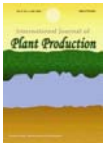

International Journal of Plant Production 6 (1), January 2012
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

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Nitrogen application affects yield and postharvest quality of okra (*Hibiscus esculentus* L. cv. 'Boyiatiou')

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Received 13 May 2011; Accepted after revision 22 August 2011; Published online 25 December 2011

Abstract

In Greece and Turkey, okra (*Hibiscus esculentus* L.) is cultivated for small pods (≤4-5 cm), which are highly perishable after harvest. In this experiment, okra was cultivated at 4 levels of N (30, 150, 300 and 450 mg l^{-1}) within the irrigation water. Pod yield was highest at 300 mg l^{-1} N. High N increased the nitrate content and decreased dry matter without affecting pod colour ($P \leq 0.05$). When pods were enclosed in polyethylene and stored for up to 10 days at 7 or 10 ^{o}C fresh weight decreased by 7% and 11-12% respectively, and by 20% and 28% respectively during 3 days subsequent shelf-life at 22 ^{o}C. Weight loss after 10 days at 7 ^{o}C and during shelf-life was higher in pods from 300-450 mg l^{-1} N and was accompanied by a corresponding decrease in % dry matter. The loss of chlorophyll during storage (i.e. increase in a*) rose with storage time and N application level, accompanied by a decrease in b*. The nitrate concentration within the pods decreased with storage irrespective of N level. It is concluded that the rate of N application affects not only the production but also the quality of okra during storage. For the production of small-sized pods N application should not exceed 300 mg l^{-1}. Although pods from high N levels (300-450 mg l^{-1} N) lose more weight, dry matter and chlorophyll than those from the lowest N level (30 mg l^{-1} N), they may nevertheless be stored satisfactorily for up to 10 days at 7 ^{o}C, which permits a 3 day ambient shelf-life.

Keywords: *Abelmoscus esculentus*; Colour; Firmness; Weight loss; Postharvest life; Nitrate content.

Introduction

Okra (*Hibiscus esculentus* L. syn. *Abelmoschus esculentus* [L.] Moench) is an important summer vegetable of countries within the Mediterranean

Basin, especially Egypt and Turkey where annual production amounts to 105.000 and 37.500 tons, respectively (Duzyaman, 2009; FAOStat, 2011). Although considerable research has been carried out on the nutrient requirements for crop growth, the effect of fertilizer application on pod quality, nitrate content and storage life has been studied less and refers exclusively to large fruiting cultivars, such as the American Clemson Spineless, the pods of which may be 10-12 cm in length (Lamont, 1999). In Greece and Turkey, however, there is a distinct market preference for small pods, <4 cm in length and often as small as 1cm (Duzyaman, 2009). These pods have a high market value, but are highly perishable and demand a major labour input during harvest (Passam and Rekoumi, 2009).

On the basis of N accumulation studies of okra cultivated in Greece, a base fertilizer dressing incorporating 25-30 kg N ha^{-1} was proposed for cultivars producing small pods (< 4 cm in length) (Rekoumi et al., 2003), which is about half that required for crops under tropical conditions (Olasantan, 1994) and about 15-25% lower than that recommended for large-fruiting American cultivars in the southern USA (Lamont, 1999). Approximately 50% of total N is taken up within 5 weeks after transplantation (Rekoumi et al., 2003) and in large-fruiting cultivars additional side dressings with N (up to 28 kg ha^{-1}) are considered beneficial. Windham (1966) reported that Clemson Spineless yielded best when provided with 48 kg N ha^{-1} while Shrestha (1983) recommended up to 60 kg N ha^{-1} for the large-fruiting Pusa Sawani cultivar. Although other studies show a linear increase in pod yield over a N range of 56-135 kg ha^{-1} (Ahmad and Tulloch-Reid, 1968; Asif and Greig, 1972), the optimum N requirement of the crop also depends on genetic, climatic and soil factors (Majanbu et al., 1985) and may relate to the mode of irrigation (Singh and Rajput, 2007). However, excessive N application may induce excessive vigour and reduce yield (Lamont, 1999).

