 0.05).

Table 20. Changes in external firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 day	20 day	Lsd	10 day	20 day	Lsd
Seeded fruit							
Unwrapped	3.35 ab	3.42 a	3.02 a	0.55	2.86 b	3.56 b	0.49
Film	3.35 a	3.03 ab	2.80 b	0.42	3.37 a	3.04 a	0.60
Parthenocarpic							
Unwrapped	3.81 a	3.12 a	3.28 a	0.87	3.14 a	3.47 a	0.68
Film	3.81 a	3.38 b	3.22 b	0.41	3.12 b	3.00 b	0.52

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). No significant differences were found between seed-containing and parthenocarpic fruit, or between wrapped and unwrapped fruit, according to the Student t-test (P ≤ 0.05).

During storage at 10ºC, the external firmness of fruit of cv. Black Beauty showed a significant increase in unwrapped naturally pollinated fruit on day 14 of the 1st greenhouse

crop and on days 7 and 14 in both wrapped and unwrapped seed-containing fruit from the open field, as well as in unwrapped parthenocarpic fruit from the field (Table 21). At 20ºC, a significant increase in external firmness was detected on days 7 and 14 in unwrapped seed-containing fruit from the 1st greenhouse and open field crops (Table 21), whereas in film-wrapped seed-containing and parthenocarpic fruit of the 2nd greenhouse cultivation a decrease in firmness was observed on day 20 (Table 22). It was also observed that naturally pollinated fruit from the 1st greenhouse and open field cultivations maintained significantly better firmness at 10°C when they were not wrapped with film (day 14) as did unwrapped parthenocarpic and seed-containing fruit from the open field at 10°C and unwrapped seed-containing fruit from the open field at 20°C (Table 21). Between seed-containing and parthenocarpic fruit, a significant difference in firmness .was observed only on day 14 at 20°C in which case the parthenocarpic fruit were less firm than the corresponding seed-containing fruit (Table 21).

Table 21. Changes in external firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 day	14 day	Lsd	7 day	14 day	Lsd
Greenhouse (1st cultivation)							
Seeded fruit							
Unwrapped	3.19 b	3.02 b	4.14 a†	0.74	3.49 a	4.07 a*	0.57
Film	3.19 a	3.68 a	3.63 a†	0.60	3.76 a	3.82 a	0.69
Parthenocarpic							
Unwrapped	3.41 a	3.73 a	3.96 a	0.86	3.65 a	3.32 a*	0.38
Film	3.41 a	3.65 a	3.50 a	0.61	4.03 a	3.47 a	0.67
Open field cultivation							
Seeded fruit							
Unwrapped	3.24 b	4.36 a	4.49 a†	0.79	3.98 a	4.40 a†	0.83
Film	3.24 b	4.14 a	3.91 a†	0.48	3.89 a	3.66 ab†	0.60
Parthenocarpic							
Unwrapped	3.78 c	4.30 b	4.96 a†	0.44	4.41 c	3.66 c	0.94
Film	3.78 a	3.99 a	4.01 a†	0.57	3.88 a	3.82 a	0.73

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test ($P \leq 0.05$).

Table 22. Changes in external firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 day	20 day	Lsd	10 day	20 day	Lsd
Seeded fruit							
Unwrapped	3.67 a	3.42 a	3.80 a	0.92	3.89 a	3.28 a	0.81
Film	3.67 a	3.77 a	3.36 a	0.44	3.77 a	2.68 b	0.70
Parthenocarpic							
Unwrapped	3.92 a	3.79 a	3.92 a	0.88	3.44 a	3.49 a	1.13
Film	3.92 a	3.83 a	3.84 a	0.90	3.91 a	3.09 b	0.56

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05).). No significant differences were found between seed-containing and parthenocarpic fruit, or between wrapped and unwrapped fruit, according to the Student t-test (P ≤ 0.05).

5.3.2.2 Internal firmness

The internal firmness of fruit of eggplant cvs. Tsakoniki and Black Beauty at harvest, measured in the flesh of the central region of the fruit, did not differ (P ≤ 0.05) between seed-containing and parthenocarpic fruit (Tables 23-26).

The internal flesh firmness of Tsakoniki varied with storage time and temperature. In seed-containing fruit, flesh firmness either did not change (unwrapped fruit from the 1st and 2nd greenhouse crops at 10 and 20°C) or increased (wrapped and unwrapped fruit from the open field at 10 and 20°C and wrapped fruit from the 2nd greenhouse crop stored at 20°C) (Tables 23 and 24). In parthenocarpic fruit of cv. Tsakoniki, flesh firmness did not change with storage time at 10 and 20°C (wrapped and unwrapped fruit from the field, wrapped fruit from the 2nd greenhouse crop) or decreased with storage time (wrapped and unwrapped fruit from the 1st greenhouse crop at 10 and 20°C and unwrapped fruit from the 2nd greenhouse crop at 20°C) (Tables 23 and 24). During storage there were no differences in flesh firmness between seed-containing and parthenocarpic fruit, except on day 14 at 10°C in the case of fruit from the 1st greenhouse crop, where the flesh of the seed-containing fruit was firmer than that of the parthenocarpic fruit irrespective of wrapping (Table 23). Similarly, there was no effect of wrapping on flesh firmness, with the exception of seed-containing fruit from the 2nd greenhouse crop in which flesh firmness was higher in film-wrapped fruit than in unwrapped fruit (Table 24).

Table 23. Changes in internal firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 day	14 day	Lsd	7 day	14 day	Lsd
Tsakoniki							
Seeded fruit							
Unwrapped	1.23 a	1.29 a	1.38 a*	0.34	1.39 a	1.43 a	0.18
Film	1.23 b	1.34 ab	1.49 a*	0.23	1.35 ab	1.11 ab	0.21
Parthenocarpic							
Unwrapped	1.42 a	0.90 b	0.94 b*	0.18	1.17 ab	0.93 b	0.37
Film	1.42 b	0.97 a	1.01 a*	0.31	1.00 a	1.07 a	0.29
Seeded fruit							
Unwrapped	1.01 b	1.33 a	1.32 a	0.29	1.34 ab	1.48 a	0.39
Film	1.01 b	1.36 a	1.17 ab	0.21	1.12 b	1.42 a	0.20
Parthenocarpic							
Unwrapped	1.24 a	1.32 a	1.19 a	0.24	1.36 a	1.19 a	0.70
Film	1.24 a	1.34 a	1.05 a	0.34	1.09 a	1.15 a	0.25

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*), while no significant differences were detected between unwrapped and wrapped fruit according to the Student t-test (P ≤ 0.05).

Table 24. Changes in internal firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 day	20 day	Lsd	10 day	20 day	Lsd
Seeded fruit							
Unwrapped	0.97 a	1.40 a	1.18 a	0.43	1.13 a	0.96 a †	0.31
Film	0.97 b	1.03 b	1.15 b	0.29	1.14 ab	1.51 a †	0.41
Parthenocarpic							
Unwrapped	1.22 a	1.22 a	0.82 a	0.55	0.88 ab	0.75 b	0.46
Film	1.22 a	0.94 a	0.97 a	0.30	1.02 a	1.18 a	0.35

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit were not detected, while between wrapped and unwrapped fruit significant differences are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

In general, the internal flesh firmness of cv. Black Beauty, did not significantly change with storage time or temperature, except in the case of film-wrapped seed-containing fruit from the 1st greenhouse crop stored at 10ºC, unwrapped seed-containing

Table 25. Changes of internal firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 day	14 day	Lsd	7 day	14 day	Lsd
Tsakoniki							
Seeded fruit							
Unwrapped	1.15 b	1.56 a	1.67 a	0.24	1.44 b*†	1.36 b	0.26
Film	1.15 b	1.59 a	1.53 a	0.20	1.02 b †	1.49 ab	0.60
Parthenocarpic							
Unwrapped	1.53 ab	1.63 a	1.65 a	0.28	1.82 a*	1.33 b †	0.33
Film	1.53 a	1.82 a	1.69 a	0.55	1.27 b	1.67 a †	0.23
Seeded fruit							
Unwrapped	1.21 b	1.94 a†	1.26 b*†	0.29	1.72 a †	1.25 b*	0.27
Film	1.21 a	1.51 ab†	1.82 a*†	0.46	1.28 a †	1.46 a	0.34
Parthenocarpic							
Unwrapped	1.38 a	1.70 a	1.76 a*	0.42	1.65 ab	1.73 b* †	0.33
Film	1.38 ab	1.52 a	1.38 a*	0.21	1.60 a	1.17 b†	0.36

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

Table 26. Changes in internal firmness (kg) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	0.96 b	0.97 b	1.41 a	0.36	1.19 b	1.72 a*†	0.30
Film	0.96 ab	1.04 a	1.59 a*	0.83	0.85 b	1.13 a †	0.24
Parthenocarpic							
Unwrapped	1.31 a	1.18 a	1.25 a	0.49	1.30 a	0.97 a*	0.45
Film	1.31 a	1.07 ab	0.98 b*	0.33	0.92 a	1.03 a	0.42

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

fruit from the 2nd greenhouse crop at 10 and 20°C, and unwrapped parthenocarpic fruit from the field crop stored at 20°C, where flesh firmness increased with storage time (Tables 26 and 26). In contrast, flesh firmness decreased with storage time in the case of

parthenocarpic fruit from the 2nd greenhouse crop stored for 20 days at 10°C (Table 26). Significant differences were detected between seed-containing and parthenocarpic fruit, but not consistently; for example unwrapped seed-containing fruit from the open field had a lower flesh firmness than parthenocarpic fruit after storage for 14 days at 10 and 20°C (Table 25), whereas in fruits from the 2nd greenhouse crop flesh firmness of the seed-containing fruit was higher (Table 26). Between unwrapped and wrapped fruit, flesh firmness tended to be higher in the former, but to a statistically significant degree mainly towards the end of storage, i.e. 14 days, (Table 25) and 20 days (Table 26).

5.3.3 Weight loss (%)

The weight loss of individual film-wrapped and unwrapped seed-containing and parthenocarpic fruit of cv. Tsakoniki during storage at 10 and 20ºC is shown in Tables 27 and 28. Weight loss of all fruit increased with storage time and tended to be higher at 20°C than at 10°C. Film wrapping significantly reduced weight loss in all cases. No significant differences, however, were detected between seed-containing fruit and parthenocarpic fruit irrespective of storage duration, temperature and treatment (Tables 27 and 28).

Table 27. Weight loss (%) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Storage duration					
	At 10º C temperature			At 20º C temperature		
	7 day	14 day	Lsd	7 day	14 day	Lsd
Greenhouse-1						
Seeded fruit						
Unwrapped	10.79 b†	16.28 a†	5.07	14.81 a†	18.18 a†	5.88
Film	3.79 a†	5.85 a†	2.49	3.72 b†	7.06 a†	1.96
Parthenocarpic						
Unwrapped	14.87 b†	20.95 a†	6.03	13.50 b†	22.35 a†	5.65
Film	3.42 b†	6.49 a†	2.27	4.03 b†	8.23 a†	1.91
Open field						
Seeded fruit						
Unwrapped	12.09 a†	17.70 a†	3.34	12.46 b†	20.31 a†	5.16
Film	3.37 b†	6.27 a†	2.41	3.62 b†	8.07 a†	1.02
Parthenocarpic						
Unwrapped	16.17 b†	20.40 a†	4.06	14.67 a†	20.46 a†	6.54
Film	4.86 b†	6.40 a†	1.33	3.84 b†	8.00 a†	1.30

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between unwrapped and wrapped fruit are indicated by an arrow (†), while no significant differences were detected between the corresponding means of seed-containing and parthenocarpic fruit according to the Student t-test (P ≤ 0.05).

Table 28. Weight loss (%) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Storage duration					
	At 10º C temperature			At 20º C temperature		
	10 day	20 day	Lsd	10 day	20 day	Lsd
Seeded fruit						
Unwrapped	14.99 b†	21.60 a†	5.33	16.36 b†	23.21 a†	3.35
Film	2.68 a†	4.03 a†	2.14	4.66 b†	10.99 a†	3.26
Parthenocarpic						
Unwrapped	10.03 b†	23.61 a†	7.02	14.85 b†	29.53 a†	8.80
Film	4.15 a†	3.84 a†	2.47	6.70 a†	9.28 a†	3.40

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between unwrapped and wrapped fruit are indicated by an arrow (†), while no significant differences were detected between the corresponding means of seed-containing and parthenocarpic fruit according to the Student t-test (P ≤ 0.05).

The weight loss of individual film-wrapped and unwrapped seed-containing and parthenocarpic fruit of cv. Black Beauty during storage at 10 and 20ºC is shown in Tables 29 and 30. Weight loss of all fruit increased with storage time and was higher at 20ºC than at 10ºC. Film wrapping significantly reduced weight loss in all cases, but between seed-containing fruit and parthenocarpic fruit no significant differences were detected irrespective of storage duration, temperature and treatment (Tables 29 and 30).

Table 29. Weight loss (%) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Storage duration					
	At 10º C temperature			At 20º C temperature		
	7 day	14 day	Lsd	7 day	14 day	Lsd
Greenhouse-1						
Seeded fruit						
Unwrapped	11.43 a†	16.55 a†	5.58	14.38 a†	18.24 a†	6.02
Film	2.96 a†	5.22 a†	2.62	3.77 a†	5.65 a†	2.18
Parthenocarpic						
Unwrapped	12.73 a†	16.71 a†	4.29	14.03 a†	18.57 a†	3.67
Film	3.22 a†	3.67 a†	2.39	3.18 a†	5.03 a†	2.13
Open field						
Seeded fruit						
Unwrapped	8.41 b†	15.12 a†	6.62	12.92 a†	19.45 a†	7.32
Film	2.40 a†	4.51 a†	2.16	3.36 a†	5.48 a†	2.62
Parthenocarpic						
Unwrapped	9.67 b†	16.67 a†	6.83	16.66 a†	20.34 a†	8.55
Film	3.36 a†	5.01 a†	2.50	5.15 a†	8.20 a†	3.55

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between unwrapped and wrapped fruit are indicated by an arrow (†), while no significant differences were detected between the corresponding means of seed-containing and parthenocarpic fruit according to the Student t-test (P ≤ 0.05).

