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# Reduction of Preharvest and Postharvest Losses of Sweet Orange (*Citrus sinensis* L. Osberck) Using Hexanal in Eastern Tanzania

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## 15.1 Introduction

Fruits are rich in phytochemicals that protect human populations against diseases (Hung et al. 2004; Dauchet et al. 2006; Bellavia et al. 2013). Nutrients contained in fruits include essential vitamins, minerals, antioxidants, fibers, and carbohydrates that improve the quality of the human diet (Barrett 2007). For example, sufficient daily consumption of fruits can reduce the risks of diabetes, hypertension, heart diseases, and certain types of cancer (Bazzano et al. 2002; Yao et al. 2004). According to FAO/WHO (2003), up to 2.7 million lives could potentially be saved each year with sufficient intake of fruits and vegetables. Much of the world's population, however, does not consume the recommended intake of at least 100 g per day of fruits daily.

Global production of citrus fruits increased from 144 876 944 tonnes in 2015 to 146 429 018 tonnes in 2016 (FAO 2017). This was coupled with increased global demand for fresh fruits (Weinberger and Lumpkin 2007). Sweet orange (*Citrus sinensis* L. Osberck) is an important tropical fruit with high global demand. Sweet oranges are consumed fresh or processed as juice. Although citrus production increased moderately in several countries in the last decade, it fell in the USA. However, citrus fruit continues to be an important crop for satisfying food and nutrition needs (United States Department of Agriculture 2018).

Sweet orange is a good source of potassium, folate, and vitamin C (Turner and Burri 2013). Vitamin C is an antioxidant that lowers risks of cancer, cataract formation, and heart-related diseases (Harats et al. 1998; Jacques et al. 1997). Folate is necessary for DNA and protein synthesis (Turner and Burri 2013), while potassium helps to maintain normal blood pressure. Sweet orange also contains phenolic compounds that are important antioxidants (Rapisarda et al. 1999; Turner and Burri 2013).

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Production of sweet orange is a source of employment, income, and livelihood to large, medium, and smallholder farmers in various parts of the globe. Global production of sweet orange increased from 116 million tonnes in 2008 to 124 million tonnes in 2017 (FAO 2017). However, despite the demand due to the nutritional and health benefits, many fruits are highly seasonal and perishable with high preharvest and postharvest losses and wastages (Idah and Aderibigbe 2007). Postharvest losses in fruits and vegetables were estimated to be 30–40% in developing countries (Karim and Hawlader 2005). This chapter presents findings from trials on the effectiveness of different preharvest and postharvest treatments on orange fruit quality. The chapter also provides background information on production, socioeconomic importance, and constraints to orange production in Tanzania.

## 15.2 Socioeconomic Importance and Production of Sweet Orange in Tanzania

Tanzania is a major sweet orange producer in East Africa (FAO 2017). Sweet orange is an important crop for smallholder and medium-scale farmers in Tanzania as a source of income, livelihood as well as food, and for nutrition security in rural and urban areas in Tanzania. Major sweet orange producers are Tanga, Pwani, and Morogoro regions that account for 52%, 16%, and 7% of the total national production, respectively (URT 2012). Orange fruits are mostly supplied to domestic markets mainly for fresh fruit consumption while some are exported to nearby countries, mostly Kenya. The most popular varieties produced in Tanzania are Jaffa, Hamlin, Cassa Grande Oasis, Early Valencia (Msasa), Late Valencia, Delta, Washington navel, Matombo sweet, Nairobi, and Zanzibar. Commercially dominant varieties are Early Valencia, Late Valencia, and Jaffa. Sokoine University of Agriculture (SUA) maintains a germplasm of several sweet orange varieties (Mwatawala et al. 2006a).

Tanzanian orange production increased from 430 418 tonnes in 2015 to 465 608 tonnes in 2016 while the area harvested increased from 37 950 ha in 2015 to 39 893 ha in 2016. Orange yield in Tanzania increased slightly from 11.34 tonnes/ ha in 2015 to 11.67 tonnes/ ha in 2016 (FAO 2017). Data further show that quantities of exported fresh orange declined from 110 856 tonnes in 2012 to 17 730 tonnes in 2013. These corresponded to a decline in export value of oranges from $US24 931 000 in 2012 to $US1 043 000 in 2013. However, production of sweet oranges in Tanzania is not optimal due to biotic and abiotic stresses. Production is also constrained by high postharvest losses largely due to limited use of appropriate orange handling methods after harvest.

