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Full Length Research Paper

Characters analysis of the *Macadamia* cv. Ikaika (333) germplasm resource

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The growth, yield, kernel quality and wind resistance of *Macadamia* cv. Ikaika (333) introduced from Hawaii, were studied. The results showed that there was no remarkable difference of trunk height, trunk diameter and canopy diameter from *Macadamia* cv. Ikaika (333), Kau (344), Own Choice, Makai (800), and Keauhou (246) at their early years. The yield of young Ikaika trees was much significantly higher than that of Keauhou, Kau, Makai and significantly higher than that of Own Choice in the test field. Furthermore, the yield of Ikaika was higher than that of Keauhou, Kau, and Makai while lower than that of Own Choice in the main *Macadamia* producing areas in South China. Compared with the main planting areas in other parts of the world, the yield of Ikaika per tree in China was similar to that in South Africa while lower than that in Australia and America. However, the yield of Ikaika per km^2 here was obviously higher than that in South Africa, the same to Australia while a bit lower than Hawaii. The kernel ratio, kernel weight and crude fat content of Ikaika were similar to those produced in Australia and Hawaii. Under the condition of tropical cyclone of scale 7 to 11, our data demonstrated that Ikaika's wind resistance was remarkably lower than Own Choice while higher than Makai, but not significantly different from Keauhou and Kau.

Key words: *Macadamia integrifolia*, Ikaika (333), yield, kernel quality, wind resistance

INTRODUCTION

Macadamia integrifolia, also called Hawaii nut, Australia walnut or Queensland nut, is an evergreen arboreal fruit tree and belongs to *Proteaceae*. It was originally produced in the southeastern Queensland and the northern New South Wales in Australia, which is the country's third biggest horticultural export (Goode and Price, 2008). Approximately 55% of the 6 million macadamia trees in Australia have yet to reach maturity. The other Countries such as South Africa, Hawaii, Kenya, Brazil, and Costa Rica have invested heavily in this nut (Goode and Price 2008).

Macadamia nuts are rich in higher monounsaturated fatty acids (MUFA) than any other food source known, predominantly oleic (60%) and palmitoleic (20%) acids (Cavaletto, 1983). Most research identified that diets containing high MUFA foods can reduce plasma LDL cholesterol levels as well as decreases the risk of cardiovascular disease (Garg, et al., 2003; Kris-Etherton et al., 1999). It not only contains 8 types of amino acids needed by human body, but is rich in mineral and vitamin as well. Moreover, Macadamia nut tastes crisp and delicate with special creamily fragrance, resulting in being regarded as the best tasty nut in the world.

M. integrifolia was firstly introduced to China around 1910. However, its commercial development and production did not set out until middle and late 1980s. Nowadays, all varieties of *Macadamia* in China are derived from Hawaii and Australia. Among them, Ikaika, the cultivar of high quality selected in the agricultural test station in Hawaii in 1936 (Trochoulias et al., 1984), was introduced by our country from Australia in 1979 in large scale and then planted in South Sub tropical Crop

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Research Institute in Zhanjiang city, Guangdong province. Although there were a few reports about the introduction and the trail planting of Ikaika (333), systematic study on Ikaika is still far from enough.

In this paper, we report the analysis of main characters of Ikaika (333) in the test fields, providing some fundamental information for its further fostering extension and variety selection in our country.

MATERIALS AND METHODS

Plant materials

Own Choice (O.C), Kau (344), Ikaika (333), Makai (800) and Keauhou (246) were five varieties of *M. integrifolia* tested in the South sub tropical Crop Research Institute in Zhanjiang city, Guangdong province. They were first planted in May 1989. Each variety grows in 4 plots with 6 trees per plot. Keauhou (246) was taken as control.

Analysis of growth and yield

In the test field, every tree was numbered and its trunk height, canopy diameter, truck diameter and fresh weight of nuts were measured in August per year from 1992 to 1994. In other trial orchards, corresponding index was obtained by random sampling.

Analysis of dry weight of kernel

At the time of fruit ripening, 50 fresh fruits that were representative and normally developed were randomly harvested. Their nuts in shell were dried at 38, 45, and then 60℃ for 48 h respectively, after the peels had been removed. When the water content of nuts decreased to 1.5% (± 0.5%), nuts were cooled and then measured on the electronic scale after shells had been removed. The average dry weight was accurate to 0.01 g.

Determination of kernel ratio

At the time of fruit ripening, 50 fresh fruits were randomly selected like above method. After the peels had been removed, the dry weight of total kernels (W1) with nutshell and total kernels (W2) without shell were measured separately. The percentage of W2 in W1 was determined as the kernel ratio.