Table 30. Weight loss (%) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Storage duration					
	At 10º C temperature			At 20º C temperature		
	10 day	20 day	Lsd	10 day	20 day	Lsd
Seeded fruit						
Unwrapped	17.89 a†	23.42 a†	7.21	18.34 a†	24.61 a†	5.37
Film	2.87 b†	4.80 a†	1.59	3.60 b†	6.72 a†	2.77
Parthenocarpic						
Unwrapped	8.91 a†	14.51 a†	5.06	13.54 b†	26.22 a†	4.58
Film	1.65 b†	4.13 a†	1.52	3.18 b†	5.35 a†	1.85

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between unwrapped and wrapped fruit are indicated by an arrow (†), while no significant differences were detected between the corresponding means of seed-containing and parthenocarpic fruit according to the Student t-test (P ≤ 0.05).

5.3.4 Rate of respiration

The rate of respiration of seed-containing and parthenocarpic fruit of cv. Tsakoniki at harvest was 27.19 and 26.20 ml CO_2 kg^{-1} h^{-1}, respectively, and the difference was statistically insignificant (P ≤ 0.05). During storage, the respiration rate decreased with increasing storage time and the decrease was generally greater at 10ºC than at 20ºC. At 10ºC, the respiration rate decreased by 58-76% in unwrapped seed-containing fruit stored for 20 days, and by 67-72% in unwrapped parthenocarpic fruit (Table 31). Between wrapped and unwrapped fruit there were no significant differences, nor between seed containing and parthenocarpic fruit (Table 31).

Table 31. Rate of respiration (ml CO_2 $kg^{-1}h^{-1}$) of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	27.19 a	11.84 b	6.60 c	4.99	15.78 b	9.33 b	6.26
Film		17.24 b	11.54 b	5.40	21.57 a	12.47 b	8.33
Parthenocarpic							
Unwrapped	26.20 a	12.01 b	7.47 b	5.12	15.36 b	7.57 b	5.37
Film		14.02 b	8.78 c	5.79	19.46 ab	13.45 b	7.12

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). No significant differences were found between seed-containing and parthenocarpic fruit, or between wrapped and unwrapped fruit, according to the Student t-test (P ≤ 0.05).

In Black Beauty, the rate of respiration of seed-containing and parthenocarpic fruit at harvest was 39.55 and 40.25 ml CO_2 kg^{-1} h^{-1}, respectively, which was significantly higher than in cv. Tsakoniki but not affected by the presence or absence of seeds. During storage, the respiration rate decreased with increasing storage time and the decrease was relatively greater at 10°C than at 20°C. At 10ºC, the respiration rate decreased by 74-80% in unwrapped seed-containing fruit stored for 20 days, and by 72-82% in unwrapped parthenocarpic fruit (Table 32). Between wrapped and unwrapped fruit there were no significant differences, nor between seed containing and parthenocarpic fruit (Table 32).

Table 32. Rate of respiration (ml CO_2 $kg^{-1}h^{-1}$) of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	39.55 a	16.72 b	7.92 c	8.22	20.01 b	9.88 c	9.74
Film		24.37 b	14.27 b	9.59	25.96 b	17.65 b	9.25
Parthenocarpic							
Unwrapped	40.25 a	15.93 b	7.42 c	6.60	18.03 b	11.24 b	8.11
Film		20.13 b	11.32 c	8.31	25.31 b	15.77 b	8.87

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05).). No significant differences were found between seed-containing and parthenocarpic fruit, or between wrapped and unwrapped fruit, according to the Student t-test (P ≤ 0.05).

5.3.5 Ascorbic acid content

The ascorbic acid concentration in the fruit of eggplant cvs. Tsakoniki and Black Beauty was measured at harvest and after storage for 7 and 14 days (greenhouse and open field crops of the first cultivation) and 10 and 20 days (for the greenhouse crop of the second cultivation). At harvest, no significant differences were observed in ascorbic acid content between seed-containing and parthenocarpic (seedless) fruit of either cultivar.

During storage, the concentration of ascorbic acid in both unwrapped and film-wrapped fruit (seed-containing and parthenocarpic) of Tsakoniki followed a decreasing trend irrespective of storage temperature (Tables 33 and 34). At 10ºC, the loss of ascorbic acid in unwrapped fruit was significant (P≤ 0.05) after 14 (Table 33) or 20 (Table 34) days in parthenocarpic fruit, but not in fruit that contained seed. On the other hand, the ascorbic acid content of fruit wrapped in film did not decrease significantly during storage at 10ºC.

In general, ascorbic acid losses in film-wrapped seeded and parthenocarpic fruit during storage at 10°C for 20 days did not exceed 14.6% and 15.6%, respectively, but film-wrapped parthenocarpic fruit lost a significantly higher amount of ascorbic acid than wrapped seed-containing fruit by day 14 (Table 33).

Table 33. The ascorbic acid content of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 days	14 days	Lsd	7 days	14 days	Lsd
Greenhouse-1							
Seeded fruit							
Unwrapped	73.82 a	69.25 a	61.11 a*	14.27	58.31 b	45.97 c	10.70
Film		72.51 a	68.00 a	11.62	62.69 ab	53.22 b	17.97
Parthenocarpic							
Unwrapped	67.19 a	65.12 a	47.86 b*	16.41	52.47 b	38.91 b	14.75
Film		67.49 a	59.68 a	14.80	59.12 ab	46.13 b	15.18
Open field							
Seeded fruit							
Unwrapped	78.90 a	75.52 a	67.54 a	11.97	67.17 a	51.77 b*	13.44
Film		77.77 a	74.29 a	18.03	70.37 ab	63.78 b	19.11
Parthenocarpic							
Unwrapped	74.38 a	68.33 a	56.85 a	20.60	54.88 b	36.33 c*†	11.33
Film		72.53 a	66.58 a	13.16	61.44 ab	52.45 b†	14.20

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test ($P \leq 0.05$).

The ascorbic acid concentration in both seed-containing and parthenocarpic fruit of Tsakoiniki decreased significantly during storage at 20ºC regardless of film wrapping (Tables 33 and 34). The content of ascorbic acid in unwrapped seed-containing fruit decreased by 39.58% compared with 53.29% in unwrapped parthenocarpic fruit during 20 days of storage at 20°C (Table 34). In most cases, the differences in ascorbic acid content between unwrapped and film-wrapped fruit were insignificant ($P \leq 0.05$), but parthenocarpic fruit grown in the greenhouse (2nd cultivation) and wrapped in film had a significantly higher ascorbic acid content than the corresponding unwrapped fruit after 20 days storage at 20°C (Table 34).

Table 34. The ascorbic acid content of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	70.24 a	65.50 a	54.06 a	17.11	54.05 a	42.44 b	12.04
Film		68.11 a	59.99 a	14.80	57.73 ab	48.11 b	19.10
Parthenocarpic							
Unwrapped	67.39 a	57.01 ab	48.11 b	16.01	50.81 b	31.48 c†	13.07
Film		62.78 a	56.89 a	12.30	55.56 a	43.75 b†	16.04

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, no significant differences were detected between the means of seed-containing and parthenocarpic fruit, while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

Similar to Tsakoniki, a decrease in ascorbic acid content in Black Beauty was recorded during storage (Table 35 and 36). At 10ºC, the loss of ascorbic acid in both unwrapped and film-wrapped seed-containing fruit from the 1st cultivation (greenhouse and open field) was not significant (P≤0.05), but in unwrapped parthenocarpic fruit from the greenhouse the decrease in ascorbic acid concentration was significantly higher than in the corresponding wrapped fruit (Table 35). In contrast, at 20ºC, both seed-containing and parthenocarpic fruit of Black Beauty from the greenhouse and the open field showed a significant decrease in ascorbic acid concentration (P≤0.05) regardless of storage treatments and duration. Similar results were obtained from the 2nd cultivation in the greenhouse except that after 20 days storage at 10°C both seed-containing and parthenocarpic fruit that were unwrapped showed a greater decrease in ascorbic acid concentration compared with the corresponding wrapped fruit (Table 36). The highest loss of ascorbic acid was recorded in unwrapped parthenocarpic fruit from the greenhouse (both cultivations) stored at 20ºC (Tables 35 and 36). A comparison of treatment means showed that seed-containing unwrapped fruit from the greenhouse contained a significantly higher (P≤0.05) ascorbic acid content than unwrapped parthenocarpic fruit after storage for 14 days at 10ºC (Table 35). In all other cases, there were no significant differences in the ascorbic acid content of seed-containing and parthenocarpic fruit of Black Beauty, irrespective of the storage treatment and temperature as well as the growing conditions (Tables 35 and 36).

Table 35. The ascorbic acid content of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 days	14 days	Lsd	7 days	14 days	Lsd
Greenhouse-1							
Seeded fruit							
Unwrapped	68.34 a	62.28 a	55.84 a*	14.08	48.81 b	37.30 b	11.94
Film		61.76 a	56.91 a	15.92	55.44 ab	46.48 b	18.50
Parthenocarpic							
Unwrapped	63.56 a	52.41 ab	43.63 b*	12.54	45.82 b	31.41 c	12.95
Film		59.09 a	53.83 a	10.19	48.73 a	36.48 b	13.74
Open field							
Seeded fruit							
Unwrapped	74.45 a	67.24 a	59.24 a	19.46	58.78 b	46.86 b	14.07
Film		70.56 a	63.56 a	15.53	67.27 ab	54.75 b	17.75
Parthenocarpic							
Unwrapped	72.13 a	63.30 a	55.22 a	19.33	59.18 a	41.59 b	16.17
Film		68.46 a	60.48 a	10.34	63.02 a	47.40 b	12.43

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P≤0.05). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*). No significant differences were detected between unwrapped and wrapped fruit according to the Student t-test (P ≤ 0.05).

Table 36. The ascorbic acid content of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	63.20 a	56.93 ab	44.06 b	14.41	47.17 b	32.33 c	14.08
Film		60.70 a	50.97 a	15.85	53.12 ab	42.74 b	16.44
Parthenocarpic							
Unwrapped	60.50 a	50.93 ab	40.44 b	15.23	42.61 b	25.05 c	15.93
Film		51.10 a	47.89 a	18.25	47.89 ab	33.85 b	13.67

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, no significant differences were detected between the means of seed-containing and parthenocarpic fruit or between unwrapped and wrapped fruit, according to the Student t-test (P ≤ 0.05).

5.3.6 Protein content

There were no significant differences in protein content at harvest between seed-containing and parthenocarpic eggplant fruit of cvs. Tsakoniki and Black Beauty (Tables 37 and 38). In cv. Tsakoniki, storage at 10ºC did not affect the protein content of wrapped or

unwrapped seed-containing and parthenocarpic fruit irrespective of storage duration (7 and 14 days) and cultivation conditions (greenhouse or open field) (Tables 37 and 38).

Table 37. The protein content of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 days	14 days	Lsd	7 days	14 days	Lsd
Greenhouse-1							
Seeded fruit							
Unwrapped	3.15 a	2.68 a	2.75 a	1.28	2.14 a	2.36 a	1.19
Film		3.21 a	2.61 a	1.13	2.57 a	2.40 a	0.97
Parthenocarpic							
Unwrapped	2.78 a	2.41 a	2.27 a	1.27	2.23 a	2.21 a	1.10
Film		2.62 a	2.26 a	1.24	2.01 a	2.16 a	1.21
Open field							
Seeded fruit							
Unwrapped	3.74 a	2.97 a	2.77 a	1.15	2.20 b	2.37 b	1.00
Film		3.22 a	2.91 a	0.99	2.77 ab	2.08 b	1.20
Parthenocarpic							
Unwrapped	3.05 a	2.53 a	2.60 a	1.19	2.03 a	2.23 a	1.40
Film		2.82 a	2.66 a	1.30	2.18 ab	1.80 b	1.23

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, no significant differences were detected between the means of seed-containing and parthenocarpic fruit or between unwrapped and wrapped fruit, according to the Student t-test (P ≤ 0.05).

At 20ºC, the protein content of unwrapped seed-containing fruit and both wrapped and unwrapped parthenocarpic fruit of cv. Tsakoniki cultivated in the open field decreased significantly during storage (Table 37), but the protein content of greenhouse-grown fruit was not affected by storage at 20°C irrespective of the wrapping treatment and the presence or absence of seeds. Similarly in the 2nd cultivation in the greenhouse, no change in protein content was detected at 10°C, while at 20°C a decrease detected on day 10 may have resulted from experimental error since no decrease was found on day 20 (Table 38). Between seed-containing and parthenocarpic fruit, as well as between wrapping treatments, no significant differences were observed, except in the case of film-wrapped seed-containing and parthenocarpic fruit from the 2nd greenhouse cultivation stored at 20°C (Table 38).

Table 38. The protein content of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	3.55 a	2.62 a	3.17 a	1.11	2.06 b	3.37 a	0.96
Film		3.13 a	3.08 a	1.36	2.35 b	3.06 ab*	1.10
Parthenocarpic							
Unwrapped	2.63 a	2.11 a	2.47 a	1.20	1.74 a	2.56 a	1.25
Film		2.51 a	2.21 a	1.09	2.28 a	2.07 a*	0.78

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*). No significant differences were detected between unwrapped and wrapped fruit according to the Student t-test (P ≤ 0.05).

Data on the protein content of Black Beauty during storage are presented in Tables 39 and 40. Similar to Tsakoniki, the protein content of cv. Black Beauty did not differ significantly (P≤0.005) at 10ºC, regardless of wrapping treatment, storage duration and cultivation conditions (Tables 39 and 40).

Table 39. The protein content of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 days	14 days	Lsd	7 days	14 days	Lsd
Greenhouse-1							
Seeded fruit							
Unwrapped	3.64 a	2.92 a	3.06 a	1.16	2.11 b	2.67 ab	1.02
Film		3.48 a	2.97 a	1.19	2.56 a	2.46 a	1.23
Parthenocarpic							
Unwrapped	3.14 a	2.92 a	3.11 a	1.14	2.43 a	2.23 a	1.11
Film		3.23 a	2.88 a	1.29	2.41 a	2.48 a	1.26
Seeded fruit							
Unwrapped	3.91 a	3.15 a	2.92 a	1.19	2.39 b	2.83 ab	1.23
Film		3.59 a	2.96 a	1.61	2.46 b	2.16 b	1.07
Parthenocarpic							
Unwrapped	3.37 a	2.90 a	3.10 a	1.43	2.21 b	2.38 ab	1.04
Film		3.18 a	2.73 a	1.08	2.37 b	2.07 b	0.94

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, no significant differences were detected between the means of seed-containing and parthenocarpic fruit or between unwrapped and wrapped fruit, according to the Student t-test (P ≤ 0.05).

