Original article

Pruning affects fruit yield and postharvest quality in mango (*Mangifera indica* L.) cv. Amrapali

Ram Asrey[1], Vishwa Bandhu Patel[2], Kalyan Barman[3]*, Ram Krishna Pal[1]

[1] Div. Post Harvest Technol., Indian Agric. Res. Inst., New Delhi, India

[2] Div. Fruits Hortic. Technol., Indian Agric. Res. Inst., New Delhi, India

[3] Dep. Post Harvest Technol., K.R.C. Coll. Hortic., Arabhavi, Univ. Hortic. Sci., Bagalkot, Karnataka, India, barman.kalyan@gmail.com

* Correspondence and reprints

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Pruning affects fruit yield and postharvest quality in mango (*Mangifera indica* L.) cv. Amrapali.

Abstract – Introduction. Mango fruits grown under high-density planting show a progressive decline in crop yield after 14–15 years, due to overcrowding of canopies, which suggests regular canopy management is necessary. Hence, the effects of pruning treatment on fruit yield and quality of 'Amrapali' mango were studied in India over two consecutive years, 2010 and 2011. **Materials and methods**. Mango trees were subjected to pruning (removal of 50 cm of shoot from the apex) in the month of September 2009 with unpruned trees serving as control. Fruits were harvested at the commercial maturity stage and quality parameters were assessed both in fresh fruits and following ripening at room temperature [(35 ± 2) °C and (80 ± 5)% RH)]. **Results and discussion**. Fruit yield of pruned trees was found to decrease during the first year compared with the fruit yield of unpruned trees; later on, it increased during the second year. Pruning resulted in significantly higher fruit weight, fruit firmness, total carotenoids, antioxidant capacity and total phenolic content. Early maturity of fruits was observed from unpruned trees with faster color change, higher total soluble solids and lower titratable acidity. The fruits harvested from pruned trees showed slower ripening, and lower respiration, ethylene evolution rate and enzyme activity as compared with fruits from unpruned trees. Both anthracnose and stem-end rot disease percentage were reduced in ripe fruits from pruned trees. **Conclusion**. Pruning treatment appears to be an alternative strategy to obtain better yield and quality in densely populated old mango orchards.

India / *Mangifera indica* / fruits / yields / quality / carotenoids / phenolic content / antioxidants / enzyme activity

L'élagage affecte le rendement en fruits et la qualité après récolte de la mangue (*Mangifera indica* L.) cv. Amrapali.

Résumé – Introduction. Les manguiers cultivés en plantations à haute densité présentent des rendements qui diminuent progressivement après 14–15 ans en raison du surdéveloppement des frondaisons ; cela justifierait une gestion régulière de leur canopée. Par conséquent, les effets d'un traitement d'élagage sur le rendement en fruits et sur la qualité de la mangue Amrapali ont été étudiés en Inde au cours de deux années consécutives, 2010 et 2011. **Matériel et méthodes**. Des manguiers ont été élagués (suppression de 50 cm à partir de l'extrémité des rameaux) en septembre 2009 ; des arbres non élagués ont servi de traitement témoin. Les fruits ont été récoltés au stade de maturité commerciale et les paramètres de qualité ont été évalués à la fois sur le fruit frais et sur le fruit après maturation à la température ambiante [(35 ± 2) °C et (80 ± 5) % HR)]. **Résultats et discussion**. Le rendement en fruits des arbres élagués a diminué la première année, puis il a augmenté l'année d'après. L'élagage a entraîné un poids de fruits, une fermeté des fruits, des caroténoïdes totaux, une capacité antioxydante et une teneur totale en composés phénoliques significativement plus élevés que les paramètres mesurés sur la production des arbres témoins. Une maturité précoce des fruits a été observée pour les arbres non élagués avec un changement de couleur rapide, une teneur en solides solubles totaux plus élevée et une acidité titrable inférieure. Les fruits récoltés sur les arbres élagués ont présenté une lente maturation, une faible respiration, un faible taux d'évolution de l'éthylène et de l'activité enzymatique par rapport aux fruits des arbres non taillés. Les pourcentages d'anthracnose et de pourriture apicale de la tige ont été réduits dans les fruits mûrs des arbres élagués. **Conclusion**. Le traitement d'élagage pourrait être une stratégie envisageable pour obtenir de meilleurs rendements et qualités du fruit en vergers âgés de forte densité.

