THE EFFECTS OF REST BREAKING AGENTS, PRUNING AND EVAPORATIVE COOLING ON BUDBREAK, FLOWER BUD FORMATION AND YIELD OF THREE PISTACHIO *(PISTACIA VERA* L.*)* CULTIVARS IN A CLIMATE WITH MODERATE WINTER CHILLING

By

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part submitted it at any university for a degree.

Signature

Date

SUMMARY

The climate around Prieska differs from other pistachio growing regions in the world in that it receives fewer winter chilling units, has higher maximum temperatures during winter and spring and receives summer rainfall. This possibly results in the observed delayed foliation, flower bud and inflorescence abortion, low fruit set and other flowering disorders, which lower yield potential. In order to increase yields, winter pruning, evaporative cooling and chemical rest breaking were investigated on ‘Ariyeh’, ‘Shufra’ and ‘Sirora’ pistachio trees.

Tip-pruning (to remove <2.5cm) and severe heading cuts (to remove 35-45%) of one-year old wood were compared and 4% hydrogen cyanimide (Dormex®), 4% mineral oil (Budbreak®) as well as the combination (0.5% Dormex® + 4% Budbreak®) used as rest breaking agents. Bud break, reproductive bud differentiation, die-back, flower bud retention during winter and early summer as well as yield were evaluated. The results emphasised the interaction of rest breaking and pruning effects, with genetic chill requirements and environmental influences - specifically winter chill build-up. Severe pruning was detrimental to flower bud formation as well as yield. The bud break data suggests that the ability of some rest breaking chemicals to promote lateral development may be explained by their potential to impede the development of apical dominance, rather than a direct effect on the lateral buds. The inability of the chemical treatments to increase yield consistently might indicate other factors involved or that the average winter chill of Prieska is below the minimum amount necessary for adequate rest breaking effects on yield.

Evaporative cooling was used to counteract potential negative effects of high maximum day temperatures during autumn and spring on flower bud retention, fruit set and yield. Cooling during autumn (May + June, Southern hemisphere), spring (August + September, Southern hemisphere) and the combination of autumn + spring were investigated during two seasons. Flower bud retention during winter and early summer, flowering patterns, as well as yield were evaluated. The significant effects obtained with evaporative cooling - specifically in autumn + spring, indicated the important role climatic conditions play during both stages of entering and exiting dormancy of pistachio trees. Although all differences are not yet clearly understood, the fact that evaporative cooling resulted in substantially higher yields in the case of ‘Ariyeh’ and ‘Shufra’ in an area with sub-optimal pre-blossom temperatures and less than 40% of the required winter chill of pistachio, emphasises its potential in horticultural management.

OPSOMMING

DIE EFFEK VAN CHEMIESE RUSBREKERS, SNOEI EN VERDAMPINGSVERKOELING OP BOT, BLOMKNOPVORMING EN OPBRENGS VAN DRIE PISTACHIO (*PISTACIA VERA*) KULTIVARS IN 'N KLIMAAT MET MATIGE WINTERKOUE

Prieska se klimaat verskil van ander pistachio-produksie areas in die wêreld deurdat minder winterkoue-eenhede opgebou word, dit hoër maksimum temperature het gedurende die winter en lente en 'n somer-reënvalgebied is. Dit dra waarskynlik by tot die waargenome vertraagde bot, blomknop- en bloeiwyse abortering, lae vrugset en ander blom-afwykings. Aangesien hierdie faktore opbrengspotensiaal verlaag, is wintersnoei, verdampingsverkoeling en chemiese rusbreking ondersoek as moontlike bestuursoplossings.

Tip- (om <2.5cm te verwyder) en topsnitte (om 35-45% te verwyder) van eenjarige lote is met mekaar vergelyk en 4% waterstofsianied (Dormex®), 4% minerale olie (Budbreak®) en hul kombinasie is as rusbrekers aangewend. Bot, blomknop-differensiasie, terug-sterwing, blomknopretensie gedurende winter en vroeë somer sowel as opbrengs is geëvalueer. Die resultate benadruk die onderlinge interaksie van rusbreking- en snoei-effekte met genetiese koue-behoeftes en omgewingseffekte - spesifiek die opbou van winterkoue. Topsnitte was nadelig vir blomknopvorming, sowel as opbrengs. Die bot-data doen aan die hand dat sommige chemiese rusbrekers se potensiaal om laterale breke te bevorder, verduidelik kan word deur hul vermoë om die ontwikkeling van apikale dominansie te onderdruk, eerder as 'n direkte effek op die laterale knoppe. Die chemiese behandelings se onvermoë om opbrengs deurggaans te verbeter, mag daarop dui dat die gemiddelde winterkoue van Prieska laer is as die minimum hoeveelheid benodig alvorens chemiese rusbreker effekte op opbrengs verwag kan word.

Potensiële negatiewe effekte van hoë maksimum dagtemperature gedurende die herfs en lente op blomknopretensie, vrugset en opbrengs is teengewerk deur middel van verdampingsverkoeling. Verkoeling gedurende herfs (Mei + Junie, Suidelike halfrond), lente (Augustus + September, Suidelike halfrond) en die kombinasie van herfs + lente is gedurende

twee seisoene ondersoek. Blomknopretensie gedurende winter en vroeë somer, blompatrone, sowel as opbrengs is geëvalueer. Die betekenisvolle verskille verkry met verdampingsverkoeling, dui die belangrike rol aan wat klimaatstoestande gedurende beide stadiums van in-, sowel as uitgang uit dormansie speel in pistachiobome. Hoewel alle verskille nog nie verklaar kan word nie, dien die feit dat verdampingsverkoeling tot substansiële opbrengste in die geval van ‘Ariyeh’ en ‘Shufra’ kon lei in ‘n area met sub-optimale voor-bot temperature en gemiddeld minder as 40% bevrediging van die kouebehoefte van pistachios, as beklemtoning van die belang daarvan as hortologiese bestuursmiddel.

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GENERAL INTRODUCTION

Pistachios is a high-chill nut crop and the climate around Prieska differs from other pistachio growing regions in the world in that it receives fewer winter chilling units, has higher maximum temperatures during winter and spring and receives summer rainfall (Van den Bergh & Manley, 2002). This possibly results in the observed delayed foliation, flower bud and inflorescence abortion, low fruit set and other flowering disorders. In order to increase yields, winter pruning, evaporative cooling and chemical rest breaking were investigated on 'Ariyeh', 'Shufra' and 'Sirora' pistachio trees.

The use of different dormancy breaking chemicals on pistachios in areas with mild winters resulted in increased yields, quality and changes in flowering patterns and lateral development (Procopiou, 1973; Küden and Küden, 1995; Rahemi and Asghari, 2004), irrespective of rootstock (Beede and Ferguson, 2002). However, these reports do not discuss the long term effects of dormancy breaking chemicals on flower bud differentiation and also did not eliminate the possible lack of overlapping of male and female bloom through the use of artificial pollination.

The first four to five pruning seasons of a pistachio tree is spent on training a strong trunk (90-120 cm in height) and well balanced scaffold branches to accommodate mechanical harvesting (Crane and Iwakiri, 1985). This is done through heading cuts which remove 30% or more of one-year-old shoots in winter (Personal observation). As pistachios bear only on one-year-old shoots, the importance of new growth is obvious. Koopmann however, reported as early as 1896 on the negative effects of severe heading cuts on flower bud differentiation (Wertheim, 1976).

In this study, the effect of pruning and rest breaking chemicals were evaluated. Tip-pruning (to remove <2.5cm) and severe heading cuts (to remove 35-45%) were compared and 4% hydrogen cyanimide (Dormex®), 4% mineral oil (Budbreak®) as well as the combination (0.5% Dormex® + 4% Budbreak®) used as rest breaking agents on three consecutive age groups of the 'Ariyeh' and 'Shufra' cultivars and one of 'Sirora'. Bud break, reproductive bud differentiation, die-back, flower bud retention during winter and early summer as well as yield were evaluated.

Sprinkler irrigation has long been used to modify the micro-environment of many crops. This was done by adding heat (sensible and latent) by sprinkling in order to protect opened flower buds from frost. However Alfaro et al. (1974) as quoted by Chesness et al. (1977) and Anderson et al. (1975) demonstrated a different approach by delaying bloom with evaporative cooling of the flower buds after completion of dormancy. Erez and Couvillon (1983) counteracted high maximum bud temperatures during the dormancy period of 'Sunred' nectarine trees with evaporative cooling, enhancing both floral and vegetative bud break.

Taking the aforementioned into account, evaporative cooling was used to counteract potential negative effects of high maximum day temperatures during both the entering and exiting of dormancy. The preliminary evaporative cooling trials resulted in increased yields and changes in flowering patterns, indicating possible direct responses to temperature change or changes in flowering time (Uzun and Caglar, 2001). Flowering patterns, flower bud retention during winter and early summer and yields were evaluated over two seasons.

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<u>LITERATURE REVIEW:</u> THE EFFECTS OF PRUNING, EVAPORATIVE COOLING AND CHEMICAL REST BREAKING AGENTS ON BUDBREAK AND FLOWER BUD FORMATION OF PISTACHIO (*PISTACIA VERA* L.)

INTRODUCTION

Pistacia is a genus with several species in the family Anacardiaccae. Some of the species, used for rootstocks, may reach a height of 8 m and a width of 9 m. Trees under irrigation are usually trained during year 1-2 to form a strong trunk (± 1.2 m) after which primary scaffold branches (0.3-0.4 m) are evenly arranged around the trunk to form a base for the ultimate open vase shape. The main reason for this canopy shape is to facilitate mechanical harvesting. Shoots of this deciduous tree grow in flushes in the Southern Hemisphere - one flush in the case of mature trees and up to three for young trees (the first flush starting at the end of September and the last terminating late March).

Single axillary buds are subtended by a leaf at each node. Depending on position and tree age, axillary buds can differentiate into simple inflorescence buds starting in October and reach their ultimate bud size by late December (Northern Hemisphere)(Takeda et al., 1979). Trees normally become more reproductive from 6th leaf, but this is dependant on tree manipulation. The terminal bud always remains vegetative. One or two axillary buds, located distally on the new shoot are usually also vegetative. They may remain paradormant due to the strong apical dominance of the vegetative terminal bud, during the following season, or develop into lateral shoots. The pistachio therefore bears fruit laterally on wood produced during the previous season. The trees are dioecious with both pistillate and staminate panicles, which either can consist of hundred to several hundred apetalous flowers. Wind is the pollinating agent (Crane, 1984).

One of the main physiological problems experienced by the pistachio industry is severe alternate bearing, where trees in their off-year yield 10% or less of the on-year yield. This phenomenon is initiated when bearing one-year-old shoots with heavy clusters of nuts on the proximal part, shed some or all the developing inflorescence buds on the current season's shoot, distal to the clusters. The bud shedding normally coincides with the beginning of nut filling i.e. important nutrient and carbon sourcing and the final flower bud differentiation processes (Crane, 1984).

Due to strong apical dominance, branches tend to elongate through a strong terminal shoot developing without many lateral shoots. The subsequent nut production, occurring progressively further from the centre of the tree gives rise to mechanical harvesting problems (Personal observation), branches that are subject to sunburn as well as the shading of lower branches resulting in lower fruiting potential (Crane, 1984).

In the regions of Anatolia, Caucasia, Iran and Turkmenistan, the areas where pistachio nuts (*Pistacia vera* L.) originate from (Özbek, 1978; Ayfer, 1990), pistachios are usually grown under dry land conditions. Under these conditions, trees become progressively reproductive with age, and vegetative development is stunted with fewer new shoots, that reach only 5 - 15 cm in length. Orchards are conventionally grown, with no tree training and the only pruning applications done are thinning cuts (removal of the entire shoots at its point of origin) on shaded branches, but no heading cuts (removal of a portion of a shoot, leaving a stub from which new growth may occur on main or lateral branches (Küden, at al., 1998).

The climate in the Prieska area differs from other pistachio growing regions in the world in that it receives fewer winter chilling units (Richardson or hours below 7º C), has higher maximum temperatures during winter and spring and receives summer rainfall (Van den Bergh and Manley, 2002). This possibly results in the observed delayed foliation, flower bud and inflorescence abortion, low fruit set and yield and other flowering disorders. These disorders e.g. lateral or terminal buds on current season's growth developing into a florescence (and setting fruit) were described by Crane and Takeda (1979) as a rare response to insufficient winter chilling. No accurate chilling requirements or detailed information regarding desired lengths of lateral shoots are known for any pistachio cultivar, except that 1000-1500 hours below 7 ºC appear to be sufficient in California, USA (Crane and Takeda, 1979).

Reviewed by many, dormancy is defined as the developmental stage through which a temperate-zone deciduous tree is able to survive unfavourable growing conditions during winter. This winter dormancy is then released by a quantitative accumulation of cold, which for apples and peaches occur at 6º to 8ºC with low activity at 0ºC and lower and none at 14ºC and higher temperatures (Saure, 1985). Erez and Lavee found as early as 1971 that mean average temperatures (as suggested by De Villiers, 1943, quoted by Erez and Lavee, 1971), alone does not reflect the effect of winter temperatures on bud opening of peach trees as when the extreme low and high temperatures are taken into consideration. They based their opinion on the steep change of efficiency they found in dormancy release of peach buds at controlled low temperatures from 6º (optimum) to 11ºC (half as efficient) and the fact that while high temperatures of 18ºC, fluctuating with low temperatures, had no effect, a temperature of 20ºC under the same conditions, nullified the chilling effect. According to them, extreme temperatures during dormancy is the decisive factor – not the average temperature.

The use of different dormancy breaking chemicals on pistachios in areas with mild winters result in increased yields, nut quality and changes in flowering patterns and lateral shoot development (Procopiou, 1973; Küden et al., 1995; Rahemi and Asghari, 2004), irrespective of rootstock (Beede and Ferguson, 2002). However, the questions in response to some pistachio rest breaking trials remain, especially where no fruit set was evaluated, a) to what degree improved bloom (the higher percentages of opened flowers in relation to vegetative buds) is responsible for the improvements in yield (Küden et al., 1995) and b) the long term effects on yield through differences in structural development (Rahemi and Asghari, 2004).

Evaporative cooling has never before been used commercially on pistachios, although its potential to prevent frost damage on pistachios and various other crops as well as to promote synchronisation of male and female blooming has been investigated in the past, which will further be reviewed in later paragraphs.

The first four to five seasons after planting of pistachio trees are spent on training a strong trunk (90-120 cm in height) and well balanced scaffold branches to accommodate mechanical harvesting (Crane and Maranto, 1988). This is done through heading cuts which remove 30% or more of one-year-old shoots in winter (Personal observation). Koopmann however, reported as early as 1896 (as quoted by Wertheim, 1976) on the negative effects of severe heading cuts on flower bud differentiation. As pistachios bear only on one-year-old shoots, the importance of new growth is obvious. Therefore, the influence of strong heading cuts on delaying the reproductive development needs to be investigated.

In this review the effect of rest breaking chemicals, evaporative cooling and pruning with special reference to pistachio will be reviewed.

PRUNING

General growth reactions following severe winter pruning:

From as early as 1896, scientists like Koopmann (Wertheim, 1976) recognised the negative effect of severe pruning on apple, pear and plum flower bud formation, which Jonkers (1960) ascribe to the low number of shorter shoots that formed following severe pruning. Koopmann (Wertheim, 1976) further noted that as one-year-old apple shoots are cut back with increasing severity, growth per bud will increase progressively as well as the number of growing buds, although in the case of cherry trees the latter will decrease. Total growth (old + new) will increase with cuts of 20-30% and stay the same with deeper cuts, as long as less than 60% of the original one-year-old shoot is removed. Such reactions are cultivar and rootstock specific and exceptions do exist, as in the case of the ‘Winston’ apple where growth increases irrespective whether the cut was more or less than 60% (Wertheim, 1976). Koopmann (Wertheim, 1976) also observed fewer leaves formed on shoots following more severe (>60%) heading cuts.

Wertheim (1976) explained these growth reactions observed by Koopmann with reference to (a) the ratio of available vascular bundles in a shoot to the number of buds prior and after pruning and (b) the fact that after severe pruning (> 60%), growth resume from less developed buds (with fewer preformed leaves). Wertheim (1976) further noted that total growth (and in other cases total and individual leaf area) after four years of not pruning young, bearing ‘Winston’ apple trees can be less than that on pruned trees, due to the inhibitory effect of the higher and earlier yields achieved by the unpruned trees. He also noted that total, as well as individual leaf area of unpruned, bearing trees are smaller due to the same reason and ascribe their smaller sized fruit to a smaller ratio between leaf area and fruit number.

Vöchting as quoted by Wertheim (1976), noted that the shoot growth on two-year-old branches will only be influenced (with increased shoot growth and fruit set) by heading cuts in the distal one-year-old wood if no sufficiently developed buds are left behind. Whether this positive influence on fruit set is still prevalent at harvest depends on the competing sink-effect of vegetative growth in the presence of high vigour. This is clearly seen on a vigorous apple branch, which after severe pruning of its one year-old wood resulted in fruit drop to such an extent that it nullified the increased fruit set, which Wertheim (1976) ascribed to the lower number of remaining sinks then attaining higher levels of cytokinen and or gibberillin which, in the case of ‘Laxton’s Superb’ resulted in parthenocarpic fruit set. Wertheim (1976) further noted even higher fruit set in both apple and pear branches after two-year-old wood was cut in half, although higher yields were only achieved in the case of pears. However, such removal of all one-year-old wood limits the development of the next season's fruiting wood and done repeatedly will have a detrimental effect on yield, although in 'Doyenné du Comice' pears, lower yields were found on trees with more one-year-old shoots (Wertheim, 1976).

Saunders et al. (1991) topped (to remove 50%) or headed (to remove 100%) of the terminal one-year old wood of 'Packham's Triumph' pear trees. Although the number of new shoots per two-year-old unit was negatively correlated with the severity of pruning while a poor negative correlation was also found with fruit set between treatments, they found that the position of this growth relative to the developing fruits is more important than the number of new shoots. The length of new shoot growth was poorly correlated with fruit set, although an increase in fruit set was found when new shoots were only permitted to grow on the two-year-old wood. However, this increase by heading failed to improve fruit set if delayed after anthesis. They deduced that correlative inhibition of subordinate fruitlets by distal shoot sinks is more important than competition between fruits and shoots for nutrients.

Individual shoot growth on a branch unit is not only dependant on the pruning of the primary shoot, but also whether or not other shoots in its immediate vicinity, was pruned, as noted by Vöchting (Wertheim, 1976). According to Vöchting, pruning of such surrounding shoots will result in more growth of a specific shoot than otherwise. He further noted that the position and orientation of a shoot play a primary role in pruning reactions, which he summarised in a few rules. According to Wertheim (1976), each branch unit is in equilibrium, which is changed more by heading than by thinning. However, he points out that younger bearing trees may need thinning cuts earlier, as lighter or unpruned trees tend to get very dense, resulting in poor fruit quality.

Winter pruning of pistachio:

Crane (1984) criticised the potential of conventional thinning cuts as a solution to strong apical dominance. Few laterals develop on branches, branches are subject to sunburn as well as the shading of lower branches resulting in lower fruiting potential (Crane, 1984). His reasoning is two-fold. Firstly, other fruit and nut trees produce at least one vegetative bud per node, where as pistachios bear only a few lateral vegetative buds. Consequently, shoots headed back indiscriminately will die back to the first lateral branch or stimulated vegetative bud, impeding the potential growth which normally occurs after similar cuts. The second factor he noted was the strong apical dominance - removal of 50% of all growing branches with thinning cuts resulted in practically no new lateral shoot development. However, when all terminal buds were removed by heading cuts, new lateral shoot growth was stimulated throughout the whole tree canopy.

Pruning in Turkey (Southeast Anatolia) is limited to thinning cuts (Arpaci et al., 1995). A pruning technique in which only three to five-year-old branches are cut every two to three years is often used. This results in reduced vegetative growth with low fruiting potential. In comparison to the conventional thinning cuts, heavy pruning (66% of shoot length headed) and lighter pruning (33% headed) on nineteen-year-old ‘Uzun’ trees had no significant effect on yield, splitting percentage or nut weight, although lateral shoot development as well as shoot length were increased in both cases (Arpaci et al., 1995). This vegetative reaction as well as lack of response in nut quality were also noted in the case of mechanical heading on ‘Kerman’ pistachios by Ferguson et al. (1988). However, Woodroof (1982) claimed a higher splitting percentage in reaction to 50% heading cuts.

Heavily pruned ‘Uzun’ also retained slightly, though significantly more flower buds in their “on” year which Arpaci et al. (1995) attributed to an increased leaf area. A similar positive effect on ‘Kerman’ flower bud retention by heavy winter pruning (30% - 50% of shoot length headed) was noted by Crane et al. (1973) and Ferguson et al. (1988).

Heavy winter pruning (66% of shoot length headed) also induced a slightly higher kernel / shell ratio and developed new shoots on three to four-year-old ‘Uzun’ wood (Arpaci et al., 1995). Although Crane (1984) also noted this rejuvenated shoot development on ‘Kerman’ scaffold limbs in reaction to severe pruning (50% of shoot headed), Wolpert (1985) noted only a few new shoots from that origin on the same cultivar with the same treatment.

Wolpert (1985) noted contrasting effects on alternate bearing of 14-year-old ‘Kerman’ trees in a pruning trial conducted simultaneously at two localities. In the one locality, “on” and “off” years shifted phase relative to the controls and in the second, produced evenly over two years. Ferguson et al. (1995) proved that severe pruning (30% - 50% of shoot length headed), specifically when performed mechanically, could reduce the severity of alternate bearing of 14-year-old ‘Kerman’ trees over three consecutive bearing cycles as a result of shoot growth alteration. However, they noted that the mitigation of the alteration in yields would probably not have persisted after the three cycles.

Alternate bearing was further brought into context with structural development by Stevenson et al. (2000) by referring to the shoot length distribution and bud abscission patterns exhibited by alternate bearing trees and explained that alternate bearing may represent an internally regulated program of canopy development, rather than the generally perceived localised response of the bud or shoot to the presence of fruit or its impact on the availability of carbon or other nutrients (Crane et al., 1973, 1976; Crane and Al-Shalan, 1977; Takeda et al., 1980; Goldschmidt and Golomb, 1982).

EVAPORATIVE COOLING

Evaporative cooling of dormant deciduous trees:

Sprinkler irrigation has long been used to modify the micro-environment of many crops. This is done by adding heat (sensible and latent) by sprinkling in order to protect opened flower buds from frost. However Alfaro et al. (1974) as quoted by Chesness et al. (1977) and Anderson et al. (1975) demonstrated a different approach by delaying bloom with evaporative cooling of the flower buds after completion of rest. Erez and Couvillon (1983) counteracted high maximum bud temperatures during the rest period of ‘Sunred’ nectarine trees with evaporative cooling, enhancing both floral and vegetative bud break.

In 1972, Utah’s fruit crop was almost completely destroyed by subfreezing temperatures during the early spring. Contrary to the conventional use of expensive (but often ineffective) heaters and wind machines to protect exposed developing buds, Anderson et al. (1975) demonstrated that by delaying full bloom of ‘Red Delicious’ apple trees (*Malus pumila* Mill) by 17 days, evaporative cooling by overhead sprinkling (in a two minute on- two minute off cycle when air temperature reached 7ºC) could successfully be used to prevent frost damage to developing buds. They attributed this to the fact that after dormancy and sufficient chilling, fruit bud development follows a temperature controlled cycle and that by reducing the bud temperature, they inhibited its developmental rate. Their maximum difference between control (46ºC) and sprinkled (12ºC) buds was 34ºC, at an ambient temperature of only 28ºC.

Anderson et al. (1975) also suggested other potential uses of evaporative cooling, namely the programming of harvesting, avoidance of summer heat and resultant poor fruit quality, as well as facilitating rest breaking of high chill varieties grown in areas with warm winter temperatures. Erez (1995) viewed evaporative cooling as a method to both counter negating temperatures - which according to Erez and Lavee (1971) is more decisive than mean average temperatures and to promote chilling. Erez (1995) lowered bud temperatures in Israel by up to 13ºC over five weeks, using 7mm of water per day.

Bauer et al. (1976) investigated cooling effects on winter hardiness of peach wood and fruit buds. They used similar cooling techniques as Anderson et al. (1975) with cooling commencing at an air temperature of 6ºC with on- and off-cycles of respectively 5 and 10 minutes and later 2.5 and 7.5 minutes; although Anderson et al. (1975) turned cooling off when their control trees reached full-bloom. Bauer et al. (1976) turned theirs off when their cooled trees reached full-bloom. They found that cooling did keep fruit buds of cooled trees more hardy than that of control trees, but only during early spring (18 September, Southern Hemisphere), after which they found a negative effect on hardiness. Cooling also reduced the number of functional flower buds per meter shoot in September (Southern Hemisphere), which is probably the reason for the increased set found after full-bloom in a larger percentage of the remaining buds and more fruit per meter. However, after December-drop (Southern Hemisphere) the number of fruit per meter shoot was less than that of the control trees and the effect on yield, detrimental. They further noted that although they delayed bloom by 15 days, date of fruit ripening did not differ significantly.

Their work further emphasised the importance of using sensitive devices to control the on- and off cycles to ensure effective evaporative cooling. They found on several occasions that if high solar radiation, high temperature and high wind speeds occurred simultaneously, it resulted in complete evaporation of water before the next on-period. Although this initially leads to a large cooling effect, the dry wood of the sprinkled trees quickly reached temperatures close to those of the non-sprinkled trees (Bauer et al., 1976).

Chesness et al. (1977) again looked at bloom delay in peaches, but also whether the “Utah Model” (Richardson et al., 1974), would predict completion of endo-dormacy and bloom dates accurately in the state of Georgia, USA. Their cooling cycles of 2.5 minutes on and 2.5 minutes off, started when ambient temperatures were 7.2ºC and above (except between midnight and 08:30 due to the small cooling effect as well as to reduce the amount of water applied), and were turned off when 25% of the sprinkled trees had reached full bloom. Although they were able to delay bloom by 14 days, they suggest that bloom delay could have been increased if cooling started at an ambient temperature of 5.5ºC instead of 7ºC. They could predict the full-bloom date of control trees to within one day, but were 12 days early in predicting the date of cooled trees. They also found a positive effect of cooling on fruit set, but unlike Bauer et al. (1976), the delay in blooming was almost identical to the delay they found in harvest maturity. Unfortunately, yield was not recorded.

Westwood and Bjornstad (1978) investigated the effect of free water (both by rain and immersion for either one or two days), on dormant buds and found that the applied water increased growth of both ‘Bartlett’ pear and ‘Starkrimson’ apple buds following forcing. They suggested the leaching of abscisic acid (ABA) as a potential reason for their results. This is supported by previous work by Tukey (1970), who showed that both mineral and organic substances can leach from plants. However, as their immersion treatments caused anaerobic conditions for at least eight hours, their effects could also have been due to the reduction in bud oxygen levels (Erez and Couvillon, 1983).

Gilreath and Buchanan (1979) did research in Florida on bloom delay by evaporative cooling, as well as accumulation of chill units by dormant cooling on low chilling peach and nectarine trees. Cooling occurred from 1 May until 13 July (Southern Hemisphere), or 1 May until bloom (end August, Southern Hemisphere). Daily cooling started when average fruiting wood temperatures exceeded 10ºC, as measured by thermocouples placed in the fruit buds. The maximum difference between cooled and control wood temperatures was 4.3ºC and 6.5ºC at 12:00 and 14:00, respectively. The longer cooling period resulted in no difference in bloom dates compared to the control trees, due to the negating effect of cooling on the advancement of bloom obtained by the early-dormancy cooling. Late cooled trees resulted in lower total bloom percentage, less bud abscission and fewer other physiological disorders, which Gilreath and Buchanan (1979) attributed to excessive water.

Gilreath and Buchanan (1979) obtained a larger advancement in bloom with their early-dormancy treatment than indicated by its accumulation of Utah chill units (with either 7.2ºC or 10ºC used as base temperature) and explained these findings by referring mainly to the leaching of potential growth substances which could influence various stages of dormancy, as indicated by Walker and Seeley (1973). They however also mentioned that the wood temperature was not reduced enough to influence the chill unit accumulation due to either high humidity or overcast conditions and suggested that leaching should be taken into account when chill units are calculated under such circumstances.

High temperatures have long been known to reduce endo-dormancy development in buds (Bennett, 1950; Weinberger, 1954; Overcash and Campbell, 1955) and Weinberger (1967) has shown that high maximum temperatures during the main endo-dormacy period could control the rate of dormancy development of peach buds. Erez et al. (1979) suggested that the model which Richardson et al. (1974) presented for the estimation of dormancy completion should incorporate a stronger negative value for temperatures of 21 ºC than its coefficient of -1.0 and based this on the data obtained by Erez and Lavee (1971) discussed previously. Erez et al. (1979) further stated that because high temperatures often occur in addition to a lack of chilling temperatures under warm winter conditions, both should be considered in a chill model, which the Utah Model (Richardson et al., 1974) does not.

Erez et al. (1979) exposed rooted peach (‘Redhaven’ and ‘Redskin’) cuttings to a daily cycle consisting of equal hours (16) at a chill promoting temperature of 6ºC and 8 hours at different high temperatures of either 15ºC, 18ºC, 21ºC or 24ºC. Their data showed that the opening of lateral peach buds is dependent on the level of exposure to high temperatures. While cycles of up to18ºC did not negate chilling, cycles over this threshold (21ºC and 24ºC) drastically reversed the chilling obtained. They also showed alternating temperatures of up to 18ºC to be more efficient than continuous temperatures at 6ºC. This is also supported in a study by Bennett as quoted by Brown (1957).

Gilreath and Buchanan (1981) separated the effects of evaporative cooling of the canopy from the root zone and showed that evaporative cooling by sprinkling nectarine trees during dormancy (from May until end July, Southern Hemisphere), lowered wood temperatures by up to 4.3ºC and advanced both lateral - (1 - 3 days) and terminal (2 days) leaf emergence, as well as bloom (11 - 12 days). They attributed this advancement to the cooling effect of the water applied to the canopy and not to increased water in the root zone. They also found that evaporative cooling had a detrimental effect on fruit set with resultant increased fruit size. Although they found no evidence of the previously suspected leaching effects (Gilreath and Buchanan, 1979) by evaporative cooling, they failed to predict dormancy completion accurately with either the Utah model (Richardson et al., 1974) or their own and stated that their bloom response could not be attributed solely to the differences they found in wood temperatures. They then suggested other factors involved in addition to temperature. Their problems in accurate prediction could possibly be explained by the argument of Erez et al. (1979) that some coefficients used in the Utah model should be altered.

Erez and Couvillon (1983) showed that under extremely low chilling conditions as well as relative high solar radiation, they were able to enhance bud break and obtain more uniform blooming and leafing by only applying evaporative cooling during dormancy (begin June until begin August) when air temperatures exceeded 16ºC (1 minute on in an 11.2 minute cycle and on very warm days 5.6 minute cycles). A total of 100 mm of water was used over the 31 days. Their control tree bud temperatures increased over air shade temperature while the cooled bud temperatures dropped below air shade values. They stated that their chilling effect was maintained as long as the buds did not dry off completely. Once buds were completely dry temperatures increased rapidly. They found that although their work did not differentiate between leaching and cooling effects, inaccuracy of existing dormancy completion models as well as other factors could still be the reason for poor prediction of dormancy termination under evaporative cooling and suggested that the role of leaching in overhead sprinkling should be investigated by night sprinkling when no further cooling could be obtained.

Anderson et al. (1975) pointed out important limitations of evaporative cooling – access to enough water, potential drainage complications and the fact that it is most effective in arid areas with low humidity. Bauer et al. (1976) also refer to relative humidity as well as temperature, wind speed and solar radiation affecting evaporation and therefore evaporative cooling. Erez (1995) agreed with the aforementioned and suggested that water quality may also limit the success of evaporative cooling if large amounts of salt should accumulate on the tree and cause damage to immature shoot tips.

Evaporative cooling of pistachio trees:

Uzun and Caglar (2001) investigated the effects of evaporative cooling on pistachio bloom delay to avoid frost damage. Overhead sprinkling was initiated after 600 “Utah chill units” had been accumulated. Apparently no fixed cooling cycle was used, although cooling commenced when fruit bud temperatures exceeded thermocouple readings of 6ºC and stopped at lower temperatures. This probably led to the excessive amount of water (900 mm) used within one month. Full bloom was delayed by 7-12 days depending on the cultivar and no phytotoxicity was observed on either trees or nuts. The improved nut quality found in the cooled treatments was attributed to the increase in soil water status.

CHEMICAL REST BREAKING OF DORMANCY

Dormancy in deciduous trees:

Winter periods with insufficient chilling usually result in delayed and irregular blooming and foliation of deciduous fruit and nut trees (Crane and Takeda, 1979). Deterioration of flower buds may also occur and in some species may abscise in considerable numbers during late winter and early spring (Brown, 1952).

Pistachios have high chilling requirements and react to insufficient chill by producing the usual symptoms, but also with incompletely developed leaflets and leaves with a reduced number of leaflets (Crane and Takeda, 1979). A further phenomenon which was only reported on in isolated incidences in Davis, California after an exceptionally warm winter, is the formation of single inflorescences forming (and setting fruit parthenocarpically) terminally or laterally on current season’s growth and extremely poor pollen production by the male inflorescences (Crane and Takeda, 1979).

The satisfaction of the chill requirement is usually essential for bud break and can only be partly substituted by other means, although rest avoidance (preventing dormancy) - possible only in regions without distinct seasons (Erez and Lavi, 1984; Saure, 1985; Edwards, 1987) and the hastening of dormancy release by several methods have been reported. These include evaporative cooling (Anderson et al. 1975; Gilreath and Buchanan, 1981; Erez and Couvillon, 1983), heat treatment at temperatures 35º to 50ºC (Chandler, 1960; Shulman et al., 1982), late autumn applications of N and irrigation (Terblanche et al., 1973, 1979) or chemical treatments (Saure, 1985).

Saure (1985) classified dormancy with terms like pre-, true- and imposed dormancy which essentially corresponds with the para-, endo- and eco-dormant stages of buds as suggested by Lang et al. (1987). According to them, para-dormancy is defined as correlative inhibition or apical dominance, while endo-dormancy is the stage when the dormancy causing factor resides within the bud and eco-dormancy is imposed by temperatures unfavourable for growth. Samish showed as early as 1954 the importance to treat every bud as an individual entity regarding endo-dormancy, but in the case of eco-dormancy it is also important to note the strong interactions among buds due to differences in dormancy depths / chilling requirements (i.e. the terminal bud usually has a much lower chilling requirement than its lateral vegetative buds, resulting in it already being eco-dormant, while the latter is still endo-dormant) (Erez, 1995; Cook et al., 1998).

The foremost theory on dormancy, according to Faust et al. (1997), indicates multifaceted control. Four major biological controlling factors were identified by them. They are hormone balance in the bud or tree, state of water within the bud, membrane structure affecting cold resistance and governing resumption of growth, as well as the anabolic potential of buds.

However, Faust et al. (1997) indicated that dormancy and its release mechanism will only be comprehended if the interactions between these factors are understood.

Fuchigami and Nee (1987) proved that the depth of dormancy changes during the dormant period, while Erez et al. (1979) showed that (1) cold accumulation is reversible, but only if given in short cycles and (2) that there is a point where the process becomes irreversible, indicating a fixation of cold accumulation.

According to Erez (1995), the influence of winter chilling - or the lack of it, on a deciduous tree is mainly reflected by the level, the time and the uniformity of bud break. Factors like strong vigour, more vertical orientation of branches, late vegetative growth, early pruning (Erez, 1995) and summer pruning - even though no new shoot growth may have occurred (Saure, 1985), can increase apical dominance and hence increase the chilling requirement or in other words, the potential for insufficient chilling symptoms of deciduous trees. Cook and Bellstedt (2001) showed that distal shoot tissues reduce the response of lateral buds to chilling, thereby increasing apical dominance development. This was further explained by Cook et al. (2001), proving that *t*-zeatin riboside (ZR) increased mostly in intact distal shoot tissues.

Therefore, producers who intend to grow temperate zone fruit trees with high chill requirements in warmer climates have two challenges: firstly to increase bud break and obtain uniform flowering and secondly to regulate dormancy and delay bud break, thus avoiding spring frosts (Faust et al., 1997).

Chemical rest breaking:

Since the beginning of the previous century, the use of several chemical rest breaking agents (RBA) has become common practice, although only a few have been found suitable for commercial use in deciduous fruit orchards (Erez et al., 1971), and none to completely substitute chilling of buds in endo-dormancy. However, the use of RBA allowed the production of deciduous fruit crops in warmer areas where it had never before been possible (Erez, 1987).

The only common characteristic among these active chemicals is that with many of them, a sub-lethal dosage has a rest breaking effect (Erez et al., 1971). However, predicting the potential rest breaking effect to be obtained from a certain RBA is complicated by the interaction of many RBA with the climatic conditions at and after treatment, the level of bud dormancy development and previous management practices.

Apical dominance is closely related with bud dormancy completion. As the apical bud has a shallower endo-dormancy than the lateral buds, lack of chilling which induces poor bud break, will strengthen apical dominance (Erez and Lavee, 1974). Therefore, late RBA treatments, coupled with late pruning will reduce the relative advancement in opening of the apical bud in poor chilling conditions. Timing of rest breaking treatment therefore, not only reflects the effect of the level of physiological bud development in relation to its response, but also its potential to prevent strong apical dominance (Erez, 1987).

In general, this rest breaking effect is both dosage- and time-dependant, with stronger effects at higher concentrations and later applications (Erez and Lavee, 1974). However these same factors also increase the risk of phytotoxicity which could lead to damage due to damaged flower buds, especially in the case of stone fruit species, having simple, less protected flower buds (Strydom and Honeyborne, 1971; Erez, 1987).

The mode of action of many RBA is to inhibit catalase, leading to the activation of certain peroxidases (Taylorson and Hendricks, 1977) or to interfere with aerobic respiration. Gibberellins and cytokinins also lead to activity, but are commercially only used in isolated cases (Erez, 1987). The relative effect on various fruit crops, the risk of phytotoxicity and their potential use in combination with oil, denitro-o-cresol and cyanimides are described in the following sections.

Oil and denitro-o-cresol (DNOC)

Commercial oil was the first chemical used to enhance bud break and was found in 1945 to be more effective on apples in combination with DNOC (Samish, 1945), and since then has been used throughout the world on deciduous trees (Erez and Lavee, 1974; Strydom and Honeyborne, 1980; Erez and Zur, 1981). On apple buds, DNOC did not improve bud break if used at a concentration higher than 0.12% but in combination with oil, the effect was correlated to the logarithm of the DNOC concentration (Erez and Zur, 1981). Both agents enhance respiration, driving it toward anaerobic conditions (Erez, 1968 cited by Erez, 1987), leading to bud break, probably due to the accumulation of anaerobic end products such as ethanol and acetaldehyde (Samish, 1954).

Reduction of oxygen permeability through the oily layer further enhances anaerobic conditions in the enclosed structure, provided respiration is high enough in the dormant buds (Erez, 1987).

This reduction of oxygen permeability depends on the thickness of the oily layer and its deterioration over time - it is not known how environmental conditions affect this deterioration, but the oily layer usually lasts 10 to 14 days.

Samish (1945) noted the difficulty to decide on the “most effective” time to spray because of the varying effects at different application times- early spraying during late dormancy causes earlier foliation and flowering (“forcing effect”), without reducing the irregularity of them, while later spraying has a very slight forcing action and is more “normalising”, generally shortening the main bloom period, reducing the time between bloom and foliation as well as reducing the number of buds remaining dormant (Saure, 1985) and inhibiting swelling terminal buds (by DNOC) (Erez and Zur, 1981). Temperature conditions during and after an oil + DNOC treatment, also have a strong effect on the reaction (Erez, 1987). Temperatures, continuously ≤ 12ºC are too low, whereas a temperature higher than 24ºC for a few hours enhances activity (Erez, 1979).

