Alternative pine hybrids and species to *Pinus patula* and *P. radiata* in South Africa and Swaziland

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Abstract

Through the collaborative efforts of companies affiliated with the International Program for Tree Improvement and Conservation (Camcore), a number of pine hybrids have been produced over the last decade. Many of these have been planted in trials across southern Africa that broadly represent winter and summer rainfall areas, with the latter ranging from warm to cold temperate sites. The five-year survival and growth of the hybrids and other pines in 12 of these trials were compared with Pinus radiata in the winter rainfall, and P. patula in the summer rainfall, regions where these species have been planted extensively. Except for the highest altitude site, where freezing conditions are common, the survival of most hybrids and tropical pines was better than P. patula or P. radiata. This was, in part, attributed to their improved tolerance to the pitch canker fungus, Fusarium circinatum, which was present in the nursery at the time of planting. In the winter rainfall area, the P. elliottii × P. caribaea hybrid, P. maximinoi and, surprisingly, the P. patula hybrids performed well. In the summer rainfall regions, hybrids with tropical parents such as P. caribaea, P. oocarpa and P. tecunumanii were more productive in the subtropical/warm temperate zone and, with increasing elevation, those hybrids crossed with P. patula performed relatively better. The P. patula × P. tecunumanii hybrid, particularly when crossed with low-elevation P. tecunumanii, performed exceptionally across most sites.

Keywords: Survival, tolerance, productivity

Introduction

Inter-specific hybrids offer the opportunity to combine traits from both parent species and this can contribute to improved growth, disease / pest tolerance and drought/cols resistance in specific environmental conditions. For this reason, and the desire for hybrid vigour, the development of pine hybrid programs is gaining impetus around the world. Assessing the performance of hybrids across diverse environmental conditions is an essential initial step towards determining where they will grow best.

Provenance trials introduced and established in the early 1970’s by the Oxford Forestry Institute, and later by the International Program for Tree Improvement and Conservation (Camcore) in the tropics and subtropics, have improved our knowledge on the growth and wood properties of species such as *P. oocarpa, P. caribaea, P. patula* and *P. tecunumanii* which are important in hybrid programmes in Southern Africa (Mitchell et al. 2012, Malan, 2015).The availability of these species presents an opportunity for them to be included in hybrid breeding programs for the purposes of improving growth and reducing the risks associated with climate change and pest and disease (Gapare and Musokonyi, 2002; du Toit and Norris, 2012; Malan, 2015).

In South Africa, the first crosses between *P. elliottii* and *P. caribaea var. hondurensis* were established in trials in the late 1960’s (Shelbourne, 1992; Malan, 2015). The primary objective was to combine the good growth characteristics of *P. caribaea* and the higher density of the *P. elliottii*. Exceptional performance was observed (van der Sijde and Roelofsen, 1986) and *P. elliottii x P. caribaea* became the first pine hybrid to achieve commercial status in South Africa. It was suited to sites with poor drainage and waterlogging. And had better wind firmness and good straightness in addition to its vigorous growth. The *P. elliottii x P. caribaea* hybrid had an advantage in adaptability over both parents.

As a result of this, and many other examples of successful hybrid combinations, companies affiliated with Camcore embarked on a program to produce a number of different hybrids for testing across South America and Africa (Camcore 2007). The objective of this paper is to compare the performance of a number of pine hybrids with current commercial species tested across 12 sites in southern Africa.

Materials and Methods

Study material

Many of the forestry companies, who are members of the Camcore research program produced a number of putative pine hybrid crosses between 2003 and 2007. All the putative hybrid crosses were made from first generation selections. These were verified by Camcore, North Carolina State University (USA) where molecular markers were used to discriminate between pure and hybrid species (Camcore, 2007). When the putative hybrids seeds were received from the members, some seeds were germinated. From the seedlings obtained, DNA was extracted and molecular markers (SNPs) were used for verification. Those seedlots where the molecular markers showed that more than 50% of the seedlings were true hybrids were distributed to regional coordinators (companies with well-established protocols for rooting cuttings). As the regional coordinator for South Africa, Komatiland Forests was responsible to propagate rooted cuttings from the hybrid seed and distribute these to other companies affiliated with Camcore in Southern Africa (Table 1). The trials were raised at Tweefontein nursery near Sabie until they were transported to the receiving company two to three months before planting.

Table 1: Site characteristics and location for the 12 hybrid trials established across southern Africa. Site numbers refer to the numbers in Figure 1). MAT = mean annual temperature, MAP = mean annual precipitation, MTO = Mountain to Ocean Forestry, KLF = Komatiland Forests