Inde / *Mangifera indica* / fruits / rendement /qualité / caroténoïde / teneur en phénols / antioxydant / activité enzymatique

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1. Introduction

The mango (*Mangifera indica* L.), commonly known as 'King of the fruits' in India, is an important tropical fruit crop belonging to the family Anacardiaceae. Because of its delicious taste and appealing aroma, it is ranked as one of the choicest fruits in the national and international markets. Unlike temperate fruit crops, the concept of high-density planting has gained momentum in mango after the development of 'Amrapali' (Dashehari × Neelum), a distinctly dwarf and regular-bearing hybrid [1, 2]. Although high-density planting has been standardized for this cultivar (2.5 m × 2.5 m), after a profitable yield for up to 14–15 years, it shows progressive decline in yield due to overcrowding of canopies [3]. The fruit production and quality depends on several factors prevailing during their growth and development. Amongst the several factors, pruning is an important cultural operation for obtaining quality yield from the fruiting trees, which involves judicious removal of vegetative parts. An unpruned tree becomes very large, which inhibits light penetration inside the canopy. As a result, leaf sprout is decreased, photosynthetic activity remains low and high incidence of pests and disease occurs due to high relative humidity [4]. Sunlight not only influences the flowering and fruit set, but also enhances quality and color development of fruits [5]. For this reason, fruits in the top of the tree always have better quality than fruits in the lower shaded part of the canopy [6]. Nowadays, due to consumer concern for quality, the concept and priorities of fruit production are changing the world over.

Both the intrinsic and extrinsic attributes are integral parts of fruit quality; previously, several studies have been conducted on pruning in the mango tree in relation to better light penetration, fruit set and yield in pruned trees [7–12]. These studies mainly focused on vegetative growth and fruiting behavior: fruit quality received either no attention or only superficial attention (shape, size, total soluble solids, acidity and aroma). However, beyond routine information, there is increasing interest on the part of consumers in the health benefits of fruits such as carotenoids, phenolics and antioxidant capacity, and these components are strongly linked with the postharvest physiology of mature or ripened fruits. Therefore, our study was undertaken to evaluate the fruit quality and physiological profile of mature and ripened 'Amrapali' mango fruits as affected by pruning.

2. Materials and methods

Our studies were conducted at the Indian Agricultural Research Institute, New Delhi (India), for two consecutive years (2010 and 2011) on 17-year-old 'Amrapali' mango plants grafted on 'Kurukkan' rootstocks and planted at a spacing of 2.5 m × 2.5 m. Selected trees of uniform canopy height (≈ 4.0 m) and spread (≈ 3.5 m) were used. Trees were subjected to uniform pruning (removal of 50 cm of shoot from the apex) during the first week of September 2009 with unpruned trees as control. All trees in a block received the same pruning treatment and uniform cultural practices throughout the experimentation period. Twenty trees were selected randomly (5 each for pruned and unpruned with two replications) at the center of a block and 15 fruits per tree were used. Mango flowering in 'Amrapali' in Delhi conditions takes place between 15th and 30th February. The impact of pruning on flowering and fruit set under high density of 'Amrapali' mango has already been studied by Kumar *et al.* [13]. Therefore, the present work focused only on the effect of pruning on fruit yield and postharvest quality in mango.

Fruits of each tree under study were picked at the commercial maturity stage on 15th July in both the years. After harvesting, fruits were immediately transported to the handling and storage laboratory. Healthy and uniform size fruits free from diseases, insects, bruises and cuts were selected for experimentation.

Selected fruits were divided into two lots (each lot containing 100 fruits). The first lot (mature green fruits) was subjected to analysis immediately after harvesting. Fruits of the second lot were wrapped individually in newspaper, packed in a single layer in commercial Corrugated Fiber Board (CFB)

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boxes and kept for ripening at room temperature (35 ± 2 °C temperature and 80 ± 5% relative humidity). The fruits reached the eating soft ripening stage at the 6th day of storage (change in color from green to light yellow). Fruit quality was evaluated on twenty ripened fruits per lot in respect of various parameters.

2.1. Physical parameters

The color of the fruit peel was determined randomly using the Hunter Color Lab System (model: Miniscan XE PLUS, Hunter Associates Laboratory Inc., USA). While using the Hunter Color Lab system, measurements were taken from the equatorial part of the fruit. The results of two determinations for each fruit were expressed as L^* (0, dark; 100, white), a^* (negative value, green; positive value, red) and b^* (negative value, blue; positive value, yellow). Fruit weight was measured by an electronic weighing balance. Firmness was measured by texture analyzer (model: TA + Di Stable Micro Systems, UK) using a 2-mm-diameter stainless steel cylinder probe in compression mode with pre-test, test and post-test speeds of (5, 2 and 10) mm·s^{-1}, respectively. Punctures were made at the sinus, shoulder and middle parts of the fruits. The results were expressed in Newton [14].

2.2. Respiration and ethylene evolution rates

Respiration and ethylene evolution rates were measured by placing each fruit in a 1-L-capacity hermetically sealed container for 1 h. From the headspace atmosphere gas, ethylene was quantified using a gas chromatograph (model: Hewlett Packard 5890, USA) equipped with a flame ionization detector (FID) and the results were expressed in mL·kg^{-1}·h^{-1}. The respiration rate was quantified using an auto gas analyzer (model: Checkmate 9900 O_2/CO_2, PBI Dansensor, Denmark) and the results were expressed in mL CO_2·kg^{-1}·h^{-1}.

