https://doi.org/10.17221/166/2024-HORTSCI

A comparison of seven macadamia cultivars for suitability to the high altitude and high latitude climate of southern Tibet in China

Jifeng Wan[1,2], Minghong Zou[2], Ximei Song[2], Qian Yang[2], Hui Zeng[2], Yang Zhao[1]**

[1]*College of Forestry, Guizhou University, Guiyang, P.R. China*
[2]*South Subtropical Crops Research Institute, Chinese Academy of Tropical Agricultural Sciences/ Key Laboratory of Tropical Fruit Biology, Ministry of Agriculture and Rural Affairs/Key Laboratory of Hainan Province for Postharvest Physiology and Technology of Tropical Horticultural Products, Zhanjiang, P.R. China*

**Corresponding authors: zenghui@catas.cn; zhy737@126.com*

Citation: Wan J.F., Zou M.H., Song X.M., Yang Q., Zeng H., Zhao Y. (2026): A comparison of seven macadamia cultivars for suitability to the high altitude and high latitude climate of southern Tibet in China. Hort. Sci. (Prague), 53: 93–99.

Abstract: The suitability of macadamia trees for different climates has been shown to affect tree growth and fruit quality. In this study, the differences in tree survival rate after frost injury, tree growth, nut mass, kernel quality and yield of seven macadamia cultivars were evaluated for field production in the high altitude and high latitude climate of southern Tibet, and the suitability of macadamia cultivars was determined. The cultivars evaluated were 'Beaumont' ('HAES695'), 'HVA16' ('A16'), 'Hinde' ('H2'), 'Own Choice' ('O.C.'), 'SSCRI-1', 'SSCRI-2' and 'SSCRI-3'. Of these, 'Beaumont', 'A16', 'H2' and 'O.C.' were Australian cultivars and 'SSCRI-1', 'SSCRI-2' and 'SSCRI-3' were Chinese cultivars. The results showed that all seven cultivars grew well under the high altitude and high latitude climate conditions of southern Tibet without continuous frost. 'A16' and 'Beaumont' in addition to their reasonable yield, nut mass and kernel quality, had the higher tree survival rate after frost injury. 'A16' and 'Beaumont' were well adapted to the high altitude and high latitude climate of southern Tibet, followed by 'O.C.', 'SSCRI-1' and 'SSCRI-2', but 'SSCRI-3' and 'H2' were unsuitable. These results indicated that it is possible to produce macadamia in the high altitude and high latitude climate of southern Tibet by planting excellent frost-resistant cultivars, with promising yields and a commercial standard of nut quality.

Keywords: *Macadamia* sp.; kernel quality; nut mass; tree growth; tree survival rate; yield

The cultivated macadamia (*Macadamia integrifolia* Maiden and Betche, *Macadamia tetraphylla* Johnson, and their hybrids) is a subtropical and evergreen fruit tree native to the lowland subtropical rainforest of eastern Australia, with a discontinuous distribution from south-eastern Queensland to north-eastern New South Wales (Powell et al. 2014; Topp et al. 2019) and grown commercially in tropical and subtropical regions around the world. In China, macadamia was first

Supported by the Central Public-interest Scientific Institution Basal Research Fund for Chinese Academy of Tropical Agricultural Sciences, Project No. 1630062018004; and Hainan Provincial Natural Science Foundation of China, Project No. 323MS094.

https://doi.org/10.17221/166/2024-HORTSCI

introduced and experimentally planted in 1979, and about 266 100 ha have been developed in the following 41 years, accounting for more than 60% of the world's planting area. It is mainly planted in Yunnan, Guangxi, Guangdong and Guizhou provinces in hilly mountainous areas below 1 300 m altitude without serious frost and wind damage, and was introduced in Chayu County, Tibet, China (Wan et al. 2024).