At 20ºC, the protein content of unwrapped seed-containing fruits tended to fluctuate, showing an initial decrease (at 7 and 10 days) but not later (14 and 20 days). In contrast, film-wrapped fruit from the open field cultivation showed a decrease in protein content at both days 7 and 14 (Table 39) irrespective of the presence or absence of seeds, but not in the 2nd greenhouse cultivation (Table 40). A significant difference in protein content was observed between unwrapped seed-containing and parthenocarpic fruit stored for 20 days at 20ºC (Table 40), but no differences were observed between wrapped and unwrapped fruit, irrespective of storage temperature and duration and the cultivation conditions (Tables 39 and 40).

Table 40. The protein content of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	4.06 a	3.26 a	3.84 a	1.30	2.41 b	3.60 a*	1.16
Film		3.56 a	3.72 a	1.05	2.72 b	3.11 ab	1.04
Parthenocarpic							
Unwrapped	3.65 a	2.85 a	3.26 a	1.12	3.16 ab	2.48 b*	1.01
Film		3.26 a	3.37 a	1.07	2.87 a	2.62 a	1.35

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*). No significant differences were detected between unwrapped and wrapped fruit according to the Student t-test (P ≤ 0.05).

5.3.7 Phenolics content

Changes in the total phenol content of the flesh of fruit of eggplant cv. Tsakoniki are shown in Tables 41 and 42. At harvest, seed-containing fruit tended to have a relatively higher concentration of phenolic compounds than parthenocarpic fruit, but not to a statistically significant degree (P≤0.05). During storage at 10°C, the level of phenolics in unwrapped seed-containing fruit from the 1st greenhouse cultivation increased significantly by day 14 (Table 41). Similarly, at 20°C the total concentration of phenolics increased by day 14 in unwrapped seed-containing and parthenocarpic fruits from the open field cultivation (Table 41). However, in fruits from the 2nd greenhouse cultivation, no differences in phenolics content were detected with time at either storage temperature (Table 42).

Table 41. The total phenolics content of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 days	14 days	Lsd	7 days	14 days	Lsd
Greenhouse-1							
Seeded fruit							
Unwrapped	84.70 b	87.81 b	101.71 a*†	13.83	81.11 b	85.50 b	22.87
Film	84.70 a	79.83 a	68.83 a†	15.74	82.74 a	89.62 a	14.38
Parthenocarpic							
Unwrapped	71.89 a	72.25 a	82.67 a*	16.32	63.60 a	74.31 a	25.33
Film	71.89 a	67.62 a	61.69 a	21.97	73.25 a	69.21 a	19.29
Open field							
Seeded fruit							
Unwrapped	91.76 b	90.72 b	104.13 b*†	17.07	95.46 ab	111.07 a	15.95
Film	91.76 a	82.71 a	81.05 †a	15.61	89.75 a	101.80 a	20.16
Parthenocarpic							
Unwrapped	82.78 b	87.48 b	74.70 b*	27.96	81.84 b	106.60 a	19.89
Film	82.78 a	77.67 a	67.81 a	20.73	84.34 a	93.32 a	17.18

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, significant differences between means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test ($P \leq 0.05$).

Between film-wrapped and unwrapped fruit of Tsakoniki, significantly lower levels of phenolics were detected in the wrapped fruits of seed-containing fruits after 14 days storage at 10°C (Table 41), as well as in the wrapped fruit of both seed-containing and parthenocarpic fruit after 20 days at 10°C (Table 42). Between seed-containing and parthenocarpic fruit, a significantly lower level of phenolics was detected in unwrapped fruit stored at 10°C for 14 days (Table 41) and in wrapped fruit stored at 20°C for 20 days (Table 42).

Fruits of eggplant cv. Black Beauty showed a similar trend in phenolics content to that of Tsakoniki (Table 43 and 44). The flesh of both seed-containing and parthenocarpic fruit stored at 10ºC tended to increase in phenol content with storage time, but only to a statistically significant level after 20 days in the case of film-wrapped seed-containing fruit (Table 44). At 20ºC, fluctuations in phenolics content with storage time were observed without a statistically significant trend (Table 43 and 44). Between the wrapping treatments, it was observed that seed-containing fruit had a relatively higher phenolics content when wrapped and stored for 14 days at 10°C (Table 43), while in the 2nd greenhouse crop the wrapped fruits of both seed-containing and parthenocarpic fruits had a

higher concentration of phenolics than the corresponding unwrapped fruit (Table 44). Between seed-containing and parthenocarpic fruit, a higher phenolics concentration was observed in unwrapped fruits of the former after 10 and 20 days storage at 20°C (Table 44).

Table 42. The total phenolics content of seed-containing and parthenocarpic fruit of eggplant cv. Tsakoniki grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	78.43 a	79.03 a	95.33 a†	17.18	77.83 a	87.99 a	26.16
Film	78.43 a	75.14 a	66.24 a†	26.75	80.02 a	91.86 a*	21.89
Parthenocarpic							
Unwrapped	65.99 a	68.17 a	82.08 a†	22.81	63.21 a	81.21 a	22.38
Film	65.99 a	60.96 a	49.74 a†	24.61	66.50 a	74.95 a*	19.33

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

Table 43. The total phenolics content of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse and open field (1st cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (7 and 14 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		7 days	14 days	Lsd	7 days	14 days	Lsd
Greenhouse-1							
Seeded fruit							
Unwrapped	70.33 ab	74.14 a	87.27 a†	17.57	67.19 b	80.11 a	18.30
Film	70.33 a	64.87 a	51.56 a†	19.20	66.16 a	72.79 a	25.81
Parthenocarpic							
Unwrapped	59.90 a	61.02 a	71.34 a	19.86	56.36 a	65.58 a	19.01
Film	59.90 a	55.55 a	49.72 a	13.49	58.20 a	67.46 a	22.54
Open field							
Seeded fruit							
Unwrapped	79.04 a	83.69 a	96.29 a†	25.23	77.35 a	86.10 a	23.35
Film	79.04 a	73.97 a	60.61 a†	18.99	79.02 a	77.98 a	20.90
Parthenocarpic							
Unwrapped	72.20 a	73.35 a	81.12 a	20.30	64.31 a	77.20 a	29.09
Film	72.20 a	69.46 a	69.48 a	25.10	70.82 a	73.79 a	24.50

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, no significant differences were detected between the means of seed-containing and parthenocarpic fruit, while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

Table 44. The total phenolics content of seed-containing and parthenocarpic fruit of eggplant cv. Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapped), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Seeded fruit							
Unwrapped	63.76 a	65.35 a	76.88 a†	21.46	57.43 a*	72.42 a*	17.36
Film	63.76 a	59.73 ab	47.34 b†	15.77	62.77 a	69.99 a	21.99
Parthenocarpic							
Unwrapped	51.40 ab	52.69 a	64.31 a†	13.62	38.10 b*	58.31 a*	17.08
Film	51.40 a	48.74 a	43.42 a†	17.37	45.10 a	50.82 a	18.47

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). Within each column, significant differences between the means of seed-containing and parthenocarpic fruit are indicated by an asterisk (*) while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test (P ≤ 0.05).

5.3.8 Anthocyanin content

The results presented in Table 45 show no significant variation (P≤0.05) in anthocyanin concentrations between naturally pollinated and parthenocarpic eggplant fruit of cvs. Tsakoniki and Black Beauty. The anthocyanin levels in both cultivars tended to decline during 20 days of storage, but only to a statistically significant degree in the case of parthenocarpic fruit of Tsakoniki, irrespective of wrapping (Table 45). No statistically significant differences were detected in the anthocyanin content of seed-containing and parthenocarpic fruit of either cultivar, or between wrapped and unwrapped fruit, with the exception of parthenocarpic fruit of Tsakoniki stored for 20 days at 20ºC in which the anthocyanin content of the wrapped fruit was higher than that of the unwrapped fruit (Table 45).

Table 45. The anthocyanin content of the skin of seed-containing and parthenocarpic eggplant fruit of cvs. Tsakoniki and Black Beauty grown in the greenhouse (2nd cultivation) in relation to storage treatment (unwrapped and film wrapping), temperature (10 and 20ºC) and duration (10 and 20 days).

Treatments	Before storage	Storage duration					
		At 10º C temperature			At 20º C temperature		
		10 days	20 days	Lsd	10 days	20 days	Lsd
Tsakoniki							
Seeded fruit							
Unwrapped	3.28 a (a)	2.53 a	2.39 a	1.26	2.43 a	2.09 a	1.21
Film		3.17 a	2.85 a	1.74	2.95 a	2.50 a	1.54
Parthenocarpic							
Unwrapped	3.74 a (a)	2.92 ab	2.07 b	1.61	2.24 b	1.36 b†	1.39
Film		3.80 a	3.49 a	2.31	2.83 ab	2.37 b†	1.05
Black Beauty							
Seeded fruit							
Unwrapped	18.07 a (a)	17.68 a	15.87 a	6.5	16.30 a	13.87 a	4.58
Film		18.72 a	17.92 a	4.74	16.02 a	15.29 a	3.32
Parthenocarpic							
Unwrapped	19.10 a (a)	18.68 a	15.27 a	4.70	16.72 a	13.18 a	5.53
Film		19.15 a	17.62 a	5.90	17.64 a	15.99 a	5.09

In each row, means followed by the same letters for each temperature separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, no significant differences were detected between the means of seed-containing and parthenocarpic fruit, while significant differences between unwrapped and wrapped fruit are indicated by an arrow (†) according to the Student t-test ($P \leq 0.05$).

5.4 Discussion

Colour and texture are two major factors in determining the freshness and quality of marketable fruits and vegetables (Ryall and Lipton, 1979). The present results indicate that the changes in pericarp colour (expressed as changes in L, C* and Hº) of both eggplant cultivars were variable in respect of storage treatment, duration and temperature. In most cases, the L value of both naturally pollinated and parthenocarpic fruit of Tsakoniki and Black Beauty were unaffected by storage treatments. A decreasing tendency in C* value was observed in Tsakoniki during storage, suggesting a reduction in red colour intensity), whilst in Black Beauty an increasing trend of C* value was observed during storage. With respect to Hº, the changes observed during storage were slight and mostly negligible. The relatively small colour change in the present results may be considered a positive result, important for eggplant shelf-life, since it indicates that the fruit colour at harvest is largely retained throughout storage irrespective of the presence or absence of seeds and the storage temperature. Although no significant differences in colour change between wrapped and unwrapped fruit were observed, the high rate of water (weight) loss of unwrapped fruit

quickly rendered them unmarketable (within about 7 days). In other studies film-wrapping has been shown to effectively maintain the colour of peppers (Miller *et al.,* 1983) and tomatoes (Risse *et al*., 1984), while according to Thanopoulos (2012) parthenocarpic peppers have less green colour at the mature green stage of development and more red at the fully ripe stage than seed-containing fruit. Parthenocarpic peppers, however, are much smaller in size than seed-containing peppers (which is not the case in eggplant), and this results in greater weight loss in the former and concomitant changes in colour during storage (Thanopoulos, 2012).

Changes in external and internal firmness of seed-containing and parthenocarpic eggplant fruit of both cultivars showed a similar pattern over the storage period. The present results showed that in most cases seed-containing and parthenocarpic fruit from all crops maintained firmness (external and internal) throughout the storage period irrespective of film-wrapping and storage temperature, the main difference between cultivars occurring in fruit from the open field. (Tables 19 and 21) where the firmness of Black Beauty (particularly seed-containing fruit) significantly increased during storage at both 10 and 20^{o}C, whereas that of Tsakoniki was essentially unchanged. Maintenance of firmness by enclosure of the fruit in plastic was reported for eggplant (Risse and Miller, 1983), pepper (Ben-Yehoshua *et al.,* 1983; Miller *et al.*, 1983) and cucumber (Dhall *et al.,* 2010). From the present experiment, however, it is clear that the maintenance of firmness in eggplant occurred in both wrapped and unwrapped fruit and irrespective of the amount of water (weight) lost. The slightly higher (but mainly insignificant) values for firmness recorded in film-wrapped eggplant fruit may result from higher turgidity of the fruit, whereas unwrapped fruit become more pliable as they lose water. Jha and Matsuoka (2002) also noted shrinkage of eggplant during storage, leading subsequently to sponginess and wrinkling (Ryall and Lipton, 1979). In either case the force required to penetrate the skin or flesh was similar, but the higher water (weight) loss of unwrapped fruit makes them unmarketable even within 7 days of storage.

Most fresh fruit and vegetable commodities become unmarketable after losing 3-10% of their initial fresh weight (Ben-Yehoshua and Rodov, 2003). In the present study, both seed-containing and parthenocarpic fruit of Tsakoniki and Black Beauty rapidly lost weight regardless of storage temperature when they were stored in an unwrapped condition, even though the RH of the storage atmosphere was relatively high (80 ± 5%). Film-wrapping significantly reduced the rate of weight loss in both cultivars, as reported previously for eggplant (Risse *et al.,* 1985; Diaz-Perez, 1998; Pahlevi *et al.,* 2009) and

tomato (Risse *et al.,* 1985). From the present results, it may be concluded that unwrapped fruit of cv. Tsakoniki become unmarketable within 7 days of storage at 10 or 20^{o}C (weight loss10-16%), irrespective of the presence or absence of seeds (Tables 27 and 28), whereas wrapped seed-containing and parthenocarpic fruit of this cultivar may be stored satisfactorily for at least 14 days at 10^{o}C (maximum weight loss <6.5%) or 20^{o}C [maximum weight loss <8.5% (Table 27) but rather high (9-11%) in fruit from the second greenhouse crop (Table 28)]. Similarly, while unwrapped fruit of cv. Black Beauty are only marginally marketable after 7 days of storage at 10^{o}C, where with one exception (18%) weight loss was 8-11% in seed-containing fruit and 9-13% in parthenocarpic fruit, unwrapped fruit stored at 20^{o}C were unmarketable after 7 days since weight loss ranged from 12-18% irrespective of the presence or absence of seeds (Tables 29 and 30). In contrast, wrapped seed-containing and parthenocarpic fruit of Black Beauty may be stored satisfactorily for at least 14 days at 10^{o}C (maximum weight loss <5.2%) or 20^{o}C (maximum weight loss <8.2%). The relatively lower rate of weight loss in Black Beauty (oval fruit) compared with Tsakoniki (elongate fruit) presumably related to the lower surface area in relation to fruit volume in the former (Passam and Karapanos, 2008).