2.3. Biochemical parameters

Total soluble solids (TSS) were determined using a Fisher hand refractometer at 20 °C and results were expressed as °Brix. Titratable acidity was determined by the titration method with 0.1 N NaOH up to pH 8.1, using 2 g of homogenized pulp in 100 mL distilled water. The results were expressed as percentage of citric acid [15]. Total carotenoid content was determined by extracting carotenoids from fruit pulp with a mixture of petroleum ether and acetone (3:1) and assayed colorimetrically by spectrophotometer (model: double-beam UV–VIS 70455, Labomed Inc., USA) at 452 nm [16]. The results were expressed as mg·100 g^{-1} fw (fresh weight). Antioxidant capacity was measured by the cupric reducing antioxidant capacity (CUPRAC) method [17]. The samples were prepared by taking 2 g pulp and adjusting the volume up to 10 mL with 80% ethanol. Then, 1 mL each of copper chloride solution (10^{-2} M), neocuproine solution (7.5×10^{-3} M), ammonium acetate buffer (pH 7.0), distilled water and antioxidant sample (or standard) solution (100 µL) were added to a test tube. The absorbance was recorded at 450 nm against a reagent blank and the results were expressed as µmol Trolox equivalent·100 g^{-1} fw. Total phenolic content (80% ethanol extract) was estimated spectrophotometrically using Folin-Ciocalteu reagent and results were expressed as µg gallic acid equivalent·g^{-1} fw [18].

2.4. Enzyme extraction and assay

Samples were prepared by homogenizing 10 g pulp in 20 mL cold (4 °C) 0.1 M sodium citrate (pH 4.6) containing 1 M NaCl, 13 mM EDTA, 10 mM β-mercaptoethanol and 1% (w/v) PVP-40 (Polyvinylpyrrolidone-40). After centrifugation, the supernatant was recovered and an aliquot (2 mL) desalted on a Sephadex G-25 (1 cm × 10 cm) column prior to assay for enzyme activities except pectin methylesterase (PME). For PME, undesalted fruit extract was used. Polygalacturonase (PG), β-galactosidase and PME were assayed as described by Lazan *et al.* [19]. Polygalacturonase activity was estimated by measuring the specific viscosity loss and the amount of reducing sugar formed [20]. Briefly, the assay mixture comprised 7.5 mL of 1.5% (w/v) polygalacturonic acid (pH 5.2), 1 mL 0.6 M NaCl, one

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to two drops of toluene, 1.5 mL or 3 mL desalted extract of ripe fruits and extracting buffer to volume, and flow times were measured by using a Euroglass viscometer (Büiten Watersloot 341, Delft, Holland) at regular intervals for the first 3 h and subsequently after (7, 10, 24, 34, 48 and 50) h of incubation at 37 °C. For PG activities, the reducing sugar released was estimated by the cyanoacetamide method [21].

2.5. Disease incidence

To study disease incidence, fruits were stored at room temperature unless the disease was visually spotted both in fruits from pruned and unpruned trees (11 days after harvesting). Stem-end rot (caused by *Botryodiplodia theobromae*) lesions appearing at the stem-end of the fruits and anthracnose (caused by *Colletotrichum gloeosporioides*) lesions seen on the peel of the fruits were rated as incidence percentage (percentage of the fruit affected).

2.6. Statistical analysis

The experiment was repeated during two consecutive years; however, data from the two experiments were analyzed separately as initial statistical analysis showed significant differences between experiments for some of the parameters evaluated. The data obtained under treatments in respect to various parameters during analytical study of matured green and ripened fruits were subjected to analysis of variance (ANOVA) with treatments as sources of variation. Mean comparisons among treatments were performed using the HSD Tukey test at a significance level of $p < 0.05$. All analyses were performed with the SPSS software package version 18.0 for Windows.

3. Results and discussion

3.1. Fruit weight

Pruning significantly affected fruit weight in both the years. Average weight was found to be higher in fruits obtained from pruned trees in comparison with unpruned trees (*table I*). On average, ≈ 15% higher weight was recorded in fruits obtained from pruned trees compared with control. A slightly higher fruit weight fluctuation was found between the two fruiting seasons in pruned trees compared with control.

Being a tropical fruit, mango responds well to pruning operations; 'Amrapali' is a regular-bearing mango hybrid and grown mostly under high-density planting systems. Average fruiting (number of fruits per tree) was recorded during the first year after pruning (data not shown). The higher fruit weight in pruned trees may be due to an improved microclimate and higher photosynthetic rates [12]. Although the photosynthetic rate was not recorded in our experiment, as reported by other authors, variation in the radiation interception of the plant canopy (leaves growing in the shade *vs.* exposed to sunlight) can affect fruit size through variation in supply of assimilated carbon [22]. However, average fruit weight was found to decrease in the second year due to an increase in the number of fruits per tree (data not shown), but still remained higher in pruned trees.