Nitrogen application increased plant height and the number of side branches per plant (Manga and Mohammed, 2006), but the effect of N on pod weight was variable, either having no effect (Manga and Mohammed, 2006) or causing an increase at up to 120 kg N ha^{-1} under conditions of high rainfall (Singh, 1995). According to Singh (1995), increasing N application causes an increase in pod length and diameter, but the effect of N on pod quality at harvest and during storage has not been reported.

Okra pods have a high rate of metabolism, but because they are susceptible to low temperature (chilling) injury they may not be stored at temperatures below 7 $^{\circ}C$ (Ryall and Lipton, 1979). Large pods (e.g.

Clemson Spineless) may be stored satisfactorily for 7-10 days at 7-10 °C and 90-95% relative humidity (Lutz and Hardenburg, 1977) and shelf-life may be extended under conditions of 5-10% CO_2 (Anadaswamy et al., 1963) or by enclosing pods in perforated plastic bags (Tamura and Minamide, 1984). Although modified atmospheres may extend storage life (Baxter and Waters, 1990a) and improve pod quality by reducing toughness and the incidence of microbial decay (Baxter and Waters, 1990b), they are not employed commercially (Roy and Behera, 2009). Even in the air, large pods may be held for up to 7 days without objectionable deterioration (Ryall and Lipton, 1979) whereas the small pods of the Mediterranean cultivars deteriorate within 2-3 days (Passam and Rekoumi, 2009).

Because to date there are virtually no experimental data on the perishability of small okra pods during storage, we examined the changes in pod quality in relation to the storage conditions and the rate of N application during cultivation. The results of this investigation are reported here.

Materials and Methods

Seeds of okra (*Hibiscus esculentus* L. syn. *Abelmoschus esculentus* [L.] Moench) cv. 'Boyiatiou' were sown in trays containing commercial peat compost (KTS1 Klasmann-Deilmann Gmbh, Geeste, Germany) in an unheated greenhouse in March. On full expansion of the cotyledons (15-20 days after sowing) the seedlings were transplanted to individual 0.1 l pots containing the same substrate. Finally, after the development of 6-8 leaves (35-40 days after sowing) plants were transplanted to 11 l plastic pots containing a substrate of peat and perlite (2:1 v/v) to which was added 20 g l^{-1} marble dust for maintenance of the pH at 6.0-6.5.

The pots were placed in 4 rows of 60 plants each at 50×50 cm in an unheated, plastic-covered greenhouse. Each plant was supplied with an individual dripper for irrigation and fertilizer application. Four treatments were applied in a completely randomized experimental design consisting of 12 replicates of 5 plants, i.e. 60 plants per treatment. The treatments comprised 4 levels of N (30, 150, 300 and 450 mg l^{-1}) supplied in the form of NH_4NO_3 dissolved within the irrigation water. The N treatments were applied once a week, with the addition of 150 mg l^{-1} K (K_2SO_4) and 150 mg l^{-1} P (0-48-0) at 15 and 30 day intervals, respectively. Plants were trained on strings attached to overhead wires and side shoots were removed. Plant height and leaf number were recorded at the end of the cultivation, 5 months after sowing.

Pods were harvested between 8 and 9 am every 2-3 days, when they were approximately 4 cm in length. The duration of harvest was 10 weeks, and the total number of harvests was 30. Pods were immediately transferred to the laboratory, where their number and fresh weight were recorded.