The rate of respiration is another factor that influences fruit quality during storage (Ryall and Lipton, 1979). The respiration rate of eggplant fruit after harvest is approximately 30-40 ml CO_2 kg^{-1} h^{-1} at 12.5^{o}C (Siller-Cepeda, 2004), but apparently differs between cultivars since the initial rate of respiration of Black Beauty (Table 32) was significantly higher than that of Tsakoniki (Table 31). The respiration rate was similar for seed-containing and parthenocarpic fruit of both cultivars, and decreased with storage time at both 10 and 20^{o}C, as is the case in most non-climacteric fruit (Kays1991). Although the respiration rate of wrapped fruit tended to be higher than that of unwrapped fruit, the differences were not statistically significant and probably resulted from an accumulation of CO_2 within the enclosed fruit during storage and release of this CO_2 after the film was removed for respiration measurements. Similarly, D'Aquino *et al.* (1997) observed an apparently higher respiratory rate in Satsuma when fruit were wrapped in plastic film and respiration measured after film removal (in comparison with fruit that was stored unwrapped), whereas in grapefruit and lemons the respiratory rate was lower in wrapped fruit than in unwrapped fruit when measured without removal of the plastic film (Ben Yehoshua, 1978; Eaks, 1990).

The results of the present study showed that the ascorbic acid concentration in both seed-containing and parthenocarpic fruit of cvs. Tsakoniki and Black Beauty progressively

decreased with increasing storage time at both 10 and 20°C, but mostly to a statistically significant degree only at the higher temperature. Similarly, losses of ascorbic acid during storage were reported for a number of fruits and vegetables (Koksal, 1989; Hussein *et al.,* 2000; Arvanitoyannis *et al.,* 2005) including eggplant (Esteban *et al.,* 1989), and is believed to result from enzyme-mediated oxidation of ascorbic acid (Lee and Kader, 2000). In contrast, Toor and Savage (2006) reported a slight increase in ascorbic acid in tomatoes stored at 7, 15 and 25ºC for 10 days, and Kalt *et al.* (1999) observed no losses in ascorbic acid during postharvest storage of strawberry and blueberry. Film-wrapping tended to delay ascorbic acid loss, possibly by reducing the rate of ascorbate oxidation, but generally not to a statistically significant level. In apple, Kropp and Ben (1985) reported a higher ascorbic acid content of fruit when stored after wrapping with different packaging materials.

The protein content of both unwrapped and film-wrapped eggplant fruit (seed-containing and parthenocarpic) fluctuated over the storage period and did not follow a definite trend. Overall, there was no effect of wrapping on protein content, but seed-containing fruit appeared to have a higher protein content than parthenocarpic fruit after 20 days storage at 20°C. According to Esteban *et al.* (1989), eggplant fruit stored in film-wrapped trays exhibited a reduction in protein content at both 10 and 20ºC until the 12th day of storage, followed by an increase until day 20, but the results of the present study do not confirm this pattern.

It has been demonstrated in several systems that phenylalanine ammonia-lyase (PAL) is involved in the biosynthesis of phenols during low temperature storage (Kozukue *et al.,* 1979). In the present study, a significant accumulation of phenols with storage time was detected only in unwrapped fruits of Tsakoniki from the 1st greenhouse crop (Table 35) stored for14 days at 10ºC. According to Massoloa *et al.* (2011) a higher phenolic content of eggplant fruit stored at 10ºC results from increased activity of the PAL enzyme. More significant in our experiment, however, was the fact that at 10ºC wrapping in film significantly reduced the phenolics concentration of both seed-containing and parthenocarpic fruit of cvs. Tsakoniki and Black Beauty. Moreover, in some cases, parthenocarpic fruit exhibited a lower phenolics level than seed-containing fruit. Reduced phenolics levels may be regarded as a positive quality trait because the fruit will have a lower tendency to brown during slicing and processing. Gajewski *et al*. (2009) reported that the total phenol content of greenhouse grown eggplant cvs. Scorpio, Oscar, Tango and DRA 2086 was not affected by wrapping in stretch film; therefore the semi-permeable

polyethylene used in the present experiment may be superior to stretch film for eggplant storage.

The stability of anthocyanins during storage largely depends on the storage temperature because high temperatures accelerate the destruction of anthocyanin pigments (Patras *et al.,* 2010). In the present study, anthocyanin concentrations within the skin of eggplant cvs. Tsakoniki and Black Beauty tended to decrease during storage, but generally not to a statistically significant level. Wrapping fruit in film slowed down the loss of anthocyanins, but only to a significant degree in parthenocarpic fruit of cv. Tsakoniki stored at 20^{o}C for 20 days (Table 39). The loss of anthocyanins could be due to moisture loss, which causes a disruption of cellular compartmentalization and accelerates enzymatic activity. For example, Concellon *et al.* (2007) reported a variable, temperature-dependent decrease in anthocyanins in the fruit of eggplant fruit cv. Money Maker-2 when stored at 10ºC for up to 15 days. The anthocyanin content also varied with the position on the fruit at which measurement was made. The present study suggests that the rate of reduction in the anthocyanin content of eggplant cvs. Tsakoniki and Black Beauty is largely independent of the presence or absence of seeds in the fruit and the wrapping treatment. In other species, e.g. litchi, film wrapping effectively prevented the destruction of anthocyanin pigments (Somboonkaew and Terry, 2010), but the fact that in eggplant a statistically significant effect of wrapping was only detected at 20^{o}C on day 20 suggests that maybe the anthocyanins within the skin of eggplant are more stable than those in litchi and that for a significant effect of other factors on anthocyanin loss to be seen a longer storage period or other storage conditions may be required.

CHAPTER 6

The effects of controlled atmosphere storage on the postharvest quality of eggplant

6.1 Introduction

Harvested fruits are living organs and continue to respire and lose moisture due to transpiration during storage (Ryall and Lipton, 1979; Kays, 1991; Burdon, 1997). Other ongoing metabolic processes in the fruit during storage can lead to detrimental fruit quality, especially when the fruit is kept under sub-optimal conditions (Burdon, 1997). Eggplant is a non-climacteric fruit since no ripening occurs after harvest and stored eggplant fruit do not produce CO_2 and ethylene peaks during maturation, as occurs in climacteric fruit (Cantwell and Suslow, 1999). Storing fruits or vegetables in controlled atmospheres (CA) enriched with high CO_2 and/or utilizing low O_2 levels can be a very beneficial tool for maintaining product quality and extending shelf-life. The main effects of CA are reduced respiration and ethylene production, leading to delayed ripening or senescence, reduced weight loss, and prolonged shelf-life (Kader *et al.,* 1989; Kays 1991). The commercial application of this technique has shown considerable promise and is expanding rapidly. Although, Kaynas *et al.* (1995) demonstrated some benefits of CA technology for the extension of eggplant shelf life, its commercial application has been questioned (Ryall and Lipton, 1979; Lawande and Chavan, 1998) and its application to parthenocarpic eggplant fruit has not been reported. Thus, the aim of this study was to investigate the physiological and biochemical changes in naturally pollinated and parthenocarpic eggplant fruit during CA storage under different atmospheres.

6.2 Materials and methods

For the controlled atmosphere (CA) storage experiment, 40 plants each of two eggplant cvs. Tsakoniki and Black Beauty were grown in the greenhouse. Seeds were sown on 7 February, 2011 and fruit set either by natural pollination or by spraying the flowers at anthesis with β-NOA (60 ppm). Details of the crop husbandry are presented in Chapter 2. Both pollinated and parthenocarpic fruit were harvested at 25 days after anthesis and pre-cooled for 4 h at room temperature (20 ± 2º C) before applying storage treatments. In all cases, 5 well-developed, uniformly sized, and injury-free fruits were selected for each treatment combination.

Three gas compositions were used in this study viz., 3% O_2 + 3% CO_2 (CA_1), 10% O_2 + 3% CO_2 (CA_2) and 21% O_2 + 0.035% CO_2 (CA_3). The balance in all CA treatments was made up with N_2. Higher CO_2 concentrations were not employed since these may be injurious for the fruit (Lawande and Chavan, 1998). The CA gas mixtures were prepared using a system (PBI Dansensor, Denmark) of pressure regulators, manifolds, and needle-valve flow-meters to blend O_2, N_2 and CO_2 from pressurized cylinders. The system was connected with a packaging system (MP Tec. Srl., Italy) in which individual fruits were instantly sealed in impermeable plastic bags (535 ml volume) containing the gas mixture. The fruits were then stored at 10ºC in a storage cabinet (Lovibond, Germany) for 20 days. The gas composition within the plastic bags was monitored daily using a headspace gas analyzer (PBI Dansensor, Denmark). The analyzer was calibrated using N_2, O_2 and CO_2 standards. Gas mixtures were changed in the bags every 2 days so as to maintain a constant gas mixture for each CA treatment. The physiological changes of eggplant fruits during CA storage, evaluated after 20 days of storage, were: weight loss (%), skin colour, ascorbic acid, protein, total phenolics and anthocyanin content, the browning potential of the flesh, the sugar and starch content, the respiration and ethylene production rate. The relevant methods for each parameter are described in Chapter 2.

6.3 Results

In the present study, both naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of Tsakoniki and Black Beauty were monitored every day. Decay symptoms were observed in the fruit of Tsakoniki after 9 days and in Black Beauty after 7 days of storage, respectively in treatment CA_1, and for this reason the results for this treatment are not presented here. Decay symptoms were not observed in the other two treatments.

6.3.1 Pericarp colour

The results presented in Table 46 show that the lightness (L) of the proximal region of the pericarp of both naturally pollinated and parthenocarpic fruit of Tsakoniki increased during storage in both CA_2 and CA_3 treatments, while in the central region of the pericarp a decreasing trend was detected. No significant differences in ΔL were detected between the two storage treatments (CA_2 and CA_3). Chroma (C*) value in both the central and proximal regions of the fruit decreased during storage, indicating a decrease in red colour

intensity, but without significant differences in ΔC between treatments (CA_2 and CA_3) (Table 46). The hue angle (Hº) tended to increase in both regions of naturally pollinated fruit stored in 21% O_2 + 0.035% CO_2 (CA_3), and in the central region of the fruit this increase was significantly higher in CA_3 than CA_2 and also higher in seed-containing fruit compared with parthenocarpic fruit. Generally, ΔH in both regions of the parthenocarpic fruit showed a slight decrease, but with no differences between treatments.

Table 46. Changes in colour attributes (L, C* and Hº) of the pericarp of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cv. Tsakoniki in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Changes in colour attributes					
	Proximal region			Central region		
	ΔL	ΔC	ΔH	ΔL	ΔC	ΔH
Seed-containing						
CA_2	0.52 a	-1.55 a	0.06 a	-0.33 a	-2.33 a	-0.01 b
CA_3	0.68 a	-2.11 a	0.12 a	0.36 a	-1.06 a	0.15 a*
Lsd	2.64	2.01	0.12	6.97	1.86	0.09
Parthenocarpic						
CA_2	0.99 a	-1.61 a	-0.06 a	-0.35 a	-1.20 a	-0.01 a
CA_3	0.76 a	-0.74 a	-0.07 a	-0.47 a	0.28 a	-0.06 a*
Lsd	2.41	3.44	0.33	3.22	2.02	0.25

In each column, means of treatments CA_2 and CA_3 of seed-containing and parthenocarpic fruit separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, significant differences according to the Student t-test ($P \leq 0.05$) between seed-containing and parthenocarpic fruit are indicated by an asterisk (*).

In Black Beauty the L value of both regions of the pericarp (proximal and central) tended to decrease slightly, but with no significant differences in ΔL between CA_2 and CA_3, or between seed-containing and parthenocarpic fruit (Table 47). In the proximal region of the fruit a small increase in C* was observed (except in parthenocarpic fruit in treatment CA_2), but without significant differences between treatments or between seed-containing and parthenocarpic fruit (Table 47). In contrast, ΔC in the central pericarp of the fruit tended to decrease (except in parthenocarpic fruit in treatment CA_3), but without significant differences between treatments or between seed-containing and parthenocarpic fruit (Table 47). In both regions of the pericarp, the value of Hº remained virtually unchanged during storage irrespective of treatment and the presence or absence of seeds within the fruit, notwithstanding a slight, but significant, increase in ΔH in treatment CA_2 of seed-containing fruit compared with CA_3.

Table 47. Changes in colour attributes (L, C* and Hº) of the pericarp of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cv. Black Beauty in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Changes in colour attributes					
	Proximal region			Central region		
	ΔL	ΔC	ΔH	ΔL	ΔC	ΔH
Seed-containing						
CA_2	-0.10 a	0.79 a	0.08 a	-0.32 a	-0.55 a	0.05 b
CA_3	-0.17 a	0.36 a	-0.01 b	0.29 a	-0.06 a	-0.01 a
Lsd	2.21	0.88	0.05	1.87	1.93	0.06
Parthenocarpic						
CA_2	-1.32 a	-0.10 a	0.07 a	-0.80 a	-1.25 a	-0.11 a
CA_3	-0.66 a	0.96 a	-0.02 a	-0.37 a	0.98 a	0.01 a
Lsd	2.06	1.23	0.11	2.70	4.44	0.52

In each column, means of treatments CA_2 and CA_3 of seed-containing and parthenocarpic fruit separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). No significant differences were found between seed-containing and parthenocarpic fruit for CA_2 and CA_3 storage, according to the Student t-test ($P \leq 0.05$).

6.3.2 Calyx colour

Discolouration of the calyx of eggplant fruit during CA storage was monitored by the changes in colour parameters L (lightness) and a* (green). In all cases, irrespective of treatment and the presence or absence of seeds, a decrease in lightness (L) of the calyx was observed in fruits of both Tsakoniki and Black Beauty after 20 days of storage (Table 48). Between treatments no statistically significant differences were detected, while between seed-containing and parthenocarpic fruit of Black Beauty the decrease in ΔL was higher in the parthenocarpic fruit stored in 21% O_2 and 0.035% CO_2 (treatment CA_3).