3.2. Fruit yield

Fruit yield (kg per tree) was significantly affected by pruning (*table I*). During the first year, pruning decreased fruit yield in comparison with unpruned trees, although a minimum difference in the yield gap of pruned and unpruned trees was observed during the second year. Pruned trees registered a sharp increase in fruit yield during the second year, and it was ≈ 9.5% higher than control trees.

Unlike the other mango varieties, 'Amrapali' utilizes its rainy season growth for developing fruiting shoots. After harvesting, new growth (fruiting shoots) requires 4–5 months of inductive (cool) temperatures for effective flowering and fruiting [23]. In our experiment, the pruning was performed during September and emergence of new shoots continued up to the middle of November. In New Delhi conditions (the site of experimentation), 'Amrapali' mango flowering starts from the last week of February, which had not fulfilled the inductive

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Table I.
Effects of pruning on physical and physiological parameters of 'Amrapali' mango fruits. Data are the means ± standard errors of three replicate determinations (n = 3).

Fruit type	Treatments	Fruit weight (g)		Fruit yield/tree (kg)		Respiration rate (mL $CO_2 \cdot kg^{-1} \cdot h^{-1}$)		Ethylene evolution rate ($\mu L \cdot kg^{-1} \cdot h^{-1}$)		Firmness (N)	
		2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Mature green	Pruned	155.4 ± 1.29 a	151.93 ± 1.75 a	30.78 ± 1.24 a	35.73 ± 1.59 b	60.17 ± 1.55 a	55.41 ± 1.99 a	–	–	18.77 ± 0.39 a	19.24 ± 0.16 a
	Unpruned	130.7 ± 2.15 b	128.23 ± 2.52 b	34.75 ± 0.83 b	32.63 ± 1.44 a	77.51 ± 2.20 b	74.51 ± 1.63 b	–	–	16.89 ± 0.31 b	17.14 ± 0.26 b
Ripe	Pruned	–	–	–	–	166.27 ± 2.54 c	149.84 ± 4.86 d	0.372 ± 0.034 a	0.341 ± 0.042 a	15.29 ± 0.32 c	16.01 ± 0.24 c
	Unpruned	–	–	–	–	215.82 ± 6.19 e	189.41 ± 7.72 f	0.865 ± 0.049 b	0.826 ± 0.047 b	13.71 ± 0.46 d	14.87 ± 0.58 c

Treatment values with the same letters are not significantly different ($p < 0.05$) as per the HSD Tukey test.

temperature requirement; this may be one of the possible reasons for poor yield during the first year after pruning. Other authors also reported poor fruit yield in 'Dashehari' mango during the first year after pruning, which kept increasing in the successive years [8]. The comparatively small canopy area during the first year in pruned trees may also have contributed to poor yield.

3.3. Respiration and ethylene evolution rates

A significant difference was recorded in the respiration rate of matured green and ripened fruits obtained from pruned and unpruned trees during both the years (*table I*). Both matured green and ripened fruits obtained from unpruned trees showed relatively higher respiration rates compared with pruned trees. Despite fluctuation in the fruit respiration rate, during the two harvesting seasons the trend remained the same and fruits harvested from pruned trees showed lower respiration rates than the control. There was a ≈ 3 times higher respiration rate in ripened fruits than matured green fruits both in the pruned and unpruned trees. No ethylene was detected in matured green fruits freshly harvested from pruned and unpruned trees. However, a significant difference in the ethylene evolution rate was recorded later on in fruits obtained from pruned and unpruned trees. The ripe fruits obtained from unpruned trees showed more than double the respiration rate compared with pruned ones during both the production years (*table I*).

The pronounced difference in respiration and ethylene evolution rates of mango fruits (mature green and ripe) harvested from pruned and unpruned trees indicates the onset of delayed maturity/ripening under pruned conditions. It is expected that pruning stimulated the vegetative growth and influenced the reproductive behavior of mango trees. The pruning-mediated vegetative growth might have increased the levels of auxins and gibberellins, which in turn affected flowering, accelerating fruit growth but retarding the aging process [24]. Furthermore, the higher respiration and ethylene evolution rates in fruits from unpruned trees were probably due to the higher daily mean temperatures during the cropping season from March to July. Other authors also recorded higher temperatures inside unpruned mango tree canopies compared with pruned trees [12]. As regards the further rise in respiration and ethylene evolution rates of ripened fruits over matured ones, this may be explained by an acceleration in physiological activities, which is a well-known established scientific fact [25].