Ethanol production explains the phytotoxicity which may occur at high DNOC or oil concentrations, extremely high temperatures during the effective period and root flooding causing poor oxygen supply to the roots (Erez, 1995). Pome fruit species with their compound buds are more resistant than stone fruit and can withstand up to 6% oil + 0.12% DNOC. Loss of flower buds in stone fruit, and hence yield reduction, is typical of a mild phytotoxicity effect. Severe phytotoxicity is usually manifested by die-back of young twigs, whole branches or even trees from fermentation due to long exposure to anaerobic conditions (Erez, 1987).

Cyanimides

The paste-like form and high concentrations of calcium cyanimide needed to break rest in some deciduous species, limited its commercial use as rest breaking agent. However, the discovery that acid cyanimide is an active rest breaking chemical (Shulman et al., 1983), paved the way for cyanimide to become the superior rest breaking agent for commercial grape vines, especially for cane-pruned cultivars, such as ‘Thompson Seedless’. Proper application timings in grapes vines enhanced bud break, advanced fruit ripening and compensated for lack of chilling (Shulman et al., 1982). Snir (1983) noted that cyanimide increased yield and advanced harvest date in raspberry when it was applied during late dormancy at a stage when DNOC, potassium nitrate and thioruea had no effect. Positive effects were noted with most deciduous fruit trees, while excellent results were obtained with apples, plums and peaches under warm winter conditions.

A marked effect of cyanimide on the enhancement of specifically vegetative bud break was also noted (Erez, 1987; 1995).

Erez (1995) discussed the difficulties with the timing of cyanimide applications and variation in trial results, which he attributed to the level of endo-dormancy of the buds. No or poor effects could be expected with applications before endo-dormancy is broken as cyanimide will not compensate for more than approximately 30% of the chilling requirement and the risk of phytotoxicity of the buds rapidly increases upon release from the endo-dormant state. Hence, timing of applications can not be safely done - as in the case of oil-DNOC- by visual symptoms like terminal bud swelling in the case of apple, but should be allowed before any visual changes are obvious (30 days before bud swell) (Erez, 1995). He further pointed out that for high chill requirement cultivars in relatively warm climates; this recommendation works well, but the physiological stage of the buds is often more important in the case of stone fruit species. George et al. (1992) further found that early applications of cyanimide on ‘Flordaprince’ peach are usually more effective in advancing floral and vegetative bud break than applications closer to normal blooming.

High concentrations of cyanimide on stone fruit species, typically leads to a marked advancement of leafing over bloom which, in cases of excessive vegetative bud break may have negative effects on fruit set due to sink competition (Erez, 1995).

Cyanimide was found to induce heavy damage to flower buds and young shoots of peaches and plums under certain climatic conditions (Erez, 1987). According to Erez (1987), the interaction between cyanimide phytotoxicity and temperature is not entirely clear but cooler temperatures seem to enhance damage. He furthermore discourages applications of cyanimide within less than 4 weeks of bud swell, especially where maximal level of bloom is desired as in the case of small fruits and nuts, but points out that where thinning is usually practised as in apple, peach or kiwi, reduced level of bloom due to phytotoxicity, may be beneficial (Erez, 1995).

Various studies with the combination of oil (2-4%) and low cyanimide (<1%) concentrations showed that they can be used with equal or better effect than oil-DNOC combinations or the separate applications of the above chemicals (refs). Erez (1995) points out that these positive effects are a potential way to prevent cyanimide damage on more susceptible stone fruit species without losing effectiveness.

Chemical rest breaking of pistachios (P. vera):

The evaluation of rest breaking agents on pistachios has gained interest during the past 10 years.

Procopiou (1973) was the first to test oil-DNOC combinations on pistachios in Greece, proving that it can successfully be used to improve bloom. Pontikis (1989) used hydrogen cyanimide in a four- year study where he reported similar yield reactions. Küden et al. (1995) found that Armobreak + cyanimide combinations improved the bud break of both vegetative and flower buds of three pistachio cultivars more than either potassium nitrate or an Armobreak + potassium nitrate combination.

Beede and Ferguson (2002) evaluated 3% mineral oil in a four-year study on ‘Kerman’ on four different rootstocks in California. They applied the oil at three different times: mid-July, mid-August and mid September (Southern hemisphere). They found no rootstock effect and support previous work on other deciduous tree species that oil applications are more effective when followed by a warm spell. Their mid-August treatment showed the greatest advancement in vegetative growth, bloom and rate of kernel filling and also the most consistent by increasing the average dry split nut yield with 2.7 kg per tree. However, as their total filling percentages at harvest, edible closed nuts or larger nut sizes did not differ between the treatments, indications were that higher fruit set was responsible.

The most recent work on chemical rest breaking of pistachio trees in Iran (Rahemi and Asghari, 2004) showed that volk oil and hydrogen cyanimide as well as combinations thereof, can successfully be used to advance blooming and increase kernel weight, lateral bud break as well as the percentage flower buds developing into fruit clusters. Although they only worked on branch-units, a positive correlation between vegetative bud break and yield was found. They attributed this increase in yield entirely to the improved synchronisation of the male and female flowers.

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<u>PAPER 1:</u> THE EFFECT OF REST BREAKING AGENTS AND PRUNING ON BUDBREAK AND FLOWER BUD DEVELOPMENT OF PISTACHIO CV. ARIYEH *(PISTACIA VERA* L.*)* IN A CLIMATE WITH MODERATE WINTER CHILLING

Abstract

Tip-pruning (to remove <2.5cm) and severe heading cuts (to remove 35-45%) of one-year-old wood were compared and 4% hydrogen cyanimide (Dormex®), 4% mineral oil (Budbreak®) as well as their combination (0.5% Dormex® + 4% Budbreak®) were used as rest breaking agents on third, fourth and fifth leaf 'Ariyeh' pistachio (*Pistacia vera* L.) trees and evaluated over five seasons. Bud break, reproductive bud differentiation, die-back, flower bud retention during winter and early summer and yields were evaluated. The trends in the results emphasised the interaction of rest breaking and pruning effects with genetic chill requirement and environmental influences - specifically winter chill build-up. Severe pruning was detrimental to flower bud formation as well as yield. The bud break data suggests that the ability of some rest breaking chemicals to promote lateral development may possibly also be explained by their potential to impede the development of apical dominance, normally strengthened by insufficient winter chilling, in addition to direct effects on the lateral buds. The inability of the chemical rest breaking treatments to increase yields consistently might indicate that the average winter chill of Prieska (29° 40'S, 22° 45'E, 945 m.a.s.l) is below the minimum amount necessary for chemical effects to be expected on this cultivar.

Introduction

The climate around Prieska differs from other pistachio growing regions in the world in that it receives fewer winter chilling units, has higher maximum temperatures during winter and spring and receives summer rainfall (Van den Bergh and Manley, 2002). This possibly results in the observed delayed foliation, flower bud and inflorescence abortion, low fruit set and yield and other flowering disorders e.g. the terminal bud developing into a florescence which Crane and Takeda (1979) described as a response to low winter chilling. No accurate chilling requirements or detailed information regarding desired lengths of lateral shoots are known for any pistachio cultivar, except that 1000-1500 hours below 7 ºC appear to be sufficient in California, USA (Crane and Takeda, 1979).

The use of different dormancy breaking chemicals on pistachios in areas with mild winters resulted in increased yields, quality and changes in flowering patterns and lateral development (Procopiou, 1973; Küden and Küden, 1995; Rahemi and Asghari, 2004), irrespective of rootstock (Beede and Ferguson, 2002). However, these reports did not discuss the long term effects of dormancy breaking chemicals on flower bud differentiation and also did not eliminate the possible lack of overlapping of male and female bloom through artificial pollination.

The first four to five pruning seasons of a pistachio tree are spent in training a strong trunk (90-120 cm in height) and well balanced scaffold branches to accommodate mechanical harvesting (Crane and Iwakiri, 1985). This is done through heading cuts which remove 30% or more of one-year-old shoots in winter (Personal observation). As pistachios bear only on one-year-old shoots, the importance of new growth is obvious. Koopmann however, reported as early as 1896 on the negative effects of severe heading cuts on flower bud differentiation (Wertheim, 1976). Therefore, the influence of strong heading cuts on delaying the reproductive development needs to be investigated.

In this paper we report on the effect of dormancy breaking chemicals and pruning on the development of lateral shoots, flower bud differentiation, yield, tree dimensions and flower bud retention during spring of 'Ariyeh' in the Prieska district, Northern Cape, RSA.

Materials and method

Plant material:

The trials were conducted at the farm Green Valley Nuts near Prieska, Northern Cape, South Africa (29° 40'S, 22° 45'E, 945 m.a.s.l) during the 2002/2003, 2003/2004, 2004/2005, 2005/2006 and 2006/2007 seasons. Trees in commercial orchards from three age groups (3rd, 4th and 5th leaf) were tagged in 2001/2002. Trees on *P. terebinthus* (3rd leaf) and *P. integgerima* (4th and 5th leaf) rootstocks were established at a spacing of 4 m x 5.78 m. Artificial pollination was used during bloom in 2004 using 100% pollen when approximately 25% of the inflorescences were receptive and again 2 days later. During bloom in 2005 and 2006, a dilution of 1% pollen in soft wheat flour was blown onto the trees using a mechanical duster daily for 9 to 16 consecutive days (Cagler and Kaska, 1995). The orchard was managed using standard commercial practices except for rest breaking and pruning.

Treatments and experimental design:

A randomised complete block design was used in a 4 x 2 factorial design with 10 single tree replicates. The four chemical rest breaking treatments were (1) control, (2) 4% Budbreak® (869g/l mineral oil), (3) 4% Dormex® (520g/l hydrogen cyanamide) and (4) a combination of 0.5% Dormex® and 4% Budbreak®. Water pH was buffered at 5.5 with 0.02% Bladbuff® for the Dormex® treatments. Applications were done by hand, using a motorised knapsack and sprayed to run-off. Four to five litres were applied to each tree. Timing was aimed at the late bud swell stage and occurred on 2 Sept. 2002, 9 Sept. 2003, 7 Sept. 2004, 23 Aug. 2005 and 18 August 2006, respectively.

The two pruning treatments consisted of either a light pruning-treatment (tip pruning; <2.5 cm heading cut) or a heading cut removing 35-45% (top pruned) of the one-year-old shoots on all shoots longer than 20 cm. The pruning was done during the end of August each year. The average lengths after pruning of lightly pruned shoots were 67±17 cm and 40±7 cm in trees receiving the heavy heading cut in 2002. In 2003 the average lengths of the lightly pruned shoots were 36±16 cm (5^{th} leaf), 58±15 cm (6^{th} and 7^{th} leaf) and for the heavy pruned trees 31±7 cm (5^{th} leaf) and 40±9 cm (6^{th} and 7^{th} leaf). In addition the number of reproductive buds was counted per one-year-old shoot.

Data recorded:

Bud break, reproductive bud differentiation and die-back

The winter following the treatments, the bud break and shoot development on 3 randomly chosen two-year-old shoots (N) per tree was recorded (Fig 1). The total number of shoots (N+1), number of N+1 shoots per length category (0, 0-2, 2.1-10, 10.1-20, 20.1-30, >30 cm) and the total length of the chosen units (N) were recorded. In 2004, similar data were recorded, but 5 two-year-old units (N) were used per seventh leaf tree. In addition the number of reproductive buds that differentiated per one-year-old shoot (N+1) was counted. In 2004 the number of reproductive buds that had developed on new growth (N+2) of two-year old N+1 spur-units ≤ 20cm was counted as shown schematically in Fig 1. Five three-year-old branch units (tip-pruned: 67 ± 17 cm, top-pruned: 40 ± 7 cm in year N), were randomly selected and the averages calculated. The total number of flower buds, the number of flower buds on 0 - 2, 2.1 - 10 and 10.1 - 20 cm two-year-old spur-units (N+1) and the total length of the chosen units (N) were recorded. In addition, dead two-year old spur-units were counted on the same units, recording the total number of two-year old spur-units (N+1) as well as the number of dead N+1 spurs (0 – 2, 2.1 – 10, 10.1 - 20 and 20.1 – 30 cm).

Flower bud retention during winter and early summer: 2005

Five one-year-old shoots (10 - 20 cm), with three or more flower buds, were randomly tagged on 11 May 2005 on all trees and the number of flower buds per shoot recorded. The percentage flower bud / fruit retention of these shoots was monitored on 21 Nov. (after shell hardening).

Yield and tree dimensions

Individual trees were harvested by hand during March 2005, 2006 and 2007 and fresh weight per tree recorded. Individual height (from ground level) and depth at the widest part of the canopy (perpendicular to tree row), were measured during winter 2005 and winter 2006 using a measuring pole with markings at every 25 cm.

Data analysis:

Data were analysed using the GLM (general linear models) procedure in the Statistical Analysis Systems (SAS), Enterprise Guide 9.0. Logit transformation was performed on flower retention data (Snedecor and Cochran, 1973).

Results

Bud break after treatment in 2002

Fourth leaf trees

Interactions between rest breaking treatment and pruning were found in total number of shoots per meter, percentage shoots 2.1 – 10 cm and 10.1 - 20 cm. All the rest breaking / pruning combinations resulted in significantly more shoots per meter than the control combinations. The Dormex® + lightly pruned combination resulted in the highest number per meter although it did not differ significantly from its severely pruned combination or that of Dormex® & Budbreak®. The Budbreak® in combination with light pruning had more laterals than with severe pruning, while the opposite is seen in the two control combinations (Fig 2a). The Dormex® treatment had the lowest percentage 0 – 2 cm shoots, with no difference between the other rest breaking treatments (Fig 2b). The lightly pruned treatment induced the highest percentage 0 – 2 cm shoots (Fig 2c). In the category 2.1 – 10 cm shoot length, the Budbreak® + severely pruned and both Dormex® combinations resulted in significantly higher percentages, with no difference between the other combinations (Fig 2d). The severely pruned Dormex® treatment induced the highest number of shoots in the category 10.1 – 20 cm (Fig 2e). The control treatment and severe pruning treatments had the highest percentage shoots > 20 cm (Fig 2f, g).

Fifth leaf trees

Slight, though significant rest breaking and pruning effects were found in the total number of shoots per meter with the control and lighter pruning having significantly more (Fig 3a, b). The control + lightly pruned combination had the highest percentage laterals 0 – 2 cm, with Budbreak®, Dormex® & Budbreak® and Dormex® having progressively fewer (Fig 3c). The Dormex® induced the highest percentage of shoots in the category 2.1 – 10 cm and control the lowest (Fig 3d). The severely pruned treatment also stimulated the highest percentage of shoots in this category (Fig 3e). The Dormex® treatment resulted in significantly the highest percentage of shoots 10.1 – 20 cm with no difference between the control, Budbreak® or Dormex® & Budbreak® (Fig 3f). The pruning treatments showed no significant effect (Fig 3g). The Budbreak®, Dormex® & Budbreak® and Dormex® treatments produced higher percentages of shoots longer than 20 cm, with no significant difference between Budbreak® and the control (Fig 3h). The severely pruned treatment had the highest percentage of shoots longer than 20 cm (Fig 3i).

Sixth leaf trees

Significant rest breaking and pruning effects were found in the total number of shoots per meter with the control and lighter pruning having significantly more, although Dormex® did not differ significantly from the control (Fig 4a, b). The control + lightly pruned combination had the highest percentage laterals 0 – 2 cm, but did not differ from the severely pruned combination. Budbreak®, Dormex® & Budbreak® and Dormex® in combination with light pruning, induced significantly less in this category (Fig 4c). Budbreak® and Dormex® & Budbreak® in combination with severe pruning produced significantly more shoots in the category 2.1 – 10 cm than their lightly pruned combinations. The Dormex® and control combinations did not differ regarding each of their two pruning combinations, but the two Dormex® combinations induced higher percentages in this category than the control combinations (Fig 4d). The Budbreak® treatment resulted in significantly the lowest percentage of shoots 10.1 – 20 cm with no difference between the control, Dormex® & Budbreak® or Dormex® (Fig 4e). The pruning treatments showed no significant effect (Fig 4f). No rest breaking effect was found but the severely pruned treatment had the highest percentage of shoots longer than 20 cm (Fig 4g, h).

Bud break after treatment in 2003

Fifth leaf trees

Marked rest breaking effects were found with Dormex® (30.1) resulting in the highest number of shoots per meter and the control with only 18.0. Budbreak® and Dormex® & Budbreak® did not differ from each other (Fig 5a). The severely pruned treatment also stimulated the highest number of shoots per meter (Fig 5b). The Dormex® treatment had the lowest and Budbreak® the highest percentage 0 – 2 cm shoots, with no difference between the Budbreak® and Dormex® & Budbreak® and between control and Dormex® & Budbreak® (Fig 5c). The lightly pruned treatment induced the highest percentage 0 – 2 cm laterals (Fig 5d). Interactions between rest breaking treatment and pruning were found in percentage shoots 2.1 – 10 cm. Dormex® + severe pruning resulted in the highest percentages, but did not differ from the control + light pruning with no difference between the other combinations (Fig 5e). The Dormex® treatment induced the highest number of shoots in the category 10.1 – 20 cm (Fig 5f). No pruning effects were found (Fig 5g). The control treatment had the highest and Dormex® the lowest percentage shoots > 20 cm although control did not differ from Dormex® & Budbreak®. Dormex® and Budbreak® also did not differ between each other (Fig 5h, i).

Sixth leaf trees

Interactions between rest breaking treatment and pruning were found in total number of shoots per meter, percentage shoots 0 - 2 cm and > 20 cm. All the rest breaking / pruning combinations resulted in more shoots per meter than the two control combinations, with significantly the highest numbers in the severely pruned combinations. The two control combinations did not differ from each other (Fig 6a). The control + severely pruned combination had a lower percentage laterals 0 – 2 cm than control + lightly pruned, although both did not differ from the two Dormex® or Dormex® & Budbreak® + severely pruned combinations. The lightly pruned Budbreak® and Dormex® & Budbreak® combinations as well as Budbreak® + severe pruning had the highest percentages in this category (Fig 6b). The Dormex® induced the highest percentage of shoots in the category 2.1 – 10 cm but did not differ from Dormex® & Budbreak® and control treatments (Fig 6c). No pruning effects were found in this category (Fig 6d). No rest breaking effects were found in the percentage shoots 10.1 – 20 cm and only a slight pruning effect with the severely pruned treatment having significantly more (Fig 6e, f). The severely pruned combinations of Dormex®, Dormex® & Budbreak® and control produced higher percentages of shoots longer than 20 cm than their lightly pruned combinations, with control having significantly the highest. No differences were found between the two Budbreak® combinations (Fig 6g).

Seventh leaf trees

A marked rest breaking effect, but only slight pruning effects were found in the total number of shoots per meter with the control and lighter pruning having significantly less. The Budbreak®, Dormex® & Budbreak® had the highest percentage laterals 0 – 2 cm, although the Dormex® & Budbreak® did not differ from the control. Dormex® induced the least, but did not differ from the control. Light pruning induced the highest percentages in this category. Dormex® produced significantly the highest and control the lowest percentages shoots in the category 2.1 – 10 cm. Budbreak® did not differ from Dormex® & Budbreak® or the control. No pruning effect was found. The control treatment resulted in significantly the highest and Dormex® & Budbreak® the lowest percentages of shoots 10.1 – 20 cm, with no significant differences between them and Budbreak® or Dormex®. Severe pruning had a slightly, though significantly higher percentage in this category. The control as well as severely pruned treatments produced the highest percentages shoots longer than 20 cm (Table 1).

Reproductive bud development after treatment in 2002

Fourth leaf trees

Very few reproductive buds were formed on one-year-old shoots and no significant rest breaking or pruning effects were found on the number of reproductive buds per meter (Data not shown). Pruning effects were found on the 2.1 – 10 cm and 10.1 – 20 cm categories, with the lightly pruned treatment resulting in the highest number of reproductive buds in each case. No reproductive buds developed on shoots 0 – 2 cm and no significant difference was found regarding reproductive buds on laterals > 20 cm (Table 2).

Fifth leaf trees

Very few reproductive buds were formed on one-year-old shoots. Only a marked pruning effect was found on the number of reproductive buds per meter with lighter pruned trees having the highest numbers (Fig 7a, b). No rest breaking or pruning effects were found on the 2.1 – 10 cm category (Fig 7c, d). Interactions between rest breaking treatments and pruning were found in percentage reproductive buds on shoots 10.1 – 20 cm with the lightly pruned control and Dormex® combinations inducing the highest percentage reproductive buds in this category. The other combinations in this category did not differ from each other (Fig 7e). Only a pruning effect was found regarding reproductive buds on laterals > 20 cm, with the lighter pruned trees having the highest percentage (Fig 7f, g). No reproductive buds developed on shoots 0 – 2 cm (Data not shown).

Sixth leaf trees

A marked pruning effect was found on the number of reproductive buds per meter with lighter pruned trees having the highest numbers (Table 3). No rest breaking or pruning effects were found on the 2.1 – 10 cm category (Table 3). Only a rest breaking effect was found in percentage reproductive buds on shoots 10.1 – 20 cm with the control and Dormex® combinations inducing the highest percentage reproductive buds in this category, although they did not differ from Dormex® & Budbreak®. Dormex® & Budbreak® and Budbreak® did not differ from each other in this category (Table 3). Only a pruning effect was found regarding reproductive buds on laterals > 20 cm, with the lighter pruning having the highest percentage (Table 3). No reproductive buds developed on shoots 0 – 2 cm (Data not shown).

Reproductive bud development after treatment in 2003

Fifth leaf trees

Both rest breaking and pruning effects were found on the number of reproductive buds per meter with Dormex® and light pruning having the highest numbers. Very few reproductive buds developed on shoots 0 – 2 cm with no significant differences. Only a pruning effect was found on the 2.1 – 10 cm category, with the lightly pruned treatment producing the highest number of reproductive buds. No significant differences were found regarding reproductive buds on laterals 10.1 - 20 cm or > 20cm (Table 4).

Sixth leaf trees

Only a pruning effect was found on the number of reproductive buds per meter and the percentage reproductive buds on shoots 2.1 – 10, with the lightly pruned treatment resulting in the highest number of reproductive buds in each case. No reproductive buds developed on shoots 0 – 2 cm and no significant differences were found regarding reproductive buds on laterals 10.1 – 20 cm or > 20 cm (Table 5).

Seventh leaf trees

Interactions between rest breaking and pruning treatments were found in reproductive buds per meter and on percentage reproductive buds on shoots > 20 cm. All the lightly pruned combinations produced higher numbers of reproductive buds per meter, with the Dormex® combination having the highest number (Fig 8a). Very few reproductive buds developed on shoots 0 – 2 cm with no significant differences (Fig 8b, c). Both rest breaking and pruning effects were found in the 2.1 – 10 cm category with Dormex® and light pruning having the highest percentages (Fig 8d, e). Only a pruning effect was found regarding reproductive buds on laterals 10.1 - 20 cm, with the lighter pruning producing the highest percentages (Fig 8f, g) The lightly pruned Budbreak® and Dormex® & Budbreak® combinations had higher percentages reproductive buds on shoots > 20 cm than their severely pruned combinations with no difference between the two control and Dormex® combinations (Fig 8h).

Total number of reproductive buds on new growth (N+2) of two-year old units (N+1) ≤ 20 cm of seventh leaf trees after treatment in 2003

The rest breaking control and lighter pruning treatments developed the highest number of reproductive buds per meter N on shoots N+2. Budbreak® had the lowest number, but did not differ from Dormex® & Budbreak®. Only a rest breaking effect was found when looking at the 0 - 2 cm (N+1) category, with the control and Dormex® & Budbreak® having the highest percentage of reproductive buds and showing no difference from the other treatments. No rest breaking or pruning effects were found regarding the percentage of reproductive buds on shoots (N+1) 2.1 – 10 cm. Only a pruning effect was found in the category 10.1 – 20 cm shoots (N+1), with the light pruning having a higher percentage reproductive buds (Table 6).

Die-back on two-year old N+1 shoots of seventh leaf trees after treatment in 2003

Interactions between rest breaking and pruning treatments were found in the number of dead N+1 shoots per meter of N unit. The control combinations had the lowest numbers and the Dormex® the highest, with no difference between the lightly or severely pruned combinations of each. All the other combinations had significantly more dead shoots per meter N relative to the two control combinations, with only the Dormex® & Budbreak® + severe pruning combination showing an increase in die-back relative to its lighter pruned combination (Fig 9a). Only a rest breaking effect was found regarding the percentage die-back of the total originally formed N+1 shoots with the control having the lowest and Budbreak®, Dormex® + Budbreak® and Dormex® having progressively higher percentages dead N+1 shoots (Fig 9b, c). Only a rest breaking effect was found looking at the percentage dead N+1 shoots 0 – 2 cm, with the control having the highest and Budbreak®, Dormex® & Budbreak® and Dormex® having progressively lower percentages, but with no difference between control and Budbreak® (Fig 9d, e). The Dormex® and severe pruning treatments caused the highest percentage die-back of N+1 shoots 2.1 – 10 cm, with no difference between Budbreak® and Dormex® & Budbreak®, but control having the lowest percentage (Fig 9f, g). Only a slight, though significant pruning effect was found in the category 10.1 – 20 cm, with the severe pruning having the highest percentages.

Flower bud retention (2005) and yield (March 2004)

No rest breaking or pruning effects were found on the percentage retention of flower buds in November of seventh leaf trees. Only a slight, though significant rest breaking effect was found in the flower bud retention of eighth and ninth leaf trees, with Dormex® being the highest. In the ninth leaf trees' case, Dormex® did not differ from Budbreak® or Dormex® & Budbreak® (Table 7). Only a significant pruning effect on yield was found on sixth leaf trees, with the highest yield from the lightly pruned trees. On seventh leaf trees, only a rest breaking effect was found, with the control trees producing the highest yield. The rest breaking control and lighter pruning treatments resulted in the highest yields of the eighth leaf trees. The Budbreak® had the lowest yield, but did not differ from the Dormex® & Budbreak®, which also did not differ from Dormex® (Table 7).

Tree dimensions after treatment in 2004

Only a significant pruning effect on tree dimensions was found on sixth leaf trees, with the lighter pruning having larger measurements in both height and depth. The lighter pruned treatment and rest breaking control of the seventh leaf trees resulted in slightly larger height and depth measurements with Dormex® having the smallest, although both the control and Dormex® did not differ from the Budbreak® or Dormex® & Budbreak®. Only a pruning effect was found on the height of 8^{th} leaf trees, with the lighter pruned trees having larger measurements. Only a rest breaking effect was found on the 8^{th} leaf trees' depth, with the control and Budbreak® having larger depths, but did not differ from Dormex® & Budbreak® (Table 8).

Tree dimensions after treatment in 2005

Significant pruning effects were found on seventh leaf trees, with the lighter pruning having slightly larger height and depth measurements, but a rest breaking effect was only found in their depths. Dormex® & Budbreak® had the highest and Dormex® the lowest measurements, with the control and Budbreak® not differing from either. Only a pruning effect was found regarding the height and depth of the eighth leaf trees, with the lighter treatment having larger measurements. No significant pruning or rest breaking effects were found in the heights or depths of the ninth leaf trees (Table 9).

Only a rest breaking effect was found regarding the percentage increase in height and depth of seventh leaf trees, with the control having the lowest percentages and no differences between the other rest breaking treatments. On eighth leaf trees, rest breaking and pruning effects were found to influence only the percentage increase of height, with the severe pruning and Dormex®

treatments resulting in the highest scores, although Dormex® & Budbreak® did not differ from it. Budbreak®, Dormex® & Budbreak® and Dormex® did not differ from each other and increased only the percentage height increment of ninth leaf trees, with control trees having lower percentages Table 10).

Discussion

Bud break

The trend seen in the total number of shoots on the control trees of the two older age groups (on *P. integgerima* rootstock) with 35 - 40 per meter in 2002 in comparison with only 15 - 18 per meter in 2003 (Fig 3a, 4a, 6a, Table 1) can be explained by comparing the climatic differences between 2002 and 2003. In comparison to the total annual chill of 2002, 153 more Richardson Chilling Units (RCU) (Richardson et al., 1974) were accumulated during 2003. Contrary to this, 2002 had 229 more RCU accumulated over 3 months by the end of July, in comparison with 2003 at the same stage. However, Cook and Jacobs (2000) found that regions with a gradual build-up of RCU during the beginning of dormancy showed a negative effect on bud break of apple shoots cv. Golden Delicious. The youngest age group (on *P. terebinthus* rootstock) did not show any marked differences in reaction to the two winters (Fig 2a, 5a, b). Furthermore, the highest total numbers of shoots per meter for the youngest group were consistently found after Dormex® treatment and the lowest in its control trees, while control trees of the two older groups was only exceeded by rest breaking treatments in 2003, again emphasising the differences between the two groups.

Taking the aforementioned into account, it is of considerable interest to note that all three chemical treatments in 2003 led to higher numbers of laterals per meter in all three age groups, either as a single effect or in interaction with pruning treatments - even though the winter was less favourable (Fig 5a, 6a, Table 1). This is probably best explained by the more gradual build-up of RCU (Richardson et al., 1974) during 2003 which could have strengthened apical dominance or increased endodormancy of the lateral buds more than in 2002. Cook and Jacobs (1999) explained an increase in apical dominance development after sub-optimal chilling, by referring to ongoing polar auxin transport in warmer winter climates (with average temperatures above 7ºC) and stated that causes of delayed foliation may reside more in the strengthened correlative inhibition than in the endodormancy of the lateral buds. Therefore, the increase in the number of lateral shoots, may also reflect on their capability to impede the development of strong apical dominance (Erez, 1987) by promoting more uniform bud break after low chilling, in addition to the general improvement of lateral bud break as found by Rahemi and Asghari

(2004) - especially when considering the similar or lower number of laterals per meter in 2002 in reaction to all three chemical treatments on fifth and sixth leaf trees (Fig 3a, 4a).

Pruning in general, showed small though significant effects with marked differences between the two seasons. After more favourable chilling in 2002, light pruning increased total lateral bud break compared with severe pruning, where as after less favourable chilling resulted in reduced total shoots per meter while severe pruning enhanced it. A possible explanation for this is (1) that the more favourable chilling of 2002, resulted in a less aggressive apical dominance development (Cook and Jacobs, 1999), allowing moderate lateral bud break and (2) the fact that pruning was done almost at bud swell, cancelling the initial apical dominance of the terminal bud in both pruning regimes and promoting lateral bud break. Severe pruning left less developed buds with lower growth potential remaining on the shoot, thereby impeding lateral development before apical dominance were restored. However, the strengthened apical dominance, resulting from less preferable winter chilling (See previous paragraph), during 2003 was probably the dominant factor which impeded lateral development after tip-pruning. Also, the small percentage of shoot taken away with tip pruning probably did not result in dramatic changes in the cytokinin / auxin ratio of the remaining vegetative buds (Oosthuyse et al., 1992) - which might have been the case after severe pruning.

Chemical rest breaking and pruning significantly affected the length of shoots of all three age groups during both years, although trends were not consistent. The control on *P. terebinthus* rootstock showed a marked increase in the 0 - 2 cm category after the 2003 treatments, while the control of the two groups on *P. integgerima* rootstock had markedly fewer of the same category in comparison with the 2002 data. In contrast with the control, Dormex® had either a similar (after less favourable winter chill) or markedly lower (after more preferable winter chill) percentage 0 - 2 cm shoots - in interaction with either pruning regime (Fig 2b, 3c, 4c, 5c, 6b, Table 1). This could probably reflect on its ability to impede apical dominance and thereby increasing the percentage of shoots in the larger categories. Light pruning of the youngest age group increased this category over both years, although the two groups on *P. integgerima* rootstock showed increases in some cases of interaction with chemical treatments, although not consistent between the two ages. However, the dominant role of light pruning in this category could probably be explained by (1) the timing of pruning at bud swell, cancelling the original apical dominance (Saunders et al, 1991) as well as (2) the insignificant change in cytokinin / auxin ratio (Oosthuyse et al, 1992) of the remaining buds resulting from the light heading cut not being able to sustain lateral growth after secondary apical dominance succeeded.

The two older groups (*P. integgerima* rootstock) reacted similarly regarding their marked increase in 2.1 - 10 cm shoots after the winter of 2003, with almost no change in the values of the youngest group *(P. terebinthus* rootstock). Although the Budbreak® and Dormex® & Budbreak® also showed signs of increasing this category, and Dormex® with about 45% - 60% showed some dramatic increases, the effects/interactions were often inconsistent. However, indications are that Dormex® can increase the percentage shoots 2.1 – 10 cm on *P. integgerima* rootstock with either pruning regime after less favourable winter chilling. Its positive effect on *P. terebinthus* rootstock was only seen after 2002 and therefore probably depends on more favourable winter chilling. The fact that Dormex® was able to support lateral growth under conditions of strengthened apical dominance (Cook and Jacobs, 1999) - even after severe pruning left less developed buds proximal to buds with higher potential, serves to illustrate its rest breaking ability. Severe pruning showed indications of increasing percentages in the 2.1 – 10 cm category in some cases, although it was inconsistent and often absent.

Dormex® as well as in interaction with severe pruning, markedly increased shoots in the 10.1 – 20 cm category after 2002. However, Dormex® treatments in 2003 showed inconsistent and very slight, though significant effects on fifth and seventh leaf trees. Severe pruning only played a role in this category in interaction with the three chemical treatments in 2002, although in 2003 increased it slightly and only on the two older age groups. Considering the lower values of this category in 2003, compared with 2002, the possible influence of an enhanced apical dominance (Cook and Jacobs, 1999) after less favourable chilling can clearly be seen.

Rest breaking effects in 2002 were inconsistent, although after less favourable winter chill in 2003, the control + severe pruning combination (sixth leaf), consistently had the highest number of shoots longer than 20 cm with markedly higher values compared to 2002. This is best explained by referring to (1) the strengthened apical dominance after insufficient chill in 2003 promoting terminal bud growth (Cook and Jacobs, 1999), as well as (2) the general distal position of shoots in this category (Personal observation). This corresponds with similar findings of Koopmann (Wertheim, 1976) in 1884 after making progressively deeper heading cuts on one-year apple shoots resulting in shoots of which the lengths correlated with the severity of pruning, up to the point when 60% were headed of the original shoot. A further explanation is probably the increase of the cytokinin / auxin ratio in the reduced number of cytokinin sinks after severe pruning (Oosthuyse et al, 1992).

Reproductive bud development

Marked differences in flower bud formation per meter shoot were found between age groups and years. In 2002, no rest breaking or pruning effects were found on fourth leaf trees, while only light pruning increased flower bud formation in both older age groups. After less favourable chilling in 2003, light pruning still increased flower bud formation, although Dormex® (on fifth leaf trees) and its interaction with light pruning on seventh leaf trees markedly increased the number of flower buds per meter shoot. It is clear from the above that light pruning enhanced flower bud formation in general, while Dormex® was the only chemical treatment which showed such a trend and then only after less favourable winter chill on fifth and seventh leaf trees. The reason for the effect by Dormex® is not quite clear, although the pruning effect is consistent with previous work by Koopmann in 1884, as quoted by Wertheim (1976), who referred to the negative effects by severe pruning on flower bud formation of apple, pear and plum.

The locality distribution of flower buds was markedly influenced by pruning treatments over both years, except in the case of fifth and sixth leaf trees in 2002 and seventh leaf trees in 2003 when rest breaking effects were found, although inconsistent and not differing from the control. Tip-pruning markedly increased the 2.1 - 10, 10.1 - 20 and > 20 cm allocations. This positive role in each category is probably due to the dominant role of light pruning increasing the total number of flower buds, taking into account that severe pruning resulted in only a few reproductive buds. However, no correlation could be found between the flower bud position favoured by a certain treatment and the shoot-length category that was increased by it - although the markedly higher number of flower buds located on shoots 2.1 - 10 cm in 2003, relative to 2002, correlated with the general increase in the same shoot category that year, probably due to its availability as location.

Reproductive buds on new growth (N+2) of two-year old units (N+1) ≤ 20 cm

It is evident from Table 6 that all three chemical treatments reduced the number of flower buds formed on N+2, probably due to the marked die-back of the number of N+1 shoots per meter N (Fig 9a, b). This becomes clear when the high percentage die-back of the 2.1 - 10 cm shoot category (up to 50%) resulting from the chemical treatments, are compared with the fact that the majority of N+2 flower buds (±65%) were located on the same shoot category, irrespective of chemical treatment.. Tip-pruning increased the N+2 flower buds, although only promoting their allocation to 10.1 - 20 cm N+1 shoots. It is difficult to gauge the economic importance of the above results except to recognise it as a potential factor contributing to yield differences.

Flower bud retention (2005)

Severe pruning (only in seventh leaf's case) and Budbreak® and Dormex® (only sixth and seventh leaf trees), were found to increase percentage flower bud retention, although only slightly (Table 7). Saunders et al. (1991) also increased fruit set on 'Packham's Triumph' pears after topping to remove 50% shoot length, which they attributed to the removal of distal correlative inhibition. Severe pruning's increase in retention may be explained by referring to severe pruning (1) reducing the number of cytokinin sinks, increasing the cytokinin / auxin relation in the flower buds (Oosthuyse et al., 1992), (2) leaving less developed vegetative buds on the one-year shoot to compete during the opening of the flower buds and (3) reducing correlative inhibition with the shorter distance between developing distal vegetative and proximal flower buds (Saunders et al., 1991).

The average maximum temperature for September (Southern Hemisphere) in Australia and California's pistachio production areas is only 20ºC (Van den Bergh and Manley, 2002). Considering the above mentioned, the relative high flower bud losses may also be attributed to a period of extremely high maximum day temperatures (>30ºC) and only 27% average relative humidity. This period lasted for twelve consecutive days during middle September coinciding with the final stages of flower bud development when pistil and carpel development occur in the case of "Kerman" (Takeda et al., 1979). Some negative effects of high spring temperatures are also referred to by Lomas (1988), stating that high day temperatures (> 32ºC), especially when accompanied by low relative humidity, are detrimental for avocado flowering and fruit set, while 7 ºC increase in daily maximum temperatures of apricot flower buds during the pre-blossom period, was found to impede pistil development as well as fruit set (Rodrigo and Herrero, 2002).

Yield

The youngest age group (*P. terebinthus* rootstock*)* only had one yield in their sixth leaf after treatment in 2004 (Fig 10, Table 7) and it was only increased by light pruning. Although unlikely, this could indicate pollination defects, as the evaporative cooling trial (See Paper 4) was pollinated in the same way, less than fifty meters distant.

The two older age groups showed comparative trends in yield after treatments in 2004 and 2006, while the extremely warm period (as stated previously) and resulting low number of remaining flower buds may have contributed to the lack of yield after 2005. The control trees had the highest yields in March 2005, with only Dormex® showing similar results in the case of the eighth leaf trees, although not exceeding that of the control (Table 7). This is in contrast with the general trend of thought that rest breaking agents can enhance yield after poor chilling (Procopiou, 1973; Küden and Küden, 1995; Rahemi and Asghari, 2004). After the 2006 treatments however, Dormex® exceeded the tenth leaf control trees' yield markedly, although not in the ninth leaf trees' case. The highest number of annual Richardson chilling units (RCU) (Richardson et al., 1974, Van den Bergh and Manley, 2002) for the whole trial period from 2002, was accumulated during 2006 with 644 RCU. The average maximum temperature for September 2006 was 26ºC (the same as the long-term average for Prieska). These more favourable climatic factors for flower bud, florescence and fruit set (Lomas, 1988; Rodrigo and Herrero, 2002) probably led to the markedly higher yields in March 2007 which dictated the three-year averages accordingly.