Chayu County, located in southern Tibet, has a humid subtropical climate and is suitable for growing subtropical crops. Since 2017, seven macadamia cultivars have been introduced for planting in Chayu Farm, Chayu County, Tibet. Studies have shown that the climatic factors such as temperature, latitude, altitude and rainfall affect the vegetative growth, fruit growth, kernel quality and yield of macadamia (Stephenson, Gallagher 1986; Stephenson et al. 1986, 1991, 2000; O'Hare et al. 2004; Hardner et al. 2009; Li et al. 2024), indicating the importance of cultivar suitability. However, research on the suitability of macadamia cultivars for the high altitude and high latitude climate of southern Tibet is lacking.

The aim of this research was to study the differences in tree survival rate after frost injury, tree growth, nut mass, kernel quality and yield of seven macadamia cultivars for field production in the high altitude and high latitude climate of southern Tibet, to determine the suitability of macadamia cultivars, which provide a cultivar base for the development of the local macadamia industry and a reference for the development of macadamia in the high altitude and high latitude climate of tropical and subtropical areas.

MATERIAL AND METHODS

Planting and establishment. A macadamia cultivar trial was established at Chayu Farm in Chayu County, southern Tibet (coordinates 97.01°E, 28.50°N, altitude 1 610 m). It is a subtropical valley climate with an average annual rainfall of 1 000 mm and a temperature of 17 °C. Extreme weather conditions with permanent frost occur occasionally in winter. The soil is sandy loam and the irrigation water is sufficient. Seven macadamia cultivars, namely 'Beaumont' ('HAES695'), 'HVA16' ('A16'), 'Hinde' ('H2'), 'Own Choice' ('O.C.'), 'SSCRI-1', 'SSCRI-2' and 'SSCRI-3', were used for this study. 'Beaumont', 'A16', 'H2' and 'O.C.' were the Australian cultivars, 'Beaumont' and 'A16' were hybrid cultivars of *Macadamia tetraphylla* and *Macadamia integrifolia*, and 'H2' and 'O.C.' were *Macadamia integrifolia* cultivars (Peace et al. 2003; Topp et al. 2019), and 'SSCRI-1', 'SSCRI-2' and 'SSCRI-3' were *Macadamia integrifolia* cultivars, selected by the researchers from the South Subtropical Crops Research Institute (SSCRI), Chinese Academy of Tropical Agricultural Sciences (Lu et al. 2010; Zeng et al. 2013a, b). These seven macadamia cultivars have performed excellently in terms of their economic traits in the suitable planting areas of Yunnan, Guangxi, Guangdong and Guizhou provinces in China. In April 2017, one-year-old representative grafted seedlings of seven macadamia cultivars, each with a stem diameter of approximately 1.0 cm, were planted in three replicate plots arranged in a randomised block design with row and tree spacing of 6 × 5 m. Fertilisation, disease and pest control were carried out according to the routine management.

Data collection. A sustained period of low temperatures was only recorded from late December 2018 to mid-January 2019, with an extreme minimum temperature of –1.0 °C (Table 1). Chayu Farm experienced continuous frost during this period, resulting in different degrees of frost injury to seven macadamia cultivars. Dead trees and surviving trees were counted to calculate the survival rate of the trees.

In early December 2018–2020, normal trees were selected for each cultivar to measure the tree height, stem diameter and canopy width. Tree height and canopy width were measured using a steel tape rule with a minimum graduation of 0.1 cm. Stem diameter at 20 cm above the ground was measured using a digital calliper gauge with a minimum graduation of 0.01 mm. The experiment was conducted in three replicate plots arranged in a randomised block design. Three normal trees were randomly selected in one replicate plot, and a total of nine normal trees were selected for each cultivar.

In November 2020, all ripe fruits were harvested from each tree of each cultivar, and the husk was removed. The mass of the fresh nuts was weighed using an electronic balance with a minimum graduation of 0.01 g to calculate the fresh nut yield per tree. The yield of each cultivar was expressed as the average fresh nut yield per tree. All fresh nuts were dried to approximately 1.5 % moisture content using