3.4. Fruit firmness

Irrespective of the ripening stage, fruit firmness was significantly affected by pruning operations during both the production years and remained higher in fruits harvested from pruned trees (*table I*). Reduction in firmness was recorded in both categories of fruits during ripening at room temperature. However, this reduction was significantly higher in the fruits harvested from unpruned trees compared with pruned trees. In the ripened fruits, firmness was found to vary between (15 and 16) N in the case of fruits from pruned trees and (13 and 15) N in unpruned trees. Among the fruiting seasons, comparatively higher fruit firmness was observed in matured fruits harvested in 2011. Mature fruits from the pruned trees showed ≈ 11% higher firmness over control, while the corresponding difference was ≈ 9% in the case of ripe fruits.

Fruit firmness is a multifactorially-influenced phenomenon *viz*. fruit size, number and size of cells, volume of intercellular space, specific gravity, harvest maturity, dry matter (pectin), mineral content, and enzyme activity [26]. In our experiment, fruits harvested from pruned trees gave the highest firmness. It is expected that pruning operations might have increased soil nutrient uptake, and altered enzyme activities, fruit histology and specific gravity. Pruning-mediated higher translocation of calcium is also reported in apple. The presence of calcium in fruit is known to strengthen the middle lamella and lower the activities of cell wall-degrading enzymes such as pectin methylesterase and polygalactouronase [27]. In our study, the higher enzyme activities (PME and PG) further support the reason for lower fruit firmness under unpruned conditions.

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3.5. Total soluble solids (TSS) and titratable acidity (TA)

A relatively higher degree of TSS and lower percentage of TA was recorded both in matured green and ripened fruits harvested from unpruned trees (*table II*). Total soluble solids was found to be nearly 15% higher in ripe fruits obtained from unpruned trees compared with pruned while, juxtaposed with TSS, 28% higher TA was recorded in fruits obtained from pruned trees. In comparison with matured green fruits, ripened fruits recorded ≈ 2-fold higher TSS and ≈ 8-fold lower TA during both the years under pruned and unpruned conditions.

Although the starch content was not analyzed in our investigation, the sharp increase in total soluble solids in fruits obtained from pruned and unpruned trees during the first six days of ripening indicates rapid starch degradation. Furthermore, the higher recovery of TSS in fruits from unpruned trees might be attributed to faster starch degradation compared with fruits from pruned trees. The effect of higher respiration and ethylene evolution rates is known to accelerate enzyme activities and cause faster degradation of starch. Higher respiration, ethylene evolution and enzyme activities (in fruits from unpruned trees) in our experiment support this assumption. Again, the higher temperature inside the unpruned tree canopy might have facilitated increased enzyme activity, which degraded starches into simple sugars, and thus higher TSS recovery. Other authors also reported that pruning applications negatively affected TSS content in peach [28–30]. The synthesis and accumulation of organic acids in fruits are influenced by several factors, but the microclimate of the canopy and phytohormones are the major ones. The level of organic acids becomes more pronounced during the early fruit growth period [31]; later on, the concentration decreases for the remainder of the growth period [32]. Since the physiological fruit maturity under pruned conditions arrived late in our investigation, the reason for higher titratable acidity in pruned conditions is quite obvious.

3.6. Total carotenoid content

The total carotenoid content was found to be significantly higher in green matured fruits obtained from pruned trees as compared with unpruned ones (*table II*). The ripened fruits obtained from both pruned and unpruned trees showed higher levels of carotenoids. This increase in the total carotenoid content of ripened fruits over matured green fruits was two and three times higher in the case of pruned and unpruned conditions, respectively.

Comparatively better performance of fruits from pruned trees in respect of total carotenoid content may be due to elevation in plant photosynthesis and the congenial microclimate created through pruning. Vegetative growth also seems to play a similar dual role in contributing to fruit quality; on one hand, by being a source for the energy and, on the other, by being a sink for nutrients and other metabolites during the course of fruit development, possibly through the hormonal pathway. Geranylgeranyl diphosphate (GGDP) is the precursor for carotenoids, and the proximity of potassium (K) as a GGDP stimulant has already been established by several authors [33]. As stated earlier, quality is a multifactorially-influenced phenomenon and the carotenoid level in fruits might have influenced other factors besides potassium-mediated translocation of photosynthates. Although we have explained a couple of factors in relation to fruit carotenoid content, this aspect needs further research attention for better understanding of the carotenoid profile in mango grown under different sets of agro-techniques (training, pruning, water and nutrient management).

3.7. Antioxidant capacity

Pruning significantly influenced the antioxidant capacity of the mango fruits and the highest levels [(424.48 and 536.64) µmol Trolox·100 g^{-1} fw] were recorded in matured green and ripened fruits, respectively, under pruned conditions (*table II*). A marked difference was recorded in the antioxidant capacity level of the fruits obtained from pruned and unpruned trees, being

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Table II.
Effects of pruning on biochemical parameters of 'Amrapali' mango fruits. Data are the means ± standard errors of three replicate determinations (n = 3).