This nine year maximum winter chilling units for Prieska is still less than 60% of the average in the pistachio regions of California or Australia (Richardson et al., 1974; Van den Bergh and Manley, 2002). Considering the above, this might indicate chilling requirement differences between age groups and that such positive Dormex® effects on 'Ariyeh' yields as were obtained, might only be expected after the minimum amount of chilling were acquired. This is best explained by referring to Erez (1995) who stated that substitution of less than approximately 30% of required chilling seemed possible with the use of rest breaking agents. However, the inconsistency of the effect of Dormex® on yield in the Prieska climate is reflected in the three-year averages, showing similar values than the control trees.

Light pruning or light pruning in interaction with control or Dormex®, consistently increased yields, probably due to their marked effect on flower bud development. It is not clear why the Budbreak® and Dormex® & Budbreak® combinations did not differ from each other. However, considering the increase in the total number of shoots (cytokinin sinks) as well as the general reduction in the shoot length as the trees progress in age (Personal observation), the pruning effect will probably lessen accordingly, due to the limiting impact severe pruning would have on individual buds' cytokinin / auxin ratio (Oosthuyse et al, 1992).

Tree dimensions

Although lighter pruned trees proved to increase more in volume than severely pruned trees (Table 8) confirming similar findings of Koopmann in 1884 (Wertheim, 1976), our measuring scale of 25cm may be considered too rough to accurately reflect the differences in dimensions.

Conclusion

The trends in our results emphasized the interdependence of rest breaking and pruning effects / interactions, genetic chill requirements and environmental influences - specifically winter chill build-up. Our bud break data suggests that the ability of some rest breaking chemicals to promote lateral development may also be explained by their potential to impede the development of apical dominance, normally strengthened by insufficient winter chilling (Cook and Jacobs, 1999), in addition to direct effects on the lateral buds. Furthermore, it indicates the rest breaking potential of Dormex®, specifically regarding lateral development and growth as well as flower bud formation after less favourable winter chilling. The opposite effects of light and severe pruning on flower bud formation in the Prieska climate is of major economic importance, considering that it is still reflected in the tenth leaf yields - especially when considering that pistachio pruning guidelines are mainly aimed at structural preparation for mechanical harvesting. Although the locality distribution of flower buds was influenced by both rest breaking and pruning treatments over both years, the effects were erratic and inconsistent, with almost no correlation between the flower bud localities favoured by a certain treatment and the shoot-length category that was increased by it. The percentage flower bud retention was found to increase slightly after severe pruning, Budbreak® and Dormex®, however indications are that the reason for the high flower bud losses during spring might reside more in external factors like high maximum spring temperatures and low relative humidity. The Dormex® & Budbreak® treatment proved to present a high risk of phytotoxicity. Lower concentrations of these products in combination are therefore suggested for further research under similar climatic conditions.

The chemical treatments' inability to increase this cultivar's yield consistently, might indicate other factors involved or that the winter chill of Prieska might be too marginal to acquire the minimum amount of chilling necessary for any positive chemical effects on yields to be expected (Erez, 1995). Due to the erratic climatic changes between the winter and spring seasons in Prieska as well as the one year's dictating role in average yields, more research is necessary to indicate long term trends, especially regarding yield. The effect of rest breaking chemicals on correlative inhibition as well as endodormancy should also be investigated.

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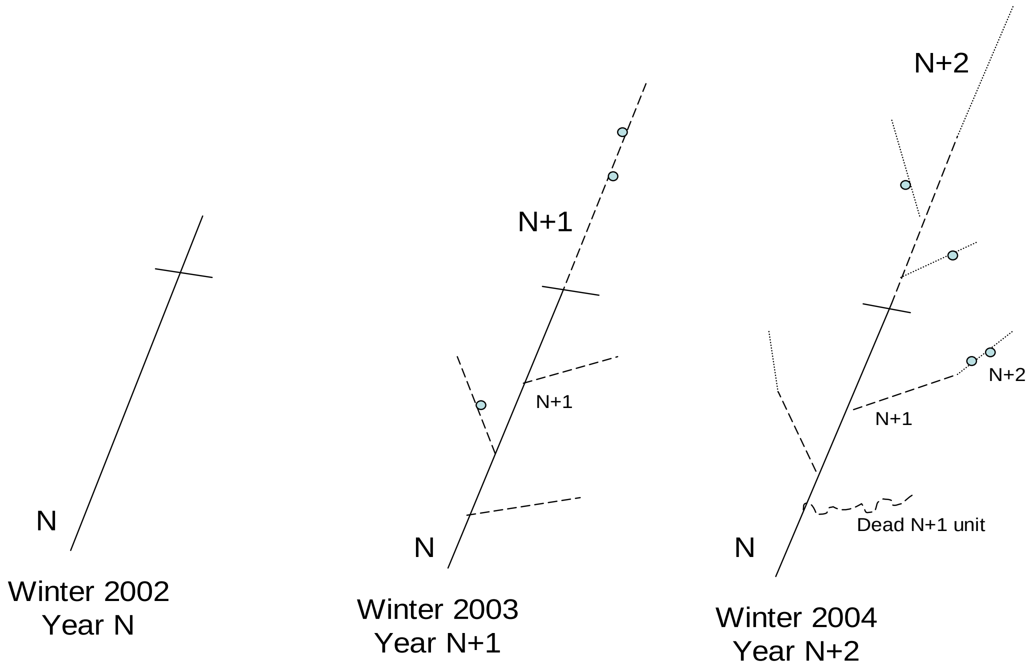

Fig 1: Schematic presentation of units used to record data on bud break and reproductive bud (º) development of 'Ariyeh' pistachio trees in Prieska, South Africa.

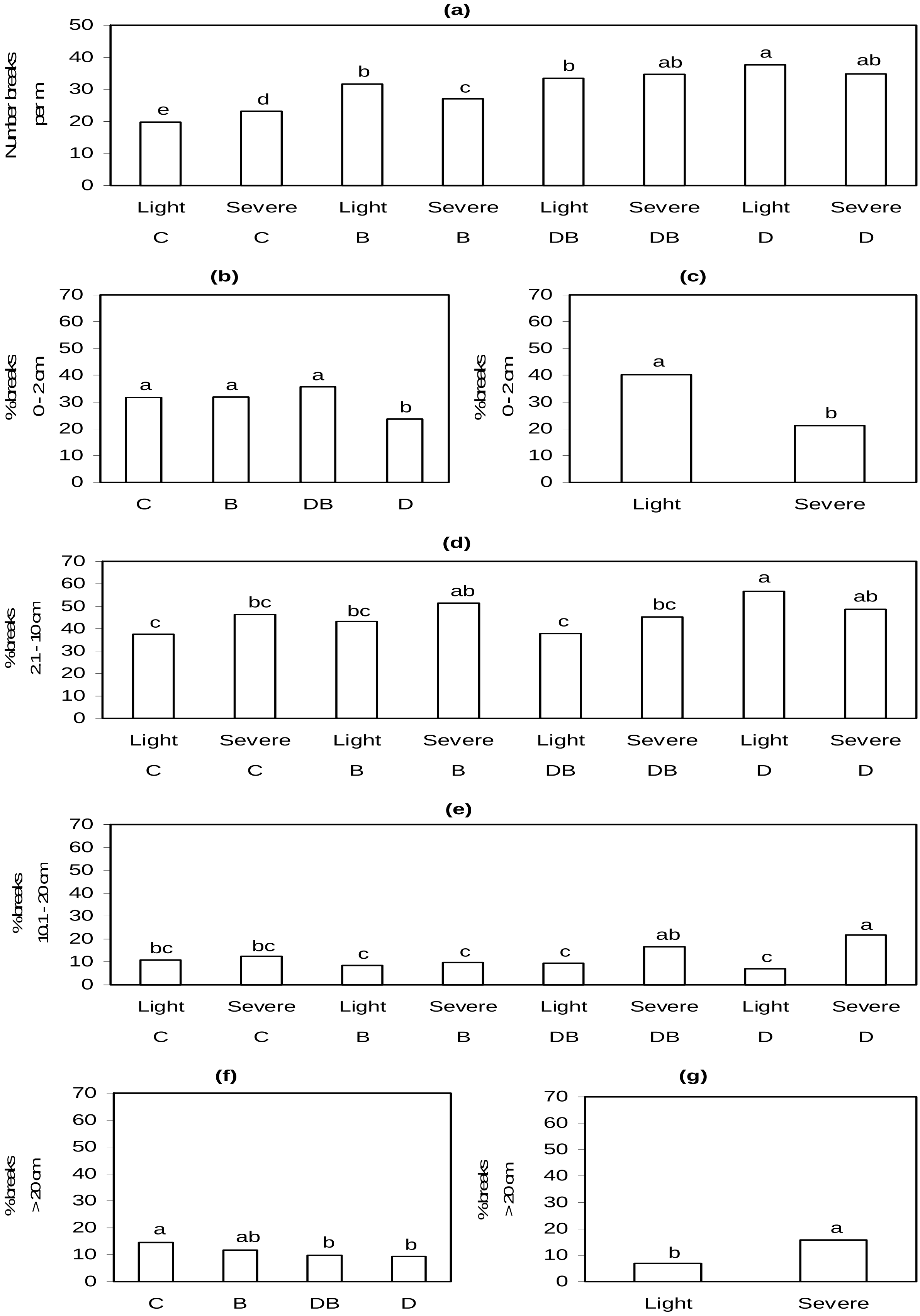

Fig 2: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2002 on the formation of shoots (N+1) on one-year-old wood (N) of 4th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0001; Pruning P<0.4470; R*P P<0.0049 (b) Rest breaking P<0.0122; R*P P<0.4495 (c) Pruning P<0.0001; R*P P<0.4495 (d) Rest breaking P<0.0044; Pruning P<0.0945; R*P P<0.0458 (e) Rest breaking P<0.0813; Pruning P<0.0001; R*P P<0.0047 (f) Rest breaking P<0.0041; R*P P<0.3702 (g) Pruning P<0.0001; R*P P<0.3702.

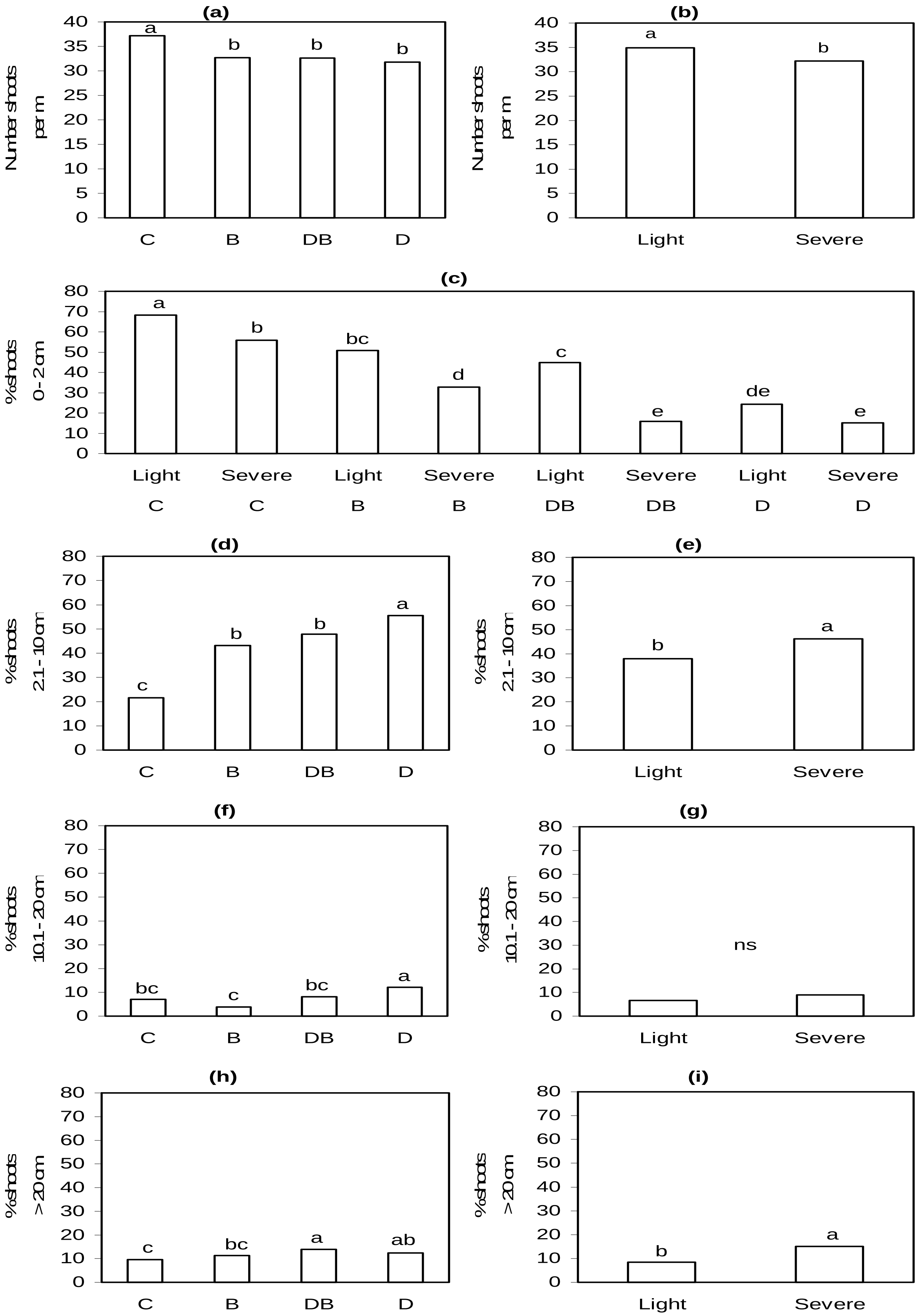

Fig 3: Effect of rest breaking applications (C=control, B=4% Budbreak®, DB=0.5% Dormex® + 4% Budbreak®, D=4% Dormex®) and pruning (light vs severe) in 2002 on the formation of shoots (N+1) on one-year-old wood (N) of 5th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0001; R*P P<0.4944 (b) Pruning P<0.0001; R*P P<0.4944 (c) Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0472 (d) Rest breaking P<0.0001; R*P P<0.1975 (e) Pruning P<0.0012; R*P P<0.1975 (f) Rest breaking P<0.0004; R*P P<0.3482 (g) Pruning P<0.0809; R*P P<0.3482 (h) Rest breaking P<0.0102; R*P P<0.8385 (i) Pruning P<0.0001; R*P P<0.8385.

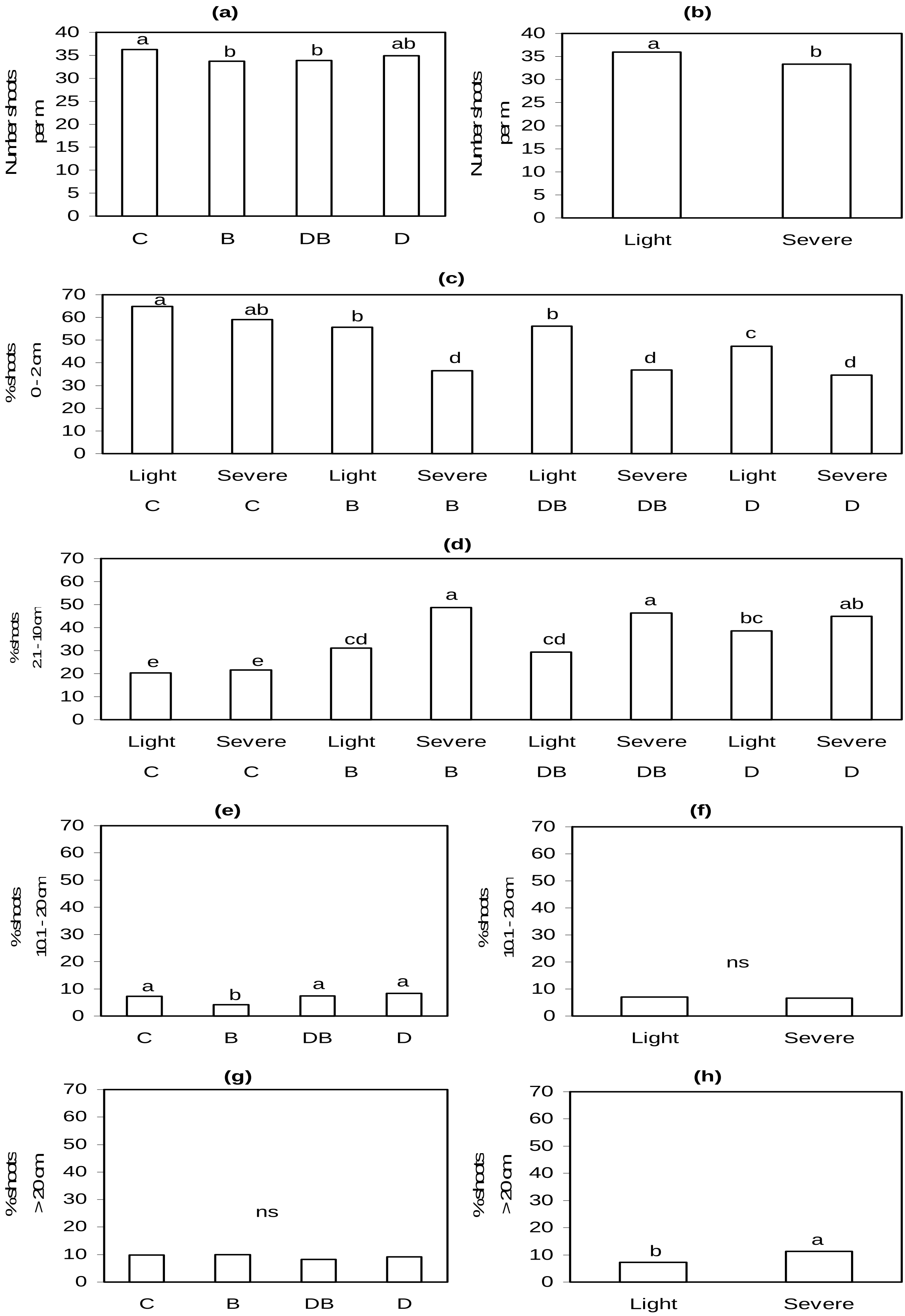

Fig 4: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2002 on the formation of shoots (N+1) on one-year-old wood (N) of 6th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0287; R*P P<0.4104 (b) Pruning P<0.0002; R*P P<0.4104 (c) Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0361 (d) Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0073 (e) Rest breaking P<0.0227; R*P P<0.4316 (f) Pruning P<0.7058; R*P P<0.4316 (g) Rest breaking P<0.1840; R*P P<0.6633 (h) Pruning P<0.0001; R*P P<0.6633.

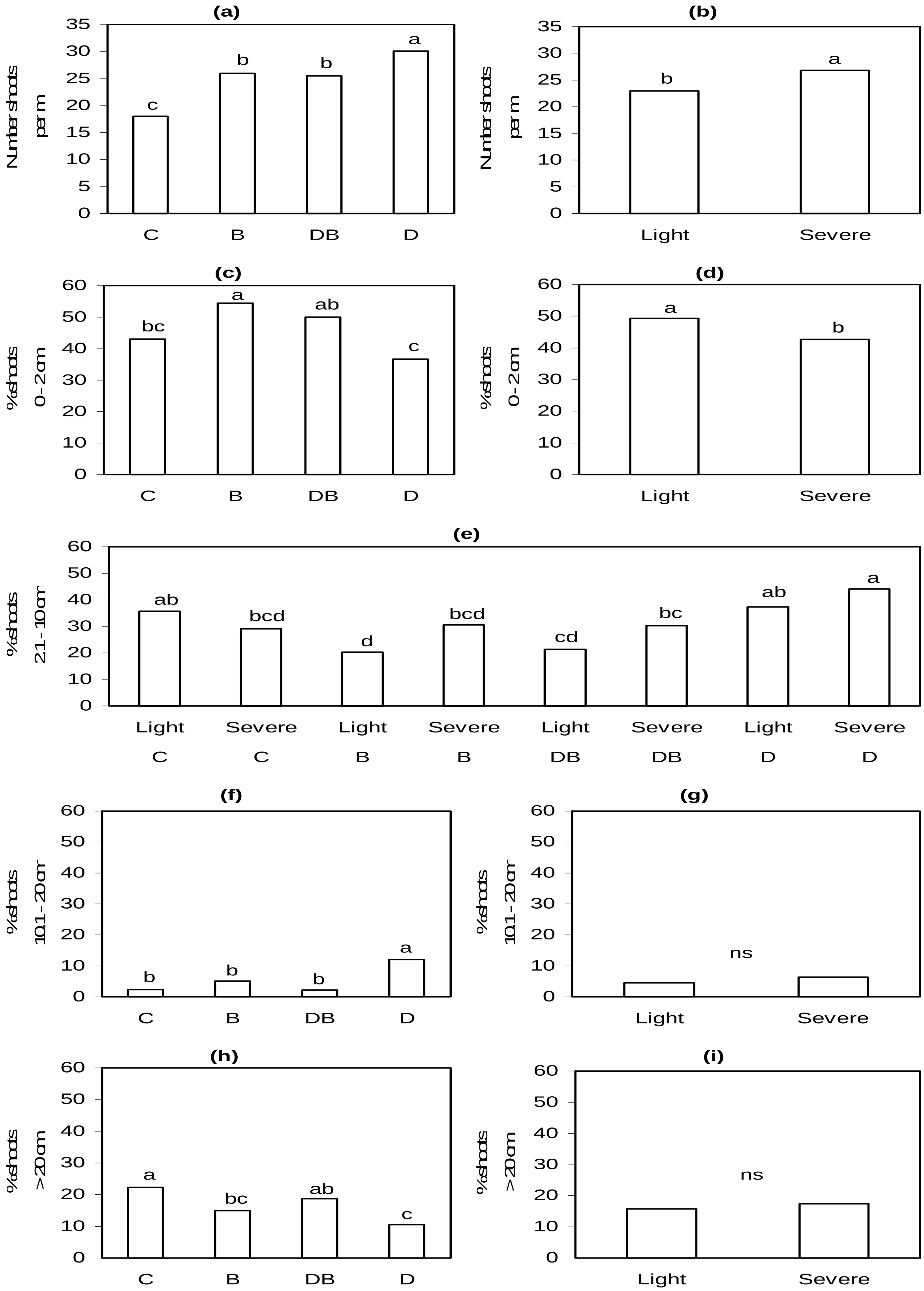

Fig 5: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of shoots (N+1) on one-year-old wood (N) of 5th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0001; R*P P<0.0650 (b) Pruning P<0.0032; R*P P<0.0650 (c) Rest breaking P<0.0003; R*P P<0.2149 (d) Pruning P<0.0219; R*P P<0.2149 (e) Rest breaking P<0.0001; Pruning P<0.0387; R*P P<0.0424 (f) Rest breaking P<0.0001; R*P P<0.5290 (g) Pruning P<0.1475; R*P P<0.5290 (h) Rest breaking P<0.0024; R*P P<0.1805 (i) Pruning P<0.4550; R*P P<0.1805.

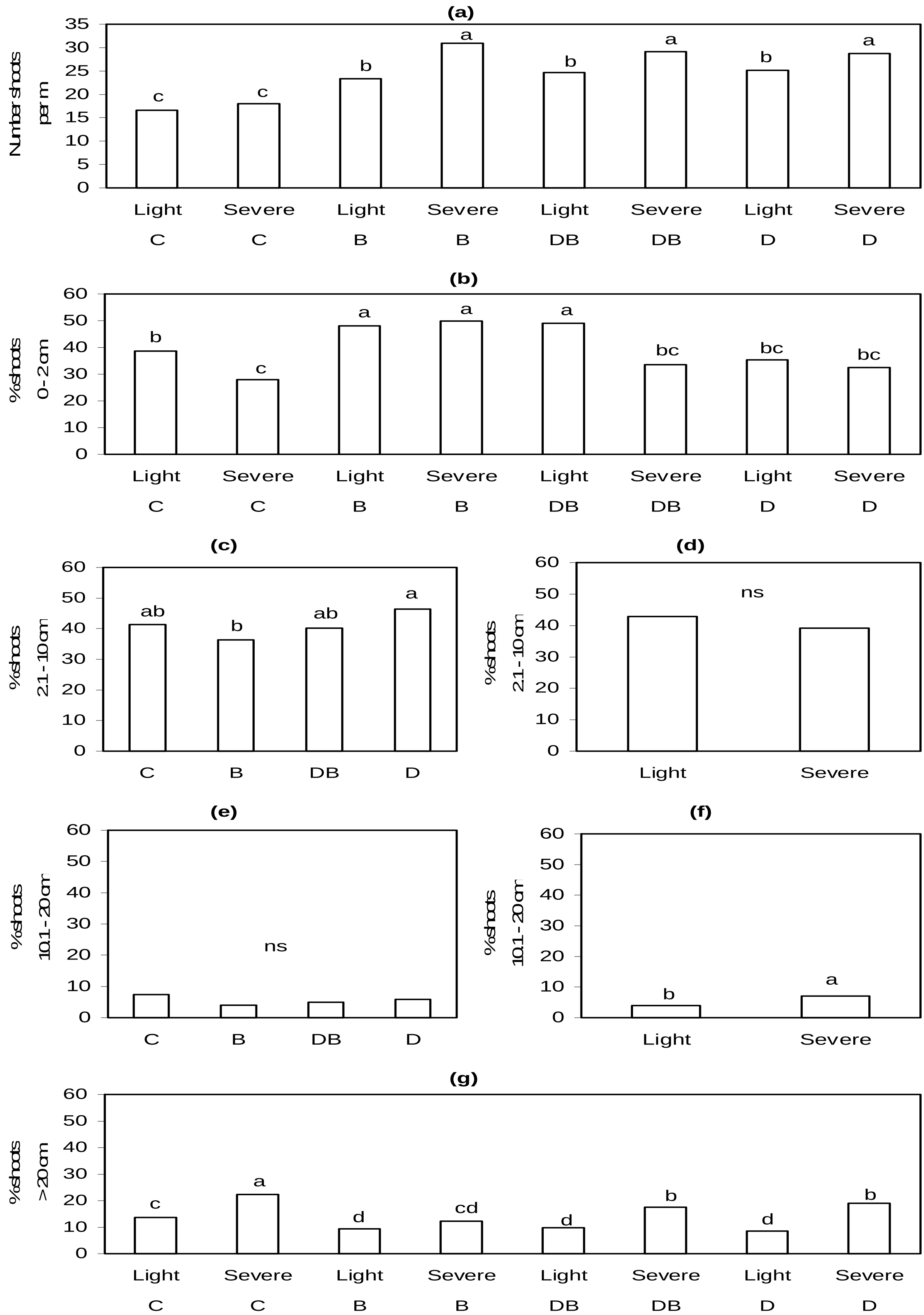

Fig 6: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of shoots (N+1) on one-year-old wood (N) of 6th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0422 (b) Rest breaking P<0.0001; Pruning P<0.0027; R*P P<0.0334 (c) Rest breaking P<0.0235; R*P P<0.2681 (d) Pruning P<0.1060; R*P P<0.2681 (e) Rest breaking P<0.1835; R*P P<0.6204 (f) Pruning P<0.0088; R*P P<0.6204 (g) Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0026.

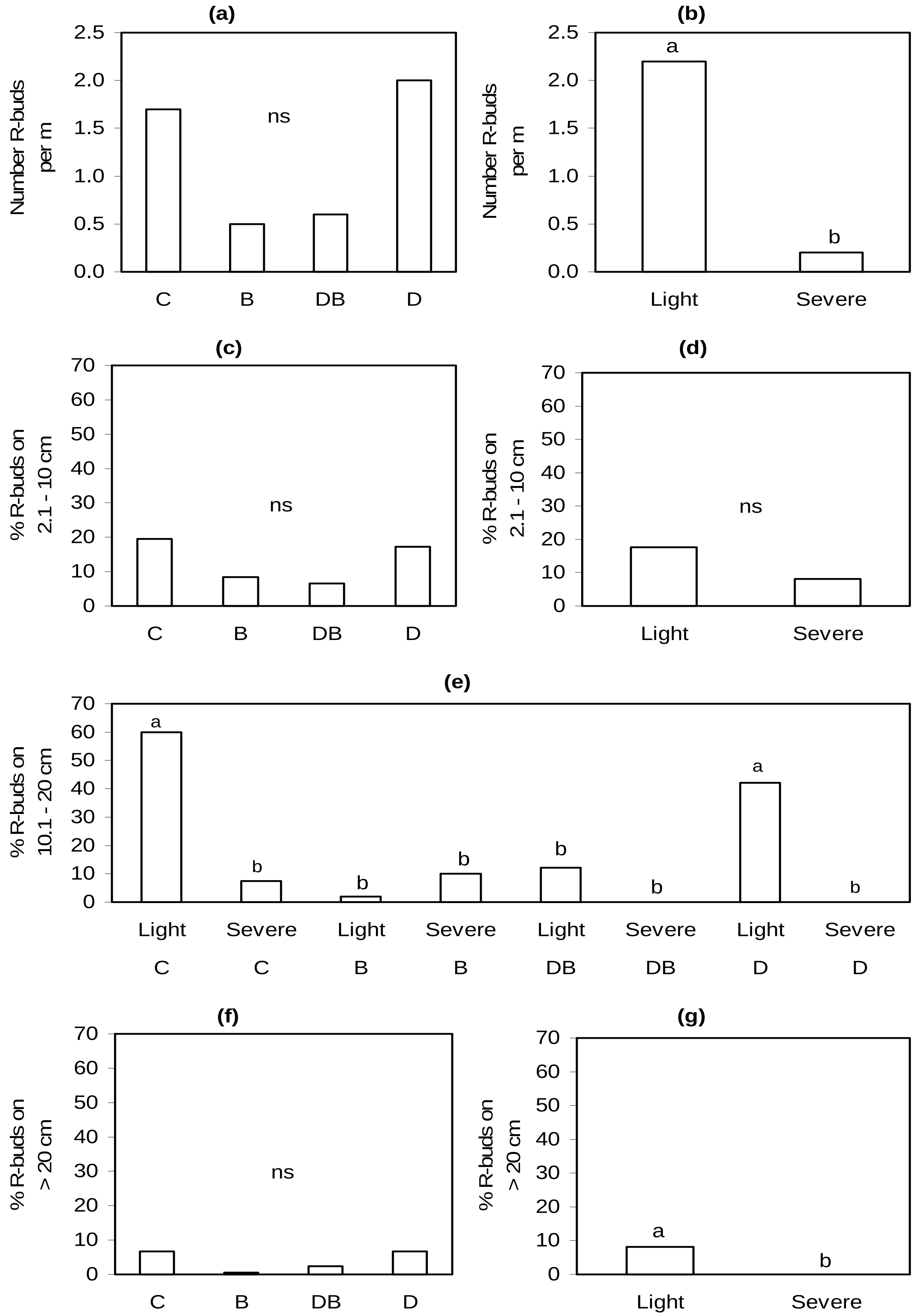

Fig 7: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2002 on the formation of reproductive buds on N+1 units of 5th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.1057; R*P P<0.1734 (b) Pruning P<0.0004; R*P P<0.1734 (c) Rest breaking P<0.3829; R*P P<0.5609 (d) Pruning P<0.1337; R*P P<0.5609 (e) Rest breaking P<0.0064; Pruning P<0.0002; R*P P<0.0044 (f) Rest breaking P<0.3636; R*P P<0.3636 (g) Pruning P<0.0076; R*P P<0.3636.

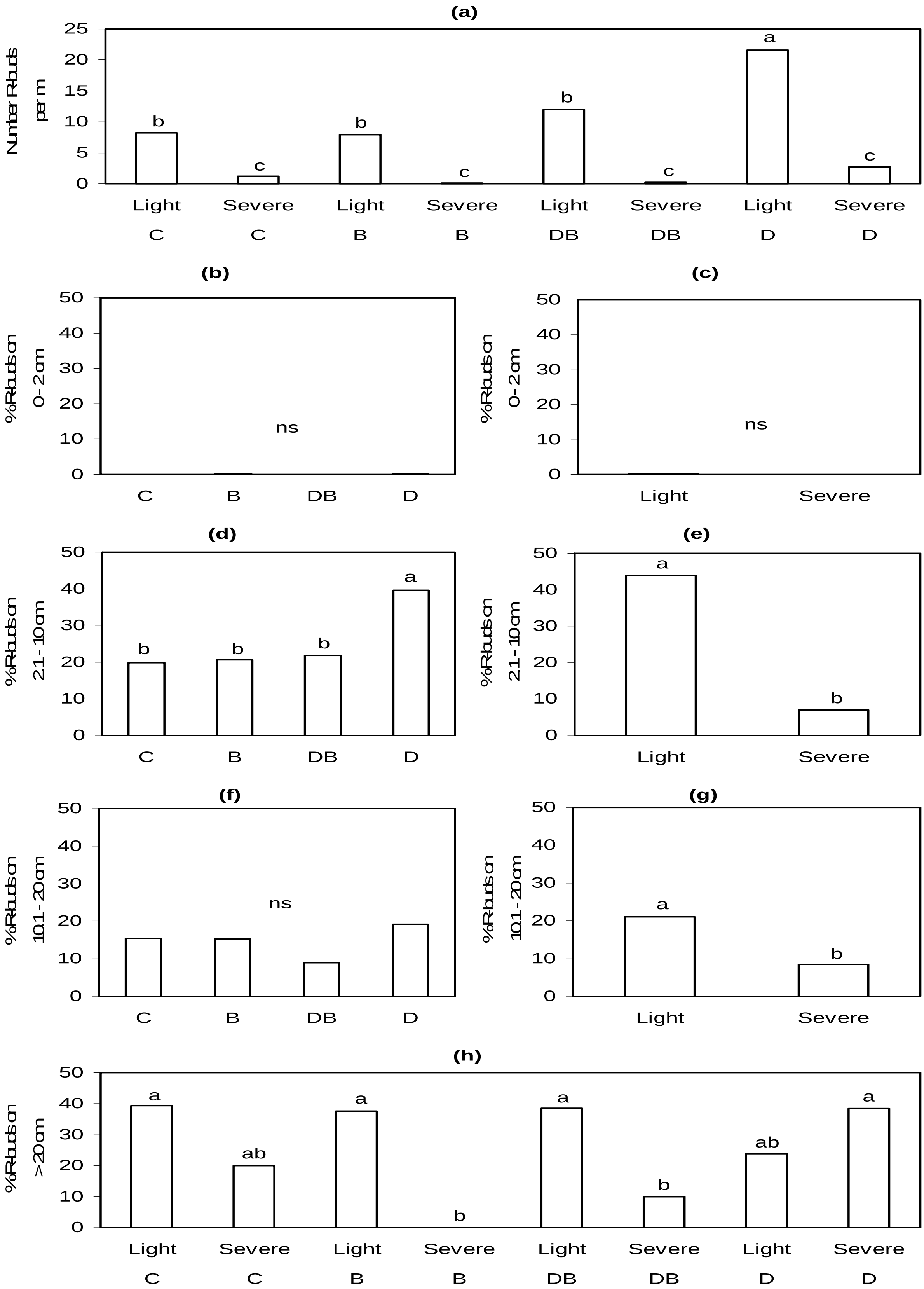

Fig 8: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of reproductive buds on N+1 units of 7^{th} leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0014 (b) Rest breaking P<0.4621; R*P P<0.4621 (c) Pruning P<0.2462; R*P P<0.4621 (d) Rest breaking P<0.0032; R*P P<0.5780 (e) Pruning P<0.0001; R*P P<0.5780 (f) Rest breaking P<0.4880; R*P P<0.7878 (g) Pruning P<0.0085; R*P P<0.7878 (h) Rest breaking P<0.4737; Pruning P<0.0050; R*P P<0.0210.

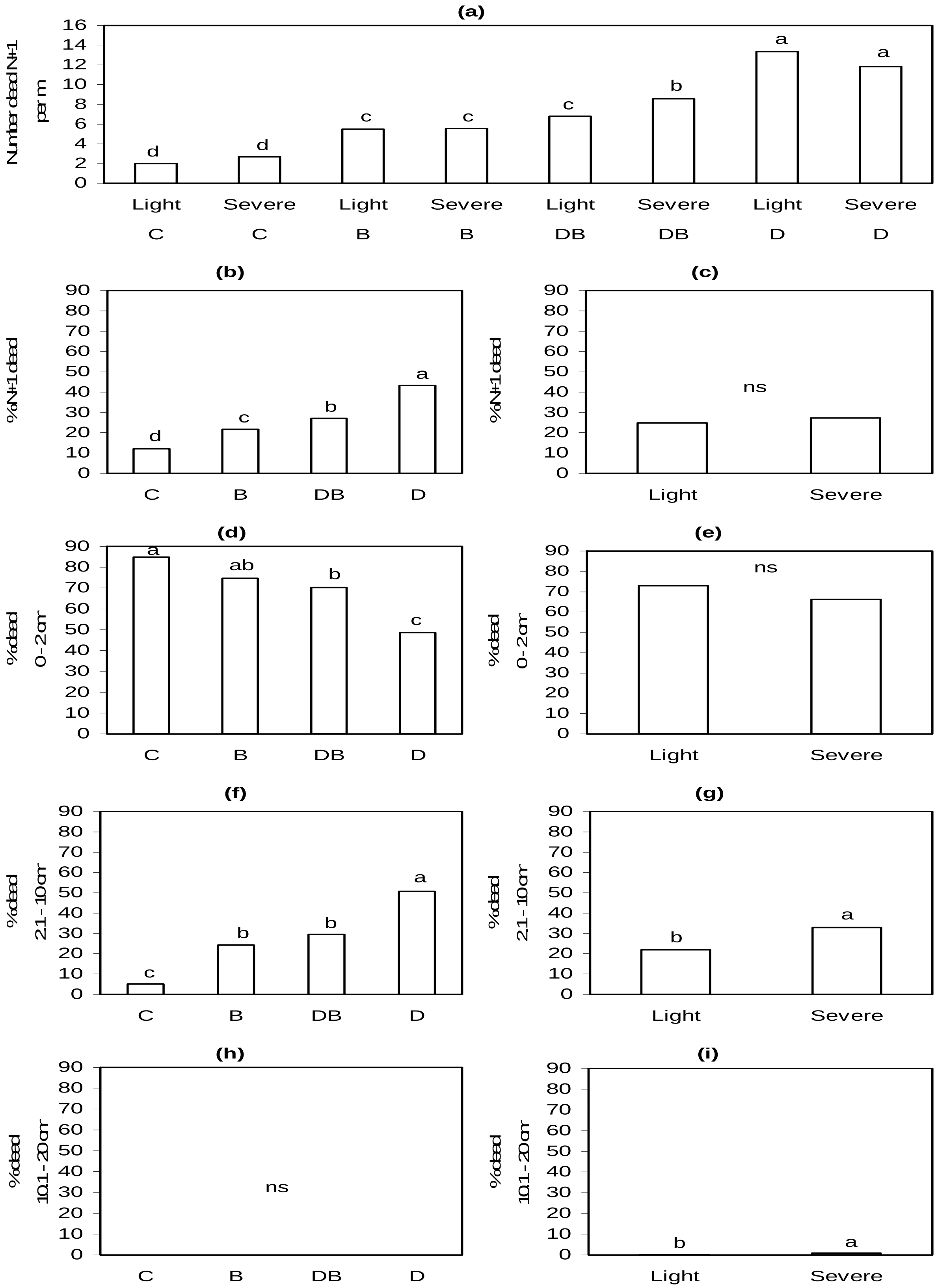

Fig 9: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning (light vs severe) in 2003 on the die-back of N+1 shoots on three-year-old wood (N) of 7th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0001; Pruning P<0.0.5560; R*P P<0.0536 (b) Rest breaking P<0.0001; R*P P<0.5129 (c) Pruning P<0.1035; R*P P<0.5129 (d) Rest breaking P<0.0001; R*P P<0.0882 (e) Pruning P<0.1423; R*P P<0.0882 (f) Rest breaking P<0.0001; R*P P<0.5338 (g) Pruning P<0.0005; R*P P<0.5338 (h) Rest breaking P<0.2298; R*P P<0.2668 (i) Pruning P<0.0226; R*P P<0.2668.