The pods from each harvest were randomly grouped into 5 replicates of 5 pods each, weighed and enclosed in boxes (11.5×8.5×10.0 cm) wrapped with polyvinyl film (AEP Packaging Industries, Spain, S.A.). According to the manufacturer, the permeability of the film to O_2 is 19000 cm^3 m^{-2} 24 h^{-1} and water vapour 190 g m^{-2}. 24 h^{-1}, while the concentration of CO_2 within the package after storage for 10 days at 7 or 10 °C was 1.19 and 1.33% respectively. The containers were placed in refrigerated cabinets at 7±0.5 °C or 10±0.5 °C for 5 or 10 days after which they were placed still wrapped at room temperature (22±1 °C) for 3 days (shelf-life). Prior to and after storage and shelf-life, the pods were evaluated for weight loss, dry matter content (in relation to the fresh weight of pods prior to storage), colour, firmness and nitrate content.

Colour was assessed by a Minolta (Model CR-300, Minolta Co. Ltd., Osaka) colour meter. Two measurements were made midway between the two ends of each pod and results expressed in terms of a* (green), b* (yellow).

Firmness was measured at a point equidistant between the two ends of the pod by recording the force required to insert a conical needle 0.5 cm in diameter to a depth of 0.5 cm in the pod using a digital force gauge (DFIS 10, Chatillon and Sons Inc., New York, USA) mounted on a vertically moving column (Model TCM 201-M, Chatillon and Sons Inc., New York, USA) and moving at a speed of 20 cm min^{-1}.

The nitrate concentration within the pods was assessed by the nitrification of salicylic acid using the method of Cataldo et al. (1975). Prior to assay, pods were dried at 70 °C for 3 days followed by grinding to a particle size of < 40 mesh. For each assay 100 mg dry tissue was used.

All results were subjected to one-way analysis of variance and the means of replicates were compared by the least significant difference test using the statistical programme Stat Graphics 5.1 plus.

Results

The height of plants of cv. 'Boyiatiou' increased when N application rose from 30 to 150 mg l^{-1} but decreased at 450 mg l^{-1} N. In contrast, the number of leaves per plant was not affected by N level above 150 mg l^{-1}. The number of pods per plant was highest at 300 mg l^{-1} N whereas pod weight

was highest at 150-300 mg l^{-1} N. The highest N application (450 mg l^{-1}) caused a significant reduction in yield by negatively affecting both the number of pods per plant and the mean pod weight (Table 1).

Table 1. The effect of N application on the growth and yield of okra cv. 'Boyiatiou' cultivated for 3 months in an unheated greenhouse.

N dose (mg l^{-1})	Height (cm)	Leaf number $plant^{-1}$	Pods $plant^{-1}$	Mean pod weight (g)	Yield (g m^{-2})
30	197.7^{c}	23.3^{b}	23.80^{c}	5.23^{b}	497.6^{b}
150	225.3^{a}	32.3^{a}	26.13^{b}	5.34^{a}	558.0^{ab}
300	214.3^{b}	30.3^{a}	28.13^{a}	5.33^{a}	599.2^{a}
450	183.7^{d}	30.0^{a}	23.07^{c}	3.96^{c}	365.2^{c}

Means in each column followed by the same letter do not differ to a statistically significant level (P=0.05).
Data are means of 12 replicates, with 5 plants per replicate.

The weight loss of pods during storage related to the storage temperature, duration of storage and the level of N applied during cultivation (Table 2). At 7 °C, pod fresh weight decreased by up to 6.00-8.21% by day 10. Over the same time at 10°C weight loss was 11.12-12.05%. When, however, the pods were subsequently removed to room temperature (22 °C) for 3 days, weight loss increased to 17.00-19.60% for pods previously stored at 7 °C, but to 22.39-28.17% for pods stored at 10 °C even though the storage containers were not opened (Table 2). If the containers were opened at the time of transfer to room temperature, the pods dehydrated even more rapidly and they became non-marketable as weight loss rose to 35-45% within 3 days (data not shown). Weight loss during storage at 10 °C was not affected by the level of N application, but after 10 days at 7 °C was significantly higher for pods from the 300 and 450 mg N l^{-1} treatments. During the subsequent shelf-life period pods from plants grown under high N levels (450 mg l^{-1}) and stored at 10 °C (for 5 or 10 days) or 7 °C (for 10 days) lost more weight than those from plants grown with less N (Table 2).