https://doi.org/10.17221/166/2024-HORTSCI

Table 1. Weather data at Chayu Farm, Tibet

Date	Temperature (°C)			Humidity (%)			Rainfall (mm)
	minimum	maximum	average	minimum	maximum	average	
2018/12/16	2.5	21.6	8.62	23.1	90.7	61.19	0.0
2018/12/17	1.6	21.2	9.43	20.4	83.9	54.33	0.0
2018/12/18	0.6	9.10	5.53	58.3	100.0	87.51	34.6
2018/12/19	1.0	7.90	4.37	100.0	100.0	100.00	33.6
2018/12/20	2.2	18.1	7.51	36.7	100.0	82.80	0.2
2018/12/21	0.5	17.6	7.06	34.2	100.0	78.77	0.0
2018/12/22	3.2	20.5	8.63	27.9	100.0	72.61	0.0
2018/12/23	1.6	20.4	8.24	25.3	97.0	68.64	0.0
2018/12/24	1.3	17.6	7.66	32.9	99.2	72.39	0.0
2018/12/25	0.5	18.1	7.67	35.1	100.0	74.32	0.0
2018/12/26	1.6	16.5	7.47	38.5	100.0	77.74	0.0
2018/12/27	1.1	17.6	7.71	36.3	100.0	75.75	0.0
2018/12/28	0.1	16.9	6.41	31.7	100.0	72.02	0.0
2018/12/29	1.6	12.5	6.07	49.9	99.3	78.96	0.0
2018/12/30	0.0	18.8	6.10	16.0	100.0	64.89	0.0
2018/12/31	–1.0	18.4	5.96	19.3	81.5	54.64	0.0
2019/01/01	0.0	19.0	6.48	21.6	85.7	59.31	0.0
2019/01/02	0.3	17.9	6.96	23.8	85.9	59.74	0.0
2019/01/03	–0.1	15.3	6.54	33.6	100.0	67.68	0.0
2019/01/04	2.1	13.8	5.74	61.9	100.0	90.91	12.2
2019/01/05	–0.4	18.2	6.03	26.7	100.0	73.57	0.0
2019/01/06	–0.3	18.1	6.15	27.9	95.3	69.31	0.0
2019/01/07	0.3	18.0	7.06	27.4	90.2	64.62	0.0
2019/01/08	2.2	18.9	7.32	26.9	86.4	64.53	0.0
2019/01/09	–0.1	15.8	7.58	28.3	94.4	63.17	0.0
2019/01/10	3.4	11.3	6.89	65.8	100.0	87.48	1.2
2019/01/11	1.5	17.8	8.05	25.9	100.0	71.76	0.2
2019/01/12	0.1	17.8	7.29	28.5	100.0	70.20	0.0
2019/01/13	0.3	19.2	7.21	27.9	97.5	67.04	0.0
2019/01/14	–0.1	18.0	7.09	26.2	96.9	66.57	0.0
2019/01/15	0.4	16.9	7.69	32.5	100.0	68.51	0.0
2019/01/16	0.0	19.3	7.26	14.5	97.5	59.62	0.0
2019/01/17	–0.1	20.0	7.90	17.1	74.4	48.03	0.0
2019/01/18	1.5	18.0	8.09	23.4	81.5	53.15	0.0
2019/01/19	–0.1	19.3	7.44	23.9	91.5	59.70	0.0
2019/01/20	1.8	20.0	9.09	21.9	84.4	55.54	0.0
2019/01/21	1.9	22.0	8.74	20.9	89.9	59.75	0.0
2019/01/22	0.7	19.0	8.09	28.3	95.8	65.93	0.0
2019/01/23	3.3	20.2	10.25	25.4	91.2	60.28	0.0
2019/01/24	2.9	19.3	9.15	33.1	100.0	70.38	0.0
2019/01/25	2.1	21.6	9.70	26.7	100.0	68.50	0.0
2019/01/26	1.8	18.0	9.58	35.6	100.0	67.59	0.0
2019/01/27	5.6	12.9	8.45	52.9	100.0	82.48	1.8
2019/01/28	4.1	16.9	9.22	48.6	100.0	80.01	0.0
2019/01/29	4.1	12.6	7.57	66.3	100.0	87.19	0.2
2019/01/30	2.9	15.0	7.50	44.6	100.0	85.02	0.0
2019/01/31	1.3	18.9	7.73	27.7	100.0	70.74	0.0