## 15.3 Constraints to Sweet Orange Production and Postharvest Handling

Citrus production in Tanzania is generally affected by poor crop husbandry and inappropriate postharvest management practices, poor market linkages and prices, lack of cold storage facilities, as well as insect pests and diseases (Izamuhaye 2008). Several insect pests affect production of sweet oranges, although much recent attention has been on frugivorous fruit fly species such as *Bactrocera dorsalis* (Hendel), *Ceratitis* *capitata* Widemann, and *Ceratitis rosa* Karsch (Mwatawala et al. 2010). Swai (1988) listed tristeza, exocortis, and multiple sprouting as diseases affecting citrus in Tanzania. Further, sweet orange in Tanzania is attacked mainly by three common field diseases, namely citrus scab (*Elsinoe fawcetii*), gummosis, and Septoria/black spot diseases.

Preharvest and postharvest losses of oranges in Tanzania are undoubtedly high. However, quantitative data on losses and wastages are sketchy and not readily accessible. A study by Mwatawala et al. (2006b) reported infestation rates of fruit flies in sweet orange of more than 11 adult flies per kilogram. Furthermore, the incidence of fruit flies in sweet orange was reported to be more than 50% (Mwatawala et al. 2009; Wakholi et al. 2015).

Studies on management of field and postharvest losses of sweet orange in Tanzania are scant. Farmers mostly manage fruit flies in the field using food baits. The major postharvest treatment of sweet orange is smoking, which is illegal because it jeopardizes the quality of fruits. Various techniques, such as applications of fertilizers, pesticides, and plant growth regulators, have been attempted elsewhere to improve orange fruit set and retention on trees after maturation. However, these techniques have never been tested in Tanzania. Recently, the preharvest application of hexanal proved to reduce premature fruit drop, superficial scald, and incidence of microbial decay, and increase fruit firmness. In addition, hexanal extends shelf-life, improves fruit peel color and delays ripening and senescence of fruits (Paliyath et al. 2003; Paliyath and Murr 2007; Paliyath et al. 2008). Application of hexanal to reduce preharvest and postharvest losses was tested in Tanga and Morogoro regions in Tanzania. The effectiveness of hexanal in reducing preharvest and postharvest losses of oranges was previously unknown.

## 15.4 Field and Laboratory Tests on Effectiveness of Hexanal

Trials were conducted in Muheza District, Tanga Region in coastal Tanzania to assess the effectiveness of hexanal in reducing preharvest losses of sweet oranges. Three orange varieties were tested: Early Valencia (Msasa), Late Valencia, and Jaffa. Early Valencia is appreciated for its fine taste, excellent aroma, and fruit color upon ripening. Late Valencia variety is commended for its late maturing characteristic, relatively longer shelf-life, and resistance to mechanical damage during packing and transportation. Jaffa variety yields fruit of larger size compared with Early and Late Valencia. However, it has a thick spongy rind which makes it prone to mechanical damage, microbial spoilage, and transpiration. Consequently, Jaffa has a short shelf-life.

Trials were conducted in farmers' fields in Muheza District, Tanga Region to evaluate concentrations of hexanal and time of application in reducing fruit drop, non-marketable yield, and pest defects of orange fruits. Hexanal formulations were sprayed on fruits at 60, 42, 21 and 7 days before harvest of fruits.

### 15.4.1 Effects of Preharvest Treatment with Hexanal on Preharvest Fruit Drop, Marketability, and Pest Damage of Sweet Oranges

The results of the present study showed that the preharvest application of hexanal reduced fruit drop in Early Valencia (Msasa), Jaffa, and Late Valencia orange varieties compared to the untreated control. Fruit drop percentage of Early Valencia was lower