Site no.	1	2	5	4	10	11
Plant date	Oct 2008	Oct 2008	Apr 2008	Sep 2008	Oct 2009	Jan 2008
Location	Eastern Cape	Western Cape	Mpumalanga	KwaZulu-Natal	Mpumalanga	Mpumalanga
Plantation	Witelsbos	Kruisfontein	Wilgeboom	Woolstone (Mvoti)	Brooklands	Tweefontein
Latitude	34°01′01.2″ S	34°02′26.53″ S	24°57′04.07″ S	29°07′ S	25°18′18.751″ S	25°03′50.67″ S
Longitude	23°54′44.9″ E	23°10′29.11″ E	30°56′25.98″ E	30°31′ E	30°45′22.148″ E	30°48′51.25″ E
Altitude (m asl)	196	236	970	1 137	1 160	1 255
Replications	6	6	8	6	6	8
MAT (°C)	24	16	19	17	18	17
MAP (mm)	942	945	1 180	930	1 050	1 180
Climatic zone	Mediterranean	Mediterranean	Warm temperate-subtropical	Warm temperate	Warm temperate-subtropical	Warm temperate
Company	MTO	MTO	KLF	Mondi	KLF	KLF
Site no.	**3**	**7**	**12**	**6**	**9**	**8**
Plant date	Jan 2009	Nov 2008	Jan 2008	Oct 2008	Jan 2009	Dec 2008
Location	Hhohho	Mpumalanga	Mpumalanga	Mpumalanga	Mpumalanga	Mpumalanga
Plantation	Usutu	Spitkop	Spitskop	Spitskop	Jessievale	Belfast
Latitude	26.503° S	25°08′8.55″ S	25°09′42.1’ S	25°08′35.67″ S	26°13′3.317″ S	25°39′10.292″ S
Longitude	31.022° E	30°48′21.85″ E	30°50′21.8’E	30°52′14.96″ E	30°34′25.1″ E	30°01′15.148″ E
Altitude (m asl)	1 294	1 300	1 470	1 610	1 725	1 890
Replications	6	6	8	6	6	6
MAT (°C)	17	17	16	15	14	13
MAP (mm)	1 150	1 180	1 300	1 300	900	900
Climatic zone	Warm temperate	Warm temperate	Cool temperate	Cool temperate	Cold temperate	Cold temperate
Company	Sappi	KLF	KLF	KLF	KLF	KLF

Trials established by four of the large forestry organizations in South Africa, namely, Komatiland Forests (KLF), Mondi, Sappi and Mountain to Ocean Forestry (MTO), between April 2008 and October 2009 were spread across the Mpumalanga, KwaZulu Natal, Eastern and Western Cape provinces of South Africa. One trial was planted in Swaziland (a land-locked country within the summer rainfall region of South Africa) (Figure 1). The climatic zones, altitude, mean annual temperature (MAT), mean annual precipitation (MAP) and planting date are summarized in Table 1 and trial locations are indicated by numbers one to twelve on both Table 1 and Figure 1. The climatic zone classification in this report is according to the description by Louw and Smith (2012) for forest site classification.

Bulk seedlots representing first generation *P. patula, P. maximinoi, P. tecunumanii* LE and HE*, P. pseudostrobus, P. chiapensis, P. elliottii, P. taeda* and *P. radiata* (F_1 and F_2) were used as controls. *Pinus radiata* was excluded from the trials established in the summer rainfall region and *P. patula* was excluded in the trials established in the winter rainfall region (Western Cape). The *P. radiata* seedling control was raised by MTO as it currently dominant in the Cape. The full names for abbreviated taxa used in the text are shown in Table 2.

Experimental Design

Depending on the availability of plant material, treatments were planted as 5 x 5 or 6 x 6 tree plots within a randomised complete block design which was replicated six times, except for three trial replicated eight times. All trees were planted at a distance of 3 x 3 m apart and two border rows were planted around the outer edge of the of the trial.

Data collection and analysis

Data collection

The first survival assessment was carried out one month after planting and the dead plants replaced with cuttings/seedlings representing the same taxa. In the cases where there was an insufficient number of plants, *P. elliottii* or *P. taeda* seedlings were used as fillers and recorded as such. Growth assessments were carried out at age three and five years. In this paper we report on the survival (%), diameter at breast height (cm), height (m) and volume (m^3) of the treatments from the five-year assessment. Tree volume was estimated using the volume equation for juvenile trees (Ladrach and Mazuera 1978):