https://doi.org/10.17221/166/2024-HORTSCI

an initial low temperature regime, and the dried nuts were bulked by cultivar. A sample of 60 dried nuts was taken from each bulk to determine the average mass of an individual nut. The nuts were then mechanically cracked, and the kernels were used to measure the average mass of an individual kernel, the percentage of kernel recovery and first-grade kernel and kernel oil content. Kernel recovery was calculated as the percentage of kernel to kernel and shell mass. The percentage of first-grade kernel was determined by the water flotation method, in which the mass of the kernel that floats after being placed in water is expressed as a percentage of the total kernel mass (Mason, Willis 1983). The oil content of the kernel was measured using the nuclear magnetic resonance (NMR) technique. The NMR analyser used for the experiment was a 0.5 T low-field instrument (Niumag, Shanghai, China) with a sampling frequency of 200 kHz. Each dried kernel was placed in a 25 mm detector and measurement of the lipid and water signals were conducted. The kernel oil content was then calculated using macadamia oil and water standards of a known mass.

Statistical analysis. Data were analysed using SPSS 22.0 software (IBM, Chicago, USA). Significant differences among the mean values were determined by Duncan's multiple range test, and the differences were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Tree survival rates of seven macadamia cultivars after frost injury. Experience in South Africa and China suggests that *Macadamia tetraphylla* cultivars and hybrids of *Macadamia tetraphylla* and *Macadamia integrifolia* are more suitable for cooler environments than *Macadamia integrifolia* cultivars (Hardner et al. 2009). As shown in Table 2, tree survival was related to cultivar, with survival rates of seven macadamia cultivars ranging from 32.0% to 70.7%. The cultivar with the highest survival rate was 'A16' and the cultivar with the lowest survival rate was 'H2'. The survival rates of hybrids including 'A16' and 'Beaumont' after frost injury were over 65%, which were higher than those of *Macadamia integrifolia* cultivars such as 'O.C.', 'SSCRI-1', 'SSCRI-2', 'SSCRI-3' and 'H2' and the survival rates of 'O.C.', 'SSCRI-1', 'SSCRI-2' after frost injury were higher than those of 'SSCRI-3' and 'H2'. These results showed that the hybrids including 'A16' and 'Beaumont' had the stronger resistance to frost injury, followed by 'O.C.', 'SSCRI-1' and 'SSCRI-2', but 'SSCRI-3' and 'H2' had weaker resistance. The frost resistance of these cultivars may be related to their genetic background. The differences in their frost resistance will be investigated further in future work.

Tree growth of seven macadamia cultivars. Tree vigour, habit, tree size, and canopy density of macadamia trees affect the production (Hardner et al. 2009). As shown in Table 3, the annual changes in stem diameter, tree height and canopy width in the three seasons of seven macadamia cultivars showed an increasing trend with increasing tree age. The stem diameter of 'SSCRI-2' grew fastest, followed by 'Beaumont', 'O.C.', 'SSCRI-1' and 'SSCRI-3', and 'A16' grew the slowest. The tallest cultivar was 'SSCRI-2', followed by 'H2', 'Beaumont', 'SSCRI-1', and the shortest cultivar was 'A16'. The cultivar with the largest canopy width was 'SSCRI-2', followed by 'SSCRI-3', 'SSCRI-1' and 'O.C.' and the smallest canopy width was 'A16' and 'H2'. The stem diameter of seven macadamia cultivars ranged from 48.50 to 70.39 mm, the tree height from 215.1 to 293.7 cm and the canopy width from 145.5 to 207.4 cm at four years after planting, which were 2.6–3.3, 1.3–1.6, 1.7–2.4 times that of the plants at one year after planting respectively, which were comparable to the tree growth of 'SSCRI-1', 'SSCRI-2', 'SSCRI-3', 'Kau' and 'Pahala' grown in Aihua Town (coordinates: 100.13°E, 24.45°N, altitude: 1 250 m), Yunxian County, Yunan Province, China (Wen et al. 2017). These results