Analysis of crude fat content, soluble sugar content and crude protein content

Samples were prepared as the same way to analyze the dry weight of kernel. Fat content of kernel in *Macadamia* was measured through the Determination Method GB/T5512 which is the standard method to examine the crude fat content in grain. Soluble sugar content of kernel was measured through the Determination Method GB 6194-1986 which is the standard method to examine the soluble sugar accumulation in fruit and vegetable. Crude protein content of kernel was measured through the Determination Method GB/T5009.5-1985 which is the standard method to examine the protein contained in food.

Determination of damaged scale of *Macadamia* trees under the tropical cyclone

Each tree from different *Macadamia* varieties was investigated after the tropical cyclone passed. The criterion of damaged degree on trees scales from 0 to 4. Grade 0: no slanted crown or broken branch was found. Grade 1: main branches from the trunk were snapped off and the bases of the branch were cleaved. Grade 2: crown slanted leading to an included angle to the trunk less than 45 degrees by visual defects. Grade 3: crown slanted leading to an included angle to the trunk no less than 45 degrees by visual defects. Grade 4: crown of the tree laid flat.

RESULTS

Growth index

Trunk height, canopy and trunk diameter are the main parameters to evaluate the growth of *M. integrifolia*. Trees of *Macadamia* in South Subtropical Crop Research Institute (SSCRI) were investigated on the trunk height, canopy and trunk diameter respectively (Figure 1). The 3-year-old Ikaika reached 279 cm in truck height, 242 cm in truck diameter and 21.7 cm in crown of the tree. The 4-year-old one was 341 cm in truck height, 333 cm in truck diameter and 32.1 cm in crown of the tree, while the 5-year-old was 365, 365 and 37.5 cm respectively. Results showed that there was no remarkable difference among *Macadamia* varieties Ikaika, Kau, Own Choice, Makai and Keauhou.

Yield index

Annual yield of *Macadamia* cultivars at their early years was determined at SSCRI test field as displayed in Table 1. Results show that the average fresh weights of Ikaika nuts with shell were 0.210, 1.044 and 2.243 kg/tree in the 5^{th}, 6^{th} and 7^{th} year respectively. The yield of Ikaika was the highest, followed by Own Choice and Keauhou, while Kau and Makai had the lowest yield.

Results from the survey (Table 2) showed that the fruit bearing and early yield per tree of 5 to 7-year-old Ikaika trees were better than those of Kau, Makai and Keauhou, but inferior to those of Own Choice in *Macadamia* orchards in Yunnan, Guangdong and Guangxi provinces. Besides, yields of the same variety varied dramatically inregions and orchards, such as the yield of *Macadamia* orchards in Yunnan was obviously higher than that in Guangxi and Guangdong province. And the yield of orchards under proper management was obviously higher than that without management. It was suggested that climate and orchard management are the main factors affecting the yield of *Macadamia*.

The data in Table 3 reflected that the average yield per tree of 5 to 7-year-old Ikaika in the *Macadamia* orchards was a little higher than that of the other domestic