$$V = 0.00003 * H * DBH^2 \qquad (1)$$

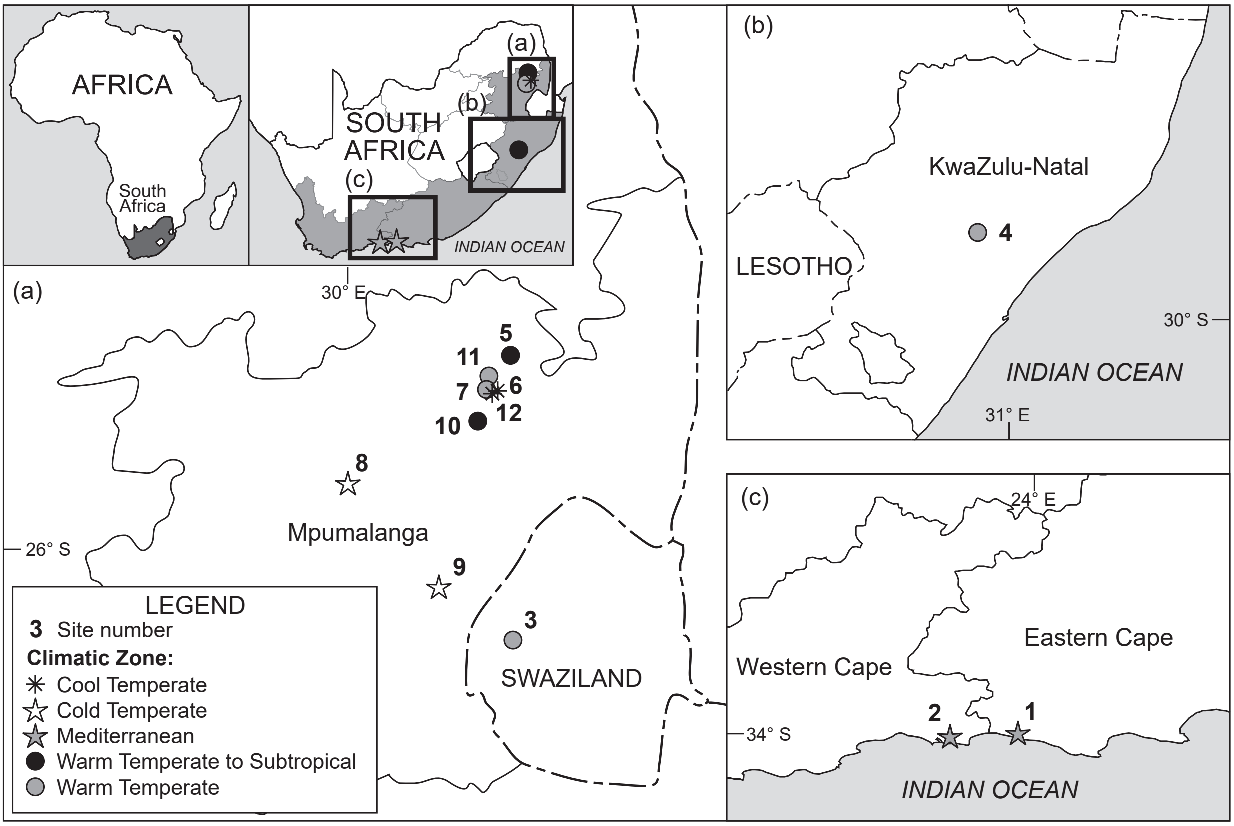

Figure 1: Location of the Camcore trials established in southern Africa between 2008 and 2009

Table 2: Taxa abbreviations used in text for all entries tested

Taxon abbreviation	Taxon full description
Pchiap	*Pinus chiapensis*
Ppat	*Pinus patula* var. *patula*
Pell	*Pinus elliottii*
Ppseu	*Pinus pseudostrobus*
Ptae	*Pinus taeda*
Prad	*Pinus radiata*
Pmax	*Pinus maximinoi*
Ptec LE	*Pinus tecunumanii* (low-elevation source; LE)
Ptec HE	*Pinus tecunumanii* (high-elevation source; HE)
TecH × Car	*P. tecunumanii* HE × *P. caribaea* var. *hondurensis*
Car × TecL	*P. caribaea* var. *hondurensis* × *P. tecunumanii* LE)
Ell × Tae	*P. elliottii* × *P. taeda*
Pat × TecL	*P. patula* × *P. tecunumanii* LE
TecL × Car	*P. tecunumanii* LE × *P. caribaea* var. *hondurensis*
Pat × Ooc	*P. patula* × *P. oocarpa*
Pat × Pring	*P. patula* × *P. pringlei*
Pat × TecH	*P. patula* × *P. tecunumanii* HE
Ell × Car	*P. elliottii* × *P. caribaea* var. *hondurensis*
Pat × GregS	*P. patula* × *P. greggii* var. *australis* (southern variety)
Pat × Ell	*P. patula* × *P. elliottii*
Car × Ooc	*P. caribaea* var. *hondurensis* × *P. oocarpa*
TecH × Ooc	*P. tecunumanii* HE × *P. oocarpa*
Tae × Car	*P. taeda* × *P. caribaea*
Ell × GregS	*P. elliottii* × *P. greggii* var. *australis* (southern variety)
Ell × TecH	*P. elliottii* × *P. tecunumanii* HE

Where V is the individual tree volume (m^3), DBH is the diameter at breast height at 1.3m and H is the tree height (m). Productivity was estimated using the individual tree volume of the surviving stems per plot across all replications per site.

Data Analysis

The survival data was not analysed using statistical procedures. Rather the survival results are presented as a ranking only. Growth data were analysed using SAS 9.3 (Enterprise guide 5.1, SAS Institute Inc., 2012). PROC GLM and the Student Newman-Keuls (SNK) test were used to distinguish treatment differences at the 5% significance level. PROC GLM for individual sites was carried out to determine if there were significant differences between taxa (species/hybrid) for volume. All ANOVA results presented are type III sum of squares.

Model 2 was used to determine taxa differences at a particular site. In order to determine if taxa by site (altitude) interaction exist, model 3 was used. In each case the SNK ranking and standard error were used to present the results. Site productivity was determined by summing the total area (m^2) of all the plots on which each treatment was planted on, and the total volume of all the surviving trees representing each treatment in these plots. The volume over the area of all plots was extrapolated to a volume per ha. All fillers used for blanking were excluded in the analysis.

$$\bar{y}_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \qquad (2)$$

Where $\bar{y}_{ij}$ is the j^{th} observed mean yield response of the i^{th} taxum.
μ is the overall mean yield of taxa at possible environment
α_i represent the fixed effect of the i^{th} rep.
β_j represent the random effect of j^{th} taxa
ε_{ij} is the random error term.

$$\bar{y}_{ij} = \mu + \alpha_{ik} + \beta_j + \gamma_k + (\beta\gamma)_{jk}\ \varepsilon_{ijk} \qquad (3)$$

Where $\bar{y}_{ij}$ is the j^{th} observed mean yield response of the i^{th} taxum.
μ is the overall mean yield of taxa at possible environment
α_{ik} represent the fixed effect of the i^{th} rep in the k^{th} site
β_j represent the random effect of j^{th} taxum,
γ_k represent the fixed altitude effect of the k^{th} site
$(\beta\gamma)_{jk}$ is the interaction random effect of the j^{th} taxa in the k^{th} site.
ε_{ijk} is the random error term.

Results

Survival

The survival of *P. patula* in the summer rainfall region was in most instances poor. This was particularly true at the Tweefontein A84 (34%) and Spitskop B31b (36%) sites (Figure 2). In several cases, the dead and dying *P. patula* seedlings displayed symptoms that were typical of those associated with the pitch canker fungus, *F. circinatum* (Mitchell et al. 2011). Samples were submitted to the Forests and Agricultural Biotechnology Institute (FABI) at the University of Pretoria, where the fungus was positively identified. Mean site survival at Belfast, where night-time freezing temperatures are common during winter, was poor at 14.6% (Figure 2). It can be speculated that the poor survival of *P. patula* at Belfast and Jessievale was due to the presence of *F. circinatum* as seen in the other trials as it was planted with seedlings that originated from the same nursery.