The results showed that in both CA_2 and CA_3 storage, the calyx of naturally pollinated and parthenocarpic fruit of Tsakoniki and Black Beauty became lighter green which corresponded to an increase in the value of a (Table 48). In Tsakoniki, the increase in a value was higher in naturally pollinated fruit than in parthenocarpic fruit, while in Black Beauty, no significant differences were observed in the changes of a value (Δa) between naturally pollinated and parthenocarpic fruit in either controlled atmosphere (Table 48). It was also observed that the changes of a value (Δa) were higher in naturally pollinated fruit of Tsakoniki when they were stored in CA_2 than in CA_3.

Table 48. Changes in colour of the calyx of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Changes in colour attributes			
	Tsakoniki		Black Beauty	
	ΔL	Δa*	ΔL	Δa*
Seed-containing				
CA_2	3.61 a	7.64 a*	1.64 a	4.87 a
CA_3	3.18 a	4.10 b*	2.85 a*	2.52 a*
Lsd	9.09	3.43	6.50	4.95
Parthenocarpic				
CA_2	0.74 a	1.28 a*	2.93 a	3.29 a
CA_3	1.40 a	2.17 a*	4.75 a*	6.89 a*
Lsd	2.65	1.87	4.54	3.98

In each column, means of treatments CA_2 and CA_3 of seed-containing and parthenocarpic fruit separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, significant differences according to the Student t-test ($P \leq 0.05$) between seed-containing and parthenocarpic fruit are indicated by an asterisk (*).

6.3.3 Firmness

At harvest, both external and internal firmness of parthenocarpic fruit was comparatively higher than that of fruit set by natural pollination, although the difference was not statistically significant ($P \leq 0.05$). In Tsakoniki, the external firmness of both seed-containing and parthenocarpic fruit decreased significantly during storage irrespective of CA treatment, while in Black Beauty a significant reduction in external firmness was only detected in parthenocarpic fruit stored in 21%O_2 + 0.035% CO_2 (Table 49). The parthenocarpic fruit of Tsakoniki were firmer than the corresponding seed-containing fruit in both storage treatments, whereas in Black Beauty differences between seed-containing and parthenocarpic fruit were not found, irrespective of storage treatment. The internal flesh firmness of both cultivars did not change during storage, irrespective of the storage treatment, with the exception of Tsakoniki stored in treatment CA_3, where flesh firmness increased significantly compared with that of the fruit at harvest (Table 49).

Table 49. Changes in the external and internal firmness of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty at harvest and in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	External firmness (kg)			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
At harvest	3.34 a	3.81 a	3.67 a	3.92 a
CA_2	2.76 b*	3.24 b*	3.56 a	4.01 a
CA_3	2.73 b*	3.85 a*	3.44 a	3.12 b
Lsd	0.39	0.42	0.63	0.45
	Internal firmness (kg)			
At harvest	0.97 b	1.22 a	0.96 a	1.31 a
CA_2	1.17 ab	1.24 a	1.07 a	1.36 a
CA_3	1.22 a	1.09 a	1.02 a	1.15 a
Lsd	0.21	0.37	0.13	0.44

In each column, means of treatments CA_2 and CA_3 of seed-containing and parthenocarpic fruit separately followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each row, significant differences according to the Student t-test ($P \leq 0.05$) between seed-containing and parthenocarpic fruit are indicated by an asterisk (*).

6.3.4 Weight loss (%)

In general, fruit of Tsakoniki lost 1.5 to 2 times more weight than that of Black Beauty regardless of CA treatments (Table 50). No statistically significant differences in weight loss were detected between treatments CA_2 and CA_3 or between seed-containing and parthenocarpic fruit in each cultivar.

The relative contribution of the calyx and the pericarp to the total weight loss of parthenocarpic fruit of both cultivars was determined by selective enclosure in polyethylene film and storage for 20 days at 10ºC. Three treatments were applied: (a) whole fruit wrapped with film, (b) fruit with only the pericarp wrapped, and (c) fruit with only the calyx wrapped calyx. Figure 35 shows the relative weight loss of eggplant fruit per day for the 3 treatments. . In both cultivars fruit weight loss (i.e. water loss) increased with time and was higher through the calyx than through the pericarp or via the whole fruit enclosed in film. In Tsakoniki, 50% of total weight loss via the calyx occurred by day 7 and by the end of storage over 20% of total weight loss occurred in fruit with the calyx exposed, compared with 6% in fruit where only the pericarp was exposed. A similar pattern of weight loss was observed in Black Beauty (Fig. 35). At the end of storage, Black

Beauty fruits showed a maximum weight loss of 17.89% through the calyx and 6.33% through the pericarp, compared with 3.46% in fruit entirely enclosed in film.

Table 50. Weight loss of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Weight loss (%)			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
CA_2	5.71 a	5.30 a	3.33 a	2.89 a
CA_3	4.88 a	6.07 a	3.85 a	3.16 a
Lsd	1.84	3.41	1.01	1.77

In each column, means followed by the same letters are not significantly different according to Fisher's least significant difference test (P ≤ 0.05). No significant differences were found between seed-containing and parthenocarpic fruit of either cultivar, according to the Student t-test (P ≤ 0.05).

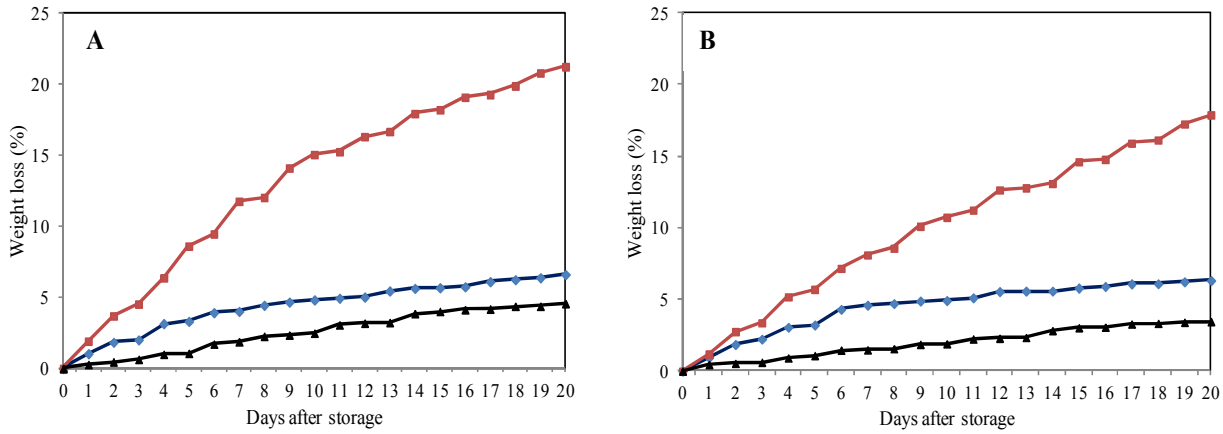

Fig. 35. Relative weight loss (%) of fruit through the calyx (■) and pericarp (♦) in comparison with that in whole fruit wrapped with film (▲): Tsakoniki (A) and Black Beauty (B) during storage at 10ºC for 20 days.

6.3.5 Rate of respiration

At harvest, the rate of CO_2 production of Black Beauty (39-40 ml CO_2 kg^{-1} h^{-1} measured at 20°C) was higher than that of Tsakoniki (26-27 ml CO_2 kg^{-1} h^{-1} at 20°C), but between seed-containing and parthenocarpic fruit of each cultivar there was no significant difference (P ≤ 0.05). During storage at 10°C, the respiration rate of fruit decreased, and when measured at 10°C at the end of storage (20 days) was 14-25 ml CO_2 kg^{-1} h^{-1} (Black Beauty) and 14-21 ml CO_2 kg^{-1} h^{-1} (Tsakoniki) (Table 51). In Tsakoniki, the respiration rate of seed-containing

and parthenocarpic fruit did not differ between storage treatments (CA_2 and CA_3) (Table 51), but in Black Beauty the respiration rate was significantly higher in treatment CA_2 than in CA_3 irrespective of the presence or absence of seeds (Table 51).

Table 51. Respiration of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty at harvest and in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC. Respiration was measured at 20ºC.

Treatments	Respiration (ml CO_2 kg^{-1} h^{-1})			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
At harvest	27.19 a	26.02 a	39.55 a	40.24 a
CA_2	19.51 b	21.04 ab	25.02 b	24.33 b
CA_3	15.57 b	14.49 b	14.60 c	16.28 c
Lsd	5.84	6.95	8.16	7.08

In each column, means followed by the same letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). No significant differences were found between seed-containing and parthenocarpic fruit of either cultivar, according to the Student t-test ($P \leq 0.05$).

6.3.6 Ethylene production

Eggplant is considered to be a non-climacteric fruit and therefore produces a low level of ethylene after harvest. The present experiment showed that the ethylene production of both cultivars stored in CA_2 and CA_3 at 10ºC was below the detection limit.

6.3.7 Ascorbic acid content

At harvest, the ascorbic acid content of fruit ranged from 60-70 mg 100 g^{-1} f.w. without significant differences between cultivars or between seed-containing and parthenocarpic fruit (Table 52). During storage the ascorbic acid content of all fruit decreased, but to a statistically significant degree only in the parthenocarpic fruit of both cultivars (Table 52). Between storage treatments, no significant differences in ascorbic acid levels were observed irrespective of the presence or absence of seeds (Table 52). Seed-containing fruit tended to retain a higher concentration of ascorbic acid than parthenocarpic fruit, but to a statistically significant level only in Black Beauty stored in CA_2 (Table 52).

Table 52. The ascorbic acid content of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty at harvest and in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Ascorbic acid (mg 100 g^{-1} f.w.)			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
At harvest	69.72 a	68.11 a	64.75 a	59.91 a
CA_2	59.43 a	54.22 ab	56.91 a*	45.64 b*
CA_3	60.71 a	48.64 b	55.40 a	42.67 b
Lsd	16.02	14.26	15.51	9.26

In each column, means followed by the same letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each row, significant differences between seed-containing and parthenocarpic fruit of each cultivar separately according to the Student t-test ($P \leq 0.05$) are indicated by an asterisk (*).

6.3.8 Protein content

The protein content of fruit of both cultivars ranged between 2.6 and 4.1 mg g^{-1} f.w. at harvest and was not affected during storage by the storage treatment or the presence or absence of seeds (Table 53). In most cases, the protein content of parthenocarpic fruit tended to be lower than that of the corresponding seed-containing fruit, but not to a statistically significant degree (Table 53).

Table 53. The protein content of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty at harvest and in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Protein (mg g^{-1} f.w.)			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
At harvest	3.55 a	2.63 a	4.06 a	3.65 a
CA_2	3.32 a	2.25 a	3.72 a	3.41 a
CA_3	2.72 a	2.37 a	4.11 a	3.06 a
Lsd	1.80	1.29	1.76	1.58

In each column, means followed by the same letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). No significant differences were found between seed-containing and parthenocarpic fruit of either cultivar, according to the Student t-test ($P \leq 0.05$).

6.3.9 Phenolics content

The results showed that storage in both CA_2 and CA_3 did not significantly affect the total phenolics content of the flesh of naturally pollinated and parthenocarpic fruit of Tsakoniki and Black Beauty, although a decrease in total phenols was detected at the end of storage (Table 54). In both cultivars, CA_2 retained phenolics better than CA_3; however, the variation remained non-significant ($P \leq 0.05$). In addition, no variation was observed in total phenols between naturally pollinated and parthenocarpic fruit irrespective of CA storage treatments.

Table 54. The total phenolics content of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Phenol (mg GAE 100 g^{-1} f.w.)			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
At harvest	78.44 a	65.98 a	63.76 a	51.40 a
CA_2	69.09 a	59.37 a	56.15 a	47.13 a
CA_3	63.18 a	60.71 a	56.66 a	40.58 a
Lsd	20.39	22.47	20.76	16.75

In each column, means followed by the same letters for each cultivar separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). No significant differences were found between seed-containing and parthenocarpic fruit of either cultivar, according to the Student t-test ($P \leq 0.05$).

6.3.10 Anthocyanin content

The concentration of anthocyanin in the skin of fruit of Black Beauty was about 4 times higher than that in Tsakoniki (as noted previously in Chapter 4) and not affected by either controlled atmosphere condition (Table 55). The anthocyanin content did not change significantly during storage and was unaffected by the storage treatment or the presence or absence of seeds within the fruit (Table 55).

6.3.11 Starch content

No significant difference ($P \leq 0.05$) in starch content was observed between seed-containing and parthenocarpic fruit of Tsakoniki and Black Beauty either at harvest or at the end of storage, regardless of the storage treatment (Table 58). However, during storage, the level of starch decreased considerably in all treatments except in the seed-containing fruit of Black Beauty (Table 58). In Tsakoniki, starch content in the seed-containing fruit

did not differ among the storage treatments, whereas in parthenocarpic fruit stored in CA_2 the starch concentration after storage was higher than in CA_3. Similarly, the starch content of parthenocarpic fruit of Black Beauty did not differ among the storage treatments (Table 58).

Table 55. The anthocyanin content of naturally pollinated (seed-containing) and parthenocarpic (seedless) fruit of eggplant cvs. Tsakoniki and Black Beauty in relation to storage treatment: CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 and 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Anthocyanin (mg l^{-1} d.w.)			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
At harvest	3.28 a	3.73 a	18.07 a	19.10 a
CA_2	3.64 a	3.43 a	16.01 a	17.42 a
CA_3	2.74 a	3.10 a	17.59 a	16.34 a
Lsd	1.24	1.71	5.65	5.26

In each column, means followed by the same letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). No significant differences were found between seed-containing and parthenocarpic fruit of either cultivar, according to the Student t-test ($P \leq 0.05$).

Table 56. The starch content of seed-containing (naturally pollinated) and parthenocarpic fruit of eggplant cvs. Tsakoniki and Black Beauty in relation to storage treatment: film-wrapped, CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 + 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Starch (mg 100 g^{-1} f.w.)			
	Tsakoniki		Black Beauty	
	Seed-containing	Parthenocarpic	Seed-containing	Parthenocarpic
At harvest	97.98 a	101.39 a	74.42 a	82.88 a
Film-wrapped	73.19 b	85.26 b	60.30 a	71.32 ab
CA_2	89.09 ab	90.18 ab	68.18 a	73.30 ab
CA_3	78.85 b	70.79 c	55.33 a	53.65 b
Lsd	16.37	14.26	21.87	20.13

In each column, means followed by the same letters are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). No significant differences were found between seed-containing and parthenocarpic fruit for film-wrapped, CA_2 and CA_3 storage, according to the Student t-test ($P \leq 0.05$).