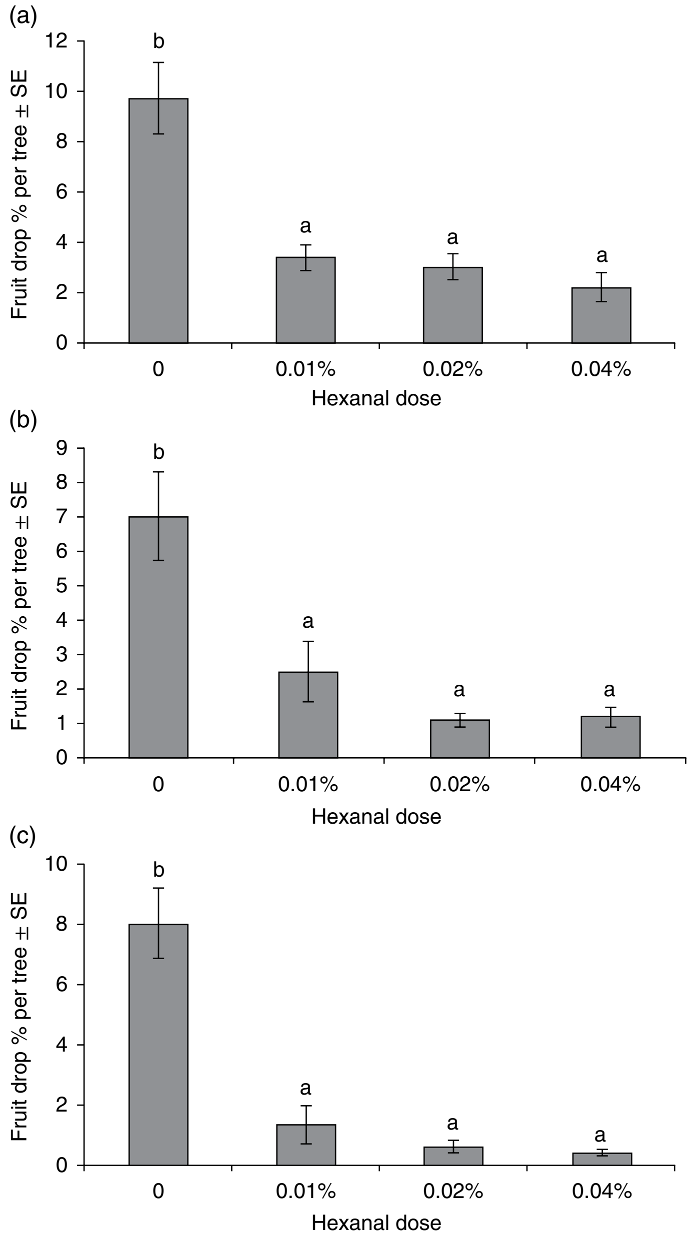


**Figure 15.1** Effects of preharvest application of hexanal formulations on fruit drop of (a) Early Valencia, (b) Jaffa and (c) Late Valencia orange varieties.

by 7.50 when exposed to 0.04% hexanal, while fruit drop percentage of Jaffa was less by 5.90 after treatment with 0.02% hexanal (Figure 15.1). Furthermore, Late Valencia had 7.64% less fruit drop when exposed to 0.04% hexanal. However, fruit drop among orange trees exposed to different concentrations of hexanal were not significantly different, although higher concentrations (0.02% and 0.04%) resulted in lower fruit drop than

0.01% hexanal. Previous studies have also shown that hexanal reduces fruit drop in mango, peach, and apple (Anusuya et al. 2016).

Field trials further showed that hexanal significantly increased the yield of the treated varieties by reducing the number of non-marketable fruit compared with untreated control. Non-marketable yield of Early Valencia variety was reduced by 7.34% with the 0.04% dose of hexanal (Figure 15.2). Non-marketable yield of Jaffa was reduced by 10.68% when treated with 0.04% hexanal. Likewise, non-marketable yield of Late Valencia dropped by 10.82% when exposed to 0.02% hexanal. However, non-marketable yields among different treatments of hexanal formulations were not significantly different.

Hexanal treatment significantly reduced the incidence of pest damage of orange varieties compared with untreated control (Figure 15.3). Incidences of pest damage in Early Valencia fruits significantly decreased, from 3.77% in the untreated control to 0.69% in hexanal (0.01%) treated fruits. Likewise, incidences of pest defects in Jaffa fruits were reduced from 4.48% to 0.73% by a dose of 0.04% hexanal. However, the results also showed a significant reduction in the incidence of pest defects depending on time to harvest rather than hexanal treatment. Anusuya et al. (2016) reported that hexanal treatment resulted in a phenomenal reduction in incidence of pests and diseases in mangoes. Hexanal has antifungal properties. It was previously reported that hexanal significantly reduced the incidence of damage by pests and diseases in stored fruits like apple and pear (Sholberg and Randall 2007; Spotts et al. 2007).