Table 2. Tree survival rates of seven macadamia cultivars after frost injury at Chayu Farm, Tibet

Cultivars	TTN	DTN	STN	TSR (%)
Beaumont	139	47	92	66.2^{ab}
A16	133	39	94	70.7^{a}
H2	50	34	16	32.0^{e}
O.C.	72	32	40	55.6^{c}
SSCRI-1	50	25	25	50.0^{c}
SSCRI-2	75	29	46	61.3^{b}
SSCRI-3	48	28	20	41.7^{d}

TTN – total trees number; DTN – dead trees number; STN – surviving trees number; TSR – tree survival rate; significant differences among the mean values were determined by Duncan's multiple range test, and different letters within the columns indicate significant differences ($P < 0.05$)

https://doi.org/10.17221/166/2024-HORTSCI

indicated that the seven cultivars grew well under the high altitude and high latitude climatic conditions of southern Tibet without continuous frost.

Yield, nut mass and kernel quality of seven macadamia cultivars. Yield varies with location, season, cultivar and level of management. The general yield pattern for grafted macadamia trees is that production begins at three to six years old, increases with age, and peaks at about 12–20 years old (Mayer et al. 2006). Commencement of production at three to four years after planting is considered a desirable trait in a cultivar as it can increase early orchard yields (Hardner et al. 2009). As shown in Table 4, except for 'H2' and 'SSCRI-3', 'Beaumont', 'A16', 'O.C.', 'SSCRI-1' and 'SSCRI-2' started bearing at four years after planting. 'O.C.' was the most productive tree with an average fresh nut yield of 1.57 kg per tree. It was followed by 'SSCRI-2' with an average fresh nut yield of 0.95 kg per tree and 'Beaumont' with an average fresh nut yield of 0.84 kg per tree. The lowest yielding cultivar was 'A16' with an average fresh nut yield of 0.61 kg per tree. These results indicated that 'SSCRI-3' and 'H2' were poorly adapted to the high altitude and high latitude climate of southern Tibet.

Nut mass and kernel mass are highly heritable traits (individual broad sense heritability, $H = 0.63$) (Hardner et al. 2001). Nut mass was related to cultivar, 'SSCRI-1' produced the largest nut of 9.16 g, followed by 'SSCRI-2', 'O.C.' and 'A16' around 8.0 g, and 'Beaumont' produced the smallest nut of 6.04 g, which were comparable to the nut mass of 'SSCRI-1' (10.05 g), 'SSCRI-2' (8.46 g), 'SSCRI-3' (9.21 g), 'Kau' (9.84 g) and 'Pahala' (7.35 g) grown

Table 3. Stem diameter, tree height and canopy width over three seasons for seven macadamia cultivars at Chayu Farm, Tibet