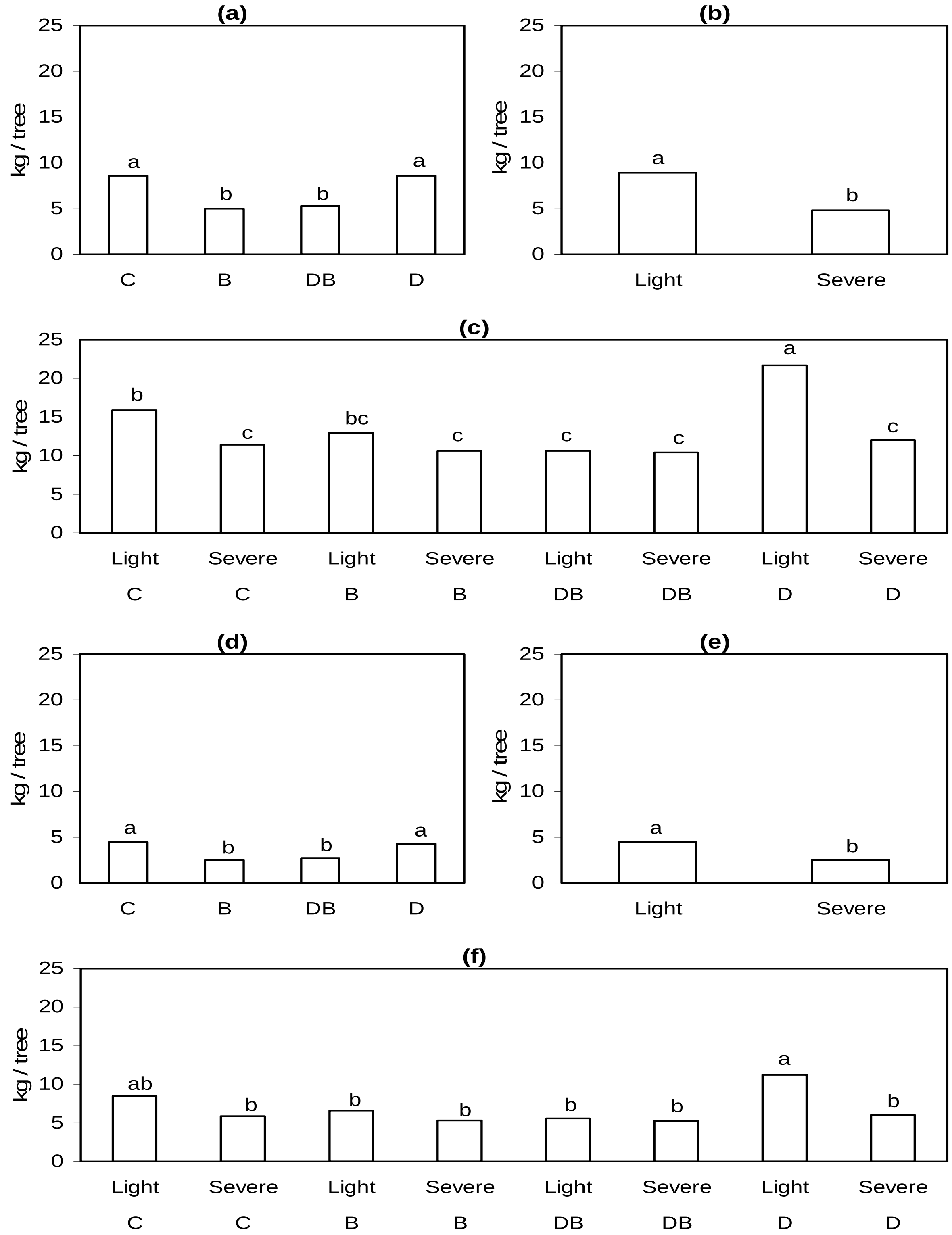

Fig 10: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning (light vs severe) in 2006 on yield (fresh weight) of 9th and 10th leaf 'Ariyeh' pistachio trees in Prieska, South Africa. (a) 9th leaf: Rest breaking P<0.0019; R*P P<0.1591 (b) 9th leaf: Pruning P<0.0001; R*P P<0.1591 (c) 10th leaf: Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0070 (d) Three-year average (9th leaf): Rest breaking P<0.0011; R*P P<0.1753 (e) Three-year average (9th leaf): Pruning P<0.0001; R*P P<0.1753 (c) Three-year average (10th leaf): Rest breaking P<0.0001; Pruning P<0.0001; R*P P<0.0051.

Table 1: Effect of rest breaking applications and pruning in 2003 on the formation of shoots (N+1) on one-year-old wood (N) of 7th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

Treatments	Total number of shoots per m	Percentage shoot distribution according to length			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application:					
Control	15.2 b	33.7 bc	34.4 c	9.6 a	22.3 a
4% Budbreak®	25.1 a	39.7 a	37.8 bc	6.9 ab	15.7 b
0.5% Dormex® + 4% Budbreak®	23.8 a	38.0 ab	42.8 b	4.4 b	14.8 b
4% Dormex®	24.0 a	28.3 c	49.9 a	6.9 ab	14.9 b
Pruning:					
Light	21.3 b	40.1 a	41.5 ns	5.7 b	12.8 b
Severe	22.7 a	29.8 b	41.0	8.2 a	21.0 a
Pr > F					
Rest breaking application (R)	0.0001	0.0009	0.0001	0.0138	0.0001
Pruning (P)	0.0490	0.0001	0.8013	0.0246	0.0001
R * P	0.4424	0.2952	0.5995	0.4417	0.8558

[z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 2: Effect of rest breaking applications and pruning in 2002 on the formation of reproductive buds on N+1 units of 4th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m	Percentage reproductive bud distribution according to length of one-year-old shoots			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	1.5 ns	-	7.8 ns	21.3 ns	10.9 ns
4% Budbreak®	0.7	-	8.9	4.7	1.4
0.5% Dormex® + 4% Budbreak®	1.9	-	11.5	21.5	12.0
4% Dormex®	2.1	-	19.4	22.6	13.1
Pruning					
Light	2.0 ns	-	20.5 a	26.7 a	12.8 ns
Severe	1.1	-	3.3 b	8.3 b	5.9
Pr > F					
Rest breaking application (R)	0.4333		0.4150	0.1579	0.3591
Pruning (P)	0.1958		0.0001	0.0053	0.1842
R * P	0.7373		0.6909	0.1606	0.5056

[z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 3: Effect of rest breaking applications and pruning in 2002 on the formation of reproductive buds on N+1 units of 6th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m	Percentage reproductive bud distribution according to length of one-year-old shoots			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	3.9 ns	-	16.2 ns	38.3 a	10.6 ns
4% Budbreak®	2.8	-	42.2	7.4 b	15.4
0.5% Dormex® + 4% Budbreak®	2.8	-	27.4	20.9 ab	11.7
4% Dormex®	2.8	-	29.9	31.7 a	8.4
Pruning					
Light	5.4 a [z]	-	32.8 ns	29.1 ns	23.0 a
Severe	0.7 b	-	25.0	20.0	0.0 b
Pr > F					
Rest breaking application (R)	0.8630	-	0.2355	0.0262	0.6589
Pruning (P)	0.0001	-	0.3794	0.2232	0.0001
R * P	0.5314	-	0.7343	0.5689	0.6589

[z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 4: Effect of rest breaking applications and pruning in 2003 on the formation of reproductive buds on N+1 units of 5th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m	Percentage reproductive bud distribution according to length of one-year-old shoots			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	2.2 b	0.0 ns	36.4 ns	1.2 ns	22.5 ns
4% Budbreak®	1.1 b	1.0	20.2	14.2	4.7
0.5% Dormex® + 4% Budbreak®	1.4 b	3.1	24.4	7.1	15.4
4% Dormex®	9.2 a	0.3	30.3	24.4	9.9
Pruning					
Light	4.9 a	2.2 ns	46.9 a	15.7 ns	15.2 ns
Severe	2.1 b	0.0	8.7 b	7.8	11.1
Pr > F					
Rest breaking application (R)	0.0001	0.5471	0.4985	0.0114	0.2249
Pruning (P)	0.0328	0.1839	0.0001	0.1186	0.5151
R * P	0.5353	0.5471	0.6867	0.4955	0.6545

[z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 5: Effect of rest breaking applications and pruning in 2003 on the formation of reproductive buds on N+1 units of 6th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m	Percentage reproductive bud distribution according to length of one-year-old shoots			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	4.5 ns	-	33.2 ns	19.4 ns	17.4 ns
4% Budbreak®	4.2	-	43.2	17.8	9.0
0.5% Dormex® + 4% Budbreak®	3.5	-	30.9	11.0	13.2
4% Dormex®	4.5	-	32.7	23.1	24.2
Pruning					
Light	6.7 a	-	55.8 a	19.0 ns	20.2 ns
Severe	1.6 b	-	14.1 b	16.7	11.7
Pr > F					
Rest breaking application (R)	0.8267		0.6002	0.6608	0.2603
Pruning (P)	0.0001		0.0001	0.7372	0.1317
R * P	0.4587		0.4800	0.8257	0.1769

[Z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 6: Effect of rest breaking applications and pruning in 2003 on the formation of reproductive buds on N+2 units of 7th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m of unit N	Percentage reproductive bud distribution according to length of N+1 shoots		
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm
Rest breaking application				
Control	12.1 a	5.3 a	65.4 ns	24.3 ns
4% Budbreak®	3.7 c	1.9 b	76.0	17.2
0.5% Dormex® + 4% Budbreak®	5.2 bc	3.4 ab	68.9	27.8
4% Dormex®	7.3 b	0.2 b	63.5	26.4
Pruning				
Light	10.6 a	3.8 ns	63.0 ns	30.8 a
Severe	3.5 b	1.6	73.9	17.0 b
Pr > F				
Rest breaking application (R)	0.0001	0.0173	0.6486	0.6741
Pruning (P)	0.0001	0.0696	0.1481	0.0405
R * P	0.0623	0.2143	0.2887	0.1993

[Z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 7: Effect of rest breaking applications and pruning in 2004 on yield and in 2005 on flower bud retention of 7th, 8th and 9th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

	Fresh yield (kg / tree)			Flower bud retention (%)		
	Leaf 6	Leaf 7	Leaf 8	Leaf 7	Leaf 8	Leaf 9
Treatments	2005	2005	2005	21/11/05	21/1105	21/11/05
Rest breaking application						
Control	0.3 ns	0.4 a	0.7 a	1.8 ns[Z]	0.9 c	1.0 b
4% Budbreak®	0.1	0.1 b	0.1 c	0.9	2.7 ab	3.2 a
0.5% Dormex® + 4% Budbreak®	0.2	0.1 b	0.3 bc	1.8	1.1 bc	2.2 ab
4% Dormex®	0.2	0.1 b	0.5 ab	4.1	7.2 a	5.1 a
Pruning						
Light	0.3 a[Z]	0.2 ns	0.6 a	2.6 ns	2.7 ns	2.0 b
Severe	0.1 b	0.1	0.1 b	1.6	3.3	3.8 a
Pr > F						
Rest breaking application (R)	0.2728	0.0028	0.0001	0.3638	0.0075	0.0215
Pruning (P)	0.0009	0.4291	0.0001	0.4748	0.3799	0.0017
R * P	0.2983	0.7034	0.1258	0.1298	0.2206	0.0715

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.
[Z]Logit transformation done on percentage retention.

Table 8: Effect of rest breaking applications and pruning in 2004 on tree dimensions of 6th, 7th leaf and 8th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

	Leaf 6 (m)		Leaf 7 (m)		Leaf 8 (m)	
Treatments	Height	Depth	Height	Depth	Height	Depth
Rest breaking application						
Control	3.1 ns	2.3 ns	3.8 a	3.1 a	3.9 ns	3.3 a
4% Budbreak®	3.1	2.1	3.8 ab	3.0 ab	3.9	3.2 a
0.5% Dormex® + 4% Budbreak®	3.1	2.2	3.8 ab	2.9 ab	3.8	3.2 ab
4% Dormex®	3.1	2.1	3.7 b	2.9 b	3.8	3.0 b
Pruning						
Light	3.3 a	2.3 a	3.9 a	3.1 a	3.9 a	3.2 ns
Severe	3.0 b	2.1 b	3.6 b	2.9 b	3.8 b	3.1
Pr > F						
Rest breaking application (R)	0.9414	0.3027	0.1226	0.1408	0.3562	0.0800
Pruning (P)	0.0003	0.0076	0.0001	0.0013	0.0324	0.1926
R * P	0.2981	0.1225	0.8319	0.1757	0.4570	0.8717

[Z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 9: Effect of rest breaking applications and pruning in 2005 on tree dimensions of 7th and 8th and 9th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

	Leaf 7 (m)		Leaf 8 (m)		Leaf 9 (m)	
Treatments	Height	Depth	Height	Depth	Height	Depth
Rest breaking application						
Control	3.5 ns	2.6 ab	4.1 ns	3.3 ns	4.1 ns	3.5 ns
4% Budbreak®	3.6	2.6 ab	4.0	3.2	4.2	3.5
0.5% Dormex® + 4% Budbreak®	3.6	2.8 a	4.1	3.1	4.2	3.4
4% Dormex®	3.6	2.5 b	4.1	3.2	4.2	3.3
Pruning						
Light	3.7 a	2.7 a	4.2 a	3.3 a	4.2 ns	3.5 ns
Severe	3.4 b	2.5 b	4.0 b	3.1 b	4.1	3.4
Pr > F						
Rest breaking application (R)	0.4511	0.1379	0.3442	0.6494	0.2719	0.1006
Pruning (P)	0.0001	0.0131	0.0001	0.0329	0.0589	0.1193
R * P	0.1883	0.1350	0.5164	0.1863	0.5449	0.9774

[z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 10: Effect of rest breaking applications and pruning in 2004 and 2005 on percentage increase of tree dimensions of 7th, 8th and 9th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

	Leaf 7 (% increase)		Leaf 8 (% increase)		Leaf 9 (% increase)	
Treatments	Height	Depth	Height	Depth	Height	Depth
Rest breaking application						
Control	10.2 b	13.5 b	6.3 b	6.1 ns	3.8 b	7.4 ns
4% Budbreak®	15.0 ab	24.2 a	5.4 b	7.1	9.2 a	8.9
0.5% Dormex® + 4% Budbreak®	14.4 ab	27.0 a	8.1 ab	7.4	8.7 a	7.3
4% Dormex®	15.7 a	22.9 a	10.0 a	9.8	9.0 a	10.3
Pruning						
Light	14.9 ns	20.4 ns	6.0 b	9.2 ns	7.3 ns	8.8 ns
Severe	12.7	23.4	8.9 a	6.0	8.0	8.2
Pr > F						
Rest breaking application (R)	0.1111	0.0009	0.0496	0.6486	0.0212	0.5922
Pruning (P)	0.2166	0.2169	0.0230	0.1262	0.5949	0.7758
R * P	0.6795	0.2040	0.8556	0.8970	0.1526	0.4881

[z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

<u>PAPER 2:</u> THE EFFECT OF REST BREAKING AGENTS AND PRUNING ON BUDBREAK AND FLOWER BUD DEVELOPMENT OF PISTACHIO CV. SHUFRA *(PISTACIA VERA* L.*)* IN A CLIMATE WITH MODERATE WINTER CHILLING.

Abstract

Tip-pruning (to remove <2.5cm) and severe heading cuts (to remove 35-45%) of one-year old wood were compared and 4% hydrogen cyanimide (Dormex®), 4% mineral oil (Budbreak®) as well as their combination (0.5% Dormex® + 4% Budbreak®) used as rest breaking agents on 'Shufra' pistachio (*Pistacia vera*) trees of three consecutive age groups and evaluated over five seasons. Bud break, reproductive bud differentiation, die-back, flower bud retention during winter and early summer and yields were evaluated. The trends in the results emphasised the interaction of rest breaking and pruning effects with genetic chill requirement and environmental influences - specifically winter chill build-up. Severe pruning was detrimental to flower bud formation as well as yield. The bud break data suggests that the ability of some rest breaking chemicals to promote lateral development may possibly also be explained by their potential to impede the development of apical dominance, normally strengthened by insufficient winter chilling, in addition to direct effects on the lateral buds. The inability of the chemical rest breaking treatments to increase yields consistently might indicate that the average winter chill of Prieska (29° 40'S, 22° 45'E, 945 m.a.s.l) is below the minimum amount necessary for chemical effects to be expected on this cultivar.

Introduction

The climate around Prieska differs from other pistachio growing regions in the world in that it receives fewer winter chilling units, has higher maximum temperatures during winter and spring and receives summer rainfall (Van den Bergh and Manley, 2002). This possibly results in the observed delayed foliation, flower bud and inflorescence abortion, low fruit set and yield and other flowering disorders e.g. the terminal bud developing into a florescence which Crane and Takeda (1979) described as a response to low winter chilling. No accurate chilling requirements or detailed information regarding desired lengths of lateral shoots are known for any pistachio cultivar, except that 1000-1500 hours below 7 ºC appear to be sufficient in California, USA (Crane and Takeda, 1979).

The use of different dormancy breaking chemicals on pistachios in areas with mild winters resulted in increased yields, quality and changes in flowering patterns and lateral development (Procopiou, 1973; Küden and Küden, 1995; Rahemi and Asghari, 2004), irrespective of rootstock (Beede and Ferguson, 2002). However, these reports did not discuss the long term effects of dormancy breaking chemicals on flower bud differentiation and also did not eliminate the possible lack of overlapping of male and female bloom through the use of artificial pollination.

The first four to five pruning seasons of a pistachio tree are spent on training a strong trunk (90-120 cm in height) and well balanced scaffold branches to accommodate mechanical harvesting (Crane and Iwakiri, 1985). This is done through heading cuts which remove 30% or more of one-year-old shoots in winter (Personal observation). As pistachios bear only on one-year-old shoots, the importance of new growth is obvious. Koopmann however, reported as early as 1896 on the negative effects of severe heading cuts on flower bud differentiation (Wertheim, 1976). Therefore, the influence of strong heading cuts on delaying the reproductive development needs to be investigated.

In this paper we report on the effect of dormancy breaking chemicals and pruning on the development of lateral shoots, flower bud differentiation, yield, tree dimensions and flower bud retention during spring of 'Shufra' in the Prieska district, Northern Cape, South Africa.

Materials and method

Plant material:

Trees on either *P. terebinthus* (3rd leaf) *or P. integgerima* (4th and 5th leaf) rootstocks were established at a spacing of 4 m x 5.78 m. For further detail on plant material refer to Paper 1.

Treatments and experimental design:

Timing was aimed at the late bud swell stage and occurred on 11 Sept. 2002, 13 Sept. 2003, 7 Sept. 2004, 26 Aug. 2005 and 31 August 2006, respectively. The average lengths of lightly pruned shoots in trees after receiving the light heading cut were 54±17 cm and 35±8 cm in trees receiving the heavy heading cut in 2002. In 2003 the average lengths of the lightly pruned units were 47±23 cm (5th leaf), 53±20 cm (6th and 7th leaf) and for the heavy pruned trees 29±6 cm (5th leaf), 34±7 cm (6th and 7th leaf). For further detail on treatments and experimental design refer to Paper 1.

Data recorded:

Bud break, reproductive bud differentiation and die-back

The data recorded in this trial was described in Paper 1. In 2004 five three-year-old branch units (tip-pruned: 55 ± 11 cm, top-pruned: 38 ± 4 cm in year N), were randomly selected and the averages calculated.

Flower bud retention during winter and early summer: 2005

Five one-year-old shoots (10 - 20 cm), with three or more flower buds, were randomly tagged on 18 May 2005 on all trees and the number of flower buds per shoot recorded. The percentage flower bud retention of these shoots was recorded after shell hardening on 22 Nov.

Yield and tree dimensions

See Paper 1.

Data analysis:

See Paper 1.

Results

Bud break after treatment in 2002

Fourth leaf trees

A significant rest breaking effect was found on the total number of shoots per meter, with control having the highest and Dormex® the lowest numbers, with the Budbreak® and Dormex® & Budbreak® not differing from either. The rest breaking control treatment had the highest percentage shoots 0 – 2 cm with Dormex® having the lowest and Budbreak® and Dormex® & Budbreak® having progressively lower percentages. The lightly pruned treatment induced the highest percentage laterals 0 – 2 cm. In the category 2.1 – 10 cm shoot length, the Dormex® and Dormex® & Budbreak® resulted in significantly the highest and control the lowest percentages. The severely pruned treatment also stimulated the highest percentage of shoots in this category. In the category 10.1 – 20 cm, only a rest breaking effect was found, with Dormex® inducing the highest number of shoots, with no difference between the other treatments. Only severe pruning increased the percentage shoots >20 cm (Table 1).

Fifth leaf trees

Only a rest breaking effect was found on the total number of shoots per meter, Dormex® having the lowest numbers, with no difference between the other treatments (Fig. 2a, b). The control and Budbreak® had the highest percentage laterals 0 – 2 cm, with Dormex® & Budbreak® and

Dormex® having progressively fewer (Fig. 2c). The lightly pruned treatment also stimulated the highest percentage of shoots in this category (Fig. 2d). An interaction between rest breaking and pruning treatments were found in the category 2.1 – 10 cm, with the two Dormex® as well as the severely pruned Dormex® & Budbreak® combinations having the highest percentages and the lightly pruned control the lowest. The severely pruned control treatment had a higher percentage 2.1 – 10 cm shoots than its lightly pruned combination, but the other combinations did not differ from either (Fig. 2e). Only Dormex® increased the percentage shoots 10.1 – 20 cm, with no difference between the other treatments (Fig. 2f, g). The Dormex® & Budbreak® treatment produced the slightly highest percentage of shoots longer than 20 cm, with no significant difference between the other treatments (Fig. 2h). The severely pruned treatment had slightly the highest percentage of shoots longer than 20 cm (Fig. 2i).

Sixth leaf trees

Significant, although small rest breaking and pruning effects were found in the total number of shoots per meter with the Dormex® & Budbreak® and the lighter pruning resulting in the highest and Dormex® the lowest numbers, with the control and Budbreak® not differing from either (Fig. 3a, b). The control had the highest and Dormex® the lowest percentage laterals 0 – 2 cm, with no difference between the other two treatments (Fig. 3c). The lightly pruned treatment also stimulated the highest percentage of shoots in this category (Fig. 3d). Dormex® produced significantly more shoots in the category 2.1 – 10 cm than the control, with no difference between the other two treatments (Fig. 3e). The severely pruned treatment also stimulated the highest percentage of shoots in this category (Fig. 3f). An interaction between rest breaking and pruning treatments was found in the category 10.1 – 20 cm. The two Dormex® as well as the severely pruned Dormex® & Budbreak® combinations had the highest percentages, with no difference between the other combinations (Fig. 3g). The Dormex® & Budbreak® treatment resulted in the highest percentage shoots >20 cm, although not differing from Dormex®, which did not differ from the other two treatments (Fig. 3h). The severely pruned treatment also increased the percentage shoots longer than 20 cm (Fig. 3i).

Bud break after treatment in 2003

Fifth leaf trees

An interaction between rest breaking and pruning treatments was found in the total number of shoots per meter (Fig. 4a). The two Dormex® combinations as well as the severely pruned Budbreak® and Dormex® & Budbreak® did not differ from each other and had the highest numbers, with the lighter pruned Budbreak® and Dormex® & Budbreak® combinations having slightly fewer (Fig. 4a). The Budbreak® and lightly pruned treatments had the highest percentage 0 – 2 cm shoots, with no difference between the other treatments (Fig. 4b, c). Only a rest breaking effect was found in the category 2.1 – 10 cm shoot length, with the Dormex® and Dormex® & Budbreak® resulting in the highest percentages (Fig. 4d, e). Only light pruning increased the number of shoots in the category 10.1 – 20 cm (Fig. 4f, g). The control and severely pruned treatments had the highest percentage shoots >20 cm, with no difference between the other treatments (Fig. 4h, i).

Sixth leaf trees

Only a slight, though highly significant rest breaking effect was found on the total number of shoots per meter, with control having the lowest numbers, with no difference between the other treatments (Fig. 5a, b). Dormex® had the lowest percentage laterals 0 – 2 cm, with no difference between the other treatments (Fig. 5c). The lightly pruned treatment also stimulated the highest percentage of shoots in this category (Fig. 5d). Only a rest breaking effect was found in the category 2.1 – 10 cm shoot length, with the Dormex® resulting in the highest percentage (Fig. 5e, f). An interaction between rest breaking and pruning treatments were found in the category 10.1 – 20 cm, with the lightly pruned control, Dormex® & Budbreak® and Dormex® combinations having the highest percentages, although they did not differ from Budbreak® + severe pruning. No differences were found between the other combinations (Fig. 5g). The Budbreak® treatment produced the highest and Dormex® the lowest percentage shoots longer than 20 cm, although Budbreak® did not differ from the control and Dormex® did not differ from Dormex® & Budbreak® (Fig. 5h). The severely pruned treatment had the highest percentage of shoots longer than 20 cm (Fig. 5i).

Seventh leaf trees

Interactions between rest breaking and pruning treatments were found in the total number of shoots per meter, 0 – 2, 2.1 – 10 and >20 cm categories (Fig. 6). The Budbreak®, Dormex® & Budbreak® and Dormex® combinations did not differ from each other and had higher percentages than the two control treatments, with the severely pruned control having the lowest number (Fig. 6a). The lighter pruned combinations of control, Budbreak® and Dormex® & Budbreak® had the highest and Dormex® & Budbreak® + severe pruning the lowest percentage laterals 0 – 2 cm, although the severely pruned control and lightly pruned Dormex® did not differ from the Dormex® & Budbreak® + severe pruning (Fig. 6b). Dormex® + light pruning and Dormex® & Budbreak® + severe pruning produced significantly the highest percentage shoots in the category 2.1 – 10 cm, although they did not differ from the severely pruned Dormex® or control trees. Dormex® & Budbreak® + light pruning had the lowest percentages in this category, but did not differ from the lightly pruned control or Budbreak® (Fig. 6c). Only severe pruning had a slightly, though significant higher percentage in the 10.1 – 20 cm category (Fig. 6d, e). The severely pruned control produced the highest percentage shoots longer than 20 cm, but did not differ from Dormex® & Budbreak® + severe pruning, which also did not differ from the severely pruned Budbreak® or Dormex® combinations. No differences were found between the lighter pruned combinations (Fig. 6f).

Reproductive bud development after treatment in 2002

Fourth leaf trees

Very few reproductive buds were formed on one-year-old shoots, although Dormex® and lighter pruning increased the number of reproductive buds per meter (Table 2). Pruning effects were found on the 10.1 – 20 cm category, with the lightly pruned treatment resulting in the highest number of reproductive buds. No reproductive buds developed on shoots 0 – 2 cm and no significant difference was found regarding reproductive buds on laterals 2.1 – 10 and >20 cm (Table 2).

Fifth leaf trees

Only a significant rest breaking effect was found on the number of reproductive buds per meter with control and Dormex® having the highest numbers (Fig. 7). No differences were found between them or between the other two treatments (Fig. 7a, b). No rest breaking or pruning effects were found in the 2.1 – 10 cm category (Fig. 7c, d). An interaction between rest breaking treatments and pruning was found in percentage reproductive buds on shoots 10.1 – 20 cm with the lightly pruned control and severely pruned Dormex® combinations inducing the highest percentage reproductive buds in this category, although the lighter pruned Budbreak® and Dormex® combinations did not differ from them. The other combinations in this category did not differ from each other (Fig. 7e). No rest breaking or pruning effects were found in the >20 cm category (Fig. 7f, g), and no reproductive buds developed on shoots 0 – 2 cm (Data not shown).

Sixth leaf trees

Interactions between rest breaking treatments and pruning were found in the number of reproductive buds per meter as well as the percentage reproductive buds on shoots 10.1 – 20 cm with the lightly pruned control and Dormex® combinations inducing the highest numbers per meter, with no difference between the other combinations (Fig. 8a). Only a rest breaking effect was found in the 2.1 – 10 cm category, with Budbreak® having the highest percentage, but did not differ from Dormex®, which did not differ from the other two treatments (Fig. 8b, c). The lightly pruned control and both Dormex® combinations induced the highest percentage reproductive buds on shoots 10.1 – 20 cm, although not differing from Budbreak® + light pruning, which did not differ from the other combinations except control + severe pruning, which had the lowest percentage (Fig. 8d). No rest breaking or pruning effects were found in the >20 cm category (Fig. 8e, f), and no reproductive buds developed on shoots 0 – 2 cm (Data not shown).

Reproductive bud development after treatment in 2003

Fifth leaf trees

Interactions between rest breaking treatments and pruning were found in the number of reproductive buds per meter as well as the percentage reproductive buds on shoots 10.1 – 20 cm with the lightly pruned control inducing the highest numbers per meter, with no difference between the other combinations (Fig. 9a). No rest breaking or pruning effects were found in the 2.1 – 10 cm category (Fig. 9b, c). The lightly pruned control combination induced the highest percentage reproductive buds on shoots 10.1 – 20 cm, although not differing from Dormex® & Budbreak® + light pruning, which did not differ from the other combinations except control + severe pruning and Dormex® + light pruning, which had the lowest percentages (Fig. 9d). No rest breaking or pruning effects were found in the >20 cm category (Fig. 9e, f), and no reproductive buds developed on shoots 0 – 2 cm (Data not shown).

Sixth leaf trees

Only a significant pruning effect was found on the number of reproductive buds per meter with lighter pruned trees having the highest numbers (Fig. 10a, b). Very few reproductive buds developed on shoots 0 – 2 cm, with no significant rest breaking or pruning effects (Fig. 10c, d). Only a rest breaking effect was found in the 2.1 – 10 cm category, with Dormex® & Budbreak® having the lowest percentage, although not differing from Budbreak®, which in turn did not differ from the other two treatments (Fig. 10e, f). An interaction between rest breaking treatments and pruning was found in percentage reproductive buds on shoots 10.1 – 20 cm with the Budbreak® + severe and lightly pruned control, Dormex® & Budbreak® and Dormex® combinations inducing the highest percentage reproductive buds in this category, although the lighter pruned Budbreak® and severely pruned Dormex® combinations did not differ from them. The other combinations in this category did not differ from each other (Fig. 10g). Only Dormex® & Budbreak® increased the percentage flower buds on shoots longer than 20 cm, although not differing from Budbreak®, which did not differ from the control. Dormex® resulted in the lowest percentages in this category (Fig. 10h, i).

Seventh leaf trees

Dormex® & Budbreak® had the highest number of reproductive buds per meter, although it did not differ from the Budbreak® or Dormex® treatments, which in turn did not differ from the control (Table 3). The lightly pruned trees also produced higher numbers of reproductive buds per meter. Very few reproductive buds were formed on the 0 – 2 cm shoots and only lighter pruning resulted in reproductive bud development in this category. The control had the highest percentage flower buds in the 2.1 – 10 cm category, although it did not differ from Budbreak® and Dormex®, which in turn did not differ from Dormex® & Budbreak®. The lighter pruned treatment also had higher percentages in this category. Only light pruning increased the percentage flower buds in the 10.1 – 20 cm category. The lightly pruned treatment and rest breaking control had the lowest percentage flower buds on shoots longer than 20 cm, with no difference between the other rest breaking treatments (Table 3).

Total number of reproductive buds on new growth (N+2) of two-year old units (N+1) ≤ 20 cm of seventh leaf trees after treatment in 2003

The Dormex® and control treatments developed the highest number of reproductive buds per meter N, although it did not differ from Budbreak®, which in turn did not differ from Dormex® & Budbreak® (Table 4). Lighter pruned trees had higher numbers of flower buds, but no pruning effects were found in their distribution. Budbreak® had the highest and Dormex® the lowest percentages when looking at the 0 - 2 cm (N+1) category, with the control and Dormex® & Budbreak® not differing from either. Control and Budbreak® induced the highest percentage reproductive buds on shoots (N+1) 2.1 – 10 cm, with no difference between the other two treatments. Dormex® had the highest percentage reproductive buds in the category 10.1 – 20 cm shoots (N+1), with no difference between the other treatments (Table 4).

Die-back on two-year old N+1 shoots of seventh leaf trees after treatment in 2003

The same interactions between rest breaking and pruning treatments were found in the number of dead N+1 shoots per meter of N unit and the percentage die-back of originally formed N+1 shoots (Fig. 11). Both pruning combinations of the rest breaking control and Budbreak® had the lowest numbers and Dormex® + severe pruning the highest, with no difference between the two Dormex® & Budbreak® and Dormex® + light pruning combinations (Fig. 11a, b). No rest breaking or pruning effects were found looking at the percentage dead N+1 shoots 0 – 2 cm (Fig. 11c, d). The Dormex® & Budbreak® and Dormex® treatments caused the highest percentage die-back of N+1 shoots 2.1 – 10 cm, although they did not differ from Budbreak®, which did not differ from the control with the lowest percentage in this category (Fig. 11e). Severely pruned trees also had higher percentages die-back of 2.1 – 10 cm N+1 shoots (Fig. 11f). No rest breaking or pruning effects were found in the percentage dead N+1 shoots 10.1 – 20 cm (Fig. 11g, h).

Flower bud retention (2005)

Only rest breaking effects were found in the percentage retention of flower buds in November of seventh and eighth leaf trees. The control and Dormex® of the seventh leaf trees had the highest percentages, with no difference between the other two treatments. Only the control treatment resulted in a relatively high percentage retention of the eighth leaf trees, with no difference between the other treatments. The ninth leaf trees also had the highest retention in the rest breaking control and the lowest in the Dormex® & Budbreak® treatment, although it did not differ from Budbreak®, which also did not differ from Dormex® (Table 5).

Pruning effects were found in both eighth and ninth leaf trees, with severely pruned trees having higher flower bud retentions (Table 5).

Yield: March 2005

No rest breaking or pruning effects were found in very low yields of sixth leaf trees (Fig. 12a, b). Interactions between rest breaking and pruning treatments were found in the yield of seventh and eighth leaf trees (Fig. 12c, d). In seventh leaf tree yield, Dormex® + lighter pruning produced the highest yield, although it did not differ from the lightly pruned control, while Dormex® & Budbreak® + lighter pruning gave the lowest yield. No differences were found between the other combinations (Fig. 12c). The eighth leaf yield of the lighter pruned control and Dormex® as well as the severely pruned Dormex® did not differ from each other and were higher than the other combinations, although Dormex® + severe pruning did not differ from most of the other combinations (Fig. 12d).

Yield: March 2006

No yields were produced by the seventh leaf trees (Data not shown) and interactions were found between rest breaking and pruning treatments in the yield of eighth and ninth leaf trees (Fig. 12e, f). The control + lighter pruning produced the highest eighth leaf yield, with progressively lower yields from the other combinations and the lowest yield from the lightly pruned Dormex® & Budbreak® combination, although it did not differ from the other combinations (Fig. 12e). On ninth leaf trees, the lighter pruned control trees produced the highest yields, followed by the severely pruned control and Budbreak® combinations. The other combinations did not differ from each other and had lower yields (Fig. 12f).

Yield: March 2007

No yields were produced by the eighth leaf trees (Data not shown) and similar rest breaking effects found in the low yields of ninth and tenth leaf trees (Table 5), with their control trees and those sprayed with 4% Dormex® having the highest yields, although the tenth leaf control's yield did not differ from Budbreak®, while Dormex® & Budbreak® had the lowest yield.

The three-year-averages of the ninth and tenth leaf trees showed the same trend as the 2007 yields with control and Dormex® treatments having the highest yields. No differences were found between the other two treatments of ninth leaf trees. In tenth leaf trees the yield of control trees did not differ from Budbreak®, while Dormex® & Budbreak® had the lowest yield (Table 5).

Tree dimensions

(Refer to Addendum A) Although some statistical differences were found, our measuring scale of 25cm was too rough to accurately reflect the differences in dimensions. Severe phytotoxicity resulting from Dormex® & Budbreak® during the early summer of 2002 (die-back of three to four-year-old branch units) further reduced the data's relevancy.

Discussion

Bud break

The trend seen in the total number of shoots on the control trees of all three age groups (on *P. integgerima* rootstock) with ± 40 per meter in 2002 in comparison with only 20 – 25 per meter in 2003 (Fig 2a, b, 3a, b, 4a, 5a, b, 6a, Table 1) can be explained by comparing the climatic differences between 2002 and 2003. In comparison to the total annual chill of 2002, 153 more Richardson Chilling Units (RCU) (Richardson et al.., 1974) were accumulated during 2003. Contrary to this, 2002 had 229 more RCU accumulated over 3 months by the end of July, in comparison with 2003 at the same stage. However, Cook and Jacobs (2000) found that regions with a gradual build-up of RCU during the beginning of dormancy showed a negative effect on bud break of apple shoots cv. Golden Delicious.

The poor lateral shoot development in 2003 is therefore best explained by the more gradual build-up of RCU during 2003 which could have strengthened apical dominance or increased endodormancy of the lateral buds more than in 2002. Cook and Jacobs (1999) explained an increase in apical dominance development after sub-optimal chilling, by referring to ongoing polar auxin transport in warmer winter climates (with average temperatures above 7ºC) and stated that causes of delayed foliation may reside more in the strengthened correlative inhibition than in the endodormancy of the lateral buds. Therefore, the increase in the number of lateral shoots, may also reflect on their capability to impede the development of strong apical dominance (Erez, 1987) by promoting more uniform bud break after low chilling, in addition to the general improvement of lateral bud break as found by Rahemi and Asghari (2004) - especially when taking the lower number of laterals per meter in 2002 by Dormex® into account (Fig 2a, 3a) as well as the absence of rest breaking effects in the fourth leaf trees of 2002 (Table 1).

Chemical rest breaking and pruning significantly affected the length-distribution of laterals of all three age groups during both years. More than 50 - 60% of the control's total laterals were only 0 - 2 cm, possibly due to the fact that pruning was done almost at bud swell, cancelling the initial apical dominance of the terminal bud in both pruning regimes and promoting lateral bud break (Saunders et al., 1991), although the marked succession of dominance by the remaining distal bud, impeded further growth of the majority of shoots. In contrast, Dormex® stimulated only 40% of 0 – 2 cm laterals (Fig 2c, 3c, 4b, 5c, 6b, Table 1). Light pruning increased this category over both years but only in interaction with control, Budbreak® and Dormex® & Budbreak® on seventh leaf trees (Fig 2d, 3d, 4c, 5d, 6b, Table 1). The dominant role of light pruning in this category could probably be explained by (1) the timing of pruning as stated above, and (2) probably the insignificant change in cytokinin / auxin ratio (Oosthuyse et al., 1992), not being able to sustain lateral growth after secondary apical dominance was established.

Dormex®, with about 40%, had consistently the highest percentage of shoots 2.1 – 10 cm, on light or severely pruned trees (Fig 2e, 3e, 4d, 5e, 6c, Table 1). In comparison to the control trees' results in this category, this serves to illustrate the ability of Dormex® to inhibit apical dominance development - even after severe pruning left less developed buds proximal to buds with higher growth potential.

Dormex® also had the highest score in the 10.1 – 20 cm category on both pruning regimes and age groups in 2002. However, after the more gradual build-up of chill units (RCU) of 2003, only light pruning increased this category on fifth and seventh leaf trees and on sixth leaf trees, in interaction with the control, Dormex® & Budbreak® and Dormex® (Fig 2f, 3g, 4f, 5g, 6d, Table

1). Considering the aforementioned, it is clear that after more favourable chilling, Dormex® was able to promote shoot growth 10.1 – 20 cm, independent of pruning, but after more marginal chilling, tip-pruning was also necessary as a complimenting factor, probably due to the removal of the apical bud and growth potential of the remaining buds - in relation to severe pruning.