6.3.12 Sugar content

The internal flesh of fruit of eggplant cvs. Tsakoniki and Black Beauty contained mainly fructose, glucose, sucrose and maltose, as noted in Chapter 4. At harvest, no significant differences in the concentrations of individual sugars were observed between seed-

containing and parthenocarpic fruit of Tsakoniki (Table 57), but in Black Beauty, the levels of fructose and glucose were higher in parthenocarpic fruit than in seed-containing fruit (Table 58).

Table 57. The sugar content of seed-containing (naturally pollinated) and parthenocarpic fruit of eggplant cv. Tsakoniki in relation to storage treatment: film-wrapped, CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 + 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Concentration of sugars (mg 100 g^{-1} f.w.)				
	Fructose	Glucose	Sucrose	Maltose	Total
Seed-containing					
At harvest	461.82 b	652.81 c	15.04 b	36.81 a	1166.48 d*
Film-wrapped	938.04 a	1032.20 a	79.04 ab	117.26 a	2167.54 b*
CA_2	774.25 a	837.09 b	129.95 ab	70.59 a	1813.82 c
CA_3	922.52 a*	1099.48 a	202.17 a	164.17 a	2396.34 a*
Lsd	207.07	163.95	172.03	168.62	196.07
Parthenocarpic					
At harvest	667.74 b	681.65 b	76.37 b	118.54 a	1544.30 b*
Film-wrapped	1105.12 a	1130.74 a	231.14 ab	55.01 a	2522.02 a*
CA_2	756.95 b	852.15 b	72.16 b	106.15 a	1793.62 b
CA_3	1301.21 a*	1117.46 a	267.10 a	0	2693.77 a*
Lsd	272.70	185.09	188.38	142.47	276.75

In each column, means followed by the same letters for seed-containing and parthenocarpic fruit separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, significant differences between seed-containing and parthenocarpic fruit for each treatment are indicated by an asterisk (*), according to the Student t-test ($P \leq 0.05$).

During storage the concentrations of all sugars, except maltose, increased significantly in the fruit of both cultivars regardless of storage treatments (Table 57 and 58). In seed-containing fruit of Tsakoniki, the concentration of fructose did not differ between storage treatments, whereas in the corresponding parthenocarpic fruit the fructose concentration after storage was highest in fruit that were film-wrapped or stored in 21% O_2 + 0.035% CO_2 (CA_3). In Tsakoniki too, the glucose concentration was highest in fruit that were film-wrapped or stored in 21% O_2 + 0.035% CO_2 (CA_3), irrespective of the presence or absence of seeds. It was also observed that the concentrations of fructose and glucose were higher than those of sucrose in both seed-containing and parthenocarpic fruit, and sucrose levels during storage tended to be higher in CA_3 than in the other treatments, though to a statistically significant level only in comparison with CA_2 in the case of parthenocarpic fruit. At the end of storage, the concentration of total sugars (fructose + glucose + sucrose + maltose) of Tsakoniki was significantly higher than that before storage, except in parthenocarpic fruit stored in 10% O_2 + 3% CO_2 (CA_2). Between seed-

containing and parthenocarpic fruit, a significantly higher concentration of total sugars was observed at harvest and in fruit that were film-wrapped or stored in 21% O_2 + 0.035% CO_2 (CA_3). Similarly, a significantly higher concentration of fructose was detected in parthenocarpic fruit stored in 21% O_2 + 0.035% CO_2 (CA_3) (Table 57).

Table 58. The sugar content of seed-containing (naturally pollinated) and parthenocarpic fruit of eggplant cv. Black Beauty in relation to storage treatment: film-wrapped, CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 + 0.035% CO_2) during 20 days of storage at 10ºC.

Treatments	Concentration of sugars (mg 100 g^{-1} f.w.)				
	Fructose	Glucose	Sucrose	Maltose	Total
Seed-containing					
Before harvest	824.37 d*	791.62 c*	65.71 b	45.80 a	1727.51 d*
Film-wrapped	1295.56 b	1112.31 ab	88.57 b*	171.81 a*	2668.25 b*
CA_2	1057.06 c	986.99 b	90.09 b	158.01 a	2292.16 c
CA_3	1539.85 a	1237.06 a*	443.22 a	84.90 a*	3302.03 a*
Lsd	170.88	165.74	155.56	161.53	258.67
Parthenocarpic					
Before harvest	1067.18 c*	1012.99 b*	6.76 b	101.62 a	2199.60 c*
Film-wrapped	1369.08 b	1129.12 b	529.82 a*	0*	3028.01 b*
CA_2	1125.11 c	1044.97 b	62.57 b	112.57 a	2345.17 c
CA_3	1736.17 a	1428.20 a*	441.35 ab	0*	3605.72 a*
Lsd	219.55	178.02	442.21	133.90	234.07

In each column, means followed by the same letters for seed-containing and parthenocarpic fruit separately are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Within each column, significant differences between seed-containing and parthenocarpic fruit for each treatment are indicated by an asterisk (*), according to the Student t-test ($P \leq 0.05$).

In Black Beauty, the concentration of fructose in both seed-containing and parthenocarpic fruit increased significantly irrespective of the storage conditions, with the exception of parthenocarpic fruit in treatment CA_2 (Table 58). In both seed-containing and parthenocarpic fruit, the highest level of fructose after storage was detected in treatment CA_3. The glucose level of seed-containing fruit also increased significantly in all storage treatments, the highest concentration being found in treatment CA_3, but in the parthenocarpic fruit a significant increase in glucose was only detected in CA_3. The concentration of sucrose in seed-containing fruit increased significantly only in treatment CA_3, while in parthenocarpic fruit, the sucrose content was highest in treatment CA_3 and in film-wrapped fruit. As in Tsakoniki, the total sugar content of fruit after storage was higher in all treatments compared with that at harvest, with the exception of parthenocarpic fruit stored in 10% O_2 + 3% CO_2 (CA_2). In both seed-containing and parthenocarpic fruit, the highest concentration of total sugars at the end of storage was found in treatment CA_3,

followed by that in film-wrapped fruit and treatment CA_2. It was also observed that parthenocarpic fruit of Black Beauty contained significantly higher levels of glucose, fructose and total sugars at harvest than seed-containing fruit. In addition, the concentration of total sugars was higher in parthenocarpic fruit that were film-wrapped or stored in 21% O_2 + 0.035% CO_2 (CA_3) than in the corresponding seed-containing fruit, as was the concentration of glucose in CA_3 and sucrose in film-wrapped fruit (Table 58).

6.4 Discussion

Soon after the start of storage (7-9 days), decay symptoms were observed in all the fruits of both cultivars in treatment CA_1 (3% O_2 + 3% CO_2); hence storage of this treatment was discontinued. This result contrasts with that of, Kaynas *et al.* (1995) who reported satisfactory storage of eggplants under the same controlled atmosphere conditions for 5-6 weeks, while at higher CO_2 levels (5%) CO_2 injury occurred. A possible reason for this difference may be the high respiration rate of the eggplant cultivars studied here (26-40 ml CO_2 kg^{-1} h^{-1} at harvest), which was higher than that in cv. Pala-49 studied by Kaynas *et al.* (1995), resulting in anaerobiosis in the former during prolonged storage under low O_2 tension (3%).

In general, low O_2 and high CO_2 tension reduces the respiratory activity of fruits and vegetables during storage and also decreases the rate of catabolic, degradation processes (Fonseca *et al.,* 2002). However, in the present study, we observed comparatively higher respiratory activity during storage at 10^{o}C in CA_2 (10% O_2 + 3% CO_2) than in CA_3 (21% O_2 and 0.035% CO_2). As discussed in the previous chapter (Chapter 5), it is possible that this difference arose from CO_2 accumulation within the fruit in the storage treatment with high CO_2 (3%), and this CO_2 being released when fruit were unwrapped at the time of respiration measurement (D'Aquino *et al*., 1997).

The present results showed that colour changes of the skin of both seed-containing and parthenocarpic fruit of Tsakoniki and Black Beauty were slight during storage, irrespective of the storage atmosphere (CA_2 and CA_3). Although improved colour retention by CA storage was observed in strawberry (Holcroft and Kader, 1999; Shin *et al.,* 2008) and pomegranate (Holcroft *et al.,* 1998), in eggplant it seems that modification of the storage atmosphere as performed in the present experiment was of relatively little value for colour retention.

Discolouration of the calyx is an important factor contributing to a reduction in eggplant quality. In the present study, the loss of lightness (L) of the calyx was minimum in both cultivars regardless of CA treatments. On the other hand, an increase in a* value of the calyx was detected during storage in both treatments, indicating a change from dark to light green. This change was significantly higher in naturally pollinated fruit of Tsakoniki than in the corresponding parthenocarpic fruit. In general, however, the changes in calyx colour were not significantly affected by the storage treatment. Indeed, it seems that calyx colour is affected more by water loss (e.g. by wrapping) than by changing the storage atmosphere.

Firmness is one of the most common physical parameters used to assess the texture of fruit, and controlled atmosphere storage is generally reported to maintain fruit firmness (Kader, 2003). Arvanitoyannis *et al.* (2005) reported that modified atmosphere packaging positively affects the flesh firmness of eggplant. But according to the present results, modification of the storage atmosphere affects the external skin firmness (both eggplant cultivars), but did not influence the internal flesh firmness, except in seed-containing fruit of Tsakoniki where the change in flesh firmness during storage was partly a result of increased weight loss.

No significant difference in weight loss was detected between treatments CA_2 and CA_3. Kaynas *et al.* (1995) reported <5% weight loss in eggplant cv Pala-49 stored under different CA conditions for 28 days, but in the present experiment weight loss was relatively higher regardless of the CA treatment. This was particularly true for Tsakoniki where the higher rate of weight loss in comparison with that of Black Beauty probably results from the larger surface area: volume ratio (Woods, 1990) in the former, as well as the relatively larger size of the calyx in relation to fruit size.

Transpiration through stomata, lenticels, cuticles and epidermal cells is the major cause of postharvest weight loss of fruits and vegetables (Ben-Yehoshua and Rodov, 2003). When comparing the microscopic structure of calyx and pericarp, we observed the presence of stomata in the calyx, on the other hand no stomata were seen in the pericarp of fruit of either cultivar (Fig. 36). The variation in stomatal density could influence the rate of water loss of fruit; however, no differences were detected in the density of stomata between the calyx of the two cultivars. In eggplant, moisture loss through the calyx and stem scar is the most important cause of weight loss and can significantly affect fruit quality (Diaz-Perez, 1998). In the present study, it was observed that water loss through the calyx and stem scar was 3-fold higher than via the pericarp. In consequence, about 75%

(Tsakoniki) and 70% (Black Beauty) of total moisture loss occurred through the calyx, the difference between the two cultivars stemming from the difference in calyx-pericarp ratio. This result is in accordance with that of Diaz-Perez (1998) who reported that about 60% of total transpiration occurred through the calyx in eggplant cv. Classic, compared with 26% in mature fruit of bell pepper (Diaz-Perez *et al.,* 2007). Therefore, to maintain fruit quality during storage the rate of moisture loss thorough the calyx of eggplant should be restricted.

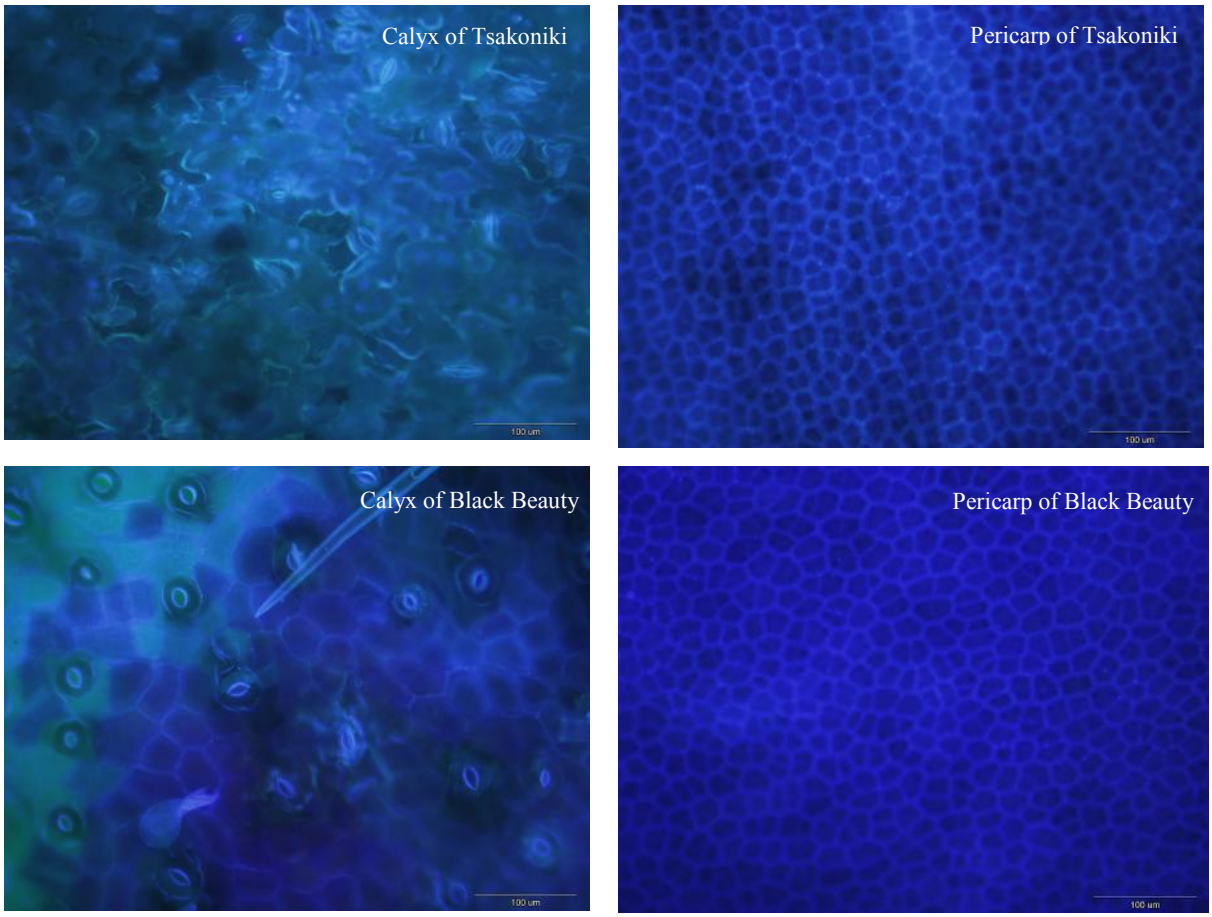

Fig. 36. Microscopic structure of calyx and pericarp of fruit of Tsakoniki and Black Beauty. Note the presence of stomata in the calyx, but not in the pericarp.