Cultivars	Stem diameter (mm)	Tree height (m)	Canopy width (m)
2018			
Beaumont	17.92 ± 1.12^{cd}	1.684 ± 0.072^{bc}	0.796 ± 0.044^{bc}
A16	17.84 ± 0.64^{cd}	1.686 ± 0.192^{bc}	0.858 ± 0.023^{ab}
H2	19.12 ± 1.26^{bc}	1.694 ± 0.077^{bc}	0.722 ± 0.066^{c}
O.C.	17.03 ± 1.19^{d}	1.723 ± 0.039^{b}	0.908 ± 0.031^{a}
SSCRI-1	20.21 ± 0.51^{b}	1.746 ± 0.010^{b}	0.869 ± 0.055^{ab}
SSCRI-2	22.92 ± 0.35^{a}	2.023 ± 0.076^{a}	0.858 ± 0.067^{ab}
SSCRI-3	16.56 ± 0.23^{d}	1.568 ± 0.116^{c}	0.936 ± 0.072^{a}
2019			
Beaumont	45.76 ± 4.78^{a}	2.087 ± 0.205^{ab}	1.230 ± 0.172^{a}
A16	31.29 ± 3.09^{c}	1.713 ± 0.024^{c}	0.932 ± 0.081^{b}
H2	41.05 ± 4.92^{ab}	2.362 ± 0.337^{a}	1.188 ± 0.256^{ab}
O.C.	40.96 ± 1.32^{ab}	1.801 ± 0.114^{bc}	1.361 ± 0.172^{a}
SSCRI-1	42.48 ± 4.51^{ab}	2.031 ± 0.063^{ab}	1.229 ± 0.057^{a}
SSCRI-2	45.42 ± 2.55^{a}	2.173 ± 0.041^{ab}	1.244 ± 0.025^{a}
SSCRI-3	38.16 ± 1.07^{b}	2.010 ± 0.247^{ab}	1.335 ± 0.174^{a}
2020			
Beaumont	56.21 ± 2.26^{bc}	2.506 ± 0.153^{bc}	1.621 ± 0.052^{cd}
A16	48.50 ± 4.30^{d}	2.151 ± 0.126^{d}	1.455 ± 0.016^{d}
H2	50.12 ± 0.90^{cd}	2.668 ± 0.113^{b}	1.468 ± 0.086^{d}
O.C.	56.86 ± 0.74^{b}	2.347 ± 0.093^{cd}	1.803 ± 0.204^{bc}
SSCRI-1	55.46 ± 3.90^{bc}	2.534 ± 0.169^{bc}	1.717 ± 0.113^{bc}
SSCRI-2	70.39 ± 4.24^{a}	2.937 ± 0.086^{a}	2.074 ± 0.196^{a}
SSCRI-3	55.47 ± 5.21^{bc}	2.380 ± 0.227^{cd}	1.901 ± 0.218^{ab}

Data are mean values ± standard deviation (SD); significant differences among the mean values were determined by Duncan's multiple range test, and different letters within the columns indicate significant differences ($P < 0.05$)

https://doi.org/10.17221/166/2024-HORTSCI

Table 4. Yield, nut mass and kernel quality of seven macadamia cultivars at Chayu Farm, Tibet in 2020

Cultivars	FNY (kg)	AMN	AMK	KRP	FKP	OC
		(g)			(%)	
Beaumont	0.84 ± 0.27[bc]	6.04 ± 0.20[c]	2.06 ± 0.09[c]	34.1 ± 0.9[ab]	100.0[a]	78.3 ± 0.8[a]
A16	0.61 ± 0.13[c]	7.87 ± 0.37[b]	2.87 ± 0.10[a]	36.5 ± 1.5[a]	100.0[a]	77.3 ± 0.5[a]
H2	–	–	–	–	–	–
O.C.	1.57 ± 0.80[a]	7.98 ± 0.49[b]	2.49 ± 0.08[b]	31.2 ± 0.9[b]	100.0[a]	76.3 ± 0.9[a]
SSCRI-1	0.69 ± 0.33[c]	9.16 ± 0.65[a]	3.01 ± 0.12[a]	32.9 ± 1.3[b]	100.0[a]	77.2 ± 0.6[a]
SSCRI-2	0.95 ± 0.45[b]	8.08 ± 0.46[b]	2.21 ± 0.10[c]	27.3 ± 1.6[c]	95.9 ± 1.5[b]	76.1 ± 0.7[a]
SSCRI-3	–	–	–	–	–	–

FNY – fresh nut yield; AMN – average mass of an individual nut; AMK – average mass of an individual kernel; KRP – kernel recovery percentage; FKP – first-grade kernel percentage; OC – oil content; data are mean values ± standard deviation (SD); significant differences among the mean values were determined by Duncan's multiple range test, and different letters within the columns indicate significant differences ($P < 0.05$)

in Aihua Town (coordinates: 100.13°E, 24.45°N, altitude: 1 250 m), Yunxian County, Yunan Province, China (Wen et al. 2017). For commercial purposes, kernels smaller than 1.5 g are considered too small and those larger than 3.5 g are considered too large, with the ideal mass being 2 to 3 g (Hardner et al. 2001). In our study, the kernel mass of five macadamia cultivars ranged from 2.06 g to 3.01 g, which was the ideal mass.