The dry matter content of pods at harvest (i.e. just prior to storage) ranged from 12.45 to 12.9%, being significantly higher at 30 mg l^{-1} N than at 300 or 450 mg l^{-1} N (Table 3). During storage at 7 °C, a decrease in the dry matter content of pods (in relation to their fresh weight prior to storage) from the 300 and 450 mg l^{-1} treatments was observed on day 10, whereas at 10 °C a reduction in percent dry matter occurred on both day 5 and day 10. The dry matter content was not however affected by the subsequent transferral of pods to room temperature for 3 days (Table 3).

Table 2. The effect of N application on the percent (%) weight loss of okra pods enclosed in polyethylene and stored for 5 or 10 days at 7 and 10 °C (A) followed by 3 days shelf-life at 22 °C (B).

N dose (mg l^{-1})	Storage temperature			
	7 °C		10 °C	
	Days of storage			
	5	10	5	10
	A			
30	3.62[a] (d)	6.00[b] (b)	4.21[a] (c)	12.12[a] (a)
150	3.72[a] (d)	6.75[b] (b)	5.20[a] (c)	12.05[a] (a)
300	3.86[a] (d)	8.21[a] (b)	5.60[a] (c)	11.12[a] (a)
450	4.02[a] (d)	7.89[a] (b)	6.24[a] (c)	11.68[a] (a)
	B			
30	14.24[a] (b)	17.00[b] (b)	15.93[b] (b)	27.36[a] (a)
150	14.07[a] (b)	17.20[b] (b)	13.15[b] (b)	22.39[b] (a)
300	14.56[a] (c)	19.13[a] (b)	14.12[b] (c)	23.42[b] (a)
450	14.14[a] (c)	19.60[a] (b)	19.51[a] (b)	28.17[a] (a)

Means in each column (separately for treatments A and B) followed by the same letter do not differ to a statistically significant level (P=0.05). Data in A refer to weight loss at the end of the storage period at 7 or 10 °C. Data in B refer to weight loss after the stored pods were subsequently retained at 22 °C for a further 3 days' shelf life.
Means in each row followed by the same letter in parenthesis do not differ to a statistically significant level (P=0.05).
Data are means of 5 replicates, with 5 pods per replicate.

Table 3. The effect of N application on the percent (% in relation to the fresh weight of pods prior to storage) dry matter content of okra pods prior to and after storage for 5 or 10 days at 7 and 10 °C enclosed in polyethylene (A) followed by 3 days shelf-life at 22 °C (B).

N dose (mg l^{-1})	Prior to storage	Storage temperature			
		7 °C		10 °C	
		Days of storage			
		5	10	5	10
		A			
30	12.90[a] (a)	12.25[a] (a)	12.82[a] (a)	12.15[a] (b)	12.00[a] (b)
150	12.54[ab] (a)	12.34[a] (a)	12.62[ab] (a)	12.10[a] (b)	11.16[a] (c)
300	12.45[b] (a)	12.42[a] (a)	12.16[bc] (b)	12.15[a] (b)	11.40[a] (c)
450	12.46[b] (a)	12.36[a] (a)	11.90[c] (b)	11.48[b] (b)	11.51[a] (b)
		B			
30	12.90[a] (a)	12.44[a] (a)	12.61[a] (a)	12.24[a] (b)	11.40[a] (c)
150	12.54[ab] (a)	12.41[a] (a)	12.02[b] (a)	12.26[a] (b)	11.35[a] (c)
300	12.45[b] (a)	12.40[a] (a)	11.65[c] (b)	12.35[a] (a)	11.32[a] (b)
450	12.46[b] (a)	12.14[b] (b)	11.96[bc] (b)	12.11[a] (b)	11.35[a] (c)

Means in each column (separately for treatments A and B) followed by the same letter do not differ to a statistically significant level (P=0.05). Data in A refer to % dry matter at the end of the storage period at 7 or 10 °C. Data in B refer to % dry matter after the stored pods were subsequently retained at 22 °C for a further 3 days' shelf life.
Means in each row followed by the same letter in parenthesis do not differ to a statistically significant level (P=0.05).
Data are means of 5 replicates, with 5 pods per replicate.