Severe pruning consistently increased shoots longer than 20 cm during both years, while the chemical treatment Dormex® & Budbreak® had the highest percentages in 2002 (Fig 2h, i, 3h, i, 4h, i, 5h, i, 6f, Table 1). This may be attributed to the severe phytotoxicity observed following Dormex® & Budbreak® treatment during the early summer of 2002 when three to four-year-old branch units died back. The above mentioned pruning effects are consistent with similar findings of Koopmann in 1884 (Wertheim, 1976) who made progressively deeper heading cuts on one-year apple shoots resulting in shoots of which the lengths correlated with the severity of pruning, up to the point when 60% were headed of the original shoot. A further possible explanation might be the increase of the cytokinin / auxin ratio in the reduced number of cytokinin sinks after severe pruning / die-back (Oosthuyse et al., 1992).

Reproductive bud development

Marked differences in flower bud formation per meter shoot were found between age groups and years. It is clear from the data that light pruning enhanced flower bud formation in general, while no chemical treatment could be singled out as showing the same trend - single chemical effects were only found in certain age groups and years. Koopmann (Wertheim, 1976) referred to similar negative effects by severe pruning on flower bud formation of apple, pear and plum.

Although the distribution of flower buds was influenced by both rest breaking and pruning treatments over both years, the effects were erratic and inconsistent. No correlation was found between the flower bud position favoured by a certain treatment and the shoot-length category that was increased by it, except in the case of severe pruning and then only on seventh leaf trees in 2003. However, marked differences between the reactions of the same age group in different years were found. For example - sixth leaf control trees formed their flower buds after more favourable chilling mostly on 10.1 – 20 cm shoots and after less, distributed their location more evenly between the three categories from 2.1 cm up to longer than 20 cm (Fig 7b, d, e, 9e, g, h).

Very few reproductive buds formed on 0 – 2 cm shoots and only in 2003 on the more mature sixth and seventh leaf trees, where light pruning had a small but positive effect on the seventh leaf trees (Fig 10c, d, Table 3). The 2.1 – 10 cm flower bud locality showed no consistent pruning or rest breaking effects, although the two older age groups had markedly higher values than the youngest in both years. The two older age groups also had markedly higher values (10%-30%) after less favourable chilling in 2003 than after 2002 (10%-20%) (Fig 7c, d, 8b, c, 9b, c, 10e, f, Table 2, 3).

Although significant interactions and effects were found in the flower bud formation on 10.1 – 20 cm shoots, the trends were not consistent over the two years. However, a comparison between the age groups showed marked differences between the youngest age group (*P. terebinthus* rootstock) and the two older age groups (*P. integgerima* rootstock). The youngest age group had percentages between 10%-30% after 2002 and after 2003, between 30%-45%. This showed an almost inverse relationship with the two older age groups (*P. integgerima* rootstock), which had values between 30%-60% after 2002 but after 2003 between 5%-25% (Fig 7e, 8d, 9d, 10g, Table 2, 3).

Although no pruning or rest breaking effects were found in the percentage flower buds formed on shoots longer than 20 cm in 2002, values increased progressively from the youngest to the oldest age group (0%-22%, 10%-20%, 20%-35%). Pruning and rest breaking effects were found after the 2003 treatments, although they were erratic and inconsistent. However, a similar marked progressive increase could be seen in the 2003 data, but with much higher values in the older age groups (10%-15%, 25%-70%, 42%-70%) (Fig 7f, g, 8e, f, 9e, f, 10h, i, Table 2, 3).

Reproductive buds on new growth (N+2) of two-year old units (N+1) ≤ 20 cm

It is evident from Table 4 that Dormex® & Budbreak® reduced the number of flower buds formed on N+2, probably due to the severe phytotoxicity in 2002 (See previous paragraph). Tip-pruning, however increased the number of flower buds formed, although not playing any role in their allocation. Small percentages (±10%) of flower buds were found on 0 - 2 cm (N+1), while the majority (±60%) of Budbreak® and control's were in the 2.1 – 10 cm (N+1) category, with Dormex®'s majority (57%) in the 10.1 – 20 cm (N+1) category. It is difficult to gauge the economic importance of the above results except to recognise it as a potential factor contributing to yield differences.

Flower bud retention (2005)

Although rest breaking effects were found (Table 5), the flower bud retention in control trees (30%-50%) could not be exceeded by any chemical treatment. A marked trend was observed in the *P. terebinthus* rootstock or seventh leaf group, where control and Dormex® did not differ, where as in both the other two age groups (*P. integgerima* rootstock*)*, the Dormex® retention was much lower than the control's.

The average maximum temperature for September (Southern Hemisphere) in Australia and California's pistachio production areas is only 20ºC (Van den Bergh and Manley, 2002). Considering the above mentioned, the relative high flower bud losses may also be attributed to a period of extremely high maximum day temperatures (>30ºC) and only 27% average relative humidity. This period lasted for twelve consecutive days during middle September 2005 coinciding with the final stages of flower bud development when pistil and carpel development occur in the case of "Kerman" (Takeda et al., 1979). The fact that the control trees' anthesis started 14 days after this period, while Dormex®'s started only 4 days later, could also have given it an advantage over the other treatments.

Severe pruning increased flower bud retention of eighth and ninth leaf trees (Table 5). This could be explained by referring to severe pruning (1) reducing the number of cytokinin sinks, increasing the cytokinin / auxin relation in the flower buds (Oosthuyse et al., 1992), (2) leaving less developed vegetative buds on the one-year shoot to compete during the opening of the flower buds and (3) reducing correlative inhibition with the shorter distance between developing distal vegetative and proximal flower buds (Saunders et al., 1991).

Yield

The youngest age group (*P. terebinthus* rootstock*)* only had one yield during their sixth leaf after treatment in 2005 (Fig 12, Table 5), with no pruning or rest breaking effects. This could indicate pollination defects, although unlikely, as the evaporative cooling trial (See Paper 4) was pollinated in the same way, less than fifty meters distant.

The two older age groups showed comparative trends in yield after treatments in 2004 and 2005, with the lightly pruned control trees consistently having the highest yields in both years, with only Dormex® (only after the 2004 treatments), showing similar results, although not exceeding the control (Fig 12c-f). The relative low values of these yields might be due to several factors, including the quality and quantity of staminate flowers on surrounding male trees (available pollen concentration in environment) or the quality of pollen used for artificial pollination. However, it is clear that the similar yields per tree of the two groups did not reflect their age differences and that the yields were and stayed extremely low for two consecutive years, even after more favourable chill were accumulated during the winter of 2005 (381 RCU compared with 197 RCU in 2004). The extremely warm period (as stated above) and markedly low number of remaining flower buds may have contributed to this lack of reaction after the winter of 2005.

The highest number of annual Richardson chilling units (Richardson et al.., 1974) in nine years was obtained during 2006 (644 RCU, Van den Bergh and Manley, 2002). The average maximum temperature for September 2006 was 26ºC (the same as the long-term average for Prieska). These more favourable climatic factors for flower bud, florescence and fruit set (Lomas, 1988; Rodrigo and Herrero, 2002) probably led to the resulting high yields in March 2007 which dictated the three-year averages. However, even under the above conditions, the control trees' yields were not exceeded with the use of rest breaking chemicals - contrasting with the general trend of thought that rest breaking agents can enhance yield after poor chilling (Procopiou, 1973; Küden and Küden, 1995; Rahemi and Asghari, 2004). This might be explained considering that substitution of not more than approximately 30% of required chilling seemed possible with chemical rest breaking according to Erez (1995), and the fact that this nine-year maximum accumulated chill for Prieska is still less than 60% of California or Australia's average winter chilling units (Van den Bergh and Manley, 2002), serve as an indication of Shufra's high genetic chilling requirement.

Conclusion

The trends in our results emphasize the interdependence of rest breaking and pruning effects / interactions, genetic chill requirements and environmental influences - specifically winter chill build-up. The bud break data suggests that the ability of some rest breaking chemicals to promote lateral development may also be explained by their potential to impede the development of apical dominance, normally strengthened by insufficient winter chilling (Cook and Jacobs, 1999), in addition to direct effects on the lateral buds. Furthermore, it implicates the complementing of pruning and chemical effects regarding certain parameters through interactions after less favourable winter chilling, whereas only single effects were observed to influence them after more optimal winter conditions. The opposite effects of light and severe pruning on flower bud formation in the Prieska climate are of major economic importance, considering that it is still reflected in the eighth and ninth leaf yields - especially when considering that early pistachio pruning guidelines are mainly aimed at structural preparation for mechanical harvesting. Although the locality distribution of flower buds was influenced by both rest breaking and pruning treatments over both years, the effects were erratic and inconsistent, with almost no correlation between the flower bud localities favoured by a certain treatment and the shoot-length category that was increased by it. Flower bud retention was found to increase after severe pruning, however indications are that the reason for the high flower bud losses during spring might reside more in external factors like high maximum spring temperatures and low relative humidity. The Dormex® & Budbreak® treatment proved to present a high risk for phytotoxicity. Lower concentrations of these products in combination are therefore suggested for further research under similar climatic conditions.

Due to several possible causes, the yields during the first two years were extremely low, with a marked increase in the 2007 yield. The chemical treatments' inability to increase this cultivar's yield, might indicate other factors involved or that the winter chill of Prieska might be too marginal to acquire the minimum amount of chilling necessary for a positive chemical effect on yields to be expected (Erez, 1995). Due to the erratic climatic changes between the winter and spring seasons in Prieska, as well as the one year's dictating role in average yields, more research are necessary to indicate long term trends, especially regarding yield. The effect of rest breaking chemicals on correlative inhibition as well as endodormancy should also be investigated.

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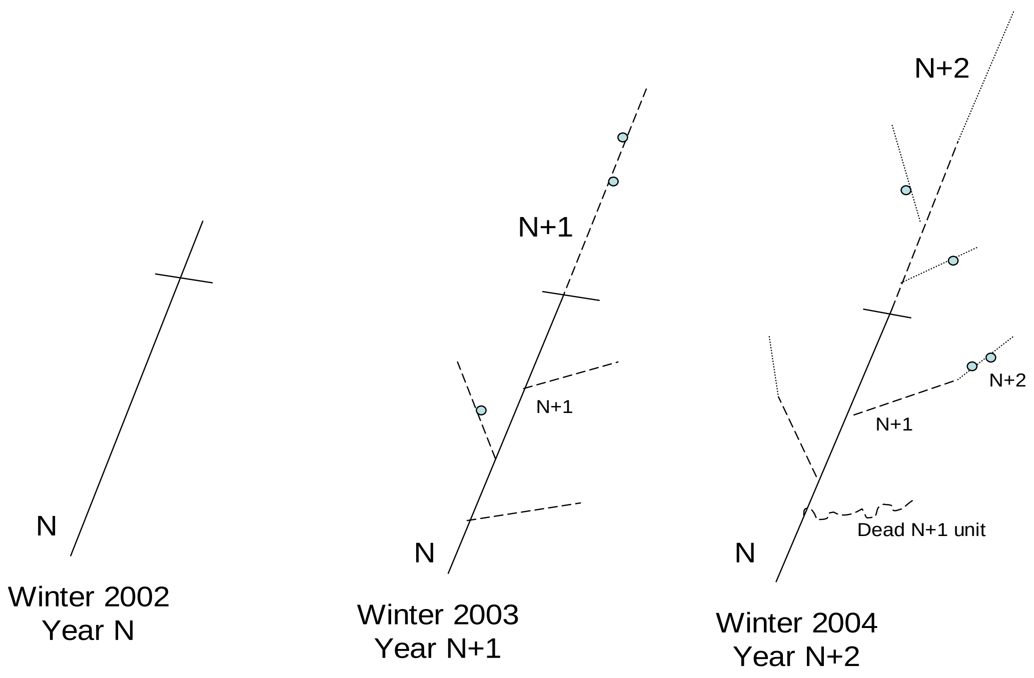

Fig 1: Schematic presentation of units used to record data on bud break and reproductive bud (º) development of ‘Shufra’ pistachio trees in Prieska, South Africa.

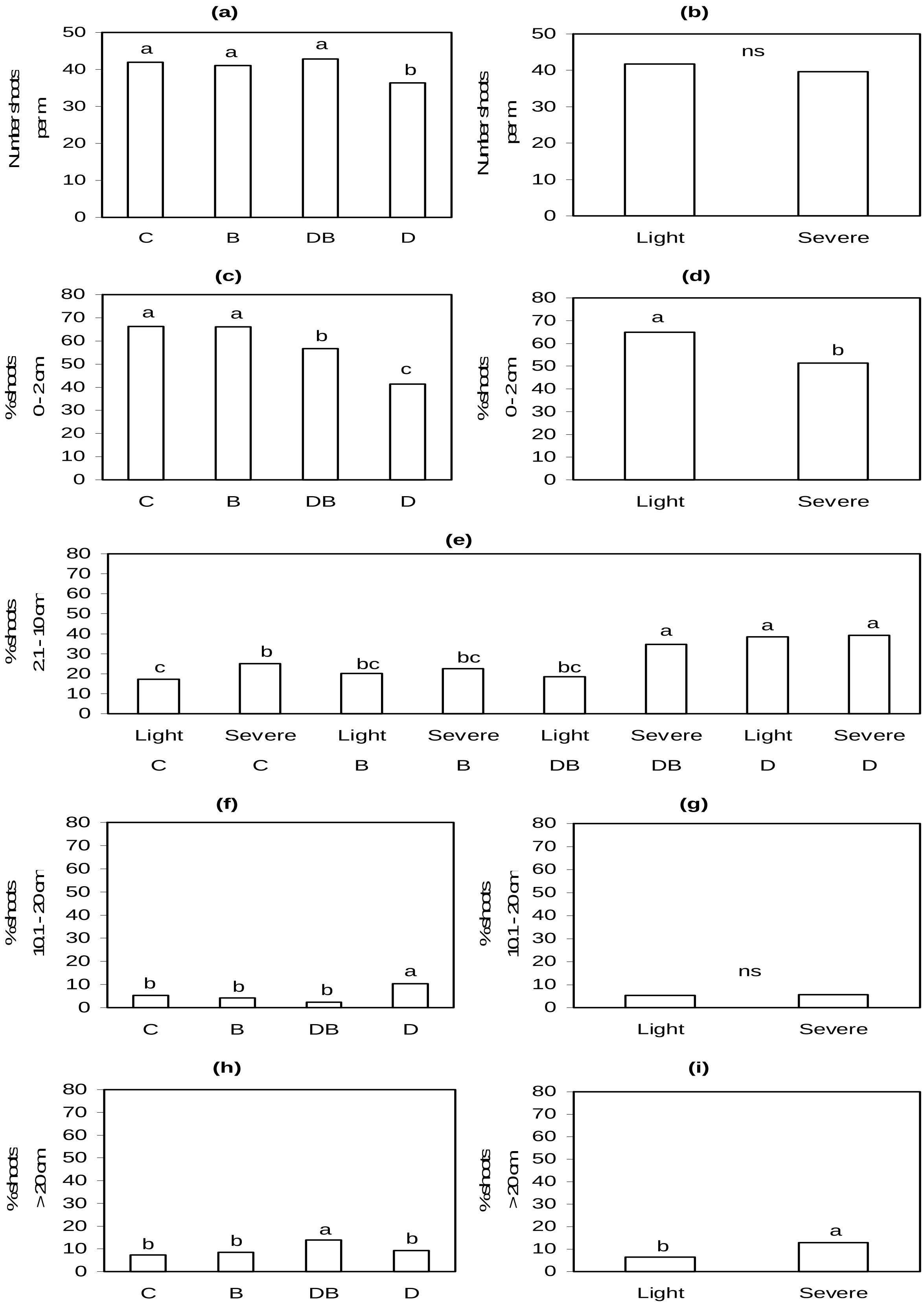

Fig 2: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2002 on the formation of shoots (N+1) on one-year-old wood (N) of 5th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0020; R*P P<0.1890 (b) Pruning P<0.0763; R*P P<0.1890 (c) Rest breaking P<0.0001; R*P P<0.2916 (d) Pruning P<0.0001; R*P P<0.2916 (e) Rest breaking P<0.0001; Pruning P<0.0007; R*P P<0.0280 (f) Rest breaking P<0.0001; R*P P<0.6107 (g) Pruning P<0.6886; R*P P<0.6107 (h) Rest breaking P<0.0005; R*P P<0.1883 (i) Pruning P<0.0001; R*P P<0.1883.

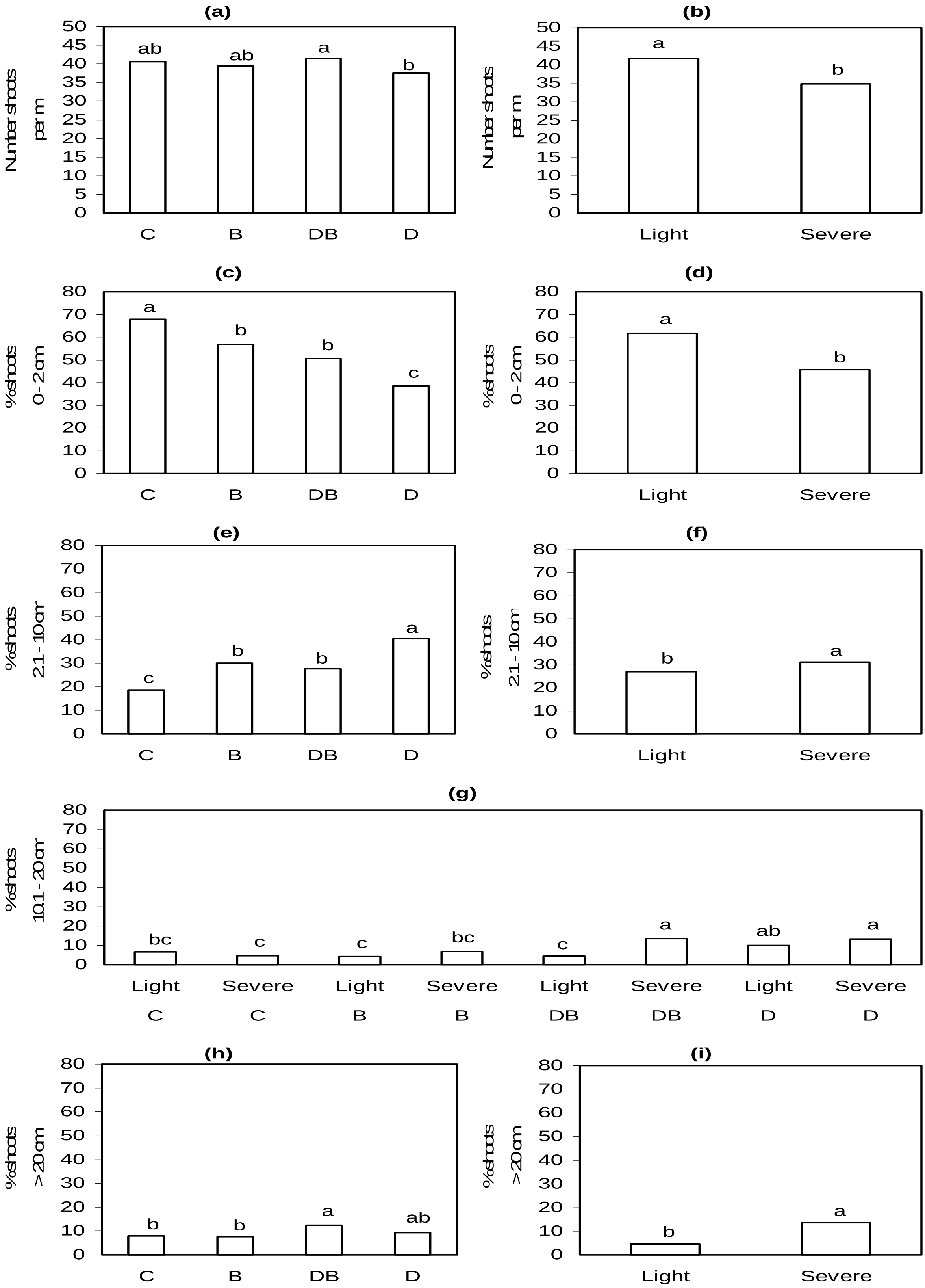

Fig 3: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2002 on the formation of shoots (N+1) on one-year-old wood (N) of 6th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0783; R*P P<0.8509 (b) Pruning P<0.0014; R*P P<0.8509 (c) Rest breaking P<0.0001; R*P P<0.0819 (d) Pruning P<0.0001; R*P P<0.0819 (e) Rest breaking P<0.0001; R*P P<0.2112 (f) Pruning P<0.0319; R*P P<0.2112 (g) Rest breaking P<0.0001; Pruning P<0.0036; R*P P<0.0045 (h) Rest breaking P<0.0246; R*P P<0.3784 (i) Pruning P<0.0001; R*P P<0.3784.

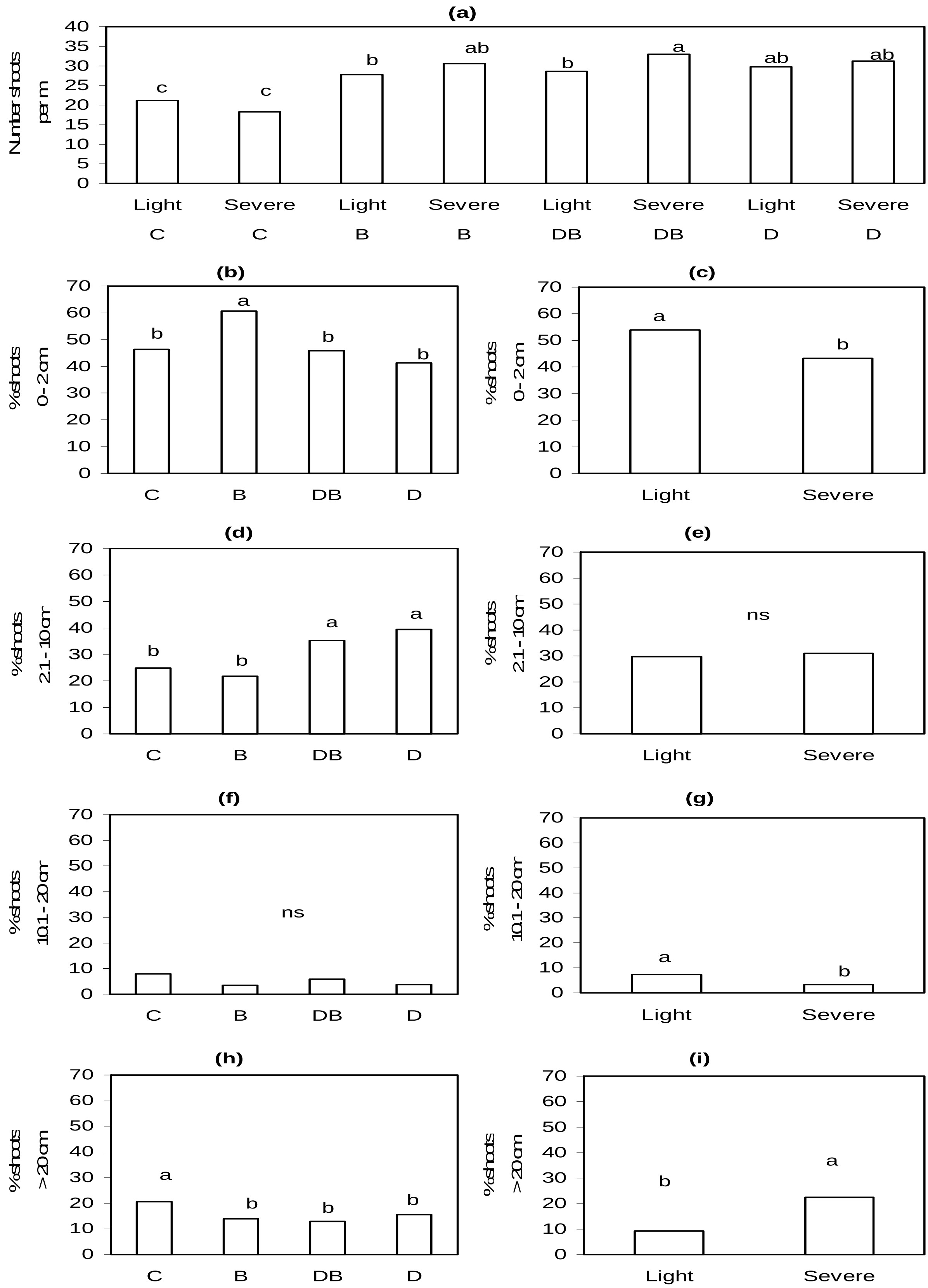

Fig 4: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of shoots (N+1) on one-year-old wood (N) of 5th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0001; Pruning P<0.1100; R*P P<0.0301 (b) Rest breaking P<0.0001; R*P P<0.0615 (c) Pruning P<0.0001; R*P P<0.0615 (d) Rest breaking P<0.0001; R*P P<0.1284 (e) Pruning P<0.5480; R*P P<0.1284 (f) Rest breaking P<0.0899; R*P P<0.6444 (g) Pruning P<0.0063; R*P P<0.6444 (h) Rest breaking P<0.0042; R*P P<0.0745 (i) Pruning P<0.0001; R*P P<0.0745.

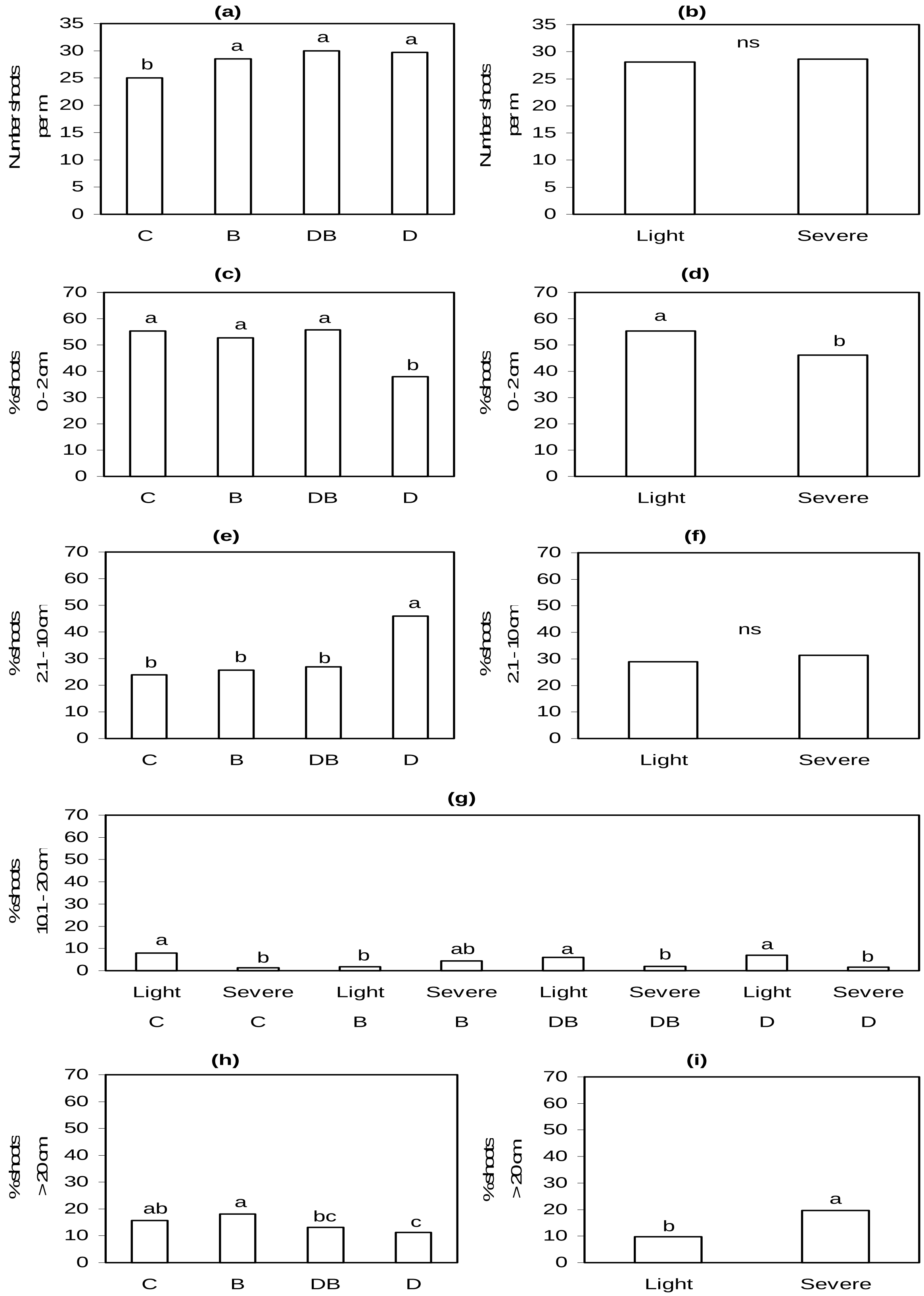

Fig 5: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of shoots (N+1) on one-year-old wood (N) of 6th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0062; R*P P<0.8678 (b) Pruning P<0.7088; R*P P<0.8678 (c) Rest breaking P<0.0006; R*P P<0.7864 (d) Pruning P<0.0042; R*P P<0.7864 (e) Rest breaking P<0.0001; R*P P<0.6930 (f) Pruning P<0.3421; R*P P<0.6930 (g) Rest breaking P<0.6498; Pruning P<0.0023; R*P P<0.0065 (h) Rest breaking P<0.0026; R*P P<0.5741 (i) Pruning P<0.0001; R*P P<0.5741.

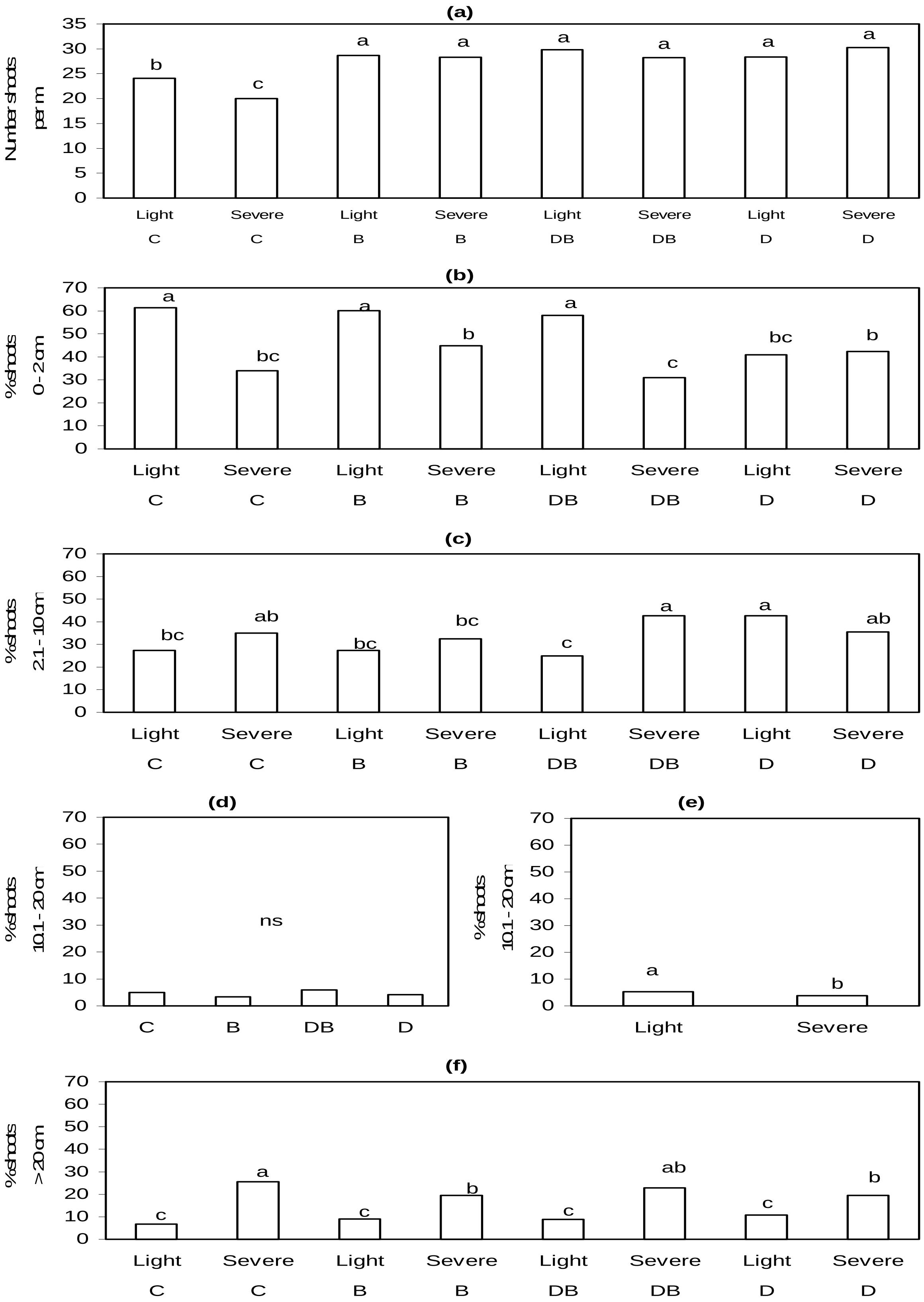

Fig 6: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of shoots (N+1) on one-year-old wood (N) of 7th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking $P<0.0001$; Pruning $P<0.0036$; R*P $P<0.0045$ (b) Rest breaking $P<0.0001$; Pruning $P<0.0036$; R*P $P<0.0045$ (c) Rest breaking $P<0.0001$; Pruning $P<0.0036$; R*P $P<0.0045$ (d) Rest breaking $P<0.0246$; R*P $P<0.3784$ (e) Pruning $P<0.0001$; R*P $P<0.3784$ (f) Rest breaking $P<0.0001$; Pruning $P<0.0036$; R*P $P<0.0045$.

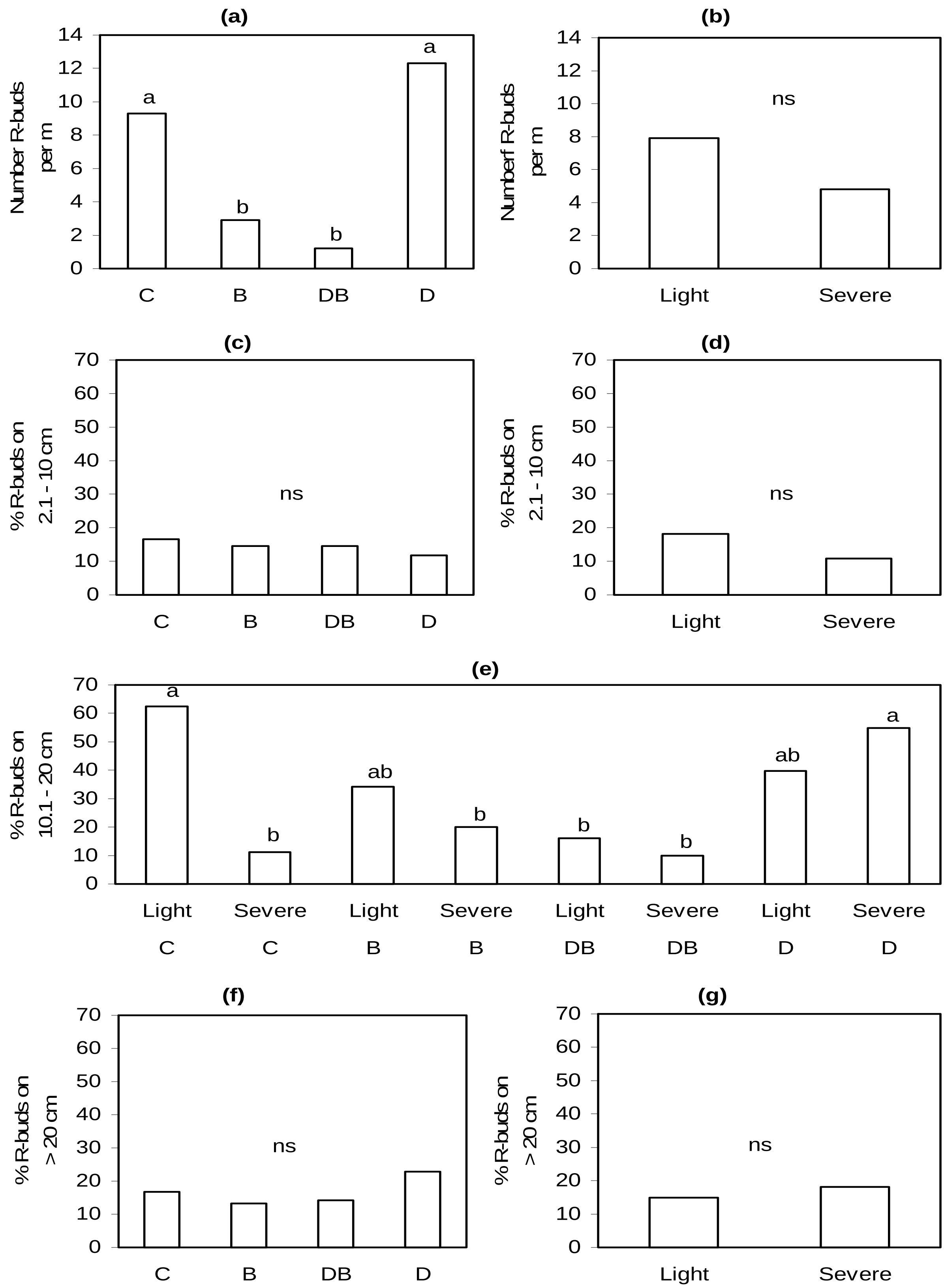

Fig 7: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2002 on the formation of reproductive buds on N+1 units of 5th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0004; R*P P<0.9416 (b) Pruning P<0.1848; R*P P<0.9416 (c) Rest breaking P<0.9495; R*P P<0.4659 (d) Pruning P<0.2148; R*P P<0.4659 (e) Rest breaking P<0.0185; Pruning P<0.0518; R*P P<0.0242 (f) Rest breaking P<0.6842; R*P P<0.9700 (g) Pruning P<0.6060; R*P P<0.9700.