Generally, the *P. patula* hybrids, and those with *P. caribaea* as a parent, survived well on the warmer sites not associated with frosts (Figure 2). With increasing elevation, the relative survival of these hybrids decreased with very poor survival in the cold temperate sites. The survival for *P. elliottii x P. caribaea* and *P. tecunumanii LE x P. caribaea* was 15% and 1% at Belfast which is the coldest and highest altitude site (Figure 2).

P. elliottii and *P. taeda* survived 20 - 40% better than *P. patula* and *P. radiata* across all sites (Figure 2). It also survived better than most of the hybrids, with the exception of *P. elliottii x P. caribaea*. *P. elliottii* and *P. taeda* were the best surviving entries both at Belfast and Jessievale where frost was common. At lower altitudes and frost free areas, *P. maximinoi and P. tecunumanii* LE and HE (henceforth referred as *P. patula x P. tecunumanii hybrids*) survival was generally above 70%. The survival of *P. pseudostrobus* was generally moderate on most sites ranging between 60 and 70%. It survived best at Jessievale (90%) and worst at Belfast (27%).

Similar to *P. patula* in the summer rainfall regions, the survival of *P. radiata* in the winter rainfall regions was very poor (below 30% at Kruisfontein and slightly over 50% at Witelsbos) (Figure 2). Although dying *P. radiata* seedlings were not assessed for the presence of *F. circinatum*, the high incidence of this pathogen in the area and susceptibility of *P. radiata* to *F. circinatum*, leads us to speculate that this pathogen was responsible for the high mortality. *Pinus patula x P. tecunumanii* hybrids, *P. patula x P. oocarpa* and *P. patula x P. greggii S* survived significantly better (66% - 90%) and were comparable to *P. maximinoi* (77 %) on both sites and *P. tecunumanii* LE (80%) and *P. tecunumanii* HE (85%) at Witelsbos.