The nitrate concentration in pods prior to storage increased with increasing levels of N application to the mother plants reaching a maximum of 350 mg NO_3^- kg^{-1} dry weight at a N application rate of 450 mg l^{-1} (Table 4). During storage the nitrate concentration within the pods progressively decreased and was less in pods stored at 10 °C than in those stored at 7 °C over a corresponding time period. The subsequent storage of pods at room temperature (22 °C) for a shelf-life of 3 days did not have any further effect on the nitrate content of the pods (Table 4).

Table 4. The effect of N application on the nitrate content (mg NO_3^- Kg^{-1} d.w.) of okra pods prior to and after storage for 5 or 10 days at 7 and 10 °C enclosed in polyethylene (A) followed by 3 days shelf-life at 22 °C (B).

N dose (mg l^{-1})	Prior to storage	Storage temperature			
		7 °C		10 °C	
		Days of storage			
		5	10	5	10
		A			
30	90^{c} (a)	83^{c} (a)	46^{c} (b)	40^{c} (b)	46^{c} (b)
150	215^{b} (a)	195^{b} (a)	102^{b} (b)	42^{c} (c)	67^{b} (c)
300	217^{b} (a)	189^{b} (a)	90^{b} (c)	121^{b} (b)	90^{ab} (c)
450	350^{a} (a)	301^{a} (a)	198^{a} (b)	190^{a} (b)	102^{a} (c)
		B			
30	90^{c} (a)	74^{d} (a)	35^{d} (b)	39^{c} (b)	38^{c} (b)
150	215^{b} (a)	147^{c} (b)	87^{c} (c)	39^{c} (c)	67^{b} (c)
300	217^{b} (a)	220^{b} (a)	158^{b} (b)	154^{b} (b)	65^{b} (c)
450	350^{a} (a)	351^{a} (a)	202^{a} (b)	202^{a} (b)	130^{a} (c)

Means in each column (separately for treatments A and B) followed by the same letter do not differ to a statistically significant level (P=0.05). Data in A refer to NO_3 content at the end of the storage period at 7 or 10 °C. Data in B refer to NO_3 content after the stored pods were subsequently retained at 22 °C for a further 3 days' shelf life.
Means in each row followed by the same letter in parenthesis do not differ to a statistically significant level (P=0.05).
Data are means of 5 replicates, with 5 pods per replicate.

At the time of harvest, pods were light green in colour with values for L*, a* and b* on the chromometer scale ranging from 64.1-65.4, -15.4 to -16.7 and +34.5 to +34.8, respectively. Pods that were produced under 30 mg/l N, were less green (a* value) at harvest than at the higher N levels, whereas the yellow colour of pods at harvest (b* value) was not affected by the N treatment. During storage at 7 °C the value of L* (lightness of colour) decreased by 0.56% after 5 days and 1.61% after 10 days (data not shown), without significant differences between N treatments. At 10 °C the

corresponding decrease in L* was 2.17% (5 days) and 2.41% (10 days), followed by a further decrease of approximately 1.5% during the subsequent 3 day shelf-life period. Overall, however, the decrease in L* was too small to affect the visual evaluation of colour shade (lightness). In contrast, the values of a* increased during storage, indicating a loss of green colour. The increase in a* was greater after 10 days storage than after 5 days and was significantly higher at 150-450 mg l^{-1} N than at 30 mg l^{-1} N in all cases, except day 10 at 7 °C when the value of a* was significantly higher only at 450 mg l^{-1} N (Table 5). The loss of green colour (increase in a*), however, did not result in yellowing because it was accompanied by a decrease in the value of b* (yellow). The decrease in b* increased with the duration of storage at 7 °C (but not 10 °C) and was significantly higher at 450 mg l^{-1} N in all cases except for that of 10 days at 10 °C (Table 6). When the pods that had been stored at 7 °C were held for 3 days at room temperature (22 °C) the value of a* increased further and that of b* decreased, with the loss of green and yellow in most cases being significantly higher at 300-450 mg l^{-1} N than at the lower N levels.