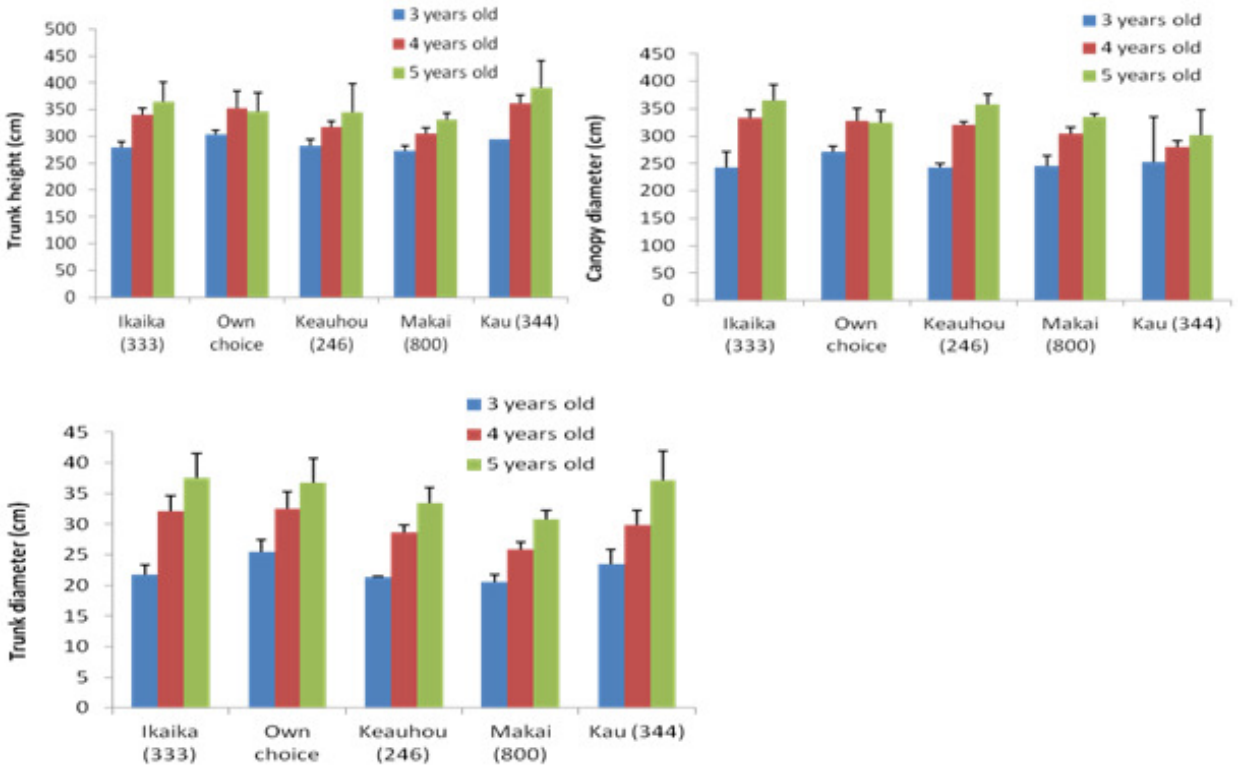

Figure1. Growth index of different *Macadamia intergrifolia* at their early years. (A) Trunk height. (B) Canopy diameter. (C)

Table 1. Yields of different *M. intergrifolia* at their early years in the test field.

Variety	Tree age (year)	Fresh weight of nuts with shell (kg/tree)					Significant difference
		Group 1	Group 2	Group 3	Group 4	Summary	
Ikaika (333)	5	0.102	0.082	0.131	0.524	0.210±0.210	a
	6	0.996	0.658	0.808	1.712	1.044±0.467	
	7	2.560	2.169	2.124	2.120	2.243±0.212	
Own Choice	5	0.066	0.976	0.053	1.044	0.545±0.730	b
	6	0.309	0.191	0.109	1.654	0.566±0.753	
	7	1.877	1.677	1.806	0.290	1.413±0.483	
Keauhou (246)	5	0.090	0.257	0.095	0.121	0.141±0.079	c
	6	0.333	0.199	0.081	0.244	0.214±0.105	
	7	1.647	1.475	1.444	0.830	1.349±0.357	
Makai (800)	5	0	0.118	0.041	0.034	0.048±0.050	d
	6	0.008	0.103	0.219	0.229	0.140±0.105	
	7	0.059	0.224	0.663	0.696	0.411±0.318	
Kau (344)	5	0.073	0.127	0.080	0.110	0.098±0.025	d
	6	0.122	0.163	0.008	0.584	0.219±0.252	
	7	0.310	0.296	0.191	0.459	0.314±0.110	

Data were analyzed by Q test. P = 0.05. Values indicate means ± SE.

Table 2. Yields of *Macadamia intergrifolia* at their early years in South China.

Plantation	Planting time	Harvest time	Tree age (year)	Fresh weight of nuts with shell (kg/tree)				
				Ikaika (333)	Kau (344)	Own Choice	Keauhou (246)	Makai (800)
Yunnan Luxi	2000	2005		1.61	1.17	3.67	0.32	0.08
Yunnan Luxi	1998	2003		0.47	0.74	0.91	0.28	0.19
Guangdong Zhanjiang	1985	1990		-	0.37	2.05	-	0.51
Guangdong Zhanjiang	1989	1994		0.21	0.10	0.55	0.14	0.05
Guangxi Huashan	1991	1996	5	0.17	0.10	0.83	0.14	0.04
Guangxi Jinguang (Feng et al., 2004)	-	-		-	0.07	-	0.14	0.08
Guoying Aobang (Jiang et al., 2000)	1991	1996		0.11	0.15	1.93	0.68	-
Guangxi (Chen et al., 2000)	1990	1995		-	0.68	-	0.01	0.79
Guangxi Suishanchang (Feng et al., 2004)	1992	1997		-	0.11	-	0.12	0.02
Summary				0.51±0.63	0.39±0.39	1.66±1.16	0.23±0.21	0.22±0.28
Yunnan Luxi	1998	2004		1.38	0.65	1.84	0.39	0.73
Yunnan Mangshi	1997	2003		2.10	-	6.82	2.38	-
Guangdong Zhanjiang	1985	1991		4.74	3.40	4.76	-	1.82
Guangdong Zhanjiang	1989	1995	6	1.04	0.22	0.57	0.21	0.14
Guangxi Huashan	1991	1997		0.44	0.14	0.87	0.26	0.12
Guangxi Jinguang (Qin and Liang, 2002)	-	-		0.17	0.22	2.32	0.13	0.06
Guangxi	1990	1996		-	0.47	-	0.04	0.00
Summary				1.65±1.66	0.85±1.26	2.86±2.44	0.57±0.89	0.57±0.75
Yunnan Luxi	1998	2005		7.30	5.21	10.29	8.66	4.12
Yunnan Yingjiang	1997	-		2.19	2.72	3.48	1.39	4.41
Yunnan Mangshi	1996	2003		5.87	-	9.28	6.51	1.08
Guangdong Zhanjiang	1985	1992	7	1.16	1.34	0.16	-	0.32
Guangdong Zhanjiang	1989	1996		0.24	0.31	1.41	0.35	0.41
Guangxi Huashan	1991	1998		0.30	0.17	0.41	0.23	0.17
Guangxi Jinguang (Qin and Liang, 2002)	-	-		0.53	-	2.04	0.36	0.43
Guangxi (Chen et al., 2000)	1990	-		-	0.12	-	0.15	0.64
Summary				2.51±2.89	1.65±2.01	3.87±4.20	1.95±2.57	0.99±0.91
Significant differences				AB	B	A	B	B