Climate has a strong influence on kernel recovery in macadamia (Hardner et al. 2001). Kernel recovery ranged from 20% to 50%, with a kernel recovery percentage of greater than 36% and 34% recommended for cultivar selection in Australia and Hawaii, respectively (Hardner et al. 2009). Apart from 'SSCRI-2', four macadamia cultivars had kernel recovery percentages greater than 30.0%, with 'A16' and 'Beaumont' having kernel recovery percentages greater than 36% and 34% respectively. Only the kernel recovery percentage of 'A16' was up to the Australian recommended threshold, and the kernel recovery percentages of 'A16' and 'Beaumont' achieved the Hawaiian selection threshold. The kernel recovery percentages of 'O.C.', 'SSCRI-1' and 'SSCRI-2' were lower than the results of He et al. (2009), Zeng et al. (2013a) and Lu et al. (2010), who reported the kernel recovery percentages of 33.0%, 37.5% and 30.6%, respectively. The threshold of 95% first-grade kernel percentage and 72% oil content has been used as the recommended standard for cultivar selection in both Australia and Hawaii (Hardner et al. 2009). In our study, the first-grade kernel percentage of five macadamia cultivars was above 95% and the difference in oil content of five macadamia cultivars was not significant, ranging from 76.1% to78.3 %. These results indicated that the first-grade kernel percentage and oil content of five macadamia cultivars met the recommended standard.

Promising yields and commercial-standard nut quality can be achieved by planting excellent frost-resistant cultivars such as 'A16' and 'Beaumont' in the high altitude and high latitude climate of southern Tibet. This serves as a reference for developing macadamia cultivation in other tropical and subtropical regions with similar climates. Furthermore, the kernels are valued at around 18–20 $/kg and the nuts-in-shell are valued at about 5–6.50 $/kg, making macadamia the world's most expensive nut (Ranketse et al. 2022). Southern Tibet is a region of China where ethnic minorities reside, and it is a key area for national poverty alleviation efforts. Developing the high-value macadamia industry could increase farmers' incomes and help them to lift themselves out of poverty.

CONCLUSION

Based on the comparative analysis of the tree survival rate after frost injury, tree growth, nut mass, kernel quality and yield of seven macadamia cultivars for field production in the high altitude and high latitude climate of southern Tibet, it can be concluded that 'A16' and 'Beaumont' were well adapted to the high altitude and high latitude climate of southern Tibet, followed by 'O.C.', 'SSCRI-1' and 'SSCRI-2', but 'SSCRI-3' and 'H2' were unsuitable. The results obtained in this study can

https://doi.org/10.17221/166/2024-HORTSCI

be used as the cultivar base for the development of the local macadamia industry and as a reference for the development of macadamia in the high altitude and high latitude climate of tropical and subtropical areas.

REFERENCES

Hardner C., Winks C., Stephenson R., Gallagher E. (2001): Genetic parameters for nut and kernel traits in macadamia. Euphytica, 117: 151–161.

Hardner C.M., Peace C., Lowe A.J., Neal J., Pisanu P., Powell M., Schmidt A., Spain C., Williams K. (2009): Genetic resources and domestication of macadamia. In: Janick J. (ed.): Horticultural Reviews. Vol. 35. Hoboken, John Wiley & Sons Ltd Press: 1–125.

He X.Y., Tao L., Ni S.B., Chen L.L. (2009): Yield and nut quality of 15 macadamia cultivars in Yunnan. Chinese Journal of Tropical Crops, 30: 1399–1407. (in Chinese)

Li Y., Zhao H., Zhong T., Wu H., Peng W., Li Z., Huang W., Huang S., Shi B., Li Y. (2024): Temperature and precipitation synergistically affect yield, harvesting time and post-processing quality of tropical macadamia nuts. Atmosphere, 15: 1299.

Lu C.Z., Zeng H., Zou M.H., Du L.Q., Zhang H.Z., Li R.R., Xu H.S., Luo L.F., Wang Y.C. (2010): A new macadamia nut cultivar 'SSCRI-2'. Acta Horticulturae Sinica, 37: 1195–1196. (in Chinese)

Mason R.L., Willis R.B.H. (1983): Evaluation of the use of specific gravity as an objective index of the quality of Australian macadamia nuts. Food Technology in Australia, 35: 245–248.