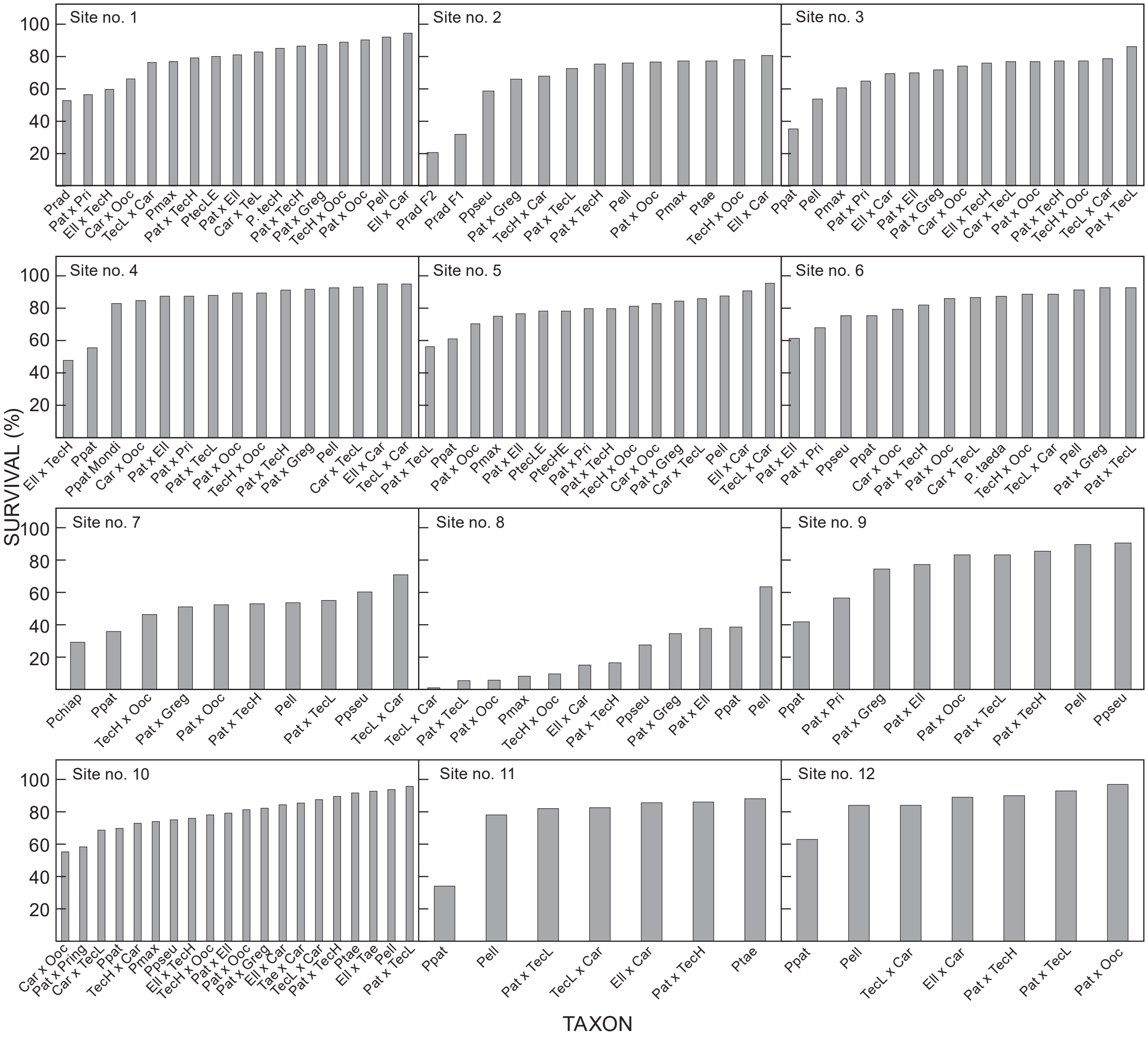

Figure 2: Survival at five years for all treatments at each of the 12 sites

Growth

Mean tree growth between the 12 sites, between taxa across sites, and the interaction between the two effects, differed significantly ($p < 0.0001$). Similarly, the mean growth performance of the trees representing each climatic zone viz. cold temperate, warm temperate, warm temperate to subtropical, and Mediterranean (Table 1) differed significantly and there was a significant change in the performance of the various taxa tested in each of the climatic zones ($p < 0.0001$).

On yield per hectare basis, *P. patula* hybrids were generally significantly better than *P. patula, P. elliottii* and *P. taeda* across most sites taking into account the survival. *P. patula x P. tecunumanii* hybrids and *P. patula x P. oocarpa* had better volume production (Figure 3), over 40 m^3/ha on warmer sites and below 15 m^3/ha on colder sites such as Jessievale and Belfast.

The growth of *P. elliottii* × *P. caribaea* and *P. caribaea* × *P. tecunumanii* LE outperformed *P. elliottii* and *P. tecunumanii* LE (Figure 4) on the lower elevation sites. The productivity of these hybrids was generally better than *P. patula* hybrids on the lower sites. The productivity of *P. elliottii* × *P. caribaea* was better at Wilgeboom than at Brooklands and Witelsbos (Figure 3). However, on the warm to cold temperate zones the *P. patula* hybrids were generally better than hybrids such as *P. tecunumanii LE* × *P. caribaea* and *P. elliottii* × *P. caribaea* .

Pinus radiate had better growth than most entries at Witelsbos. On this site, it was not significantly different from *P. elliottii x P. caribaea* and *P. elliottii*. However, at Kruisfontein *P. radiata* performed poorer than *P. elliottii x P. caribaea* for both generations (Figure 4). The individual tree volume for *P. radiata* (F_1) was higher at Kruisfontein, 0.03 m^3 and 0.02 m^3 at Wiltelsbos and a similar observation was made for volume per hectare; it was higher at Kruisfontein than at Witelsbos (Figure 3).The growth performance of *P. maximinoi and P. tecunumanii* LE was generally as good as or better than the commercial species *viz*., *P. radiata, P. patula* and *P. elliottii* on the sites that did not experience frost., with the exception of the lowest elevation Mediterranean site at Witelsbos.

Pinus patula x P. tecunumanii hybrids and *P. patula x P. oocarpa* showed significant potential on the warm to cool temperate regions (Figure 3). No differences in volume were found between *P. patula* and *P. patula x P. tecunumanii* LE at the cold temperate site of Belfast. However survival of *P. patula* was 38% and only 5 % for the hybrid.

Generally, *P. elliottii x P. caribaea* performed better in most sites across the climatic zones than *P. elliottii* and *P. patula*. In the Mediterranean zone which is located in the Cape, *P. elliottii x P. caribaea* had a mean volume of 0.0318 m^3 which was better than *P. radiata* and *P. elliottii* in the same region.