Table 5. The value of a* prior to storage and the relative change in a* during storage for 5 or 10 days at 7 and 10 °C enclosed in polyethylene (A) followed by 3 days shelf-life at 22 °C (B).

N dose (mg l^{-1})	Prior to storage	Storage temperature			
		7 °C		10 °C	
		Days of storage			
		5	10	5	10
		A			
30	-15.84[b]	0.28[b] (b)*	1.27[b] (a)	0.25[b] (b)	0.63[b] (ab)
150	-16.54[a]	0.49[a] (b)	1.30[b] (a)	0.55[a] (b)	1.31[a] (a)
300	-16.78[a]	0.49[a] (b)	1.63[b] (a)	0.58[a] (b)	1.54[a] (a)
450	-16.58[a]	0.55[a] (c)	2.73[a] (a)	0.59[a] (c)	1.48[a] (b)
		B			
30	-15.84[b]	1.35[b] (a)	1.89[c] (a)	0.76[b] (b)	0.89[b] (b)
150	-16.54[a]	1.49[b] (b)	2.32[b] (a)	0.86[b] (c)	0.95[b] (c)
300	-16.78[a]	1.80[a] (b)	3.38[a] (a)	1.12[ab] (b)	1.32[a] (b)
450	-16.58[a]	1.46[b] (b)	3.45[a] (a)	1.46[a] (b)	1.36[a] (b)

* The values for the change in a* are calculated from a* (before storage)-a* (after storage). Positive values indicate a decrease in green colour.

Means in each column (separately for treatments A and B) followed by the same letter do not differ to a statistically significant level (P=0.05). Data in A refer to the change in a* at the end of the storage period at 7 or 10 °C. Data in B refer to the change in a* after the stored pods were subsequently retained at 22 °C for a further 3 days' shelf life.

Means in each row followed by the same letter in parenthesis do not differ to a statistically significant level (P=0.05).

Data are means of 5 replicates, with 5 pods per replicate.

Table 6. The value of b* prior to storage and the relative change in b* during storage for 5 or 10 days at 7 and 10 °C enclosed in polyethylene (A) followed by 3 days shelf-life at 22 °C (B).

N dose (mg l^{-1})	Prior to storage	Storage temperature			
		7 °C		10 °C	
		Days of storage			
		5	10	5	10
		A			
30	34.51[a]	0.25[b] (b)*	1.21[b] (a)	0.58[b] (b)	0.51[a] (b)
150	34.75[a]	0.57[b] (b)	1.26[b] (a)	0.44[b] (b)	0.39[a] (b)
300	34.70[a]	0.57[b] (b)	1.27[b] (a)	0.48[b] (b)	0.72[a] (b)
450	34.87[a]	1.87[a] (a)	2.19[a] (a)	1.01[a] (b)	0.84[a] (b)
		B			
30	34.51[a]	1.61[b] (a)	1.81[c] (a)	1.16[b] (b)	1.38[a] (ab)
150	34.75[a]	2.36[a] (a)	2.20[b] (a)	1.20[b] (b)	1.47[a] (b)
300	34.70[a]	2.58[a] (a)	2.74[a] (a)	1.59[ab] (b)	1.85[a] (b)
450	34.87[a]	2.34[a] (b)	2.84[a] (a)	1.83[a] (c)	1.75[a] (c)

* The values for the change in b* are calculated from b* (before storage)-b* (after storage). Positive values indicate a decrease in green colour.