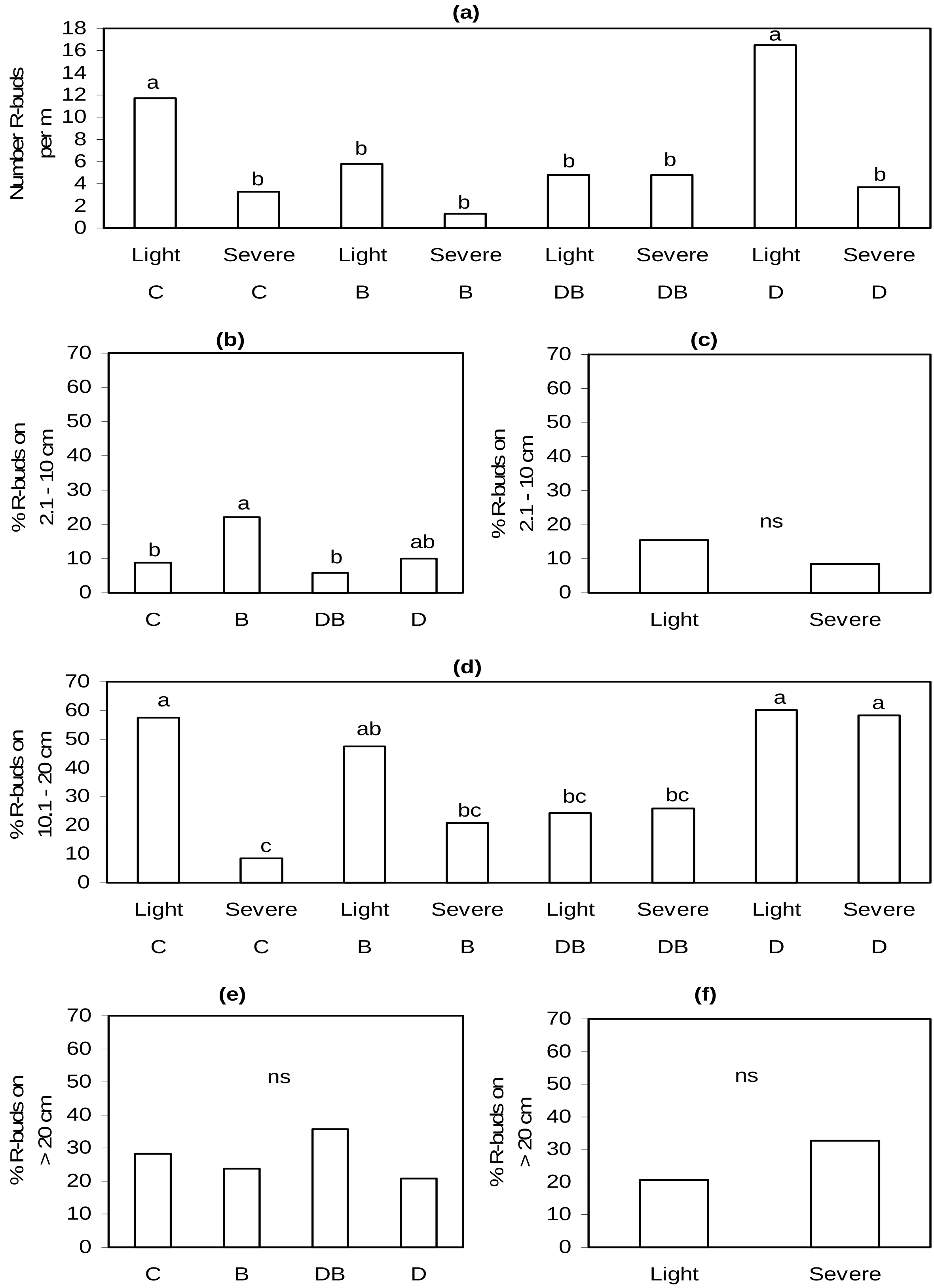

Fig 8: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2002 on the formation of reproductive buds on N+1 units of 6th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking $P<0.0034$; Pruning $P<0.0001$; R*P $P<0.0088$ (b) Rest breaking $P<0.0686$; R*P $P<0.1856$ (c) Pruning $P<0.1580$; R*P $P<0.1856$ (h) Rest breaking $P<0.0051$; Pruning $P<0.0048$; R*P $P<0.0368$ (b) Rest breaking $P<0.5919$; R*P $P<0.1322$ (c) Pruning $P<0.0782$; R*P $P<0.1322$.

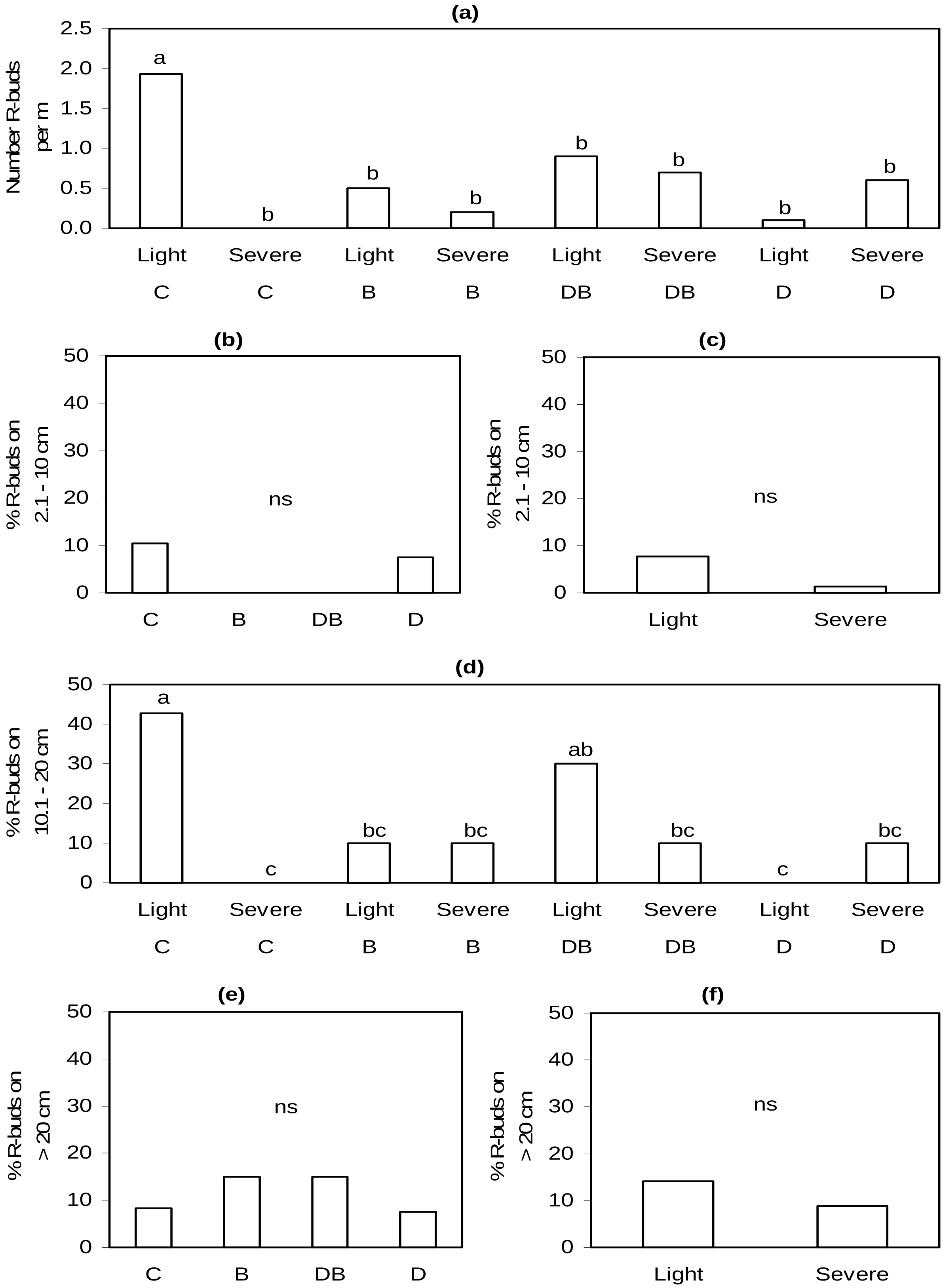

Fig 9: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of reproductive buds on N+1 units of 5th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking $P<0.2507$; Pruning $P<0.0566$; R*P $P<0.0125$ (b) Rest breaking $P<0.1884$; R*P $P<0.2452$ (c) Pruning $P<0.1238$; R*P $P<0.2452$ (d) Rest breaking $P<0.3208$; Pruning $P<0.0734$; R*P $P<0.0605$ (e) Rest breaking $P<0.7958$; R*P $P<0.5937$ (f) Pruning $P<0.4496$; R*P $P<0.5937$.

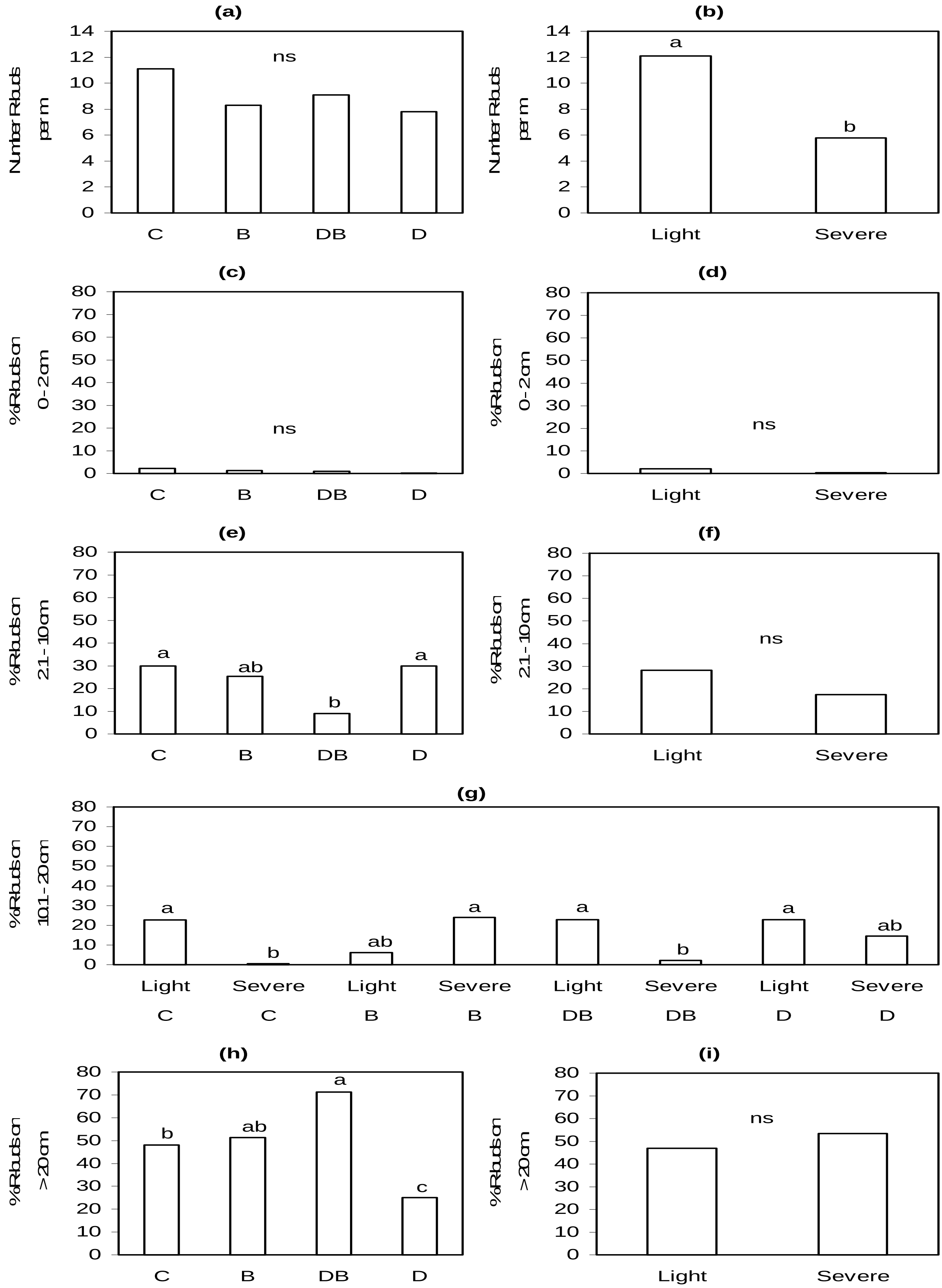

Fig 10: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning (light vs severe) in 2003 on the formation of reproductive buds on N+1 units of 6th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.6370; R*P P<0.5864 (b) Pruning P<0.0009; R*P P<0.5864 (c) Rest breaking P<0.6519; R*P P<0.4812 (d) Pruning P<0.0941; R*P P<0.4812 (e) Rest breaking P<0.0734; R*P P<0.2212 (f) Pruning P<0.0912; R*P P<0.2212 (g) Rest breaking P<0.7538; Pruning P<0.1298; R*P P<0.0246 (h) Rest breaking P<0.0028; R*P P<0.7144 (i) Pruning P<0.3710; R*P P<0.7144.

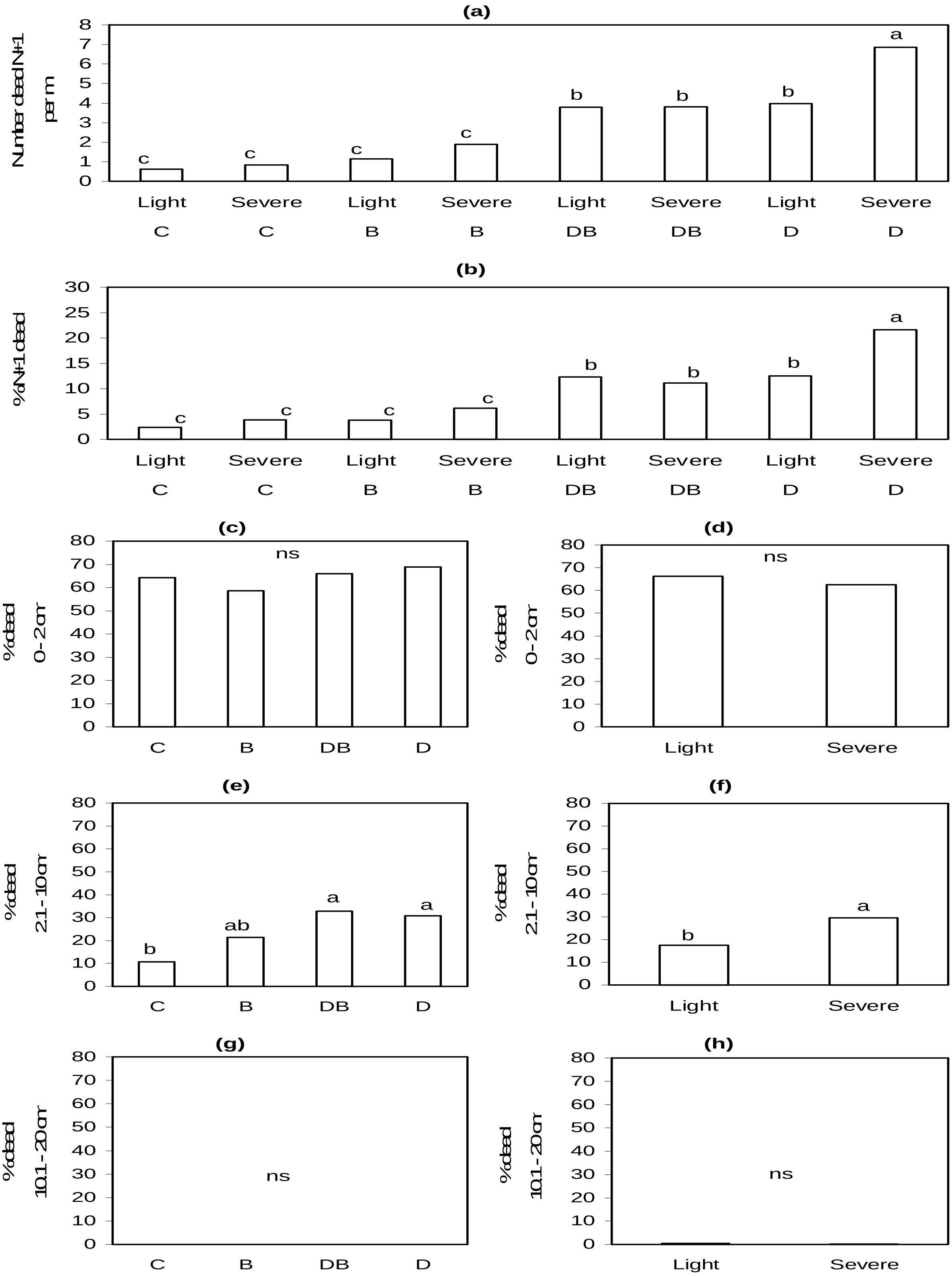

Fig 11: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning (light vs severe) in 2003 on the die-back of two-year-old shoots (N+1) on three-year-old wood (N) of 7th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking $P<0.0001$; Pruning $P<0.0067$; R*P $P<0.0227$ (b) Rest breaking $P<0.0001$; Pruning $P<0.0119$; R*P $P<0.0253$ (c) Rest breaking $P<0.8091$; R*P $P<0.5408$ (d) Pruning $P<0.6575$; R*P $P<0.5408$ (e) Rest breaking $P<0.0106$; R*P $P<0.6694$ (f) Pruning $P<0.0269$; R*P $P<0.6694$ (g) Rest breaking $P<0.4047$; R*P $P<0.1920$ (h) Pruning $P<0.4698$; R*P $P<0.1920$.

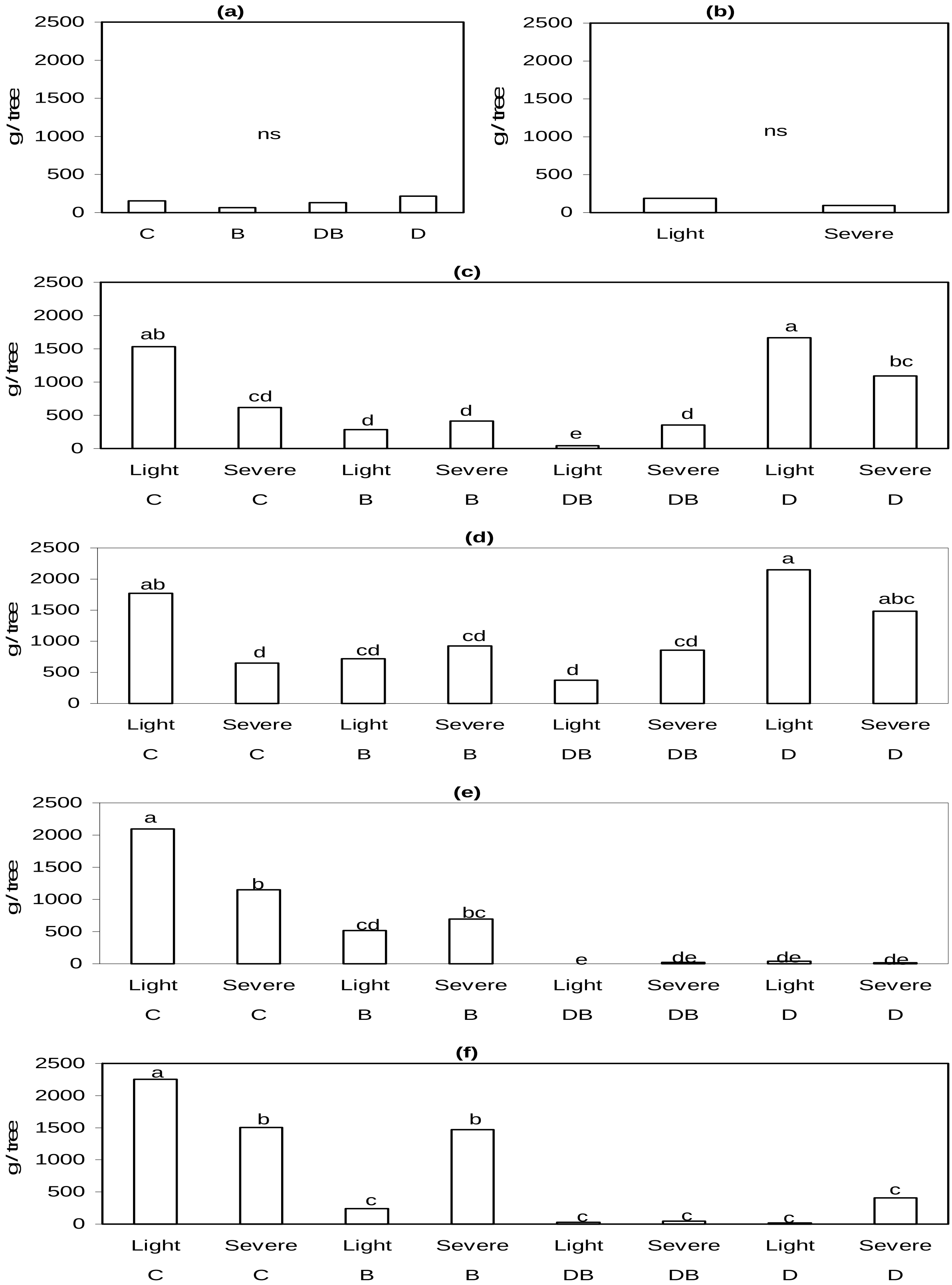

Fig 12: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning (light vs severe) in 2004 and 2005 on the fresh yield of 'Shufra' pistachio trees in Prieska, South Africa. (a) 6th leaf: 2005 Rest breaking P<0.1979; R*P P<0.1328 (b) 6th leaf: 2005 Pruning P<0.0516; R*P P<0.1328 (c) 7th leaf: 2005 Rest breaking P<0.0001; Pruning P<0.0925; R*P P<0.0100 (d) 8th leaf: 2005 Rest breaking P<0.0004; Pruning P<0.1236; R*P P<0.0180 (e) 8th leaf: 2006 Rest breaking P<0.0001; Pruning P<0.1981; R*P P<0.0092 (f) 9th leaf: 2006 Rest breaking P<0.0001; Pruning P<0.1716; R*P P<0.0018

Table 1: Effect of rest breaking applications and pruning in 2002 on the formation of shoots (N+1) on one-year-old wood (N) of 4th leaf 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	Total number of shoots per m	Percentage shoot distribution according to length			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	40.4 a	63.3 a	20.3 c	7.3 b	9.1 ns
4% Budbreak®	38.7 ab	51.8 b	31.5 b	6.4 b	10.4
0.5% Dormex® + 4% Budbreak®	38.3 ab	44.5 c	39.4 a	6.9 b	9.3
4% Dormex®	37.5 b	38.2 d	41.9 a	10.8 a	9.1
Pruning					
Light	39.4 ns	57.4 a	28.8 b	8.2 ns	5.7 b
Severe	38.0	41.5 b	37.8 a	7.5	13.3 a
Pr > F					
Rest breaking application (R)	0.1494	0.0001	0.0001	0.0491	0.9029
Pruning (P)	0.1196	0.0001	0.0001	0.5562	0.0001
R * P	0.0945	0.4962	0.9203	0.2226	0.5106

Z Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 2: Effect of rest breaking applications and pruning in 2002 on the formation of reproductive buds on N+1 units of 4th leaf 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m	Percentage reproductive bud distribution according to length of one-year-old shoots			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	0.6 bZ	.	5.0 ns	11.5 ns	18.5 ns
4% Budbreak®	0.6 b	.	10.0	15.0	0.0
0.5% Dormex® + 4% Budbreak®	0.7 b	.	0.0	21.4	13.6
4% Dormex®	2.1 a	.	4.9	32.9	22.2
Pruning					
Light	1.5 a	.	5.8 ns	29.2 a	20.0 ns
Severe	0.5 b	.	4.2	11.3 b	7.1
Pr > F					
Rest breaking application (R)	0.0336	.	0.5106	0.3129	0.1079
Pruning (P)	0.0236	.	0.7296	0.0402	0.0570
R * P	0.3269	.	0.1300	0.8951	0.1285

Z Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 3: Effect of rest breaking applications and pruning in 2003 on the formation of reproductive buds on N+1 units of 7th leaf 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m	Percentage reproductive bud distribution according to length of one-year-old shoots			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	9.4 b[z]	2.6 ns	29.8 a	20.5 ns	47.1 b
4% Budbreak®	10.6 ab	1.3	20.0 ab	12.0	66.7 a
0.5% Dormex® + 4% Budbreak®	13.4 a	1.3	14.1 b	14.9	69.8 a
4% Dormex®	10.9 ab	0.8	18.9 ab	18.4	61.9 a
Pruning					
Light	13.2 a	3.0 a	27.4 a	22.3 a	47.3 b
Severe	8.8 b	0.0 b	14.7 b	10.8 b	71.9 a
Pr > F					
Rest breaking application (R)	0.3641	0.5762	0.0575	0.4599	0.0054
Pruning (P)	0.0016	0.0028	0.0023	0.0088	0.0001
R * P	0.2504	0.5743	0.9185	0.4788	0.8696

[z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 4: Effect of rest breaking applications and pruning in 2003 on the formation of reproductive buds on N+2 units of 7th leaf 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m shoot (N)	Percentage reproductive bud distribution according to length of N+1 shoots		
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm
Rest breaking application				
Control	8.7 a[z]	10.3 ab	60.0 a	19.7 b
4% Budbreak®	6.8 ab	17.5 a	58.9 a	18.6 b
0.5% Dormex® + 4% Budbreak®	4.1 b	12.9 ab	39.8 b	35.6 b
4% Dormex®	9.9 a	2.9 b	39.8 b	57.3 a
Pruning				
Light	9.1 a	14.3 ns	49.0 ns	31.4 ns
Severe	5.9 b	7.4	50.9	34.0
Pr > F				
Rest breaking application (R)	0.0043	0.067	0.0374	0.0001
Pruning (P)	0.0097	0.0881	0.7654	0.7055
R * P	0.5275	0.0672	0.2277	0.1771

[z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 5: Effect of rest breaking applications and pruning in 2005 on flower bud retention and in 2006 on fresh yields of 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	Percentage flower bud retention:			Fresh yield: 2007[X]		Three-year average fresh yield	
	Leaf 7	Leaf 8	Leaf 9	Leaf 9	Leaf 10	Leaf 9	Leaf 10
	21/11/05	22/11/05	22/11/05	kg / tree	kg / tree	kg / tree	kg / tree
Rest breaking application							
Control	32.5 a[YZ]	48.6 a	53.0 a	11.5 a	15.3 ab	4.7 a	6.1 ab
4% Budbreak®	6.0 b	25.3 b	28.3 b	6.7 b	14.8 b	2.5 b	5.5 b
0.5% Dormex® + 4% Budbreak®	7.2 b	19.7 b	24.9 b	6.2 b	9.1 c	2.2 b	3.3 c
4% Dormex®	35.3 a	29.6 b	36.5 b	11.4 a	18.8 a	4.3 a	7.0 a
Pruning							
Light	19.8 ns	27.6 b	29.7 b	8.7 ns	15.6 ns	3.4 ns	5.9 ns
Severe	19.3	34.7 a	43.1 a	9.1	13.8	3.4	5.2
Pr > F							
Rest breaking application (R)	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001
Pruning (P)	0.2874	0.0314	0.0005	0.6914	0.3009	0.9612	0.2971
R * P	0.8759	0.0710	0.0832	0.5753	0.2780	0.3575	0.3937

[X]Leaf 8 trees did not have any yield.

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on percentage retention.

<u>PAPER 3:</u> THE EFFECT OF REST BREAKING AGENTS AND PRUNING ON BUDBREAK AND FLOWER BUD DEVELOPMENT OF PISTACHIO CV. SIRORA *(PISTACIA VERA* L.*)* IN A CLIMATE WITH MODERATE WINTER CHILLING.

Abstract

Tip-pruning (to remove <2.5cm) and severe heading cuts (to remove 35-45%) of one-year old wood were compared and 4% hydrogen cyanimide (Dormex®), 4% mineral oil (Budbreak®) as well as their combination (0.5% Dormex® + 4% Budbreak®) used as rest breaking agents on fifth leaf 'Sirora' pistachio (*Pistacia vera* L.) trees and evaluated over five seasons. Bud break, reproductive bud differentiation, die-back, flower bud retention during winter and early summer and yields were evaluated. The trends in the results emphasised the interaction of rest breaking and pruning effects with genetic chill requirement and environmental influences - specifically winter chill build-up. Severe pruning was detrimental to flower bud formation as well as yield. The bud break data suggests that the ability of some rest breaking chemicals to promote lateral development may possibly also be explained by their potential to impede the development of apical dominance, normally strengthened by insufficient winter chilling, in addition to direct effects on the lateral buds. The inability of the chemical treatments to increase yields consistently might indicate that the average winter chill of Prieska (29° 40'S, 22° 45'E, 945 m.a.s.l) is below the minimum amount necessary for chemical effects to be expected on this cultivar.

Introduction

The climate around Prieska differs from other pistachio growing regions in the world in that it receives fewer winter chilling units, has higher maximum temperatures during winter and spring and receives summer rainfall (Van den Bergh and Manley, 2002). This possibly results in the observed delayed foliation, flower bud and inflorescence abortion, low fruit set and yield and other flowering disorders e.g. the terminal bud developing into a florescence which Crane and Takeda (1979) described as a rare response to low winter chilling. No accurate chilling requirements or detailed information regarding desired lengths of lateral shoots are known for any pistachio cultivar, except that 1000-1500 hours below 7 ºC appear to be sufficient in California, USA (Crane and Takeda, 1979).

The use of different dormancy breaking chemicals on pistachios in areas with mild winters resulted in increased yields, quality and changes in flowering patterns and lateral development (Procopiou, 1973; Küden and Küden, 1995; Rahemi and Asghari, 2004), irrespective of rootstock (Beede and Ferguson, 2002). However, these reports did not discuss the long term effects of dormancy breaking chemicals on structural development or flower bud differentiation and also did not eliminate the possible lack of overlapping of male and female bloom through artificial pollination.

The first four to five pruning seasons of a pistachio tree are spend on training a strong trunk (90-120 cm in height) and well balanced scaffold branches to accommodate mechanical harvesting (Crane and Iwakiri, 1985). This is done through heading cuts which remove 30% or more of one-year-old shoots in winter (Personal observation). As pistachios bear only on one-year-old shoots, the importance of new growth is obvious. Koopmann however, reported as early as 1896 on the negative effects of severe heading cuts on flower bud differentiation (Wertheim, 1976). Therefore, the influence of strong heading cuts on delaying the reproductive development needs to be investigated.

In this paper we report on the effect of dormancy breaking chemicals and pruning on development of lateral shoots, flower bud differentiation, yield, tree dimensions and flower bud retention of 'Sirora' during spring in the Prieska district, Northern Cape.

Materials and method

Plant material:

Trees in a commercial orchard (5th leaf) were tagged in 2001/2002. Trees on *P. integgerima* rootstocks were established at a spacing of 5.2 m x 5.78 m. For further detail on plant material refer to Paper 1.

Treatments and experimental design:

Timing was aimed at the late bud swell stage and occurred on 14 Sept. 2002, 16 Sept. 2003, 15 Sept. 2004, 8 Sept. 2005 and 2 September 2006, respectively. The average length of lightly pruned shoots were 63 ± 16 cm and 41 ± 4 cm in trees receiving the heavy heading cut in 2002, and 47 ± 14 cm and 33 ± 5 cm, respectively in 2003. For further detail on treatments and experimental design refer to Paper 1.

Data recorded:

Bud break, reproductive bud differentiation and die-back

The data recorded in this trial was described in Paper 1. In 2004, five three-year-old branch units (tip-pruned: 61 ± 10 cm, top-pruned: 41 ± 2 cm in year N), were randomly selected and the averages calculated.

Flower bud retention during winter and early summer: 2005

Five one-year-old shoots (10 - 20 cm), with three or more flower buds, were randomly tagged on 23 May 2005 on all trees and the number of flower buds per shoot recorded. The percentage flower bud retention of these shoots was monitored on 26 July, 31 Oct. (after anthesis) and 30 Nov. (after shell hardening).

Yield and tree dimensions

See Paper 1.

Data analysis:

See Paper 1.

Results

Bud break

Only a slight, though significant pruning effect was found in the total number of shoots per meter after treatment in winter 2002 with the lighter pruning having significantly more. The control treatment had the highest percentage laterals 0 – 2 cm, with Budbreak®, Dormex® & Budbreak® and Dormex® having progressively fewer. The lightly pruned treatment had the highest percentage laterals 0 – 2 cm. The Dormex® & Budbreak® treatment induced the highest percentage of shoots in the category 2.1 – 10 cm, but did not differ significantly from Budbreak®. The control, Budbreak® and Dormex® did not differ significantly from each other in this regard. The lightly pruned treatment also stimulated the highest percentage of shoots in this category. The Budbreak®, Dormex® + Budbreak® and Dormex® treatments resulted in significantly higher percentages of shoots 10.1 – 20 cm than the control, but did not differ between each other. The pruning treatments showed no significant effect. The Dormex® treatment produced the highest percentage of shoots longer than 20 cm, with no significant difference between the other rest breaking treatments and the control. The severely pruned treatment had the highest percentage of shoots longer than 20 cm (Table 1).

Interactions between rest breaking treatment and pruning were found in total number of shoots per meter and percentage shoots 2.1 – 10 cm and > 20 cm following treatment in winter 2003. The Dormex® + lightly pruned combination resulted in significantly more shoots per meter than any other treatment combination whereas Dormex® & Budbreak® + severe pruning, gave the lowest number, although it did not differ significantly from the two control treatments or the severely pruned Budbreak® and Dormex® treatment combinations (Fig 2a). Dormex® & Budbreak® + severe pruning did not differ significantly from the other combinations except from Budbreak® + lightly pruned and Dormex® & Budbreak® + lightly pruned (Fig 2a). The Dormex® treatment had the lowest percentage shoots 0 – 2 cm, with no difference between the other rest breaking treatments (Fig 2b). The lightly pruned treatment induced the highest percentage shoots 0 – 2 cm (Fig 2c). In the category 2.1 – 10 cm shoot length, the Dormex® & Budbreak® + lightly pruned and Dormex® + lightly pruned combinations resulted in significantly higher percentages, with no difference between the other combinations (Fig 2d) Only the severely pruned treatment induced more shoots in the category 10.1 – 20 cm (Fig 2e and f). The Dormex® + severely pruned treatment had the highest percentage shoots > 20 cm. All the other severely pruned combinations had a significantly higher percentage laterals > 20 cm than the lightly pruned combinations, but showed no significant differences between the different rest breaking treatments (Fig 2g).

Reproductive bud development

In response to the treatments performed in 2002, very few reproductive buds were formed on one-year-old shoots (data not shown). Only a pruning effect was found after treatment in 2003 for the total number of reproductive buds per meter and percentage of reproductive buds on one-year-old shoots (year N+1) 2.1 – 10 cm and 10.1 – 20 cm (Table 2). The lightly pruned treatment resulted in the highest number of reproductive buds in each case. No reproductive buds developed on shoots 0 – 2 cm and no significant difference was found regarding reproductive buds on laterals > 20 cm (Table 2).

Total number of reproductive buds on two-year old units (N+2) ≤ 20 cm: 2004

The rest breaking control developed the highest number of reproductive buds per meter on shoots N+2, but did not differ from Budbreak® (Fig. 3a). No significant differences were found between Budbreak® and the other rest-breaking treatments, neither was there a significant pruning effect (Fig 3a, b). An interaction was found when looking at 2.1 – 10cm long shoots (N+2) with the control and lightly pruned combination having the highest percentage of reproductive buds, with no significant difference between the other combinations (Fig 3c). Only a pruning effect was found regarding the percentage of reproductive buds on shoots 10.1 – 20 cm (N+2), with the light pruning stimulating more reproductive buds (Fig 3d, e).

Die-back on two-year old shoots (N+1): 2004

Slight pruning and rest breaking effects were found in both the number of dead two-year-old shoots per meter, as well as the percentage die-back of the total originally formed N+1 shoots (Fig 4a, b, c, d). The Dormex® & Budbreak® and Dormex® treatments did not differ significantly from each other, but had significantly more dead shoots per meter than the control and Budbreak®. The severely pruned trees had more dead laterals per meter as well as a higher percentage die-back of originally formed shoots than the lighter pruned treatment. Dormex® with 28% resulted in the highest percentage die-back of original shoots. Dormex® & Budbreak® had a significantly higher percentage die-back than the control, but Budbreak® did not differ significantly from the control or the combination treatment (Fig 4a, c).

No significant pruning effects were found in the percentage shoots which showed die-back in the category 0 – 2, 2.1 – 10 or 20.1 – 30 cm (Fig 4f, h, k). However, significant rest breaking effects were found in these categories (Fig 4e, g, j). The control (66.1%) and Budbreak® (64.5%) did not differ significantly from each other, but were significantly higher than the Dormex® & Budbreak® (38.7%) and Dormex® (29.5%) treatments in the 0 – 2 cm category (Fig 4e). Dormex® & Budbreak® (52.3%) and Dormex® (48.5%) did not differ significantly from each other, but were more aggressive than the control (32.5%) and Budbreak® (29.1%) treatments in the 2.1 – 10 cm category in stimulating die-back (Fig 4g). Very little die-back was observed in the category 20.1- 30 cm, but Dormex® with 5.5% was the most severe treatment (Fig 4j).

An interaction was found in the die-back of shoots 10.1 – 20 cm. The severely pruned Dormex® treatment with 24.0% showed the highest percentage die-back, with no significant differences between the other treatments except for the severely pruned control treatment (0.0%) which differed significantly from the severely pruned Dormex® & Budbreak® (9.4%) and lighter pruned Dormex® (9.1%) treatments (Fig 4i).

Flower bud retention and yield

No significant rest breaking or pruning effects were found in the flower bud retention of 2005 (Table 3). Slight, though significant rest breaking and pruning effects were found in the yields of March 2005, with the highest yield from the tip-pruned and control trees (Fig 5a, b). Budbreak® did not differ significantly from the control or from Dormex® & Budbreak® and Dormex®.

Only a pruning effect was found in the yield of March 2006 (Fig 5c, d). An interaction between pruning and chemical treatments was found in the yields of March 2007 with the highest yields from the lightly pruned Dormex® & Budbreak® and Dormex® trees and the lowest from the Budbreak® + severe pruning, although it did not differ from Budbreak® + light pruning, control or Dormex® + severe pruning (Fig 5e).

The three-year average showed both rest breaking and pruning effects with the highest yields from tip pruning and Dormex® & Budbreak®, although it did not differ from the Dormex®.

Tree size

Rest-breaking treatments had no effect on tree size (Table 4). Lighter pruned trees increased more in volume than severely pruned trees (Table 4).

Discussion

Bud break

The trend seen in the total number of shoots on the control trees of the two older age groups (on *P. integgerima* rootstock) with 30 per meter in 2002 in comparison with only 20 - 25 per meter in 2003 (Table 1, Fig 2a) can be explained by comparing the climatic differences between 2002 and 2003. In comparison to the total annual chilling of 2002, 153 more Richardson Chilling Units (RCU) (Richardson et al., 1974) were accumulated during 2003. Contrary to this, 2002 had 229 more RCU accumulated over 3 months by the end of July, in comparison with 2003 at the same stage. However, Cook and Jacobs (2000) found that regions with a gradual build-up of RCU during the beginning of dormancy showed a negative effect on bud break of apple shoots cv. Golden Delicious.

It is evident from Table 1 and Fig 2a that light pruning in 2002 was the only positive effect (although very slight) on total numbers of shoots (Saunders et al., 1991) and that it was only increased in 2003 by interaction between Dormex® and light pruning. The markedly reduced lateral shoot development in 2003 is best explained by the more gradual build-up of RCU during 2003 which could have strengthened apical dominance or increased endo dormancy of the lateral buds more than in 2002. Cook and Jacobs (1999) explained an increase in apical dominance development after sub-optimal chilling, by referring to ongoing polar auxin transport in warmer winter climates (with average temperatures above 7ºC) and stated that causes of delayed foliation may reside more in the strengthened correlative inhibition than in the endo dormancy of the lateral buds. Therefore, the increasing number of lateral shoots in 2003 (Fig 2) relative to 2002, may reflect on the potential of Dormex® to impede the development of strong apical dominance (Erez, 1987) by promoting more uniform bud break after low chilling, in addition to a general improvement of lateral bud break as found by Rahemi and Asghari (2004) - especially when taking the absence of rest breaking effects in 2002 regarding total number of shoots per meter, into account (Table 1). Another factor to consider is that pruning was done almost at bud swell, thereby cancelling the initial apical dominance of the terminal bud in both pruning regimes, promoting lateral bud break.

However, chemical rest breaking significantly affected the length-distribution of shoots during both years with control trees of which more than 30 - 40% of total shoots were 0 - 2 cm (Table 1, Fig 2b). This differed consistently with Dormex®, which in contrast had only 10% of shoots 0 – 2 cm (Table 1, Fig 2b). Light pruning also promoted the development of 0 - 2 cm shoots. The dominance of the control and light pruning in this category may again refer to the timing of pruning, cancelling the initial apical dominance of the terminal bud and promoting lateral bud break, but with a marked succession of apical dominance (due to poor winter chilling) by the remaining distal bud, impeding further growth (Cook and Jacobs, 1999). Also, the small percentage of shoot taken away with tip pruning probably did not result in dramatic changes in the cytokinin / auxin relations of the remaining vegetative buds (Oosthuyse et al., 1992).