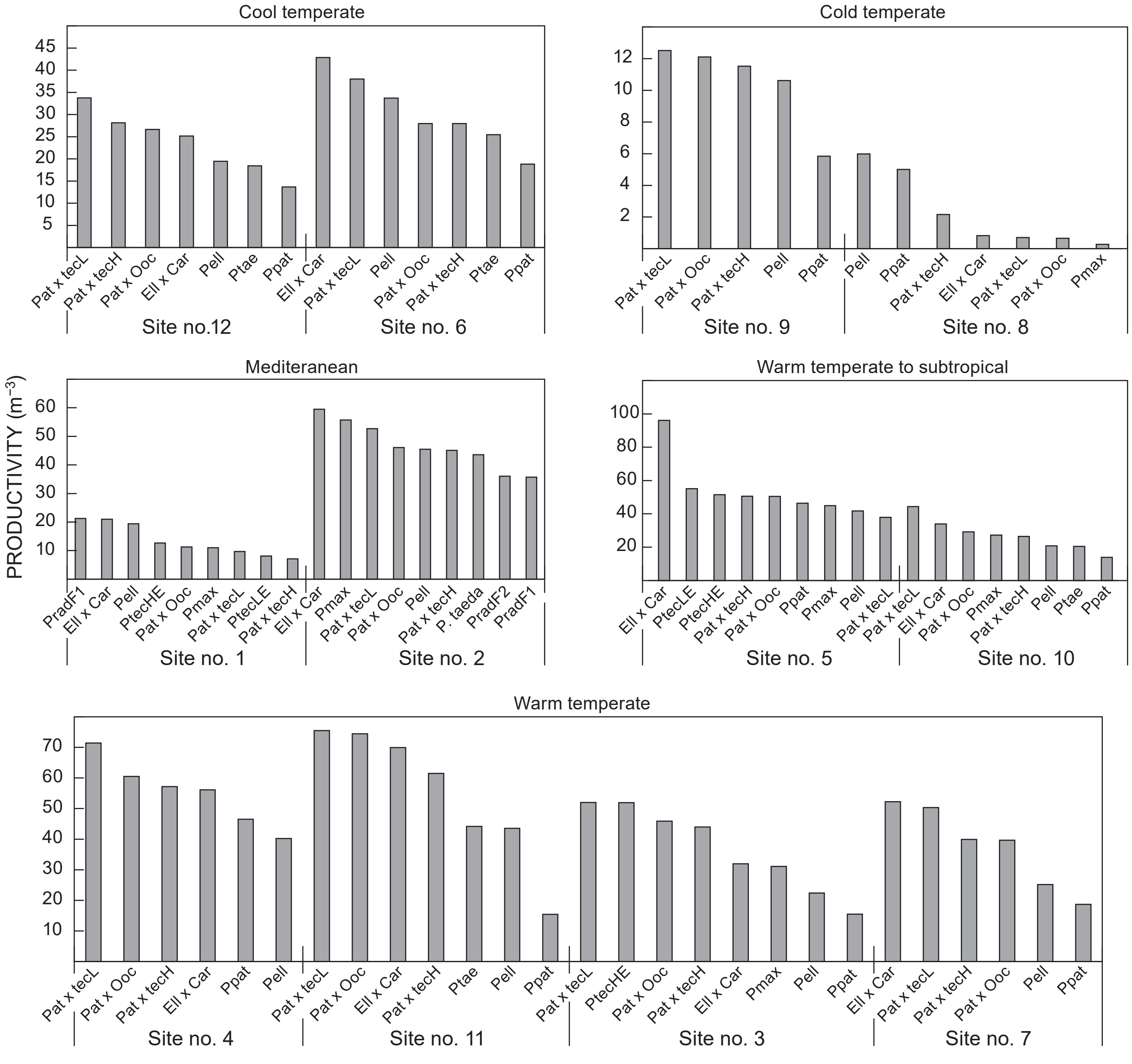

Figure 3: Volume production per hectare at 5 years for selected treatments (commercial species and key potential hybrids) at each site

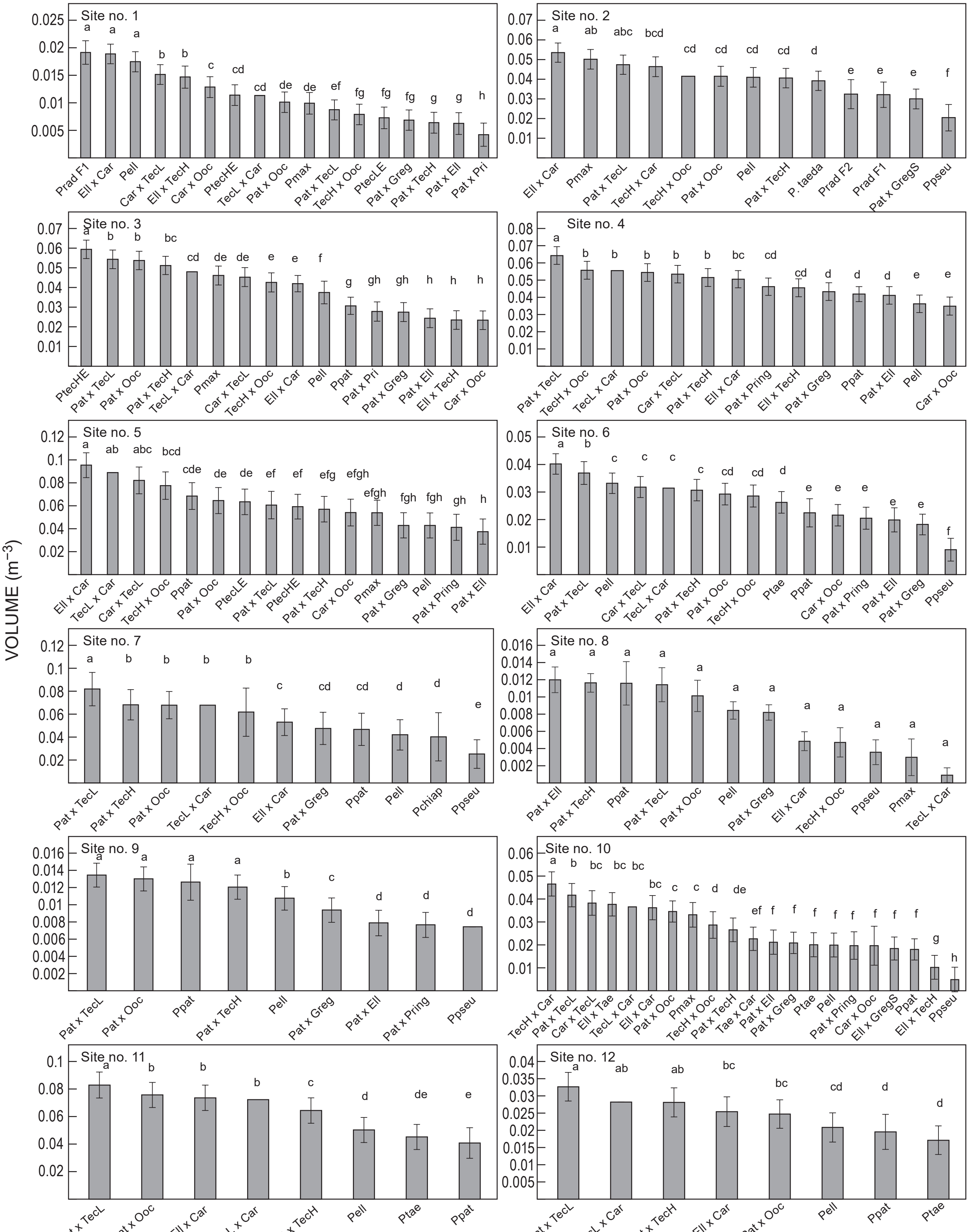

Figure 4: Individual tree volume at 5 years for all entries at each site. Error bars represent the SE. Different letters above bars indicate a significant difference at the 5% significance level

Discussion

Mediterranean region

The average survival was higher at Witelsbos than Kruisfontein, and *P. radiata* had the poorest survival on both sites. The average survival for *P. radiata* (F1 and F2) was lower at Kruisfontein than at Witelsbos (Figure 2). The poor survival is likely to be associated with *F. circinatum* as it was an established pathogen in the nursery at the time. An outbreak of *F. circinatum* on young *P. radiata* between 5 and 9 years was reported in the Western Cape in 2005 (Coutinho et al. 2007). The trials reported on in this study were planted between 2008 and 2009; the *P. radiata* seedlings were supplied by the nursery in the same area where the outbreak was first reported.