Means in each column (separately for treatments A and B) followed by the same letter do not differ to a statistically significant level (P=0.05). Data in A refer to the change in b* at the end of the storage period at 7 or 10 °C. Data in B refer to the change in b* after the stored pods were subsequently retained at 22 °C for a further 3 days' shelf life.

Means in each row followed by the same letter in parenthesis do not differ to a statistically significant level (P=0.05).

Data are means of 5 replicates, with 5 pods per replicate.

Pods derived from plants that had been fertilized with 150 mg l^{-1} N tended to be firmer than those from lower or higher N levels (Table 7). Pod firmness decreased with the duration of storage irrespective of temperature and N treatment, and decreased further when pods were subsequently held at room temperature for 3 days.

Discussion

Although the small pods characteristic of Greek and Turkish okra cultivars are highly susceptible to water loss and rapidly lose their market value under ambient conditions (Passam and Rekoumi, 2009), provided they are enclosed in polyethylene and stored at 7-10 °C they retain good, marketable quality for 10 days. Furthermore, the pods that have been stored at 7 °C may be satisfactorily held at room temperature (22 °C) for a shelf-life period of 3 days and, despite an increase in weight loss (up to 20%), they are still marketable,

whereas those stored at 10 °C lose more weight during the same shelf-life period and after 3 days show visible signs of desiccation. The duration of storage is thus similar to that which is recommended for the large-sized pods of American cultivars, such as Clemson Spineless (Ryall and Lipton, 1979).

Table 7. The effect of N application on okra pod firmness (kg) prior to and after storage for 5 or 10 days at 7 and 10 °C enclosed in polyethylene (A) followed by 3 days shelf-life at 22 °C (B).

N dose (mg l^{-1})	Prior to storage	Storage temperature			
		7 °C		10 °C	
		Days of storage			
		5	10	5	10
		A			
30	1.29^{b} (a)	1.15^{a} (b)	0.87^{b} (c)	0.88^{b} (b)	0.89^{a} (b)
150	1.36^{a} (a)	1.22^{a} (b)	1.00^{a} (c)	1.03^{a} (b)	0.74^{a} (c)
300	1.33^{ab} (a)	1.19^{a} (b)	0.97^{a} (c)	0.97^{a} (b)	0.81^{a} (c)
450	1.29^{b} (a)	1.19^{a} (b)	0.98^{a} (c)	0.97^{a} (b)	0.70^{a} (c)
		B			
30	1.29^{b} (a)	0.83^{a} (b)	0.72^{a} (b)	0.72^{a} (b)	0.54^{ab} (c)
150	1.36^{a} (a)	0.88^{a} (b)	0.75^{a} (b)	0.72^{a} (b)	0.63^{a} (b)
300	1.33^{ab} (a)	0.72^{b} (b)	0.68^{a} (b)	0.74^{a} (b)	0.60^{a} (b)
450	1.29^{b} (a)	0.73^{b} (b)	0.69^{a} (b)	0.74^{a} (b)	0.41^{b} (c)

Means in each column (separately for treatments A and B) followed by the same letter do not differ to a statistically significant level (P=0.05). Data in A refer to pod firmness at the end of the storage period at 7 or 10 °C. Data in B refer to pod firmness after the stored pods were subsequently retained at 22 °C for a further 3 days' shelf life.
Means in each row followed by the same letter in parenthesis do not differ to a statistically significant level (P=0.05).
Data are means of 5 replicates, with 5 pods per replicate.