Fruit type	Treatments	TSS (°Brix)		Titratable acidity (% citric acid)		Total carotenoids (mg·100 g^{-1} fw)		Antioxidant activity (µmol Trolox·100 g^{-1} fw)		Total phenols (µg gallic acid·g^{-1} fw)	
		2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Mature green	Pruned	10.3 ± 0.15 a	9.8 ± 0.20 a	0.70 ± 0.02 a	0.74 ± 0.03 a	5.15 ± 0.09 a	5.32 ± 0.12 a	401.15 ± 9.52 a	424.48 ± 13.90 a	421.2 ± 19.22 a	471.25 ± 13.37 b
	Unpruned	11.9 ± 0.21 b	12.0 ± 0.18 b	0.56 ± 0.02 b	0.58 ± 0.02 b	3.08 ± 0.19 b	3.17 ± 0.14 b	264.84 ± 12.06 b	287.76 ± 22.93 b	317.92 ± 11.58 c	374.17 ± 9.85 d
Ripe	Pruned	22.8 ± 0.26 c	21.9 ± 0.25 c	0.17 ± 0.01 c	0.18 ± 0.01 c	11.24 ± 0.20 c	12.18 ± 0.21 c	506.75 ± 12.16 c	536.64 ± 14.89 c	646.67 ± 7.51 e	686.25 ± 18.21 e
	Unpruned	25.9 ± 0.18 d	25.4 ± 0.55 d	0.11 ± 0.01 d	0.14 ± 0.01 d	9.57 ± 0.19 d	9.98 ± 0.14 d	401.97 ± 13.63 d	442.08 ± 17.89 e	533.75 ± 13.52 f	593.75 ± 9.01 g

Treatment values with the same letters are not significantly different ($p < 0.05$) as per the HSD Tukey test.

more than two times higher under pruned conditions. The difference in the antioxidant capacity level of the fruits obtained from pruned and unpruned trees was much greater in matured green fruits compared with ripe ones.

Total carotenoids, phenolic compounds and ascorbic acid are mainly responsible for the total antioxidant capacity of the fruits [34]. The higher level of antioxidant capacity in fruits obtained from pruned trees at the mature green and ripe stages was found to be high, as the level of functional compounds such as total carotenoids and phenolics were increased under pruned conditions. Although photosynthetic and mineral absorption was not recorded in our experiment, it has been shown that pruning in mango improves mineral absorption and translocation, photosynthetic activities, and net assimilation of carbohydrates [35]. Generally, variation in the total antioxidant capacity in fruits persisted due to different preharvest treatments, which is much greater during fruit development and subsequently narrows down towards ripening. In our experiment, the findings contrast with this hypothesis; this may be explained by the different nature of mango crops (climacteric peak and carotenoid dominant ripening). Lower respiration and ethylene evolution rates were also observed in fruits from pruned trees; both these activities are known to lower the levels of antioxidant activities contributing substrates through the catabolic process.

3.8. Total phenolic content

The total phenolic content followed a similar trend to the case of the antioxidant capacity level of fruits harvested from pruned and unpruned trees. Pruned trees produced fruits with higher levels of total phenolics, which were in the range of (421.25 to 471.25) µg gallic acid·g^{-1} fw in green matured fruits (*table II*). Compared with unpruned trees, 32% and 21% higher total phenolic contents were recorded in matured green and ripened fruits, respectively, harvested from pruned trees.

Phenolics are secondary plant metabolites known for their role in plant defense mechanisms against stress [36]. It is important to note that higher recovery of total phenolics was recorded under pruned conditions, both in mature and ripened fruits. Further, there was a noticeable difference in the total phenolic content (higher during the first year after pruning) in fruits harvested from pruned trees during 2010 and 2011. It is presumed that pruning imparted shock/stress to the trees and consequently elevated the synthesis of phenolics. The gradient of stress in pruned trees might have minimized during the second year; thus, less phenolics were produced, as recorded in this study.