### 15.4.2 Effect of Postharvest Treatment with Hexanal Formulation on Postharvest Quality of Orange Fruit

Sweet orange fruit varieties (Early Valencia and Jaffa) harvested locally were subjected to dip treatments at SUA to assess the effectiveness of hexanal in reducing postharvest losses and preserving fruit quality. Fruit were dipped in hexanal formulations (hexanal concentrations of 0.01%, 0.02%, and 0.04%) stored at either cold or ambient temperature. Various fruit quality parameters, such as physiological weight loss (PWL), firmness, total soluble solids (TSS), and titratable acidity (TA), were measured at specified time intervals of 4, 8, and 12 days of storage.

The results further showed that postharvest treatments affected PWL of oranges. PWL increased with storage duration regardless of conditions and postharvest treatments used. PWLs were higher under ambient than cold storage conditions. Dipping orange fruits in hexanal solution at 0.01%, 0.02%, and 0.04% (m/v) significantly reduced postharvest weight loss of orange fruits of Early Valencia (Msasa) variety compared to untreated controls. Hexanal solution at 0.01% reduced PWL of orange fruits by up to 4.80%, 2.20%, and 1.37% after 4, 8, and 12 days of storage, respectively (Figure 15.4). The lowest PWL was 1.80% on the fourth day, which was higher by 4.80% compared to untreated fruits. Hexanal reduced fruit PWL of Jaffa orange variety by up to 1.8% and 1.4% after four and eight days of storage, respectively, compared to untreated fruits. Hexanal act as a strong inhibitor of phospholipase D action, and thus slows down ethylene stimulation of fruit ripening and softening processes (Cheema et al. 2014, 2018).

Our results showed that hexanal improved firmness of fruits. Hexanal treatment increased firmness of Early Valencia fruits by 3.39 N $mm^{-2}$ under ambient storage and

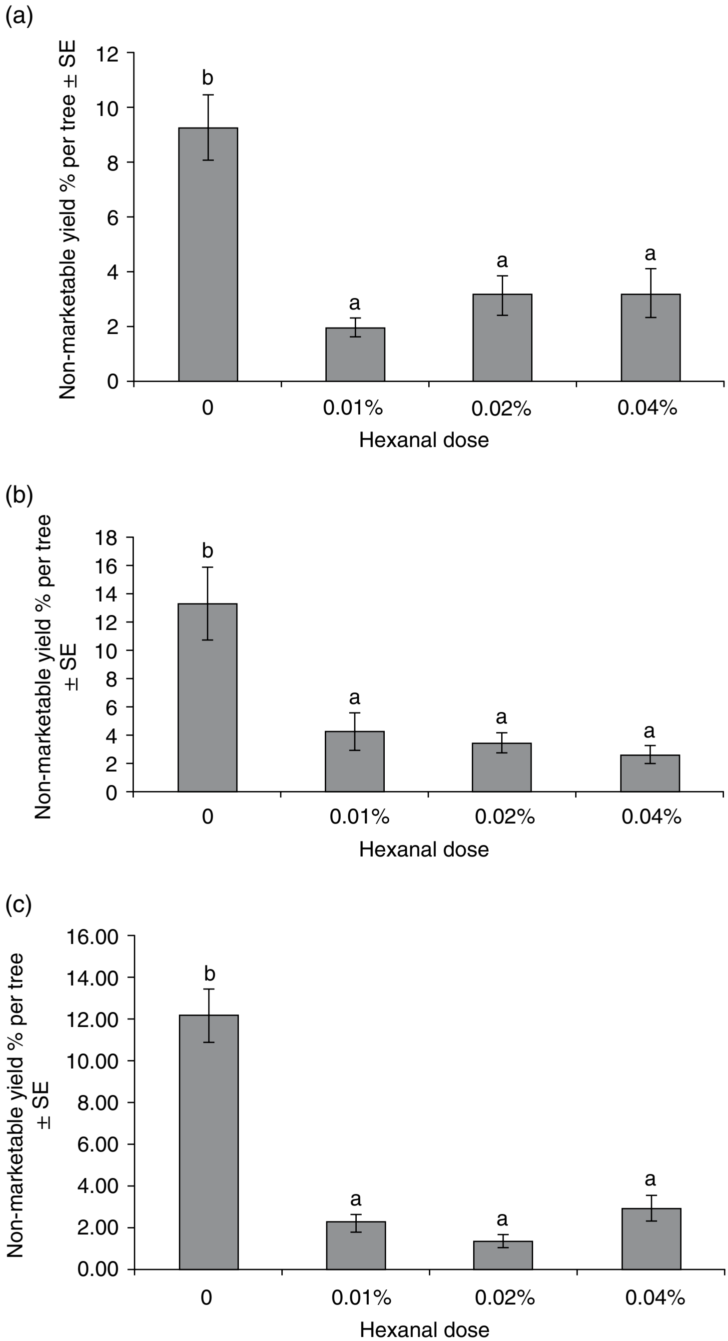


**Figure 15.2** Effects of preharvest application of hexanal formulations on non-marketable yield of (a) early Valencia, (b) Jaffa, and (c) late Valencia orange varieties.