Pinus elliottii × *P. caribaea* was the best surviving entry at both sites (94% and 81% at Witelsbos and Kruisfontein, respectively). Other combinations such as *P. elliottii, P. tecunumanii* (HE) × *P. oocarpa* and *P. patula* × *P. oocarpa* could be alternatives to improve survival as they performed better than *P. radiata* on both sites. This is likely due to their higher levels of tolerance to *F. circinatum* (Hodge and Dvorak 2000).

On volume productivity, *P. elliottii* × *P. caribaea* ranked better than most of the entries; at Witelsbos there was no observed differences between *P. elliottii* × *P. caribaea* and *P. radiata*, whereas at Kruisfontein P*. elliottii* × *P. caribaea* was highly significantly better than *P. radiata* (Figure 4). Generally, in the Mediterranean zone, *P. elliottii* × *P. caribaea* showed the best performance in terms of mean volume (Figure 3).

Alternatively, *P. tecunumanii* (LE and HE*), P. patula* × *P. tecunumanii* HE and *P. patula* × *P. oocarpa* showed promising results in terms of survival and mean volume at Kruisfontein. These species could be alternatively used in place of *P. radiata* to improve both survival and volume productivity. There were huge differences in volume productivity at the sites Kruisfontein and Witelsbos (Figure 3). This could reflect a direct impact of site index and differences in soil properties between the two sites.

Warm temperature regions

The warm temperate regions are located on the escarpment of Mpumalanga province. This area is mostly covered by fog and misty weather at most times. In this area the survival of most hybrids was better than *P. patula* at most sites. The poor survival of *P. patula* was confirmed to be due to the pitch canker fungus*, F. circinatum* (Hongwane et al. 2017).

In the warmer temperate region, the survival of the *P. patula* × *P. tecunumanii* hybrid was improved because of the *F. circinatum* tolerance of the *P. tecunumanii* parent

(Mitchell et al. 2011). *Pinus tecunumanii* LE is reported to be more tolerant to *F. circinatum* than *P. tecunumanii* HE (Mitchell et al. 2011). Although the *P. patula* × *P. tecunumanii* HE hybrid may be able to tolerate mild frost, it will not survive as well as *P. patula* under heavy frost conditions (du Toit 2012). *Pinus patula* × *P. oocarpa* is also expected to show good survival due to its resistance to *F. circinatum* and drought (Dvorak et al. 2009) on sites that are free of frost. It may not be expected to survive better in harsher environments at higher altitudes as it is not frost tolerant.

In the absence of freezing temperatures, pine hybrids such as *P. elliottii* × *P. caribaea, P. patula* × *P. tecunumanii* hybrids and *P. patula* × *P. oocarpa* will survive significantly better than *P. patula* due to their increased levels of tolerance to the pitch canker pathogen, *F. circinatum*, and they are also better adapted to the environmental conditions where they were planted. Partly due to this reason they are becoming the preferred choice on warmer sites in the summer rainfall region.

In the warm temperate regions, care must be taken not to deploy hybrids in areas that experience localised frost. In addition, deploying them in areas prone to strong winds or hail should be avoided (Dvorak et al. 2000). Generally, under favourable conditions, hybrids such as *P. patula* × *P. tecunumanii* LE and *P. elliottii* × *P. caribaea* can perform better than *P. patula, P. elliottii, P. taeda* and *P. radiata.*

Hybrids such as *P. elliottii* × *P. caribaea* have the potential on the lower elevation sites to replace *P. radiata and P. patula* because of growth advantage (du Toit 2012; Malan 2015). *Pinus patula* × *P. tecunumanii* hybrids are potentially preferred to replace *P. patula* over a wide range of sites (Kanzler et al. 2014). Both of these hybrids have maintained a good stocking over *P. radiata* (in the Mediterranean region) and *P. patula* (in summer rainfall areas).

Cool to cold temperate regions

In the cold temperate regions, i.e. above 1 400 m above sea level (asl) in the Jessievale and Belfast areas, the survival of *P. patula* was less than 40%, which was similar to that at Tweefontein, Usuthu and Spitskop. *Pinus pseudo-strobus, P. elliottii* and *P. patula* × *P. tecunumanii* (LE and HE) had the highest survival rates at Jessievale (above 80%) and at Belfast *P. elliottii* showed 63% survival. Belfast is a very harsh site, with night temperature falling below zero degrees Celsius for consecutive days. Figure 5 depicts the actual winter minimum temperatures for the first four years (2009 to 2012) for Belfast, Mpumalanga province where the trial was planted (data provided by the South African Weather Service 2017). Freezing temperatures for consecutive days (Figure 5) could have a significant impact on the survival of less than six-month-old seedlings and cuttings, as temperatures started to drop below 5 °C in May 2009 and more than three days of freezing nights in its first winter.