3.9. Enzyme activities

Different levels of pectin methylesterase (PME), polygalacturonase (PG) and β-galactosidase activities were recorded in matured green and ripened fruits obtained from pruned and unpruned trees during both the years (*table III*). The activity of PME was low both in matured and ripened fruits harvested from pruned trees compared with control. Very high PME activity was detected in ripened fruits compared with matured green fruits under both the treatments. The activities of PG in all the green matured and ripened fruits ranged from (1.4 to 6.2) nkatal·g^{-1} fw, with the higher activity found in ripened fruits obtained from unpruned trees. In ripened fruits, a substantial 3- and 2.5-fold increase was registered compared with matured green fruits obtained from pruned and unpruned trees, respectively. A sharp increase (105%) in PG activity was registered in matured green fruits harvested from unpruned trees compared with pruned ones. The activity of β-galactosidase in green mature and ripened fruits, like PG, also varied with the pruning operation and fruit maturity stage. A comparatively lower β-galactosidase activity level was recorded both in mature and ripened fruits obtained from pruned trees. Regardless of the treatment, an increase in β-galactosidase activity was observed in ripened mango fruits. At ripening, a marked difference (> 60% higher) was observed in fruits harvested from unpruned trees. As

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Table III.
Effects of pruning on enzymatic activity of 'Amrapali' mango fruits. Data are the means ± standard errors of three replicate determinations (n = 3).

Fruit type	Treatments	Pectin methylesterase activity (nEq·s^{-1}·g^{-1} fresh weight)		Polygalacturonase activity (nkatal·g^{-1} fresh weight)		β-Galactosidase (nkatal·g^{-1} fresh weight)	
		2010	2011	2010	2011	2010	2011
Mature green	Pruned	428 ± 31 a	416 ± 26 a	1.6 ± 0.3 a	1.4 ± 0.4 a	3.4 ± 0.3 a	3.1 ± 0.4 a
	Unpruned	506 ± 38 b	527 ± 46 b	2.7 ± 0.5 b	3.4 ± 0.3 b	6.4 ± 0.8 b	5.7 ± 0.5 b
Ripe	Pruned	712 ± 73 c	676 ± 57 c	4.8 ± 0.6 c	4.5 ± 0.4 c	27 ± 4.8 c	25 ± 3.7 c
	Unpruned	789 ± 55 d	724 ± 24 c	6.2 ± 0.3 d	5.7 ± 0.3 d	42 ± 6.7 d	39 ± 4.1 d

Treatment values with the same letters are not significantly different ($p < 0.05$) as per the HSD Tukey test.

higher respiration and ethylene evolution rates were recorded in fruit harvested from unpruned trees, it could have hastened the climacteric peak and β-galactosidase activity of fruits.

Mango is a tropical fruit; based on the climacteric peak during ripening, it has been placed in the low softening group of fruits [37]. Fruit softening is very dependent on enzyme activities besides other reasons. Higher ethylene evolution, respiration rate and total soluble solids content and lower firmness in fruits harvested from unpruned trees indicate a faster ripening process. Here, it seems that pectin/starch modifications might be one of the reasons for the observed differential softening rates amongst the fruits harvested from pruned and unpruned trees. In our study, greater activities of PME, PG and β-galactosidase are also concomitant with early onset of maturity as well as the climacteric peak in mangoes harvested from unpruned trees compared with pruned ones [38].

3.10. Fruit color

Mango peel color is a variety-specific character and different cultivars exhibit a range of colors during fruit development, maturity and ripening. However, the Amrapali mango hybrid does not show much variation in its peel color during fruit development and remains dark green at maturity. At ripening, the dark green peel color turns into light yellow or sunset yellow depending upon the temperature and humidity prevailing during ripening. Regardless of the maturity/ripening conditions, higher L^* values and lower a^* and b^* values were recorded in fruits obtained from unpruned trees (*table IV*). This indicated that there was an early onset of ripening and faster degradation of peel chlorophyll in fruits sourced from unpruned trees.

Variation in L^*, a^* and b^* values was observed both in mature green and ripened fruits obtained from pruned and unpruned trees. However, it is important to note that the variation was much more contrasted in ripened fruits than in mature green fruits. The reason for this may be that the variation occurring in mature green fruits pertains to the intensity of the sunlight, while in ripened fruit, variation in color is an ethylene-governed phenomenon. Ethylene was not detected in mature green fruits harvested from pruned and unpruned trees during both the years. During ripening, ethylene evolution was detected two days earlier in fruits from unpruned trees compared with pruned ones. Ethylene is known for degradation of chlorophyll via chlorophyllase enzyme activity acceleration during fruit ripening [39].

3.11. Fruit diseases

Disease incidence was significantly affected by pruning treatment. Pruning reduced the disease incidence percentage both of anthracnose and stem-end rot in ripe fruits stored at room temperature for 11 days. Compared with stem-end rot, a higher percentage of

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Table IV.
Effects of pruning on fruit color and postharvest disease incidence of 'Amrapali' mango fruits. Data are the means ± standard errors of three replicate determinations (n = 3).