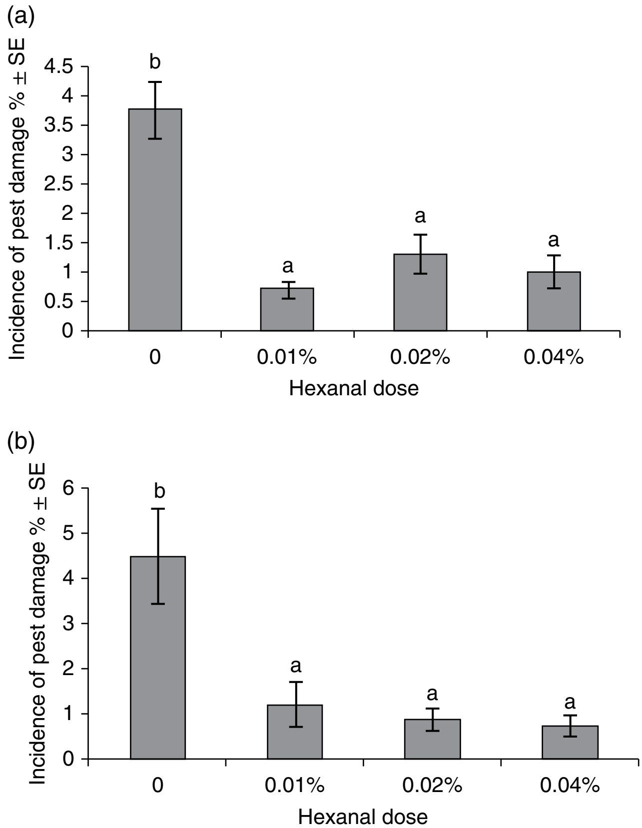


**Figure 15.3** Effects of preharvest application of hexanal formulations on pest incidence of fruits of (a) Early Valencia and (b) Jaffa.

by up to 2.82 $N\,mm^{-2}$ under cold storage conditions (Figure 15.5). The highest firmness of 13.39 $N\,mm^{-2}$ was recorded with the 0.02% hexanal treatment under ambient storage, which was higher by 3.39 $N\,mm^{-2}$ compared to the untreated control. Likewise, hexanal increased fruit firmness by 3.60, 8.00, and 7.60 $N\,mm^{-2}$ after 4, 8, and 12 days of storage, respectively compared with the untreated controls of orange Jaffa variety. The highest fruit firmness was 17.40 $N\,mm^{-2}$ recorded on the fourth day, which was higher by 11 $N\,mm^{-2}$ compared to the untreated fruits. The higher firmness in hexanal-treated fruits can also be associated with fruit cells turgidity, which maintains fruit freshness and increases fruit shelf-life. Similar results on fruit firmness were reported by Sharma et al. (2010) and Cheema et al. (2014).

The effects of hexanal on titratable acidity of fruits of both varieties were not significant. Furthermore, hexanal did not significantly affect TSS/TA ratio of fruits of Early Valencia and Jaffa.

These trials concluded that preharvest treatment of hexanal formulation at 0.01% (m/v) significantly improved orange marketable yield by reducing fruit drop, non-marketable fruits and pest-infected fruits of Early Valencia, Jaffa, and Late Valencia orange varieties. Similarly, postharvest dip treatment of hexanal at 0.02% (m/v)