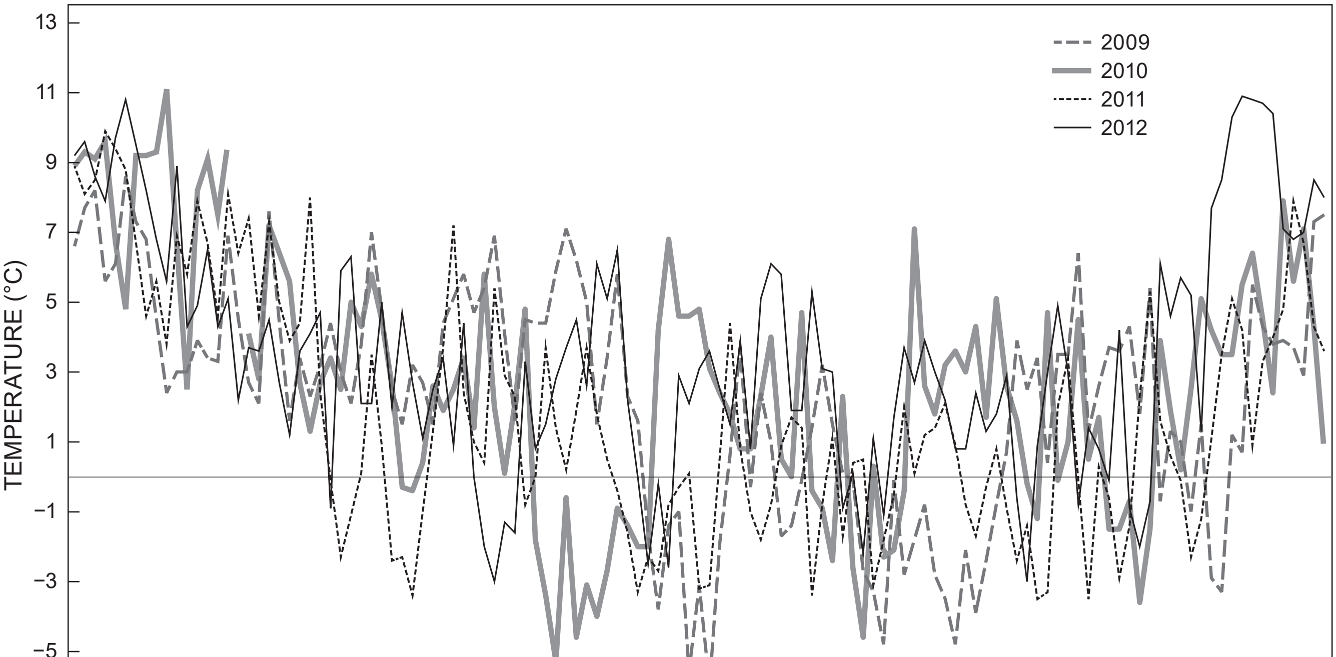

Figure 5: Minimum temperatures for Belfast between May and August in 2009 to 2012 (data provided by South African Weather Service 2017)

On individual tree volume, there was no significant difference between *P. patula* × *P. tecunumanii* (LE and HE), *P. patula* × *P. oocarpa* and *P. patula* at Jessievale (Figures 2 and 4). At Belfast no significant differences were observed in tree volume, which was caused by the extremely poor survival and small sample size. There is an opportunity for *P. patula* × *P. tecunumanii* HE to replace *P. patula* in frost-free areas in the Highveld. However, *P. patula* remains the preferred species of choice in colder and harsher sites such as Belfast.

The *P. patula* × *P. tecunumanii* HE hybrid may show some tolerance to mild frost and may be expected to survive. However, *P. patula* would still survive better (du Toit 2012). *Pinus patula* × *P. oocarpa* is also expected to show good survival due to its resistance to *F. circinatum* and some drought tolerance (Dvorak et al. 2009). It may not be expected to survive better in harsher environments at higher altitudes as it is not frost tolerant, but it is drought tolerant (Kanzler et al. 2014). From 1 000 m asl and above, *P. patula* × *P. tecunumanii* hybrids are preferred for deployment to improve survival. However, as the conditions become too harsh, cold and dry, *P. patula* is the preferred specie. *Pinus patula* shows some tolerance to drought after it is well established in the field (Dvorak et al. 2000).

No conclusive observation was made on survival of *P. pseudostrobus* on the higher elevation sites and *P. patula* × *P. greggii* South also survived poorly on the same sites. Poynton (1979) reported similar results for *P. pseudostrobus* in these same areas. *Pinus pseudostrobus* was reported to perform better in the warmer temperate zone in the mist belt areas. However, it did not perform well for survival, growth and volume yield across all climatic zones in these series of trials. As a species, *P. greggii* has greater tolerance to drought and is better suited to harsher sites than *P. patula*. The northern population of *P. greggii* is, however, more cold and drought tolerant than the southern population and *P. patula* (Kanzler et al. 2014). In South Africa, heavy snow had little impact on both populations of *P. greggii* (Dvorak et al. 1996). The *P. patula* × *P. greggii* South hybrid may be expected to survive better than *P. patula* with respect to cold tolerance (Kanzler et al. 2014).

Conclusion

The survival of most hybrids and tropical pines was better than *P. patula or P. radiata* except at the highest altitude sites. Tolerance to the pitch canker fungus, *Fusarium circinatum*, contributed to the survival of certain hybrids over *P. patula* and *P. radiata*. In the winter rainfall area, the *P. eliiottii* × *P. caribaea hybrid, P. maximinoi* and the *P. patula* hybrids performed well. In the summer rainfall regions, hybrids with tropical parents such as *P. caribaea*, *P. oocarpa* and *P. tecunumanii* were more productive in the subtropical/warm temperate zone, and with increasing elevation those hybrids derived from crosses with *P. patula* performed relatively better.

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