Control of ethylene is of prime importance in postharvest management of fruits and vegetables. Although eggplant is a non-climacteric fruit, chilling stress stimulated the production of ethylene in eggplant fruit during storage (Rodriguez *et al.,* 2001; Concellon *et al.,* 2005; Concellon *et al.,* 2007). The presence of ethylene within the storage atmosphere increases the respiratory rate of non-climacteric fruit and accelerates chlorophyll degradation in green organs (e.g. the calyx) (Kays, 1991). However, in the present experiment it is unlikely that ethylene influenced fruit quality during storage since

no detectable ethylene was found in either cultivar during storage at 10ºC in either controlled atmosphere.

The beneficial effects of high CO_2 and low O_2 concentrations in reducing the loss of ascorbic acid during fruit and vegetable storage are well documented (Saari *et al.,* 1995; Lee and Kader, 2000; Simoes *et al.,* 2009). The present results confirm that enclosure of fruit within polyethylene maintained the ascorbic acid content of naturally pollinated fruit of Tsakoniki and Black Beauty, as reported for eggplant stored under modified atmosphere packaging (MAP) by Arvanitoyannis *et al.* (2005). However, a significant decrease in ascorbic acid concentration was detected in the parthenocarpic fruit of both cultivars, indicating that the ascorbic acid content of parthenocarpic fruits is more susceptible to oxidation during storage than in the corresponding seed-containing fruit. There was no beneficial effect, however, of changing the storage atmosphere, although Kaynas *et al.* (1995) reported that various CA and MAP treatments may reduce the decrease in ascorbic acid content of eggplant cv Pala-49 fruit during 14-42 days of storage.

In the present study, the protein content of both seed-containing and parthenocarpic fruit of Tsakoniki and Black Beauty appeared to be relatively stable, and was unaffected by the storage atmosphere and the presence or absence of seeds. Similarly the concentration of CO_2 within the atmosphere did not affect the protein content of strawberry fruit during storage (Holcroft and Kader, 1999). However, Rothan *et al.* (1997) detected a 33% reduction of extractable protein in tomato fruit stored in 20% CO_2 for 2 days. This difference between species, however, may relate to the ripening pattern of the fruit since both eggplant and strawberry are non-climacteric, whereas tomato is a climacteric fruit (Kays, 1991).

There are a number of reports on the beneficial effects of CA in preventing the loss of total phenolics in horticultural commodities such as strawberry (Holcroft and Kader, 1999; Pelayo *et al.,* 2003), pear (Veltman *et al.,* 1999), guava (Singh and Pal, 2008) and apple (Addie *et al.,* 2001). In eggplant, the total phenol content of the flesh did not change during storage irrespective of the storage atmosphere and the presence or absence of seeds. It seems therefore that although film-wrapping may affect the phenolics content of eggplant fruit (Chapter 5), there was no benefit of atmosphere modification as performed in the present experiment. The effect of CA may, however, vary between cultivars and growing conditions; for example, in apple CA inhibited the decrease in phenolics during storage in one case (Addie *et al.,* 2001), but caused a greater decrease in another (Piretti *et al.,* 1994).

In the present experiment the concentration of anthocyanins within the fruit did not change with storage irrespective of the storage atmosphere and the presence or absence of seeds. It may therefore be concluded that the modification of the storage atmosphere, as performed here, was of no benefit to colour retention, the major factor in fruit colour both at harvest and during storage being the cultivar. Enrichment of the storage atmosphere with CO_2 has been reported to inhibit the postharvest biosynthesis of anthocyanin in strawberry (Kalt and MacDonald, 1996; Gil *et al.,* 1997; Shin *et al.,* 2008) and pomegranate (Holcroft *et al.,* 1998). However, a contradictory report for apple showed an increase in anthocyanin during CA storage (Kolensik *et al.,* 1977).

The present results showed that the starch content of eggplant fruit decreased during storage. In most cases, maximum loss of starch was detected in CA_3, followed by film-wrapping and treatment CA_2. This result indicates that the lower O_2 tension in CA_2 retards starch metabolism during storage, possibly as a result of reduced respiration. Similarly, Kaynas *et al.* (1995) observed that low O_2 concentration slow down starch degradation in eggplant.

In the present study, we found fructose and glucose to be the major sugars in both seed-containing and parthenocarpic fruit of Tsakoniki and Black Beauty (see also Chapter 4). The present results showed that fructose, glucose and sucrose increased considerably during storage, whereas maltose was not affected. It is important to note that CA_3 storage induced the highest level of all sugars, probably due to the hydrolysis of starch and other polysaccharides as a consequence of the high O_2 concentration in the storage atmosphere. On the other hand, low O_2 and high CO_2 concentrations in treatment CA_2 appeared to reduce the metabolic activity of both seed-containing and parthenocarpic fruit in comparison with other storage treatments. The cumulative effect storage on the total sugar concentration was generally a significant increase under all storage conditions compared to the initial values. Kaynas *et al.* (1995) also observed an increase in total sugars in CA storage after 14 days storage, but after 28 days of storage the total sugars increased only in 3% O_2 + 3% CO_2. In contrast, the present results indicate that CA_2 was the best storage treatment for maintaining starch and sugar content in eggplant fruit.

In conclusion, it is clear that modification of the storage atmosphere by decreasing O_2 to 10% and increasing CO_2 to 3% has relatively little effect on eggplant quality during storage for 20 days at 10^{o}C, irrespective of whether the fruits contain seeds or not. It is clearly not possible to reduce O_2 to as low a level as 3% (due to anaerobiosis) whereas increasing the CO_2 beyond 3% is risky due to possible CO_2 injury (Viraktamath, 1963

Lawande and Chavan, 1998). The most promising method of extending storage life and maintaining quality is apparently the reduction of water loss by transpiration via the calyx (Diaz-Perez, 1998), which is achieved primarily by fruit wrapping.

CHAPTER 7

General discussion and conclusions

The experiments described in the present thesis were carried out in order to define the pattern of growth and development, the quality characteristics and the post-harvest behaviour of parthenocarpic (seedless) fruits of eggplant set by the application of plant growth regulators in comparison with seed-containing fruit set by natural pollination.

In the first experiment, two Greek eggplant cultivars (Tsakoniki and Emi) and two imported cultivars (Black Beauty and Black Boy) were cultivated in the greenhouse and in the open field during two seasons, spring (2009) and autumn (2008). The growth pattern and external colour of the fruit was recorded from the time of fruit set until harvest and harvested fruits were analysed for their dry matter content. In parallel with fruit growth, the production of pollen per flower was recorded and pollen viability and vigour assessed in *in vitro* germination tests. The results showed that the application of β-naphthoxyacetic acid (NOA) to emasculated eggplant flowers at anthesis resulted in the production of parthenocarpic (seedless) fruit set in all four cultivars both in the greenhouse and open field, irrespective of season, while the application of benzyl adenine (BA) alone failed to induce fruit set in any of the cultivars and the application of NOA together with BA had a similar effect to NOA alone. The fruit length and diameter of parthenocarpic fruit set by NOA was higher than that of seed-containing fruit set by natural pollination, resulting in improved fruit size and increased mean individual fruit weight, which thus enhanced potential yield and marketability; however, growth regulators caused a reduction in fruit dry matter accumulation. Although no significant differences in colour attributes L, C* and Hº were observed between parthenocarpic and seed-containing fruit of the eggplant cultivars during fruit development, visually at harvest parthenocarpic fruits were shiny in appearance with as good if not better colour formation than seed-containing fruit. In spring, all the cultivars attained their characteristic final colour at 21 DAA, while in the autumn colour development took 28 DAA, indicating that harvest in spring may take place 7 days earlier than in autumn irrespective of the presence or absence of seeds in the fruit. It was observed that growth regulators did not affect the length of the calyx or the peduncle, part or all of which is left attached to the fruit at harvest.

Fruit set under typical growing conditions is largely dependent on the success of pollination and fertilization. The results of the present investigation showed that pollen production, viability and pollen tube elongation varied between cultivars and between seasons. Tsakoniki was highly thermo-susceptible and no pollen germination was observed during the months when excessively high (July) or low (January) temperatures prevailed. In contrast, Black Boy showed tolerance to high and low temperatures whereas in Emi although pollen viability was susceptible to high and low temperatures (as in Tsakoniki) nevertheless fruit-set occurred because this cultivar has the natural ability to produce parthenocarpic fruit under unfavourable climatic conditions. Overall, pollen production per flower and pollen germinability and vigour were higher in all the cultivars during May, due to favourable temperatures (and probably light). However, for greater clarification of the effects of environment on pollen productivity and viability, further research is required, with special reference to different cultivation seasons.

Although growth regulators have been previously proposed as a means of setting fruit during adverse climatic conditions, to our knowledge this is the first time that the quality characteristics of parthenocarpic eggplant fruits have been described. Thus, in the second experiment, selected quality parameters of the fruits of four eggplant cultivars, produced parthenocarpically in the greenhouse or open field during spring (2009) and autumn (2008) by the application of NOA or NOA in combination with BA, were examined in the laboratory after harvest and compared with those of seed-containing fruit set by natural pollination. From the results, it was found that the application of PGR did not significantly affect either the external or the internal firmness of eggplant fruits, irrespective of cultivar, growth season and method of cultivation (greenhouse or open field). Similarly, the ascorbic acid content of the fruit was not affected by PGR application, except in Tsakoniki and Black Beauty during the autumn, where ascorbic acid levels were lower in parthenocarpic fruit produced in the greenhouse than in the corresponding seed-containing fruit. The protein content of all cultivars was not affected by the method of fruit set, irrespective of cultivar, growth season and method of cultivation (greenhouse or open field). High variability in the anthocyanin content of the fruit pericarp was detected between cultivars, as well as between individual fruit of the same cultivar, but growth regulators did not appear to affect the anthocyanin levels. Another important antioxidant component of eggplant fruit, phenolics, showed variation between cultivars and was comparatively higher in the central part of seed-containing fruit than in parthenocarpic fruit. The present results showed that the application of PGR decreased the total phenolics

both in the proximal and central part of the fruit, which therefore increased the lightness (L) of the flesh colour. This in turn led to a possibly positive effect of growth regulator application on fruit quality by reducing the degree of browning both in the placental tissue and at a distance from the placenta, even if not to statistically significant level. Browning is a negative quality attribute and its possible reduction by PGR application is therefore beneficial for fruit quality. Fructose, glucose, sucrose and maltose were identified as the major sugars in eggplant fruit and the application of PGR for fruit set significantly increased the content of the reducing sugars fructose and glucose. However, growth regulators did not affect the starch content of the eggplant fruit.

In most cases, the quality parameters of eggplant fruit studied here were not affected to a statistically significant level by the cultivation season. However, higher light intensity and increasing day length in spring generally appeared to improve some of the quality parameters, especially ascorbic acid and sugars (fructose and glucose) in both seed-containing and parthenocarpic fruit. In contrast with other members of the Solanaceae family (tomato and pepper) where auxin improves fruit set under unfavourable growth conditions but at the expense of fruit quality, in eggplant it is clear that the application of NOA or NOA + BA not only sets fruit but may also improve (or at least not affect) fruit quality. This method of obtaining fruit set under unfavourable environmental conditions may therefore be recommended unhesitatingly.

Because there is no available information in the literature concerning the storage ability of parthenocarpic eggplant fruit, in the third experiment the fruit of two cultivars (Tsakoniki and Black Beauty) derived from two spring cultivations in the greenhouse (2009 and 2011) and one in the open field (2009) were stored at 10 and 20^{o}C for 7, 14 or 20 days with or without enclosure in plastic film. The results showed that the pericarp colour (L, C* and H^{o}) of both cultivars was unaffected by storage treatment (wrapped or unwrapped), temperature and storage duration. It was also observed that in most cases both seed-containing and parthenocarpic fruit wrapped in film maintained better firmness (external and internal) than unwrapped fruit, irrespective of storage temperature and duration. Film-wrapping effectively reduced weight loss throughout storage (7-20 days), while unwrapped fruit became unmarketable within 7 days of storage at 10 or 20^{o}C, irrespective of the presence or absence of seeds. Fruits of Tsakoniki (elongate in shape) were more prone to water loss than those of Black Beauty (flask-shaped) because of their relatively higher surface area to volume ratio and relatively larger calyx in relation to fruit size. The film-wrapped fruit had an apparently higher respiration rate than the unwrapped

fruit, but this was probably due to the gradual release of CO_2 that had accumulated in the wrapped fruit prior to measurement rather than respiration *per se*. In general, the ascorbic acid content of both seed-containing and parthenocarpic fruit progressively decreased with increasing storage time, but mostly to a statistically significant degree only at 20ºC. Film-wrapping tended to delay ascorbic acid loss, possibly by reducing the rate of ascorbate oxidation, but generally not to a statistically significant level. The protein and anthocyanin content of fruit was relatively stable during storage, and film-wrapping delayed the loss of these components. With regard to total phenols in the flesh, it was observed that film-wrapping effectively reduced the phenol content of both seed-containing and parthenocarpic fruit at 10ºC, whereas an accumulation of phenolics was detected in unwrapped fruit, maybe in response to stress due to rapid water loss. In all cases, storage at 10ºC maintained better fruit quality than at 20ºC. Overall, the results of this experiment revealed that film-wrapping effectively prolonged eggplant storage in comparison with unwrapped fruit, mainly due to a reduction in the rate of water loss. After 20 days of storage at 10^{o}C, film wrapped fruit were generally of excellent appearance and it is clear that parthenocarpic (seedless) fruit have a similar storage capability to seed-containing fruit produced by natural pollination.