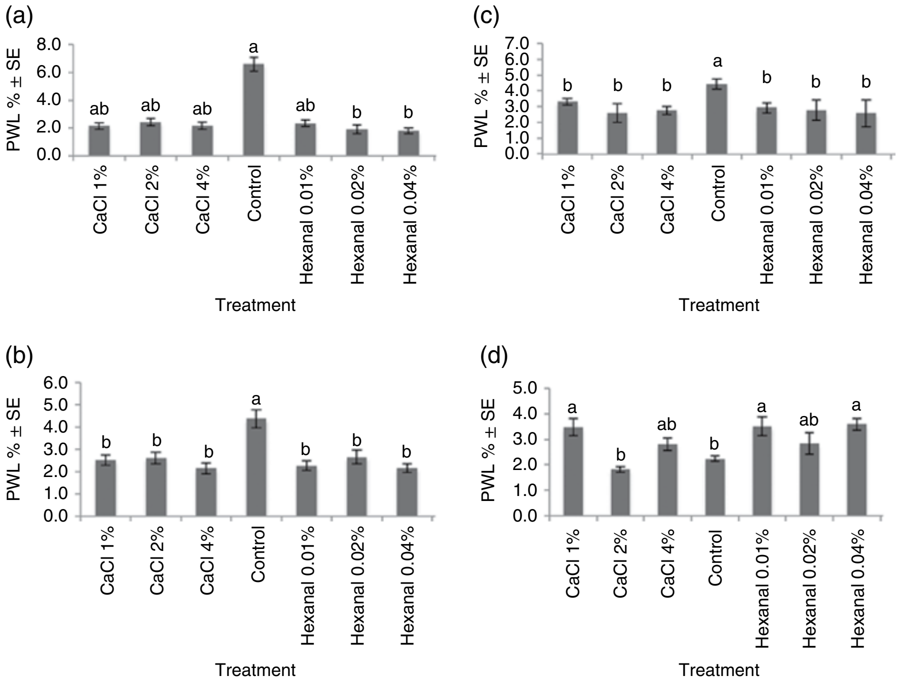


**Figure 15.4** Effects of postharvest dip treatments with hexanal formulations on physiological weight loss (PWL) in Early Valencia oranges at (a) four days and (b) eight days after harvest, and in Jaffa oranges at (c) four days and (d) eight days after harvest. Different lower case letters between values indicate statistical significance.

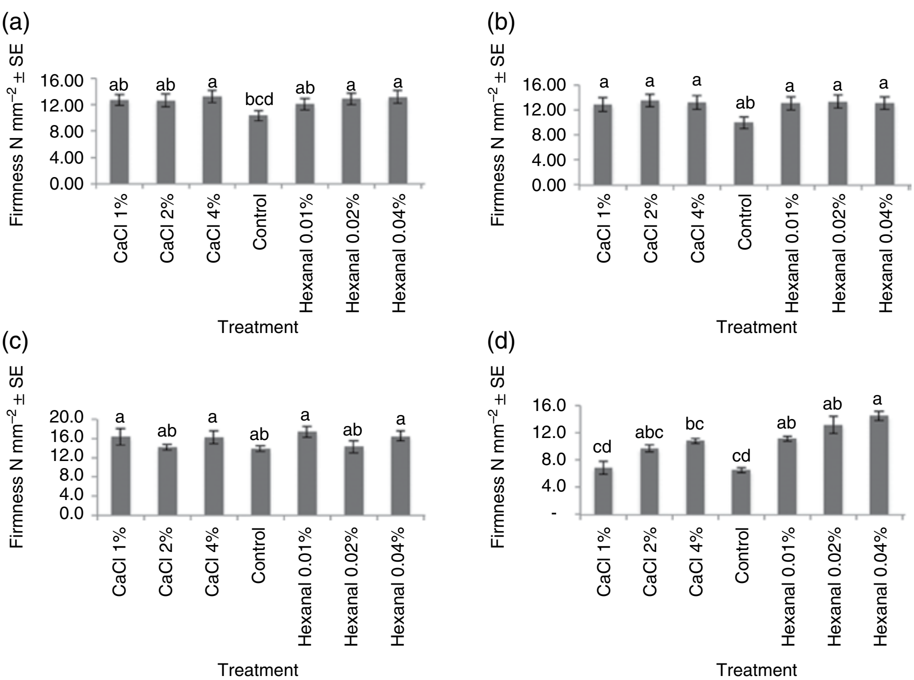


**Figure 15.5** The effects of postharvest dip treatments with hexanal formulations on firmness ($N\,mm^{-2}$) in Early Valencia oranges under (a) ambient storage conditions and (b) cold storage conditions, and in Jaffa oranges at (c) four days after storage and (d) eight days after storage. Different lower case letters between values indicate statistical significance.

significantly maintained fruit freshness and firmness of the tested orange varieties. Fruit freshness, firmness and absence of pest defects on fruits are the most important market attributes that guide consumers when buying fresh oranges.

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