Fruit type	Treatments	L^*		a^*		b^*		Anthracnose incidence (%)		Stem-end rot incidence (%)	
		2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Mature green	Pruned	39.14 ± 2.31 a	40.73 ± 1.39 a	– 6.01 ± 1.28 a	– 8.41 ± 1.47 a	18.07 ± 1.82 a	18.76 ± 1.64 a	–	–	–	–
	Unpruned	41.64 ± 1.25 a	43.69 ± 1.47 a	– 12.05 ± 0.25 b	– 12.87 ± 1.53 b	20.18 ± 2.47 b	19.70 ± 1.29 b	–	–	–	–
Ripe	Pruned	50.16 ± 0.92 b	53.25 ± 1.21 b	– 9.29 ± 0.19 c	– 8.91 ± 1.04 c	15.74 ± 1.53 c	16.49 ± 2.25 c	56.45 ± 0.99 a	57.82 ± 0.92 a	22.04 ± 0.75 a	24.48 ± 0.87 a
	Unpruned	65.75 ± 2.19 c	69.84 ± 1.57 c	2.72 ± 2.32 d	7.08 ± 1.26 e	30.13 ± 3.13 d	35.22 ± 1.83 d	88.62 ± 1.11 b	86.26 ± 0.67 b	45.06 ± 0.98 b	48.59 ± 0.85 b

Treatment values with the same letters are not significantly different ($p < 0.05$) as per the HSD Tukey test.

anthracnose incidence was observed both in fruits from pruned and unpruned trees (*table IV*). While considering the effectiveness of pruning against postharvest diseases, it proved more suppressive for stem-end rot compared with anthracnose.

The reducing effects of pruning on fruit disease have been reported earlier [40]. The most serious problems for mango growers across all the growing regions are anthracnose and stem-end rot, caused by *Colletotrichum gloeosporioides* and *Botryodiplodia theobromae*, respectively. Anthracnose and stem-end rot infection occur during fruit development and remain quiescent until fruit ripening [41]. Lower anthracnose incidence with pruning would have been partly because of a reduction in the disease inoculum load, possibly through better penetration of sunlight, which reduced the preharvest growth of the organisms down the inflorescence and peduncle across the canopy. Another reason for better protection of fruits from anthracnose and stem-end rot, especially in pruned trees, may be associated with rains (less precipitation retention) [42]. Further, pruning might have increased the natural resistance of fruit to disease development during ripening through the enhanced antifungal compound activity of phenolic compounds [43].

4. Conclusion

According to our results, almost all the mango quality parameters were significantly influenced by pruning treatment. Pruning of 'Amrapali' mango trees resulted in significant increase in fruit weight and other quality attributes as compared with fruits harvested from unpruned trees. Two-fold higher total carotenoid content and antioxidant activities were observed in fruits harvested from pruned trees compared with unpruned ones. Further, lower physiological activity and higher fruit firmness (desirable self-life contributing factors) were recorded in fruits harvested from pruned trees. As regards future work, the long-lasting effect of pruning on yield and various postharvest quality parameters requires further research attention.

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La poda afecta a la producción de frutos y a la calidad postcosecha del mango (*Mangifera indica* L.) cv. Amrapali.

Resumen – **Introducción**. Los mangos cultivados en plantaciones con alta densidad presentan rendimientos que disminuyen progresivamente tras los 14–15 años, debido al subdesarrollo de la foliación, lo que justificaría una gestión regular de su dosel. Por lo tanto, se estudiaron los efectos de un tratamiento de poda en el rendimiento en la producción de frutos y en la calidad del mango Amrapali en la India durante dos años consecutivos, 2010 y 2011. **Material y métodos**. Los mangos se podaron (con una supresión de 50 cm a partir del extremo de las ramas) en septiembre de 2009; otros árboles no podados sirvieron de tratamiento de control. Las frutas se recolectaron en un estado de madurez comercial y se evaluaron los parámetros de calidad tanto de la fruta fresca como de la fruta tras su maduración a temperatura ambiente [(35 ± 2) °C y (80 ± 5) % HR)]. **Resultados y discusión**. La producción de frutas de los árboles podados disminuyó el primer año y aumentó al año siguiente. La poda incrementó significativamente el peso de las frutas, su firmeza, los carotenoides totales, la capacidad antioxidante y el contenido total en compuestos fenólicos, con respecto a los parámetros medidos en la producción de los árboles de control. En los árboles no podados se observó una maduración precoz, con un cambio de color rápido, un contenido en sólidos solubles totales más elevado y una acidez valorable inferior. Las frutas recolectadas de los árboles podados presentaron una maduración lenta, una respiración débil y un índice reducido de etileno y actividad enzimática con respecto a los árboles no podados. Los porcentajes de antracnosis y de podredumbre apical de las ramas eran menores en las frutas maduras de los árboles podados. **Conclusión**. El tratamiento de poda podría ser una estrategia a considerar para obtener una mayor producción y una mejor calidad del fruto en cultivos de edad avanzada con alta densidad.

India / *Mangifera indica* / frutas / rendimiento / calidad / carotenoides / contenido fenólico / antioxidantes / actividad enzimática

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