Although increasing N application has previously be been shown to increase plant height (Manga and Mohammed, 2006) and pod yield (Windham, 1966; Shrestha, 1983; Singh, 1995; Olasantan, 2009) of large-fruiting cultivars under tropical conditions, the small-fruiting cultivars of the Mediterranean region show a lower requirement for N (Rekoumi et al., 2003), but also lower yields, due mainly to the small pod size at harvest (Duzyaman and Vural, 2003). In the present experiment, yield was highest at 300 mg l^{-1} N, while at 450 mg l^{-1} N yield was lower due to a reduction in the number of pods per plant and mean pod weight (Table 1). Ahmad and Tulloch-Reid (1968) also found increased yield in an okra cultivar with large pods with N doses up to 112 kg N ha^{-1}, whereas higher N doses were

not beneficial. High N concentrations also reduced fruit quality and storage ability. In a similar pot experiment, the yield and quality of 4 radish cultivars (*Raphanus sativus* L.) were adversely affected by high N rates (450 mg l^{-1}) in both the winter and spring crops (Akoumianakis et al., 2011). Pod quality of cv. 'Boyiatiou' is characterized by uniform small size, homogenous, light green colour and relative firmness. Although the intensity of green colour, assessed by the value of a* of pods from all treatments decreased during storage (Table 5), the highest rate of colour loss was observed at the highest N rate (450 mg l^{-1}). Loss of green colour (i.e. chlorophyll) was not accompanied by yellowing, however, because the value of b* decreased (Table 6), and pods simply acquired a paler shade of green during storage. Since pods were harvested at the same length in all treatments, pods at the 450 mg/l N level which have less mean weight, were thinner than pods from the other N levels. Therefore their faster deterioration could be related to their smaller diameter, since the dry weight of pods was not affected by N application.

Pod firmness at harvest was lower at 450 mg l^{-1} N than at 150-300 mg l^{-1} N and although N did not affect the rate of decrease in firmness during storage at 7 or 10 °C, the firmness of pods stored at 10 °C and subsequently held for 3 days at room temperature fell significantly (Table 7). Moreover, the concentration of nitrate within the pods rose with increasing N application and was highest throughout storage and shelf-life in the 450 mg l^{-1} N treatment (Table 4). Similarly, low nitrate levels (80-150 mg NO_3^- Kg^{-1} d.w.) in okra pods are reported by Abo-Bakr et al. (1986), and Asif and Greig (1972) showed an increase in nitrate accumulation within okra pods at higher doses of N fertilization. The nitrate content of pods recorded in this experiment was far lower than the maximum levels for lettuce or spinach permissible under European Union regulations (European Commission, 1997) and this may be considered beneficial for human health (Santamaria, 2006). As low nitrate levels have also been reported for garden bean pods irrespective of the N application (Stancheva et al., 2004), it can be assumed that pods which are consumed as vegetables (e.g. bean, okra and pea pods) have a considerably lower nitrate content than leafy vegetables.

The decrease in nitrate content during storage can also be considered advantageous, although in spinach Chung et al. (2004) observed that a decrease in nitrate content during storage at ambient temperature was accompanied by an increase in nitrite, which is also considered potentially harmful for the consumer's health. This hypothesis is further supported by

the findings of Abo-Bakr et al. (1986) that although okra pods at harvest were free of nitrites, after 3 months of frozen storage nitrites accumulated and nitrates decreased. By contrast, in lettuce nitrate content was not significantly affected during storage at temperatures up to 10 °C (Poulsen et al., 1995; Siomos et al., 2002; Konstantopoulou et al., 2010), while in spinach the leaf nitrate content did not change during storage at 5 °C for 7 days, but rapidly decreased at higher temperatures (Chung et al., 2004).

In conclusion, on the basis of the present experiment N application for the production of small okra pods should not exceed 300 mg l^{-1} since a higher level (450 mg l^{-1}) not only reduces yield but also adversely affects pod quality at harvest (higher nitrate concentration) and during storage (colour deterioration). In contrast to published literature concerning the storage of large okra pods (Ryall and Lipton, 1979; Lamont, 1999), the small pods characteristic of the Mediterranean region (< 4 cm in length) may not be stored for more than a few days in air (Passam and Rekoumi, 2009), but can be successfully stored for up to 10 days at 7 °C.

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