In order to obtain additional information on the quality of parthenocarpic and seed-containing eggplant fruits during storage, a further experiment was performed in which fruits of Tsakoniki and Black Beauty grown in the greenhouse in spring 2011 were stored under controlled atmospheres (CA_1: 3% O_2 + 3% CO_2, CA_2: 10% O_2 + 3% CO_2 and CA_3: 21% O_2 + 0.035% CO_2) at 10^{o}C for up to 20 days. Due to the development of anaerobic conditions in treatment CA_1 (3% O_2 + 3% CO_2) in both Tsakoniki and Black Beauty 7-8 days after the start of storage and concomitant decay, this treatment was discontinued. However in treatments CA_2 (10% O_2 + 3% CO_2) and CA_3 (21% O_2 + 0.035% CO_2) fruits of both cultivars were stored for up to 20 days at 10ºC. The freshness of the calyx and the pericarp colour are important quality parameters for eggplant, and these two parameters were successfully retained during storage in both CA_2 and CA_3. Firmness, another important physical quality parameter, was largely unaffected by CA; however, in the case of parthenocarpic fruit of Tsakoniki the external pericarp was firmer than in seed-containing fruit, while internal firmness was not affected. It was observed that water lost through the calyx was significantly higher than via the pericarp, and due to the higher calyx: pericarp ratio, Tsakoniki lost a higher amount of water during storage than Black Beauty. However, film wrapping, as observed in the previous experiment, effectively

reduced water loss through calyx and in consequence reduced weight loss during storage. A significant loss of ascorbic acid was detected in parthenocarpic fruit, while no differences were observed in seed-containing fruit in both storage atmospheres. Similar to the film-wrapping treatment of the previous experiment, CA storage also inhibited the degradation of protein and anthocyanins in both seed-containing and parthenocarpic fruit. CA storage prevented the loss of phenolics in the flesh, and the reduced O_2 concentration in CA_2 inhibited the degradation of starch, while the higher O_2 concentration in CA_3 enhanced starch degradation resulting in increased sugar concentrations (mainly glucose, fructose and sucrose) in the fruit at the end of storage. Based on the above results, the main benefit of CA storage seems to be the preservation of the physical appearance (calyx and pericarp colour) of the fruit; all other quality parameters were not positively affected. Therefore, CA storage does not appear to confer a significant advantage on eggplant fruit storage beyond that obtained by fruit enclosure in polyethylene film and overall the storage behaviour of parthenocarpic fruit obtained by the application of NOA or NOA + BA for fruit set is similar to that of seed-containing fruit derived from natural pollination.

Conclusions, originality and recommendations

Although the use of PGR to set eggplant fruit has been described in the past, this is the first time that the growth and quality characteristics of hormone-set fruit have been described. Additionally, in the present experiment all hormone-set fruit were parthenocarpic, i.e. seedless, since flowers were emasculated at the time of PGR application, whereas in most published studies of the effect of PGR on eggplant fruit-set emasculation was not performed, hence fruit may have contained seeds. To the best of our knowledge, this is the first time too that the postharvest behaviour of parthenocarpic eggplant fruits during storage has been documented, both under open and closed storage, as well as in controlled atmospheres. Hence, the data presented here are highly original.

From the results of our experiments, we conclude that

1. The application of NOA to emasculated eggplant flowers at the time of anthesis is a satisfactory method for setting fruit at times of adverse climatic conditions (excessively high or low temperatures), whereas BA is ineffective for this purpose when applied alone, and does not confer any significant benefit on NOA when NOA and BA are applied together.

2. In general, the growth of parthenocarpic fruit is more rapid than that of seed-containing fruit, and parthenocarpic fruit are larger at harvest, due to an increase in fruit length and diameter.

3. The quality characteristics of parthenocarpic eggplant fruit are on the whole quite similar to those of fruit set by natural pollination, with the exception of phenolics and sugars.

4. Overall, the storage ability of parthenocarpic fruit does not differ significantly from that of seed containing fruit.

5. For satisfactory storage of both parthenocarpic and seed-containing eggplants, fruit must be enclosed in polyethylene to reduce the rate of water (weight loss), which in unwrapped fruit is so rapid as to render fruit unmarketable within 7 days after harvest. Water loss is closely related to transpiration via the calyx, and the fruit : calyx ratio significantly affects the susceptibility of the cultivar to weight loss.

6. The use of controlled atmospheres is not indicated for either parthenocarpic or seed-containing eggplant fruit since CA does not confer any significant advantage over that offered by film wrapping.

In conclusion, beyond their use for fruit set, PGR offer some advantages to eggplant growers (e.g. reduced browning). The resulting parthenocarpic fruit store equally as well as seed-containing fruit, and their quality is as good as (or even better than) that of seed-containing fruit.

The results obtained apply to all four cultivars used in the present study, as well as to the type of cultivation (greenhouse or open field) and the season of production.

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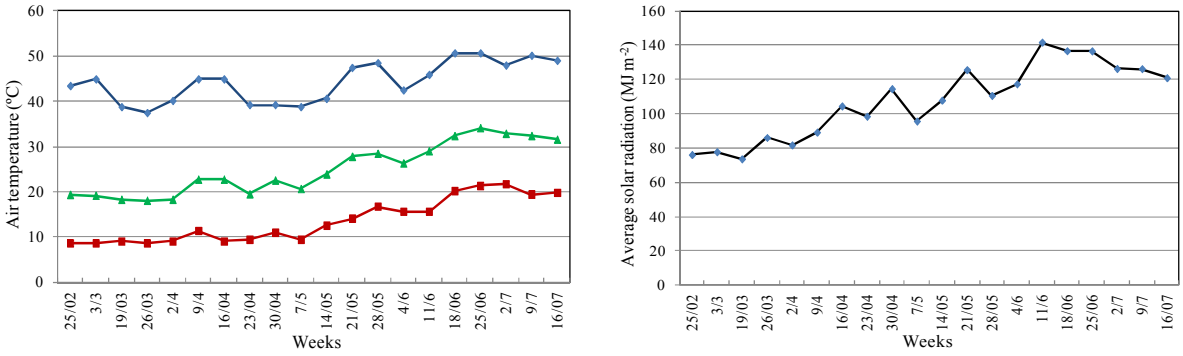
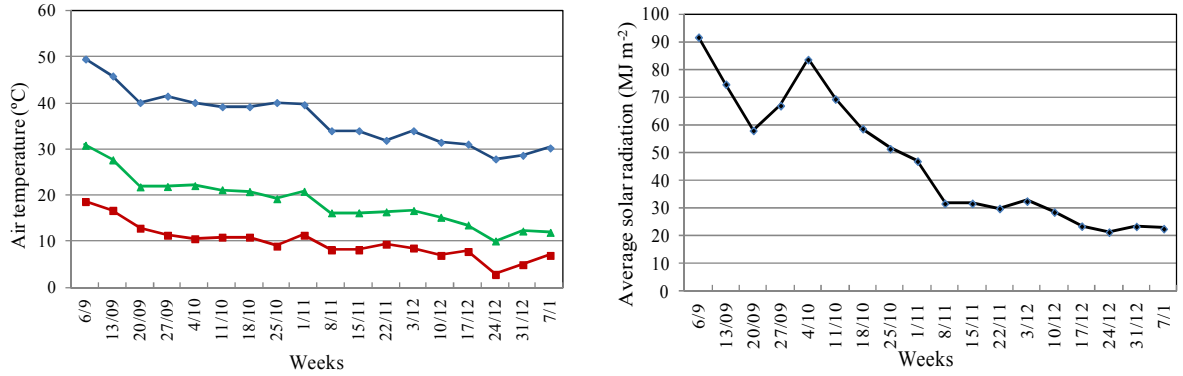
Appendix

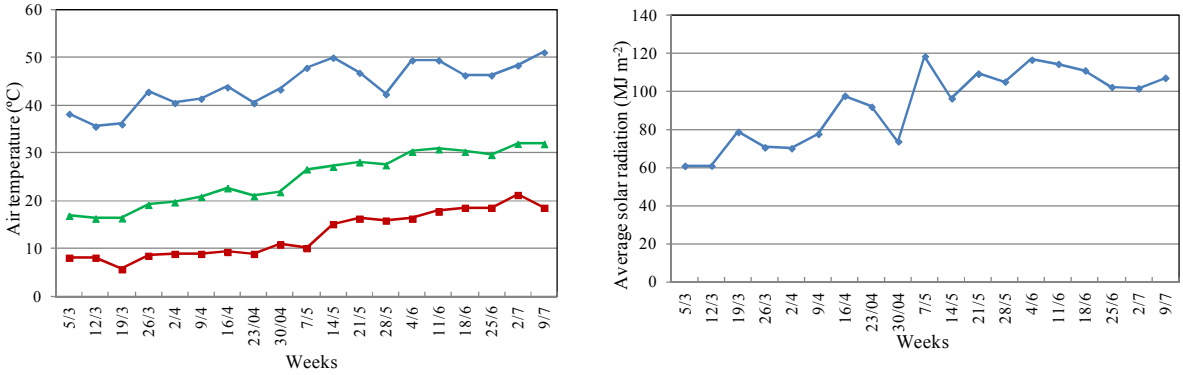
Appendix 1. Weekly metrological data for unheated greenhouse during 2008-2009.



Appendix 1..1 Weekly metrological data for unheated greenhouse showing maximum (♦), minimum (■) and average temperature (▲), and average solar radiation during spring, 2008.

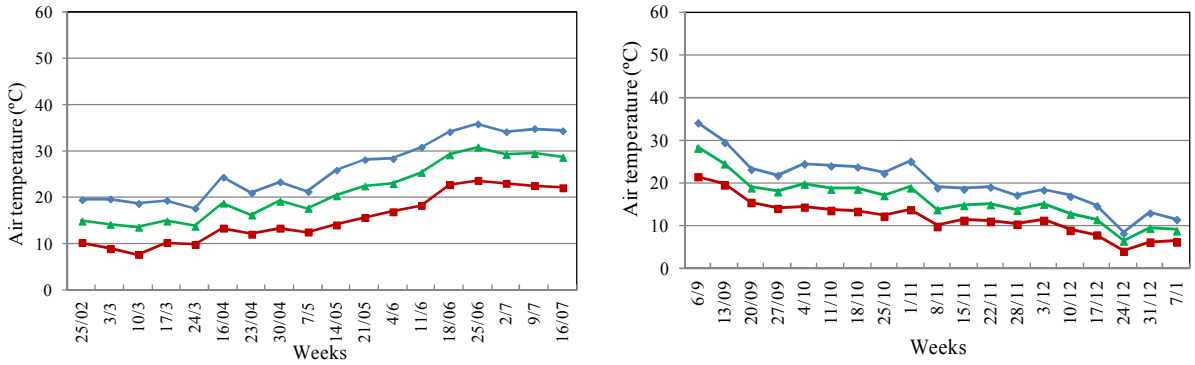


Appendix 1.2 Weekly metrological data for unheated greenhouse showing maximum (♦), minimum (■) and average temperature (▲), and average solar radiation during autumn, 2008-2009.

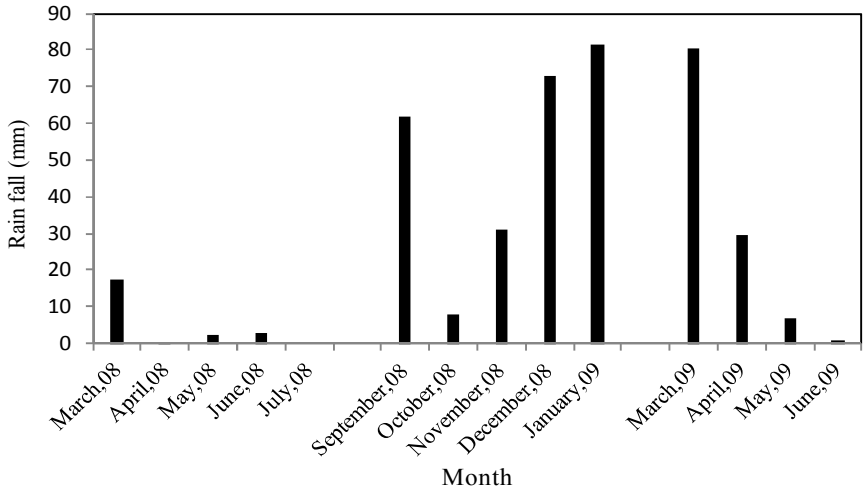


Appendix 1.3 Weekly metrological data for unheated greenhouse showing maximum (♦), minimum (■) and average temperature (▲), and average solar radiation during spring, 2009.

Appendix 2. Weekly metrological data for open field during 2008-2009.

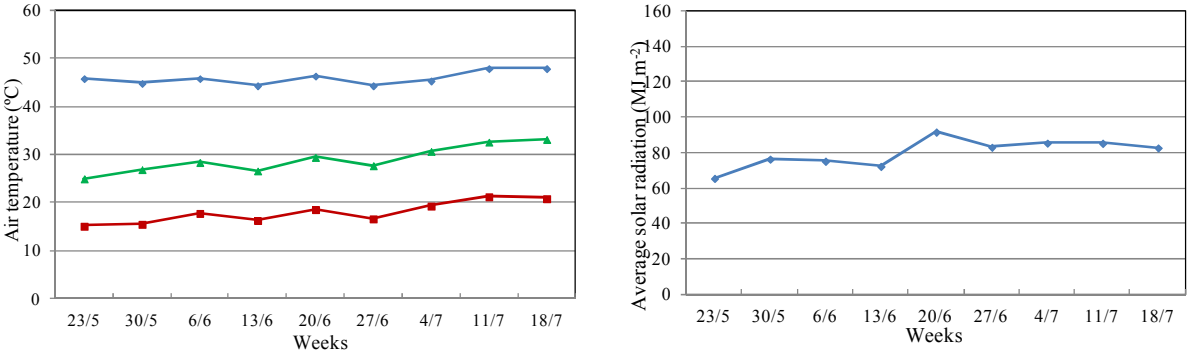


Appendix 2.1 Weekly metrological data for open field showing maximum (♦), minimum (■) and average (▲) temperature during spring and autumn, 2008-2009.



Appendix 2.2 Average rainfall (mm) in the open field during 2008-2009.

Appendix 3. Weekly metrological data for unheated greenhouse during 2011.



Appendix 3. Weekly metrological data for unheated greenhouse showing maximum (♦), minimum (■) and average temperature (▲), and average solar radiation during spring, 2011.