Dormex®, Dormex® & Budbreak® as well as light pruning increased the percentage shoots 2.1 – 10 cm in 2002 (Table 1) while only light pruning in interaction with both Dormex® and Dormex® & Budbreak® increased it in 2003 (Fig 2d) - after less favourable chilling. By promoting development of this longer shoot category in comparison with the increase of the 0 – 2 cm in the case of control trees (30 - 40%), this serves as indication of their ability to increase lateral development. Furthermore, it appears as if pruning and chemical rest breaking complimented each other after less favourable winter chilling. While the separate effects were sufficient in increasing this category after a more favourable winter period, it was only increased in interaction with each other after less winter chilling.

All three rest breaking treatments sharply increased the percentage shoots 10.1 – 20 cm in 2002, but had no effect during 2003, while severe pruning had no effect in 2002, although a slight, though significant effect was found in 2003 on the same category (Table 1, Fig 2e, f). The same argument regarding the weaker apical dominance development (See previous paragraph) after 2002 explains the rest breaking effect while its absence after 2003 merely points out the boundary of the effect and its interdependence upon environmental changes, specifically in the context of winter chilling. The absence of a dominant pruning effect – specifically the role of severe pruning in the 10.1 – 20 cm category, is probably due to its usual proximal and therefore subordinate location relative to the dominant terminal remaining bud (Personal observation). It should also be taken into account that these proximal buds, available for this category after severe pruning, would also have been less developed than those distally located - further lowering their potential to react to possible increases in their cytokinen / auxin ratio (Oosthuyse et al., 1992).

Dormex® as well as severe pruning increased the percentage shoots >20 cm in 2002, and in 2003 it was enhanced by severe pruning in interaction with all rest breaking treatments - especially with Dormex® (Table 1, Fig 2g). Considering the aforementioned as well as the exclusive distal location of this category (Personal observation), it appears that of all chemical treatments, only Dormex® had the potential to reduce the apical dominance in close vicinity to the terminal bud - taken into account that the single effect was only observed after more favourable winter chilling, although Dormex® + severe pruning was also the most significant interaction. The dramatic increase and dominant role resulting from severe pruning in this shoot-category is as one would expect when both the >20 cm category's distal location (Personal observation) and the potential increase in the remaining buds' cytokinen / auxin relations following 35% - 45% heading cuts is taken into account. However, this trend in results correspond with the one found in the 2.1 - 10cm category over the two consecutive years and again reflect on (1) limits of the single effects or interdependence of the single effects to chilling conditions and (2) the complementary interaction of severe pruning and all chemical treatments, promoting this category.

Reproductive bud development

Reproductive buds were only found on tip-pruned trees after the 2002 treatments, although in insignificant numbers (Data not shown). This pruning effect was repeated in 2003 when the total number of reproductive buds was only increased after light pruning. This is consistent with previous findings when the general vigour of 'Sirora' as well as the negative effect of severe pruning on flower bud formation as observed by Koopmann in 1896 (Wertheim, 1976) are taken into account. However, more research is necessary to discuss the significance of the obtained flower bud distribution.

Reproductive buds on new growth (N+2) of two-year old units (N+1) ≤ 20 cm

Only the control and Budbreak® trees had reasonable numbers of reproductive buds on the N+2 shoots. This allocation of reproductive buds was clearly reduced with the use of Dormex® and Dormex® & Budbreak®, probably due to the observed phytotoxisity of the two-year old N+1 units, especially the 2.1 - 10cm category (Fig 4c, g). Although pruning did not affect the total number of reproductive buds on N+2 growths, the interaction of control + light pruning shows clearly its effect on their distribution by enhancing the allocation to 2.1 – 10 cm shoots (Fig 3c, e). It is difficult to gauge the economic importance of the above results except to recognise it as a potential factor contributing to yield differences.

Dead two-year old shoots (N+1): 2004

It is clear from Fig 4a, c, e and g that Dormex® and Dormex® & Budbreak® significantly increased the number of dead N+ 1 shoots to 20 – 30% of their original number, of which nearly 50% was 2.1 – 10 cm whereas Budbreak® and control trees lost less than 20% of their original number, of which 65% was 0 – 2 cm. The extent of phytotoxicity resulting from the Dormex® treatment is further reflected in the loss of 10.1 – 20 cm shoots (in interaction with severe pruning) as well as those >20 cm (Fig 4i, j). Pruning effects in general, appears secondary for this parameter, with only a very slight, though significant increase in total die-back by severe pruning in interaction with Dormex®, qualitatively reflected by the increase in percentage dead 10.1 – 20 cm shoots (Fig 4b, d and i).

Flower bud retention during winter and early summer: 2005

Neither rest breaking, nor pruning showed any significant effects on flower bud retention prior and after the flowering period (Table 3). This could be a preliminary indication of external causes which (for example) a possible increase in the cytokinen / auxin ratio due to severe pruning, could not counter (Oosthuyse et al., 1992).

The average maximum temperature for September (Southern Hemisphere) in Australia and California's pistachio production areas is only 20ºC (Van den Bergh and Manley, 2002). Considering the above mentioned, the relative high flower bud losses may also be attributed to a period of extremely high maximum day temperatures (>30ºC) and only 27% average relative humidity. This period lasted for twelve consecutive days during middle September 2005 coinciding with the final stages of flower bud development when pistil and carpel development occur in the case of 'Kerman' (Takeda et al., 1979). Some negative effects of high spring temperatures are also referred to by Lomas (1988) stating that high day temperatures (> 32ºC), especially when accompanied by low relative humidity, are detrimental for avocado flowering and fruit set, while a 7 ºC increase in daily maximum temperatures of apricot flower buds during the pre-blossom period, was found to impede pistil development as well as fruit set (Rodrigo and Herrero, 2002). More results are necessary to evaluate the possible causes of the observed flower bud losses.

Yield

No significant increase in yield of 8th (2005) and 9th (2006) leaf trees could be accomplished with chemical rest breaking, but light pruning proved to be an essential factor in determining yield (Table 3), even in older trees. The relatively low values of the previous seasons' yields might be due to the quality and quantity of staminate flowers on surrounding male trees (available pollen concentration in environment) or the quality of pollen used for artificial pollination. However, marked increases were found in the 2007 yields. The highest number of RCU per winter for the trial period from 2002, was accumulated during 2006 with 644 RCU. The average maximum temperature for September 2006 was 26ºC (the same as the long-term average for Prieska). These more favourable climatic factors for flower bud, florescence and fruit set (Lomas, 1988; Rodrigo and Herrero, 2002) probably led to the resulting high yields in March 2007 which dictated the three-year averages (Fig 5f, g).

The lack of previous chemical rest breaking effects, contrasted with the light pruning + Dormex® and + Dormex® & Budbreak® combinations increased the yield after the highest number of accumulated chilling units (644 RCU) in nine years (previous average 341 RCU). This did not correspond with the general trend of thought that chemical rest breaking agents can enhance yield after poor chilling (Procopiou, 1973; Küden and Küden, 1995; Rahemi and Asghari, 2004). However, this might indicate that such positive chemical effects on pistachio yields might only be expected after this minimum amount of chilling was acquired (Erez, 1995), considering that this nine year maximum for Prieska is still less than 60% of the winter chilling obtained in the pistachio growing regions like California or Australia (Van den Bergh and Manley, 2002). The winter chill of the previous two years was obviously too marginal.

Tree size

Although lighter pruned trees proved to increase more in volume than severely pruned trees (Table 4) confirming similar findings of Koopmann (Wertheim, 1976), our measuring scale of 25cm may be considered too rough to accurately reflect the differences in dimensions.

Conclusion

The trends in these results emphasise the interaction of rest breaking and pruning effects with genetic chill requirements and environmental influences - specifically winter chill build-up. The bud break data further suggests that the ability of some rest breaking chemicals to promote lateral development may also be explained by their potential to impede the development of apical dominance, normally strengthened by insufficient winter chilling (Cook and Jacobs, 1999), in addition to direct effects on lateral buds. Furthermore, it implicates the complementary effects of pruning and chemical use through interactions after less favourable winter chilling, whereas only single effects were observed after more optimal winter conditions.

The promotion of flower bud formation following light pruning in the Prieska climate is of major economic importance, especially when considering that early (4-5 years) pistachio pruning guidelines are mainly aimed at structural preparation for mechanical harvesting. Although the positional distribution of flower buds was influenced by both rest breaking and pruning treatments over both years, the effects were erratic and inconsistent, with almost no correlation between the flower bud localities favoured by a certain treatment and the shoot-length category that was increased by it. Indications are that the reason for the high flower bud losses during spring, might reside in external factors like high maximum spring temperatures and low relative humidity.

The inability of the chemical treatments to increase the yield of ‘Sirora’ consistently, might indicate other factors involved or that the winter chill in Prieska is too marginal to acquire the minimum amount of chilling necessary for any positive chemical rest breaking effects on yield (Erez, 1995). Due to the erratic climatic changes between the winter and spring seasons in Prieska as well as the one year’s dictating role in average yields, more research is necessary to indicate long term trends, especially regarding yield. The effect of rest breaking chemicals on correlative inhibition as well as endo dormancy should also be investigated.

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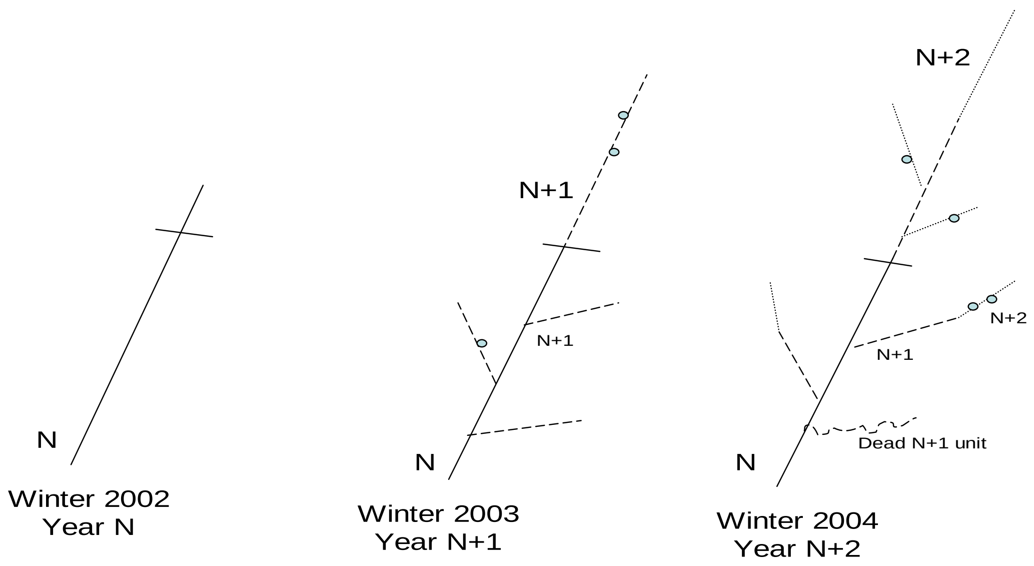

Fig 1: Schematic presentation of units used to record data on bud break and reproductive bud (º) development of 'Sirora' pistachio trees in Prieska, South Africa.

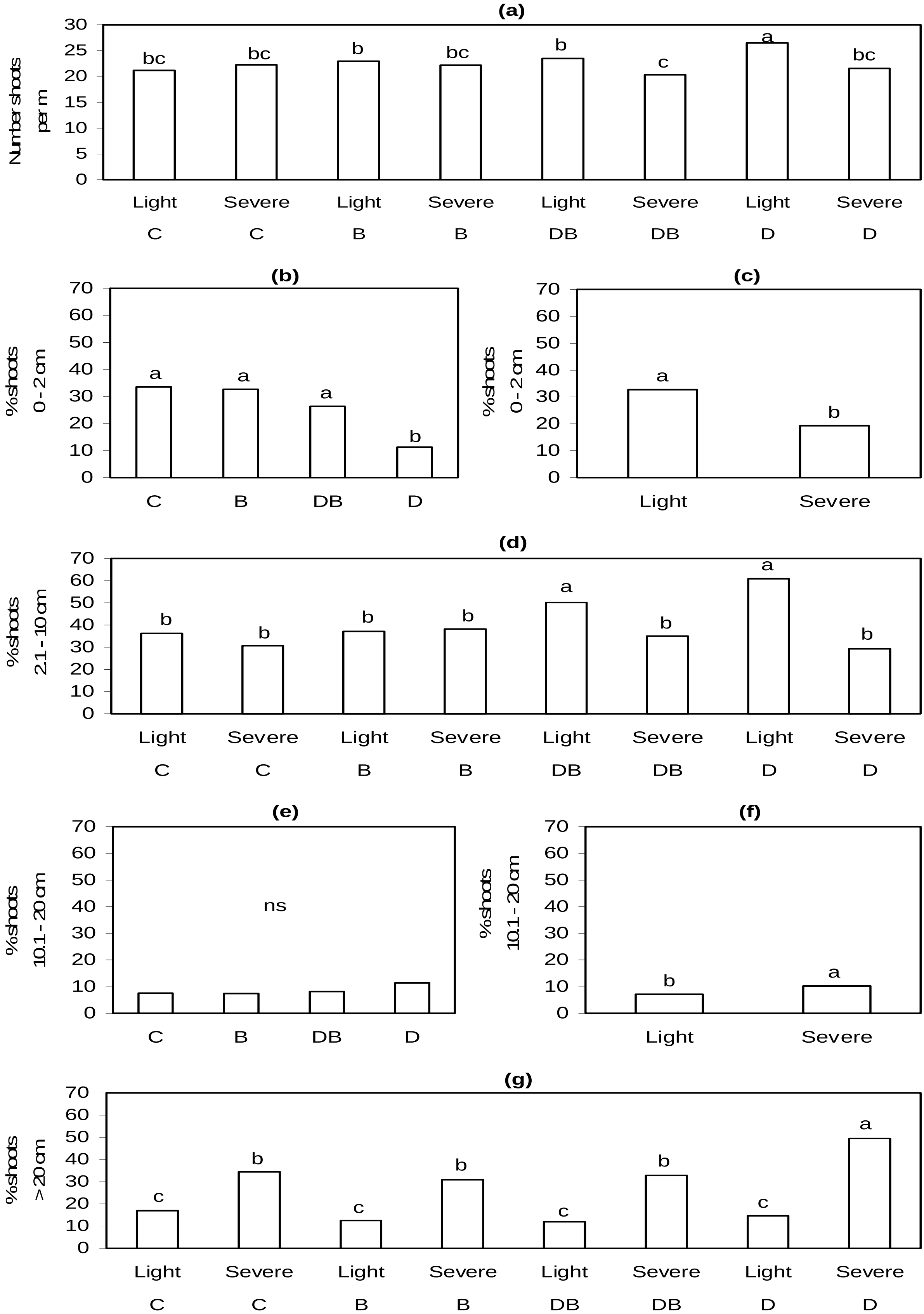

Fig 2: Effect of rest breaking applications (C=control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning in 2003 on the formation of shoots (N+1) on one-year-old wood (N) of 7th leaf 'Sirora' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0218; Pruning P<0.0011; R*P P<0.0051 (b) Rest breaking P<0.0001; R*P<0.1242 (c) Pruning P<0.0001; R*P<0.1242 (d) Rest breaking P<0.0296; Pruning P<0.0001; R*P<0.0003 (e) Rest breaking P<0.1473; R*P<0.2319 (f) Pruning P<0.0249; R*P<0.2319 (g) Rest breaking P<0.0056; R*P<0.012.

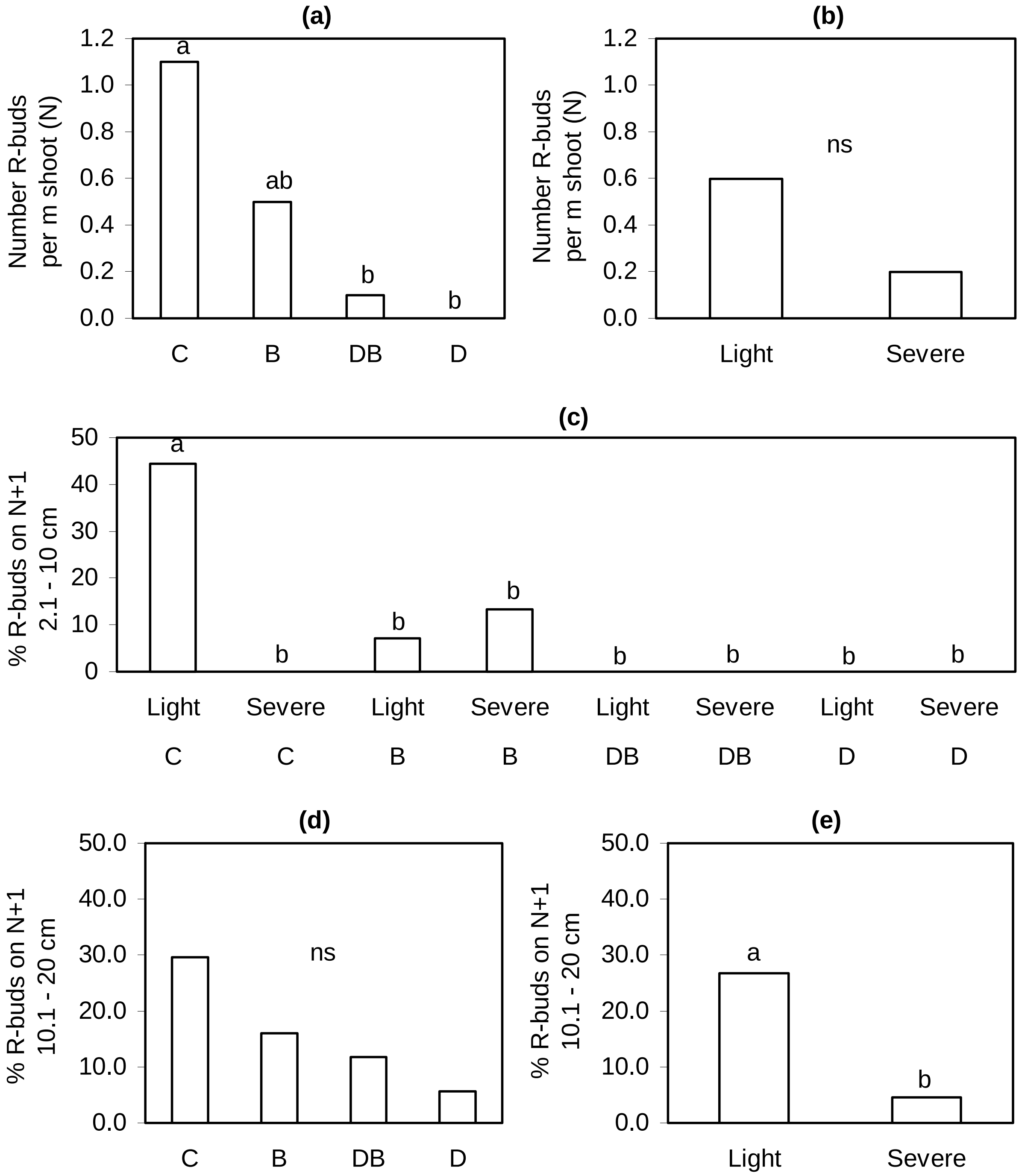

Fig 3: Effect of rest breaking applications (C = control, B = 4% Budbreak®, DB = 0.5% Dormex® + 4% Budbreak®, D = 4% Dormex®) and pruning in 2003 on the formation of reproductive buds on N+2 units of 7th leaf Sirora pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.0083; R*P P<0.0579 (b) Pruning P<0.0653; R*P P<0.0579 (c) Rest breaking P<0.0082; Pruning P<0.1336; R*P P<0.0058 (d) Rest breaking P<0.2150; R*P P<0.8416 (e) Pruning P<0.0091; R*P P<0.8416.

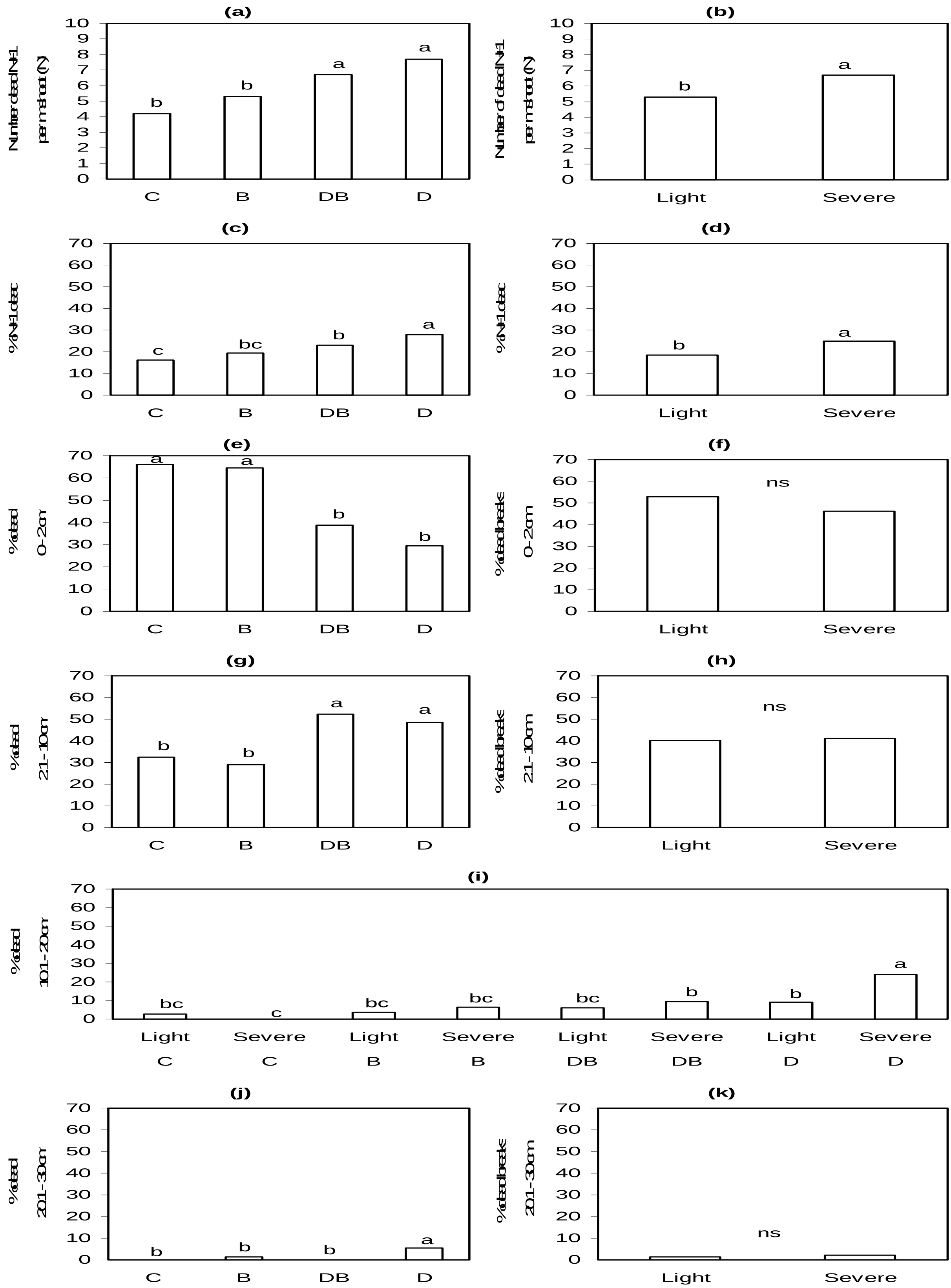

Fig 4: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning in 2003 on the die-back of two-year-old shoots (N+1) on three-year-old wood (N) of 7th leaf 'Sirora' pistachio trees in Prieska, South Africa. (a) Rest breaking $P<0.0001$; Pruning $P<.0.5560$; R*P $P<0.0536$ (b) Rest breaking $P<0.0001$; R*P $P<0.5129$ (c) Pruning $P<0.1035$; R*P $P<0.5129$ (d) Rest breaking $P<0.0001$; R*P $P<0.0882$ (e) Pruning $P<0.1423$; R*P $P<0.0882$ (f) Rest breaking $P<0.0001$; R*P $P<0.5338$ (g) Pruning $P<0.0005$; R*P $P<0.5338$ (h) Rest breaking $P<0.2298$; R*P $P<0.2668$ (i) Pruning $P<0.0226$; R*P $P<0.2668$.

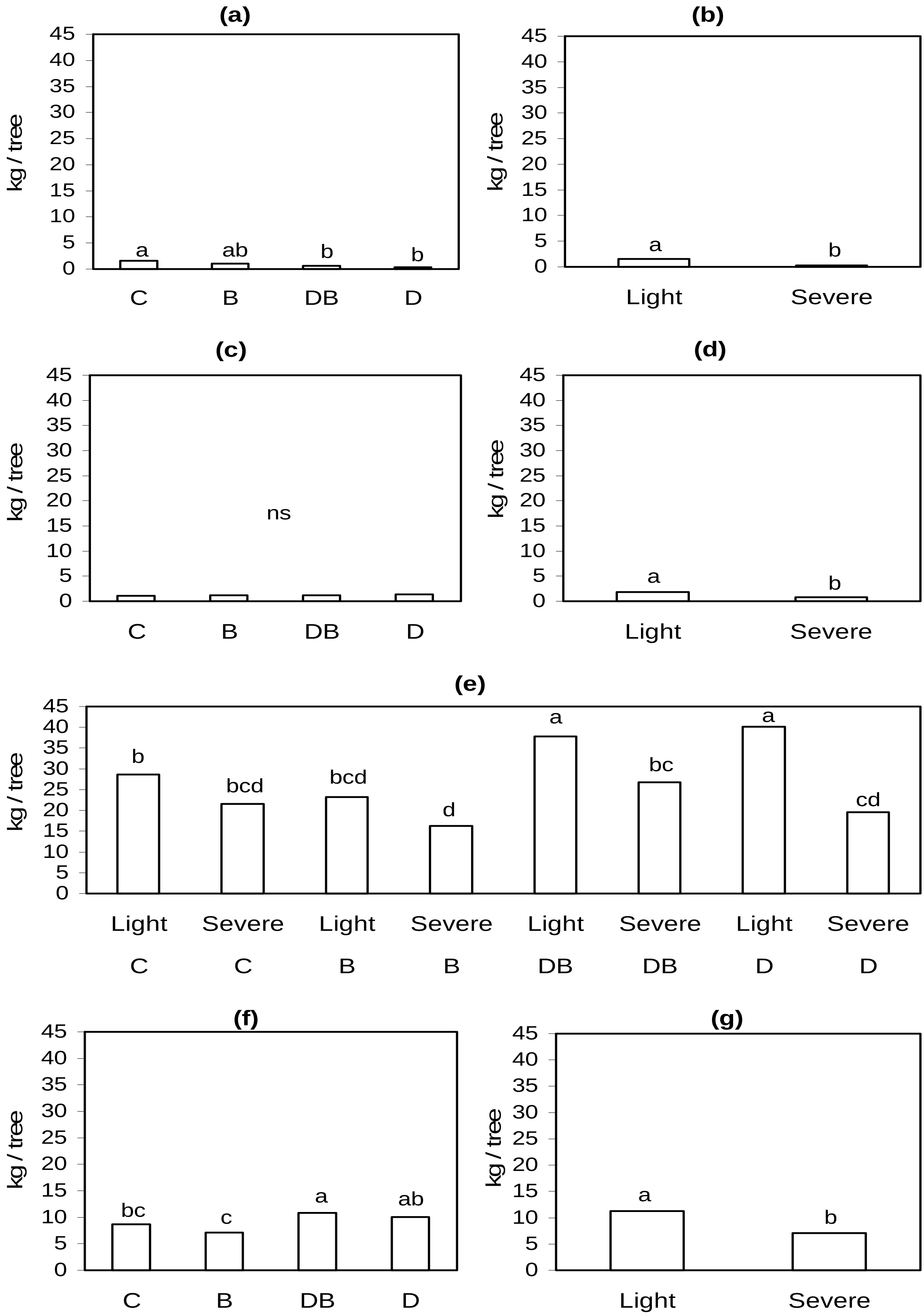

Fig 5: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning in 2004, 2005 and 2006 on fresh yield of 8th, 9th and 10th leaf 'Sirora' pistachio trees in Prieska, South Africa. (a) 2005 (8th leaf): Rest breaking $P<0.0266$; R*P $P<0.2474$ (b) 2005 (8th leaf): Pruning $P<0.0001$; R*P $P<0.2474$ (c) 2006 (9th leaf): Rest breaking $P<0.8295$; R*P $P<0.3116$ (d) 2006 (9th leaf): Pruning $P<0.0002$; R*P $P<0.3116$ (e) 2007 (10th leaf): Rest breaking $P<0.0001$; Pruning $P<0.0001$; R*P $P<0.0412$ (f) 2007 (Average): Rest breaking $P<0.0009$; R*P $P<0.0755$ (g) 2007 (Average): Pruning $P<0.0001$; R*P $P<0.0755$.

Table 1: Effect of rest breaking applications and pruning in winter 2002 on the formation of shoots (N+1) on one-year-old wood (N) of 6th leaf 'Sirora' pistachio trees in Prieska, South Africa.

Treatments	Total number of shoots per meter	Percentage shoot distribution according to length			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application:					
Control	30.4 ns	39.8 a[z]	25.2 b	9.3 b	25.7 b
4% Budbreak®	30.6	24.6 b	30.2 ab	20.4 a	24.9 b
0.5% Dormex® + 4% Budbreak®	30.6	17.2 c	36.9 a	18.7 a	27.1 b
4% Dormex®	28.8	10.3 d	29.3 b	22.3 a	38.1 a
Pruning:					
Light	30.8 a	25.9 a	34.8 a	19.5 ns	19.9 b
Severe	29.5 b	19.5 b	26.6 b	16.6	37.3 a
Pr > F					
Rest breaking application (R)	0.1683	0.0001	0.0117	0.0001	0.0004
Pruning (P)	0.0460	0.0042	0.0007	0.0627	0.0001
R * P	0.1579	0.6134	0.1404	0.1833	0.2128

[z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 2: Effect of rest breaking applications and pruning in 2003 on the formation of reproductive buds on N+1 units of 7th leaf 'Sirora' pistachio trees in Prieska, South Africa.

Treatments	Total number of reproductive buds per m	Percentage reproductive bud distribution according to length of one-year-old shoots			
		0 – 2 cm	2.1 – 10 cm	10.1 – 20 cm	> 20 cm
Rest breaking application					
Control	2.1 ns	-	6.7 ns	16.6 ns	30.0 ns
4% Budbreak®	1.8	-	12.1	12.8	17.2
0.5% Dormex® + 4% Budbreak®	1.2	-	12.0	10.0	19.2
4% Dormex®	0.7	-	7.6	10.3	15.4
Pruning					
Light	2.8 a[z]	-	19.4 a	25.6 a	24.7 ns
Severe	0.1 b	-	0.9 b	0.0 b	15.7
Pr > F					
Rest breaking application (R)	0.2091	-	0.7772	0.7620	0.5901
Pruning (P)	0.0001	-	0.0001	0.0001	0.2820
R * P	0.3046	-	0.6340	0.8876	0.2962

[z] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 3: Effect of rest breaking applications and pruning in 2005 on flower bud retention of 8th leaf 'Sirora' pistachio trees in Prieska, South Africa.

Treatments	Percentage flower bud retention: 30 / 11 / 05
Rest breaking application	
Control	53.6 ns[Z]
4% Budbreak®	54.1
0.5% Dormex® + 4% Budbreak®	56.6
4% Dormex®	52.4
Pruning	
Light	49.9 ns
Severe	58.7
Pr > F	
Rest breaking application (R)	0.9412
Pruning (P)	0.4398
R * P	0.2672

[Y] Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on percentage retention.

Table 4: Effect of rest breaking applications and pruning in 2004 and 2005 on tree dimensions of 8th and 9th leaf 'Sirora' pistachio trees in Prieska, South Africa.

Treatments	2005 (m)		2006 (m)			Percentage increase	
	Height	Depth	Height	Depth	Width	Height	Depth
Rest breaking application							
Control	3.3 ns	3.2 ns	3.6 ns	3.7 ns	3.8 ns	9.3 ns	16.0 ns
4% Budbreak®	3.3	3.1	3.6	3.6	3.7	8.7	13.0
0.5% Dormex® + 4% Budbreak®	3.3	3.2	3.6	3.6	3.9	9.9	15.3
4% Dormex®	3.2	3.2	3.6	3.7	3.6	12.5	14.4
Pruning							
Light	3.3 ns	3.3 a[Z]	3.6 ns	3.7 ns	3.9 a	8.2 ns	12.8 ns
Severe	3.2	3.1 b	3.6	3.6	3.6 b	11.9	16.3
Pr > F							
Rest breaking application (R)	0.4454	0.9429	0.8939	0.8311	0.3724	0.5741	0.7848
Pruning (P)	0.0541	0.0030	0.6943	0.1154	0.0216	0.0849	0.1216
R * P	0.4395	0.8299	0.4069	0.6467	0.7501	0.1394	0.8660

[Z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

PAPER 4: THE EFFECT OF EVAPORATIVE COOLING ON YIELD AND FLOWER BUD RETENTION DURING SPRING OF THREE PISTACHIO CULTIVARS *(PISTACIA VERA* L.*)* IN A CLIMATE WITH MODERATE WINTER CHILLING AND HIGH SPRING TEMPERATURES.

Abstract

Evaporative cooling of three pistachio (*Pistacia vera* L.) cultivars in Prieska (29° 40'S, 22° 45'E, 945 m.a.s.l), South Africa was used to counteract potential negative effects of high maximum day temperatures during autumn and spring on flower bud retention, fruit set and yield. Cooling during autumn (May + June, Southern hemisphere), spring (August + September, Southern hemisphere) and the combination of autumn + spring were investigated during two seasons. Flower bud retention during winter and early summer, flowering patterns, as well as yields were evaluated. Each cultivar's autumn cooling treatment flowered consistently first and spring cooling last. Cooling effects on flower bud retention were only found during and after anthesis for all three cultivars. Autumn + spring cooling resulted in commercial yields for 'Ariyeh' and 'Shufra'. The improved yields obtained with evaporative cooling indicates the important role climatic conditions play during both stages of entering and exiting dormancy of pistachio nut trees. Although some effects obtained are not easy to explain, the fact that evaporative cooling resulted in substantial yields in an area with sub-optimal pre-blossom temperatures and less than 40% of the required winter chill of pistachios, emphasised its potential in orchard management.

Introduction

The climate around Prieska differs from other pistachio growing regions in the world in that it receives fewer winter chilling units, has higher maximum temperatures during winter and spring and receives summer rainfall (Van den Bergh and Manley, 2002). This possibly results in the observed delayed foliation, flower bud and inflorescence abortion, low fruit set and yield and other flowering disorders e.g. the terminal bud developing into a florescence which Crane and Takeda (1979) described as a response to low winter chilling. No accurate chilling requirements are known for any pistachio cultivar, except that 1000-1500 hours below 7 ºC appear to be sufficient in California, USA (Crane and Takeda, 1979).

Preliminary evaporative cooling trials in Prieska resulted in increased yields and changes in flowering patterns, indicating possible direct responses to temperature change or changes in flowering time (Uzun and Caglar, 2001).

Sprinkler irrigation has long been used to modify the micro-environment of many crops. This was done by the latent heat of sprinkled water to opened flower buds to protect them from frost. However Alfaro et al. (1974) as quoted by Chesness et al. (1977) and Anderson et al. (1975) demonstrated a different approach by delaying bloom with evaporative cooling of the flower buds after completion of dormancy. Cooling occur when applied water evaporates, reducing both the surrounding atmospheric and plant tissue temperatures. Erez and Couvillon (1983) counteracted high maximum bud temperatures during the dormancy period of ‘Sunred’ nectarine trees with evaporative cooling, enhancing both floral and vegetative bud break.

Taking the aforementioned into account, we used evaporative cooling to counteract potential negative effects of high maximum day temperatures during autumn and spring on accumulation of chill units, flower bud retention, fruit set and yield. In this paper we report on the effect of evaporative cooling on pistachio flower bud retention during spring, flowering patterns and yield.

Materials and method

Plant material:

The trial was conducted at the farm Green Valley Nuts near Prieska, Northern Cape, South Africa (29° 40’S, 22° 45’E, 945 m.a.s.l) during the 2005/2006 and 2006/2007 seasons. Trees of the cultivars ‘Ariyeh’, ‘Shufra’ and ‘Sirora’ in their seventh, sixth and ninth leaf, respectively, were tagged during April 2005 in commercial orchards. The ‘Ariyeh’ and ‘Shufra’ trees on P. integgerima and *P. terebinthus* rootstocks respectively, were established at a spacing of 4 m x 5.78 m. The older ‘Sirora’ on *P. integgerima* rootstock were planted at 5.2 m x 5.78 m. Artificial pollination was used during bloom in both years using a dilution of 1% pollen in soft wheat flour which was daily blown onto the trees using a mechanical duster for 9-12 consecutive days (Cagler and Kaska, 1995). Standard commercial practices were used except that no rest breaking treatment was applied.

Treatments and experimental design: 2005

A randomised complete block design was used with four blocks. One block consisted of 108 trees and four randomly chosen, uniform trees per block were used. The 4 treatments were (1) control, (2) autumn cooling (7 May – 1 July), (3) spring cooling (25 July – 21 September) and (4) a combination of autumn and spring cooling. Water was applied using the existing micro-sprinkler irrigation system and extending each tree's sprinkler above canopy height fastened to a pole. Nozzles delivering 41 litres at 1 bar were used. Working pressure was 2.5 bar at ground level. Cooling cycles of 30 minutes on and 30 off, started at 10:00 and ended at 18:00.

Treatments and experimental design: 2006

The same as stated previously, except for the spring treatment periods and cycles. The end-date of the spring cooling period for each cultivar corresponded with 10% anthesis. The 4 treatments were (1) control, (2) autumn cooling (4 May – 2 July), (3) spring cooling (1 August –10% anthesis) and (4) a combination of autumn and spring cooling. Water was applied as in 2005, but cooling cycles had to change due to commercial system requirements to 15 minutes on and 15 off, starting at 10:00 and ending at 18:00.

Data recorded:

Flowering periods

Trees were monitored daily during the spring of 2005 and 2006 and the calendar dates for 10% and 90% bloom recorded.

Reproductive bud and inflorescence retention during winter and early summer: 2005

Five one-year old shoots (20 - 10 cm), with three or more reproductive buds, were randomly tagged during April 2005 on all trees and the number of reproductive buds per shoot recorded. The percentage reproductive buds and later inflorescence retention of these shoots were monitored during July (dormancy), August (bud-swell), October (after anthesis) and November (shell hardening).

Reproductive bud and inflorescence retention during winter and early summer: 2006

Five one-year old shoots (20 - 10 cm), with three or more reproductive buds, were randomly tagged during April 2006 on all trees and the number of reproductive buds per shoot recorded. The percentage reproductive buds and later inflorescence retention of these shoots were monitored during July (dormancy), August (bud-swell), September-October (50% bloom of each treatment) (total buds as well as opened buds were recorded), October (after anthesis) and November (shell hardening).

Yield

All nuts were harvested by hand during March 2006 and 2007 and total fresh weight recorded.

Data analysis:

Refer to Paper 1.

Results

Flowering periods: 2005

The three cultivars receiving the autumn treatment started (10%) blooming 8 - 12 days earlier than the control and completed flowering (90%) 9 - 12 days earlier as well. The autumn + spring treatment resulted in flowering 2 - 4 days (‘Ariyeh’ and ‘Sirora’) and ‘Shufra’ 10 days earlier than the control, but ended 1 - 4 days later (‘Ariyeh’ and ‘Sirora’) and in the case of ‘Shufra’, 4 days earlier. In the case of ‘Ariyeh’ the spring treatment was delayed by 10 days and ‘Shufra’ and ‘Sirora’ only 5 and 4 days, respectively. Ninety percent bloom was similarly delayed by 13, 8 and 7 days, respectively (Fig 1a, c, e).