Mayer D.G., Stephenson R.A., Jones K.H., Wilson K.J., Bell D.J.D., Wilkie J., Lovatt J.L., Delaney K.E. (2006): Annual forecasting of the Australian macadamia crop-integrating tree census data with statistical climate-adjustment models. Agricultural Systems, 91: 159–170.

O'Hare P., Stephenson R., Quinlan K., Vock N. (2004): Growing Guide: Macadamia Grower's Handbook. Nambour, Queensland Department of Primary Industries and Fisheries.

Peace C.P., Vithanage V., Turnbull C.G.N., Carroll B.J. (2003): A genetic map of macadamia based on randomly amplified DNA fingerprinting (RAF) markers. Euphytica, 134: 17–26.

Powell M., Accad A., Shapcott A. (2014): Where they are, why they are there, and where they are going: Using niche models to assess impacts of disturbance on the distribution of three endemic rare subtropical rainforest trees of macadamia (Proteaceae) species. Australian Journal of Botany, 62: 322–334.

Ranketse M., Hefer C.A., Pierneef R., Fourie G., Myburg A.A. (2022): Genetic diversity and population structure analysis reveals the unique genetic composition of South African selected macadamia accessions. Tree Genetics & Genomes, 18: 15.

Stephenson R.A., Gallagher E.C. (1986): Effects of temperature during latter stages of nut development on growth and quality of macadamia nuts. Scientia Horticulturae, 30: 219–225.

Stephenson R.A., Cull B.W., Mayer D.G. (1986): Effects of site, climate, cultivar, flushing, and soil and leaf nutrient status on yields of macadamia in South East Queensland. Scientia Horticulturae, 30: 227–235.

Stephenson R.A., Winks C.W. (1991): *Macadamia integrifolia*. In: Verheij E.W.M., Coronel R.E. (eds): Plant resources of South-East Asia: Edible Fruits and Nuts. Leiden, Backhuys Publishers: 195–198.

Stephenson R.A., Gallagher E.C., Doogan V.J., Mayer D.G. (2000): Nitrogen and environmental factors influencing macadamia quality. Australian Journal of Experimental Agriculture, 40: 1145–1150.

Topp B.L., Nock C.J., Hardner C.M., Alam M., O'Connor K.M. (2019): Macadamia (*Macadamia* spp.) breeding. Chapter 7. In: Al-Khayri J.M., Jain S.M., Johnson D.V. (eds): Advances in Plant Breeding Strategies: Nut and Beverage Crops. Vol. 4. Cham, Springer Nature Switzerland, AG: 221–251.

Wan J., Zeng H., Zou M., Song X., Yang Y., Yang Q., Bai H. (2024): Investigation and analysis on heat tolerance of macadamia germplasm resources. South China Fruit, 53: 80–86. (in Chinese)

Wen D.Q., Zou M.H., Zeng H., Lu C.Z., Yang W.H., Zhang H.Z., Liang Q.Z., Xiong X.X. (2017): Preliminary study on macadamia new variety in high elevation region. Chinese Journal of Tropical Crops, 38: 2050–2055. (in Chinese)

Zeng H., Lu C.Z., Zou M.H., Du L.Q., Zhang H.Z., Li R.R., Xu H.S., Luo L.F., Wang Y.C. (2013a): Breeding of a new macadamia nut cultivar 'SSCRI-1'. China Fruits, 1: 1–3. (in Chinese)

Zeng H., Lu C.Z., Zou M.H., Yang W.H., Wang Y.C., Zhang H.Z., Luo L.F., Du L.Q., Li R.R., Xu H.S. (2013b): Breeding and characteristics of a new macadamia nut cultivar 'SSCRI-3'. Chinese Journal of Tropical Crops, 34: 207–210. (in Chinese)

Received: September 4, 2024
Accepted: October 15, 2025
Published online: March 13, 2026