The average length of the bloom period of ‘Ariyeh’, ‘Shufra’ and ‘Sirora’ were 7, 4 and 13 days, respectively (Fig 1 a, c, e). Autumn cooling shortened the flowering period of ‘Sirora’ by 4 days and extended that of ‘Ariyeh’ and ‘Shufra’ by 1 - 2 days. The autumn + spring treatment however extended the flowering period of ‘Ariyeh’, ‘Shufra’ and ‘Sirora’ by 3, 6, and 8 days, respectively, while the spring treatment extended the flowering period of all three cultivars by 3 days (Fig 1a, c, e).

Flowering periods: 2006

The autumn treatment advanced 10% flowering of ‘Ariyeh’ and ‘Sirora’ by 5 - 11 days respectively, and in the case of ‘Shufra’, by 18 days. This was also reflected in the 90% blooming dates. The ‘Sirora’ autumn + spring treatment began blooming on the same date as the control, 3 days later in the case of ‘Ariyeh’ and 13 days earlier for ‘Shufra’. However, ‘Sirora’ and ‘Ariyeh’ reached 90% bloom 3-4 days and ‘Shufra’ 11 days before their respective control treatments. The 10% bloom of the Ariyeh’ spring treatment was delayed by 13 days and ‘Shufra’ and ‘Sirora’ by only 7 - 8 days. Spring cooling further delayed 90% bloom in the case of ‘Ariyeh’ by 21 days and by 8 and 2 days respectively for ‘Shufra’ and ‘Sirora’ (Fig 1).

The average length of the flowering period of ‘Ariyeh’, ‘Shufra’ and ‘Sirora’ were 8, 9 and 15 days, respectively (Fig 1b, d, f). Autumn cooling shortened the flowering period of ‘Sirora’ by 2 days and extended that of ‘Ariyeh’ and ‘Shufra’ by 0 - 1 day. The autumn + spring treatment however extended bloom in ‘Ariyeh’ and ‘Shufra’ trees by 1 and 2 days, respectively, while shortening bloom in ‘Sirora’ trees by 3 days. The spring treatment extended bloom in ‘Shufra’ and ‘Ariyeh’ by 1 and 8 days, respectively, while shortening that of ‘Sirora’ by 6 days (Fig 1b, d, f).

Reproductive bud and inflorescence retention during winter and early summer: 2005

No effects of cooling were found on reproductive bud and inflorescence retention in ‘Ariyeh’ during winter until after anthesis (17 Oct. 2005), when the control trees had retained significantly fewer inflorescences compared to all other treatments. Progressively higher percentages were retained following evaporative cooling in autumn, spring and autumn + spring (Table 1). The same significant trend was still apparent after shell hardening (17 Nov. 2005). In the case of the inflorescence retention in ‘Shufra’ it was generally higher than in ‘Ariyeh’ (Table 2). Again no cooling effects were found during winter, but after anthesis, the autumn + spring cooling had higher inflorescence retention, with the other three treatments not differing from each other (Table 2). ‘Sirora’ showed no cooling effects on flower bud retention during winter. After anthesis however, all three evaporative cooling treatments had higher inflorescence retention than the control. The autumn + spring treatment resulted in the highest retention, although it did not differ significantly from spring, which in turn did not differ from autumn (Table 3). Retention in ‘Sirora’ was generally higher than that in ‘Shufra’.

Reproductive bud and inflorescence retention during winter and early summer: 2006

No cooling effects were found in ‘Ariyeh’ during winter until full-bloom, when the spring cooled trees had the lowest total (buds + inflorescences) flower bud retention with no differences between the other treatments. However, the control had the lowest percentage inflorescences, followed by spring and autumn and autumn + spring which did not differ from each other. This relationship between the treatments is still evident after anthesis (30 Oct. 2006) and at shell hardening (27 Nov. 2006) (Table 4).

No cooling effects were found in the case of the total flower bud retention in ‘Shufra’ until full-bloom of each treatment (Table 5). At full bloom, control trees had the lowest percentage retention, although it did not differ significantly from spring, which in turn did not differ from autumn + spring. No difference was found between the reproductive bud retention of autumn and autumn + spring treated trees. This same trend was seen in the percentage inflorescences at full-bloom. After anthesis and at shell hardening however, autumn had the lowest retention, with no difference between the other treatments (Table 5).

‘Sirora’ displayed no effect of evaporative cooling on flower bud retention during winter. At full-bloom however, the total reproductive bud retention of autumn treated trees was the highest and spring the lowest, with no difference between that of the other treatments. This trend was also seen in the percentage inflorescences, except that in the latter case, the autumn + spring treatment did not differ from the control or the autumn treatments. The same trend was seen after anthesis, but at shell hardening, autumn cooled trees again had the highest and spring the lowest percentage retention, with no difference between that of the other treatments (Table 6).

Yield: March 2006

In ‘Ariyeh’, the autumn + spring treatments resulted in the highest yield (14.6 kg/tree), while control trees had the lowest (0.9 kg/tree) (Table 7). The autumn cooling treatment did not differ from the control, while the spring treatment (7.0 kg/tree) improved fresh yield but not to the same extent that the combined treatment did. In ‘Sirora’, the autumn treatment resulted in the lowest nut yield (26.6 kg/tree) (Table 7). The autumn + spring cooled trees had the highest yield (38.2 kg/tree), but did not differ significantly from the spring or control treatments. No filled nuts were found in any treatment in the case of ‘Shufra’.

Yield: March 2007

The control ‘Ariyeh’ trees had the lowest fresh yield (20.8 kg/tree) and autumn the highest (31.8 kg/tree), while the autumn + spring and spring did not differ from each other, although spring did not differ from control and autumn + spring did not differ significantly from autumn treated trees (Table 7). The autumn + spring trees’ two-year average had the highest yields (21.8 kg/tree) and the control trees the lowest (10.9 kg/tree), with no difference between the other two treatments.

The autumn + spring cooled ‘Shufra’ trees had the highest yields (12.2 kg/tree), with no difference between the other three treatments (3-5 kg/tree) (Table 7). In ‘Sirora’ the spring treatment resulted in the lowest nut yield (21.0 kg/tree), followed by autumn + spring, then the control trees, with autumn having the highest yields (52.2 kg/tree). Autumn had the highest two-year average (39.4 kg/tree) and spring the lowest (28.3 kg/tree), although the control did not differ from the autumn or autumn + spring treatments (Table 7).

Discussion

Flowering periods:

Marked differences were observed in the flowering periods between cultivars, treatments, as well as seasons. The control trees of ‘Ariyeh’ and ‘Shufra’ started flowering 9 - 5 days earlier (10% bloom) in 2006 than in 2005, while ‘Sirora’ started one day later. The advancement in bloom in 2006 is best explained by the possible increase in chill units accumulated that year, probably satisfying the chill requirements of ‘Ariyeh’ and ‘Shufra’ but not of ‘Sirora’. Unfortunately the number of chill units could not be calculated for the different treatments. However, the above argument does not explain the shorter bloom periods (days) in 2005, though it may be attributed to a period of extremely high maximum temperatures (>30ºC), during mid-September 2005. These temperatures lasted for twelve consecutive days and probably hastened bud opening (Faust et al., 1997; Richardson et al., 1974).

The effect of the different evaporative cooling treatments on the sequence of the flowering period was reasonably consistent for the two seasons. Autumn and spring treatments, which involved the cooling of different phenological stages (entering and exiting dormancy, respectively), showed a consistent trend irrespective of cultivar, with autumn constantly flowering first and spring last. The advancement in flowering following autumn cooling could be related to an earlier entrance into dormancy resulting from lower temperatures (Cook and Jacobs, 2000; Faust et al., 1997; Gilreath and Buchanan, 1979).

The delay in bloom after spring cooling (4 - 13 days) was similar to that obtained by Uzun and Caglar (2001) on other pistachio cultivars. They found a 7 - 12 days delay following 600 RCU. This delay is best understood if the cooling is considered as partly isolating the wood/buds from growth by enhanced environmental conditions (high spring temperatures), thereby impeding the development of endodormant or ecodormant buds (Erez et al., 1979; Faust et al., 1997). The above is further explained by the fact that the spring delay was less pronounced in 2005 (4 - 10 days) in comparison to 2006 (7 - 13 days), although only 380 RCU were obtained in 2005 and 644 RCU in 2006 (Richardson et al., 1974). Therefore, if only the winter chill (or an earlier induced ecodormancy) were considered, one would rather anticipate a longer bloom delay after the less favourable 2005 winter. However, the period of extremely high maximum day temperatures (see previous paragraph) during spring 2005, probably negated the isolation or cooling effect by the water (Bauer et al., 1976) and hastened blooming.

The close resemblance in the flowering patterns of autumn + spring and control may be attributed to the simultaneous cooling of opposing phenological stages - the spring cooling directly impeding growth by preventing ecodormant buds from reaching growth enhancing temperatures for sufficient periods of time, thereby negating the advance in ecodormancy accomplished by autumn cooling. This corresponds with results found by Gilreath and Buchanan (1979).

Comparing the 10% or 90% bloom date differences between the control and autumn + spring treatments of the different cultivars over the two year period may indicate possible differences in chilling requirement. This could be explained by the fact that these two treatments resulted in maximum differences in accumulated winter chill and is reflected by the relative small differences (0 - 4 days) found in ‘Ariyeh’ and ‘Sirora’, while the control trees in ‘Shufra’ consistently flowering 10 and 13 days later than its autumn + spring treatment. The latter might indicate a higher chilling requirement. However, the flowering disorder where lateral or terminal buds on current season’s growth develop into inflorescences (and setting fruit), which Crane and Takeda (1979) described as a rare response to insufficient winter chilling, was observed in all four treatments during both seasons.

Flower bud retention during winter and early summer

Cooling effects on flower bud retention were only found during and after anthesis for all three cultivars. The cultivars differed in their ability to retain inflorescences under the experimental conditions in 2005, with ‘Ariyeh’ the least able, and ‘Shufra’ and ‘Sirora’ progressively better. Inflorescence retention was higher in all cultivars in 2006 (34 - 64%) in comparison to 2005 (3 - 38%).

The majority of abscised reproductive buds showed no external signs of growth, although some losses also occurred only after anthesis (Personal observation). According to Takeda et al. (1979), pistachio pistil and carpel development takes place during the last month before anthesis (pre-blossom period) in the case of ‘Kerman’. It is not known whether high spring temperatures during this stage are detrimental to the pistachio flower bud. Lomas (1988) found that high day temperatures (> 32ºC), especially when accompanied by low relative humidity, are detrimental for avocado flowering and fruit set, while Rodrigo and Herrero (2002) found that a 7 ºC increase in daily maximum temperatures during the pre-blossom period, was found to impede pistil development as well as fruit set in apricot.

Considering the aforementioned as well as the fact that the average maximum temperature for the pre-blossom period in Australia and California's pistachio production areas is only 20ºC (Van den Bergh and Manley, 2002), the period of twelve consecutive days with extremely high maximum temperatures (> 30ºC) and only 27% average relative humidity during middle September 2005, may have contributed to the marked increase in flower bud and florescence losses, relative to the cooler 2006 spring. However, the fact that autumn + spring had the highest flower bud retention for each cultivar during 2005, may indicate a possible synergistic role of cooling during the entering as well the exiting of dormancy. This may be explained by earlier evaporative cooling resulting in an earlier entrance into endodormancy and chill unit accumulation (Bauer et al., 1976) while during spring the cooling directly influences the micro-climate by lowering average bud and air temperatures (Erez and Couvillon, 1983). Cooling in spring also increases relative humidity, further protecting the developing florescence (Lomas, 1988). The increase in inflorescence retention in 2006 following autumn cooling of 'Ariyeh' and 'Sirora' compared with autumn + spring may be understood in the same way, with the same positive effect of autumn cooling on dormancy development (Bauer et al, 1976) while spring was more moderate and therefore spring cooling less critical. However, the low flower bud retention following the autumn treatment of 'Shufra' is not quite clear.

Yield

The three cultivars differed in yield response between treatments and season. The marked differences in yield observed between the three cultivars indicated genetic differences (in both chilling requirement and spring heat tolerance), as well as the important influence which different micro-climates during autumn and, or spring have on yield. This becomes obvious when one considers the two years' yield results as well as the major climatic differences between them. To summarize: Only 380 RCU (Richardson et al, 1974) were accumulated during the winter of 2005 in sharp contrast with 644 RCU during 2006, while a twelve day period of extremely high maximum temperatures were experienced during the pre-blossom period of 2005.

The pistil development in 'Ariyeh' may have been impeded (Takeda et al., 1979; Rodrigo and Herrero, 2002) by the high temperatures during the late spring of 2005, reflected by the marked increase in the 'Ariyeh' yield following spring cooling. The higher yields resulting from autumn cooling during 2006 are probably due to an earlier induced endodormancy (Bauer et al., 1976). However, the combination of autumn + spring cooling appears to have complimented each other under these circumstances by having the highest yield.

In contrast to ‘Ariyeh’, the yield of ‘Sirora’ control trees in 2006 did not differ from the autumn + spring or spring treated trees. This response could indicate the possibilities of a higher heat tolerance and/or that the high spring temperatures during late-endodormancy/ecodormancy acted in a supplementary role to the deficit winter chilling. However, the reasons for this response as well as that of ‘Shufra’ are not clear.

Considering the aforementioned, the higher ‘Ariyeh’ yields of autumn and autumn + spring during 2007 as well as the similarity between spring and control, may be explained by the absence of abnormal spring heat and therefore not necessitating additional thermo-protection although benefiting from the enhanced chilling conditions during autumn. The same argument, as well as the major increase in winter chilling without any cooling, probably explain the high yield of the autumn + spring treatment in ‘Shufra’.

In contrast with what one would have expected after a winter with the highest chill unit accumulation in nine years, the autumn treatment of ‘Sirora’ still resulted in the highest yields during 06/07, followed by control, then autumn + spring and spring having the lowest yield. The fact that the yield of ‘Sirora’ still increased due to autumn cooling may indicate its high chill requirement. The relative high yield of control trees, compared with the other treatments, can only be explained as previously mentioned. However the reason for the relative lower yields of spring and autumn + spring is not quite clear.

Taking the marked differences into account, it is important to note that the same climatic conditions (high temperatures and low relative humidity) which were counteracted by evaporative cooling probably enhanced its cooling effect (Erez and Couvillon, 1983).

Conclusion

The significant differences obtained in blooming, flower bud retention as well as yield indicate the important role climatic conditions play during both stages of entering and exiting dormancy of pistachio nut trees. Although all differences are not yet clearly understood, the fact that evaporative cooling resulted in commercial pistachio yields in an area with sub-optimal pre-blossom temperatures and less than 40% of pistachio’s required winter chill, emphasized its potential in horticultural management. Further research, investigating the application of evaporative cooling through out winter is recommended, in addition to a detailed comparison between different chill unit models based on the winter chill of Prieska and other pistachio producing areas.

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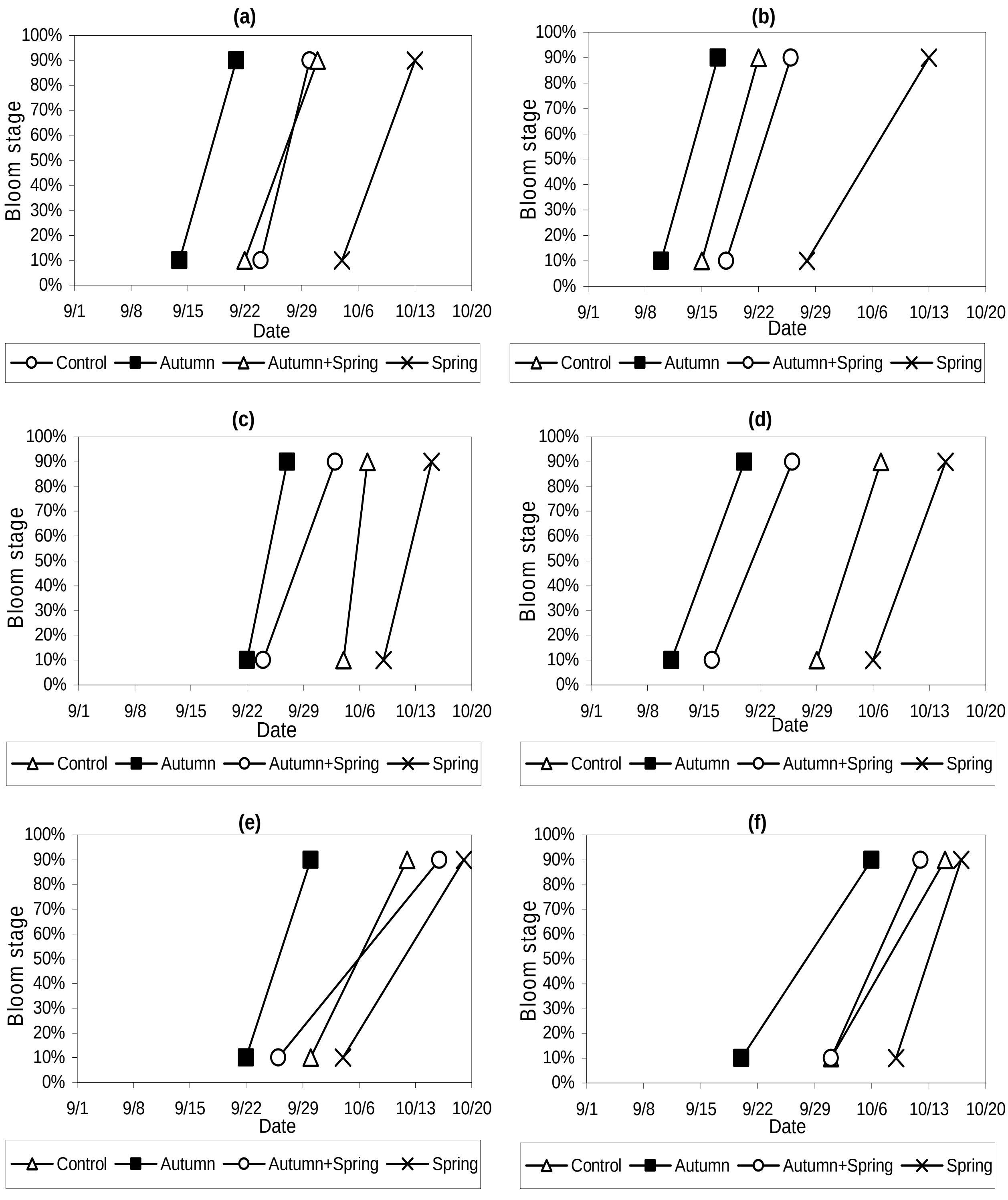

Fig. 1: Calendar dates of 10% and 90% bloom of three pistachio cultivars after four different evaporative cooling regimes: (a) 'Ariyeh': 2005, (b) 'Ariyeh' : 2006, (c) 'Shufra': 2005, (d) 'Shufra': 2006, (e) 'Sirora': 2005, (f) 'Sirora': 2006.

Table 1: Effect of evaporative cooling in 2005 on flower bud retention of 7th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

	Percentage flower bud retention:			
	8/7/05	30/9/05	17/10/05	17/11/05[Z]
Treatments	Dormant	Bud-swell	Post anthesis	Shell hardening
Evaporative cooling				
Control	92.6 ns	91.4 ns	3.0 d[Y]	2.0 d
Autumn	93.2	89.6	14.3 c	12.8 c
Spring	95.8	94.3	25.9 b	23.8 b
Autumn + Spring	94.3	93.5	38.5 a	36.8 a
Pr > F	0.5179	0.2069	0.0001	0.0001

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on final retention.

Table 2: Effect of evaporative cooling in 2005 on flower bud retention of 6th leaf 'Shufra' pistachio trees in Prieska, South Africa.

	Percentage flower bud retention:			
	7/7/05	31/8/05	19/10/05	22/11/05[Z]
Treatments	Dormant	Bud-swell	Post anthesis	Shell hardening
Evaporative cooling				
Control	81.5 ns	80.2 ns	34.8 b[Y]	32.1 b
Autumn	74.2	72.9	37.9 b	37.3 b
Spring	82.2	79.6	45.3 b	41.3 b
Autumn + Spring	88.3	86.8	64.8 a	63.2 a
Pr > F	0.2410	0.2404	0.0027	0.0015

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on final retention.

Table 3: Effect of evaporative cooling in 2005 on flower bud retention of 9th leaf 'Sirora' pistachio trees in Prieska, South Africa.

Treatments	Percentage flower bud retention: 15/7/05 Dormant	1/9/05 Bud-swell	19/10/05 Post anthesis	29/11/05[Z] Shell hardening
Evaporative cooling				
Control	98.2 ns	97.6 ns	62.8 c[Y]	53.1 c
Autumn	98.4	96.9	74.3 b	67.4 b
Spring	97.5	96.7	82.1 ab	77.9 a
Autumn + Spring	98.5	97.7	85.9 a	80.2 a
Pr > F	0.8517	0.8903	0.0001	0.0001

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on final retention.

Table 4: Effect of evaporative cooling in 2006 on flower bud retention of 8th leaf 'Ariyeh' pistachio trees in Prieska, South Africa.

Treatments	Percentage flower bud retention: 27/7/06 Dormant	25/8/06 Bud-swell	50%-bloom Total buds	50%-bloom Open buds	30/10/06 Post anthesis	27/11/06[Z] Shell hardening
Evaporative cooling						
Control	97.4 ns	95.7 ns	85.0 a[Y]	52.9 c	49.9 c	44.7 c
Autumn	98.8	97.1	89.6 a	85.5 a	79.3 a	76.5 a
Spring	95.9	92.2	67.6 b	67.6 b	59.3 b	56.2 b
Autumn + Spring	99.2	98.1	90.5 a	84.2 a	79.5 a	79.2 a
Pr > F	0.3773	0.0616	0.0001	0.0001	0.0001	0.0001

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on final retention.

Table 5: Effect of evaporative cooling in 2006 on flower bud retention of 7 th leaf 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	Percentage flower bud retention: 26/7/06 Dormant	31/8/06 Bud-swell	50%-bloom Total buds	50%-bloom Open buds	31/10/06 Post anthesis	28/11/06[Z] Shell hardening
Evaporative cooling						
Control	95.8 ns	88.1 ns	73.6 c[Y]	73.6 c	72.8 a	67.9 a
Autumn	96.8	91.4	85.9 a	84.9 a	35.5 b	32.2 b
Spring	95.0	85.1	76.2 bc	76.2 bc	75.5 a	71.7 a
Autumn + Spring	97.7	90.5	84.6 ab	84.1 ab	71.6 a	68.9 a
Pr > F	0.5893	0.2058	0.0101	0.0210	0.0001	0.0001

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on final retention.

Table 6: Effect of evaporative cooling in 2006 on flower bud retention of 7 th leaf 'Sirora' pistachio trees in Prieska, South Africa.

Treatments	Percentage flower bud retention:					
	25/7/06 Dormant	1/9/06 Bud-swell	50%-bloom Total buds	50%-bloom Open buds	1/11/06 Post anthesis	30/11/06[Z] Shell hardening
Evaporative cooling						
Control	98.8 ns	97.9 ns	79.7 b[Y]	72.4 b	71.7 b	70.7 b
Autumn	98.8	96.1	91.5 a	87.8 a	86.8 a	85.2 a
Spring	97.5	92.8	68.3 c	52.6 c	53.7 c	51.2 c
Autumn + Spring	96.6	92.1	78.5 b	75.7 ab	75.9 ab	74.5 b
Pr > F	0.3492	0.1494	0.0002	0.0001	0.0001	0.0001

[Y]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Z]Logit transformation done on final retention.

Table 7: Effect of evaporative cooling in 2005 and 2006 on total fresh yields of 8th and 9th leaf 'Ariyeh', 8th leaf 'Shufra' and 9th and 10th leaf 'Sirora' pistachio trees in Prieska, South Africa.

Treatments	Total fresh yield (kg / tree)						
	Ariyeh	Ariyeh	Ariyeh	Shufra[Y]	Sirora	Sirora	Sirora
	2006	2007	Average	2007	2006	2007	Average
Evaporative cooling							
Control	0.9 c[Z]	20.8 c	10.9 c	4.3 b	34.5 a	37.4 b	36.0 ab
Autumn	1.1 c	31.8 a	16.5 b	3.4 b	26.6 b	52.2 a	39.4 a
Spring	7.0 b	23.7 bc	15.4 b	5.0 b	35.5 a	21.0 d	28.3 c
Autumn + Spring	14.6 a	28.4 ab	21.5 a	12.2 a	38.2 a	29.7 c	34.0 b
Pr > F	0.0001	0.0004	0.0001	0.0001	0.0010	0.0001	0.0001

[Z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

[Y]No yields were obtained during 2006.

GENERAL CONCLUSION

The trends in our results emphasised the interaction of rest breaking and pruning effects with genetic chill requirements and environmental influences - specifically winter chill build-up. The bud break data suggests that the ability of some rest breaking chemicals to promote lateral development may be explained by their potential to impede the development of apical dominance, normally strengthened by insufficient winter chilling (Cook and Jacobs, 1999), rather than a direct effect on the lateral buds. The 'Ariyeh' results indicated the rest breaking capabilities of Dormex®, specifically regarding lateral development and growth as well as flower bud formation after less favourable winter chilling. The 'Shufra' and 'Sirora' results implicated the complementing of pruning and chemical rest breaking effects regarding certain parameters through interactions after less favourable winter chilling, whereas only single effects were observed to influence them after more optimal winter conditions. Shoot length distribution was markedly influenced by pruning, rest breaking or interactions between them. In general, in control trees more shorter shoots (0 - 2 cm) developed, while Dormex® and Dormex® + Budbreak® increased the 2.1 - 10 cm as well as 10.1 - 20 cm categories after more favourable chilling and in interaction with tip-pruning after less chilling. Dormex® as well as severe pruning promoted shoots to develop longer than 20 cm after more favourable chilling, while severe pruning in interaction with any chemical rest breaking treatment increased it after less chilling.

The beneficial effect of light vs severe pruning on flower bud formation in the Prieska climate is of major economic importance, considering that it is still reflected in the tenth-leaf yields, although pistachio pruning guidelines for the first 4-5 years are mainly aimed at structural preparation for mechanical harvesting. The distribution of flower buds on shoots was influenced by both rest breaking and pruning treatments over both years, but the effects were erratic and inconsistent, with almost no correlation between the flower bud localities favoured by a certain treatment and the shoot-length category that was increased by it. Flower bud retention was found to increase slightly after severe pruning, Budbreak® and Dormex®; however indications are that the reason for the high flower bud losses during spring might reside more in external factors like high maximum spring temperatures and low relative humidity. The Dormex® & Budbreak® treatment proved to present a high risk of phytotoxicity, especially in 'Shufra'. Lower concentrations of these products are therefore suggested for further research under similar climatic conditions.

Due to several possible causes, the yields of all three cultivars during the first two years were extremely low, with marked increases in 2007. The inability of the chemical rest breaking treatments to increase yield consistently, might indicate other factors involved or that the winter chill at Prieska is too marginal to acquire the minimum amount of chilling necessary for any positive chemical effects on yield (Erez, 1995).

Each cultivar's autumn cooling treatment flowered consistently first and spring cooling last. Cooling effects on flower bud retention were only found during and after anthesis for all three cultivars. According to Takeda et al. (1979), pistachio pistil and carpel development takes place during the last month before anthesis in the case of 'Kerman'. The cultivars differed in their ability to retain inflorescences under the experimental conditions in 2005, with 'Ariyeh' the least able, and 'Shufra' and 'Sirora' progressively better. The significant effects obtained with evaporative cooling - specifically autumn + spring cooling, indicated the important role climatic conditions during both stages of entering and exiting dormancy play in pistachio trees. Although all differences are not yet clearly understood, the fact that evaporative cooling resulted in commercial fresh pistachio yields in the case of 'Ariyeh' and 'Shufra' in an area with sub-optimal pre-blossom temperatures and less than 40% of the required winter chill of pistachios emphasised its potential as a horticultural management tool when properly applied.

Due to the erratic climatic changes between the winter and spring seasons in Prieska, as well as between seasons during this research project, more research is necessary to indicate long term trends, especially regarding yield. Further research, investigating the application of evaporative cooling through out winter is also recommended, in addition to a detailed comparison between different chill unit models based on the winter chill of Prieska and other pistachio producing areas. The combination of evaporative cooling and Dormex® treatments, especially on 'Ariyeh', should also be considered.

Literature cited

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Takeda, F., J.C. Crane and J. Lin, 1979. Pistillate flower bud development in pistachio. J. Amer. Soc. Hort. Sci. 104:229-232.

ADDENDUM A

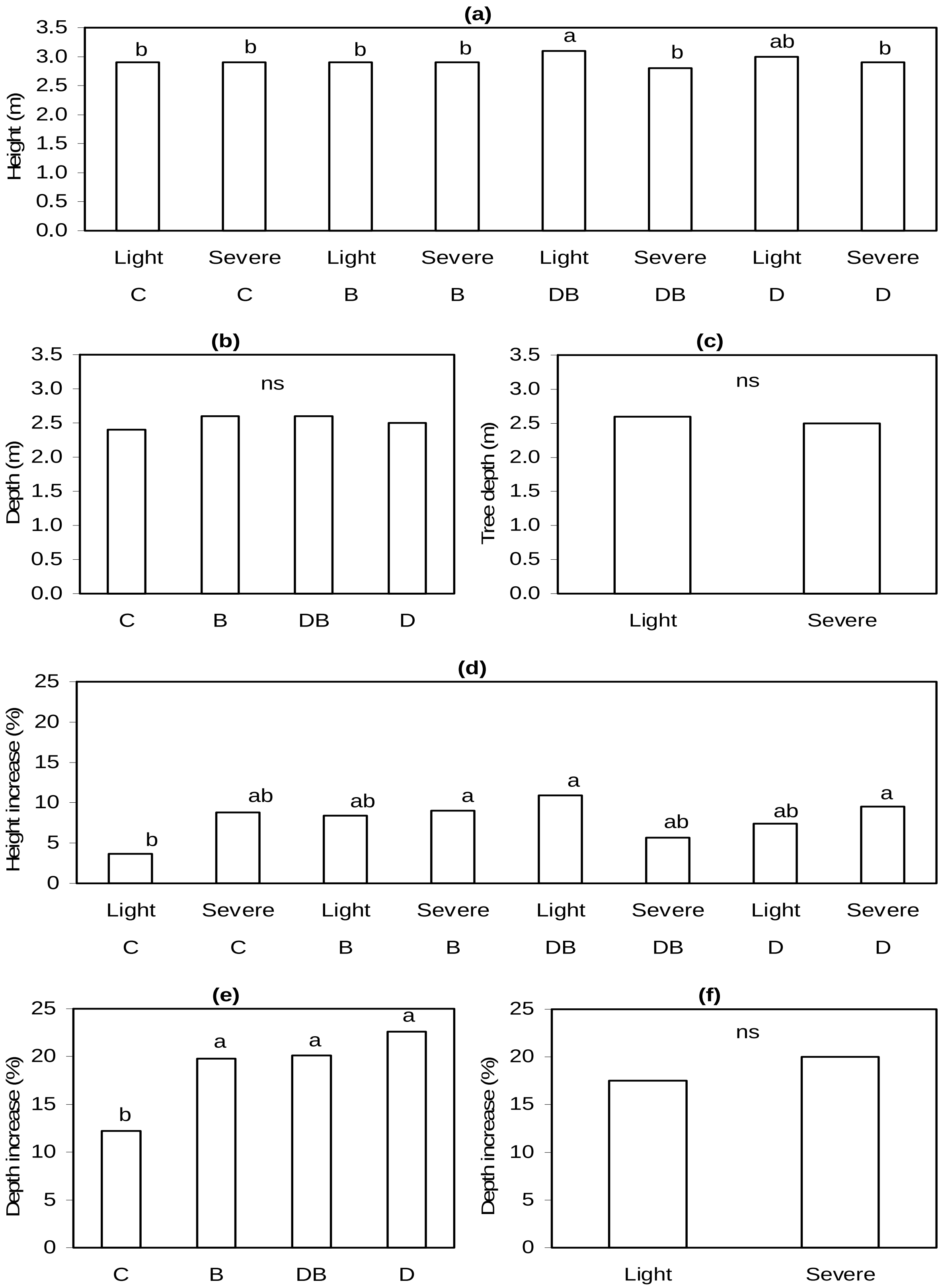

Fig 13: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning in 2005 on tree dimensions of 7th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.3453; Pruning P<0.0222; R*P P<0.0358 (b) Rest breaking P<0.6068; R*P P<0.1751 (c) Pruning P<0.0827; R*P P<0.1751 (d) Rest breaking P<0.4761; Pruning P<0.6543; R*P P<0.0522 (e) Rest breaking P<0.0458; R*P P<0.7552 (f) Pruning P<0.3991; R*P P<0.7552.

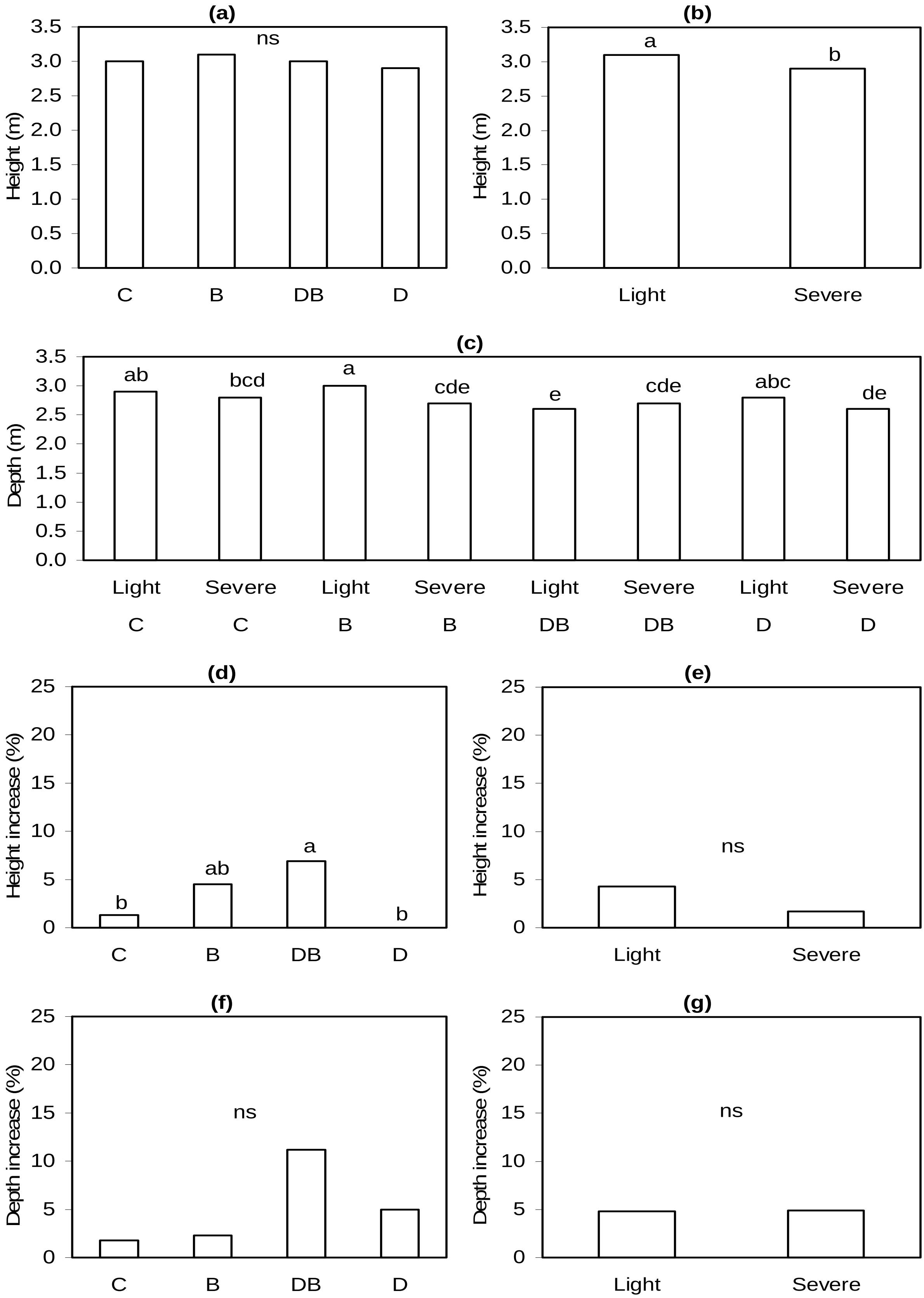

Fig 14: Effect of rest breaking applications (C= control, B= 4% Budbreak®, DB= 0.5% Dormex® + 4% Budbreak®, D= 4% Dormex®) and pruning in 2005 on tree dimensions of 9th leaf 'Shufra' pistachio trees in Prieska, South Africa. (a) Rest breaking P<0.3483; R*P P<0.5723 (b) Pruning P<0.0194; R*P P<0.5723 (c) Rest breaking P<0.0147; Pruning P<0.0015; R*P P<0.0163 (d) Rest breaking P<0.0324; R*P P<0.8571 (e) Pruning P<0.1434; R*P P<0.8571 (f) Rest breaking P<0.1703; R*P P<0.6755 (g) Pruning P<0.9731; R*P P<0.6755.

Table 6: Effect of rest breaking applications and pruning in 2004 on tree dimensions of 6th, 7th and 8th leaf 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	6th leaf trees (m)		7th leaf trees (m)		8th leaf trees (m)	
	Height	Depth	Height	Depth	Height	Depth
Rest breaking application						
Control	2.7 ns	2.2 ns	2.8 a	2.3 ns	3.0 ns	2.8 a
4% Budbreak®	2.7	2.2	2.8 a	2.4	2.9	2.8 a
0.5% Dormex® + 4% Budbreak®	2.8	2.1	2.6 b	2.3	2.9	2.5 b
4% Dormex®	2.7	2.1	2.8 a	2.3	2.9	2.6 ab
Pruning						
Light	2.8 a[Z]	2.2 a	2.7 ns	2.4 ns	3.0 ns	2.8 a
Severe	2.7 b	2.1 b	2.8	2.3	2.9	2.6 b
Pr > F						
Rest breaking application (R)	0.5390	0.6561	0.0391	0.8796	0.5879	0.0043
Pruning (P)	0.0141	0.0323	0.7920	0.2455	0.4191	0.0167
R * P	0.8970	0.3988	0.2695	0.1341	0.8947	0.4711

[Z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 7: Effect of rest breaking applications and pruning in 2005 on tree dimensions of 8th leaf 'Shufra' pistachio trees in Prieska, South Africa.

Treatments	2006 (m)		Percentage increase	
	Height	Depth	Height	Depth
Rest breaking application				
Control	3.0 ab[Z]	2.5 ns	5.4 ab	8.4 ns
4% Budbreak®	3.0 a	2.6	8.5 a	8.7
0.5% Dormex® + 4% Budbreak®	2.8 bc	2.6	9.0 a	12.6
4% Dormex®	2.8 c	2.4	1.2 b	5.1
Pruning				
Light	2.9 ns	2.5 ns	6.7 ns	8.3 ns
Severe	2.9	2.5	5.6	9.3
Pr > F				
Rest breaking application (R)	0.0067	0.1671	0.0110	0.1689
Pruning (P)	0.6865	0.3383	0.4660	0.7323
R * P	0.2535	0.4831	0.3396	0.1999

[Z]Means followed by the same letter within the same column do not differ significantly at P = 0.05.