Data were analysed by Q test. P = 0.05. Values indicate means ± SE.

varieties. Compared with the main producing areas abroad, the average yield of Ikaika per tree in China was close to that in South Africa and a little lower than that in Australia but much lower than America. However, the planting density of *Macadamia* in our country was about 2.17, 1.50 and 1.88 times higher than that in America, Australia and South Africa respectively. Thus, domestic yield of Ikaika per hm^2 was 29.1, 71.6 and 40.9% higher than that in South Africa at their 5^{th}, 6^{th} and 7^{th} year respectively, but similar to those in Australia while a little lower than Hawaii.

Quality analysis

Average dry weight of kernel and kernel ratio of Ikaika, Kau, Own Choice, Makai and Keauhou were analyzed as shown in Table 4. The average weight of kernel of Own Choice is the heaviest, followed by Kau, Makai and Ikaika while that of Keauhou is the lowest. These results were similar to those in Hawaii and Australia (two main *Macadamia* orchards in the world) according to reports. The kernel ratio from 5 varieties, which were between 30.8 and 36.4%, appeared the same to that in Australia and a little lower than Hawaii. Nevertheless both the average kernel weight and kernel ratio of Ikaika agreed to the average levels in Australia and Hawaii.

Soluble sugar, soluble starch, crude fat and protein contents of the chief ingredients of kernel were analyzed on Ikaika, Kau, Own Choice, Makai and Keauhou as reflected in Figure 2. Soluble sugar content and soluble

Table 3. Yields of *Macadamia intergrifolia* in main producing areas in the world.

Tree age (year)	Yield*	China		America (Shigeura and Ooka 1984)	Austrialia (Richarde et al., 1983)	South Africa (Richard et al., 1984)
		Average	Ikaika (333)			
5	kg/tree	0.66 ± 0.60	0.51±0.63	0～4.54	1	0.74
	kg/hm^2	247	191	393	250	148
6	kg/tree	1.3 ± 0.98	1.65±1.66	0.45～9.07	2	1.8
	kg/hm^2	488	618	824	500	360
7	kg/tree	2.19 ± 1.09	2.51±2.89	3.63～18.14	4	3.43
	kg/hm^2	821	941	1884	1000	668

*kg/tree represents fresh weight of nuts with shell per tree. kg/hm^2 represents the fresh weight of nuts with shell from 375 trees per hm^2 in China, 173 trees per hm^2 in America, 250 trees per hm^2 in Australia and 200 trees per hm^2 in South Africa, respectively. Values indicate means ±*SE*.

Table 4. Quality analysis of kernel in different *M. intergrifolia*

Variety	China				Australia (O'Hare and Vock 1990)		Hawaii (Richard et al., 1984)	
	Weight per nut (g)	Significant difference	Kernel ratio (%)	Significant differences	Weight per nut (g)	Kernel ratio (%)	Weight per nut (g)	Kernel ratio (%)
Ikaika (333)	2.21±0.27	AB	34.2±4.2	AB	2.2～2.6	31～35	2.2	34
Own choice	3.42±0.26	A	36.4±2.0	A	2.5～3.0	32～36	-	-
Makai (800)	2.42±0.31	AB	34.2±3.1	B	2.4～2.8	33～36	3.2	40
Keauhou (246)	1.93±0.25	B	30.8±2.2	AB	2.5～3.0	31～35	2.8	39
Kau (344)	2.91±0.27	A	32.6±2.4	AB	2.4～2.8	30～34	2.9	38

Data were analysed by Q test. P = 0.05. Values indicate means ± SE.

starch content of Ikaika were 2.21 and 2.19% separately, which were significantly lower than those of Kau, Own Choice or Keauhou whilesignificantly higher than those of Makai. Crude fat content of Ikaika was 77.34%, which is the highest among all the varieties tested, although there was no significant difference between them. Crude protein content was 8.27% and it was much higher than that of Kau, Makai or Keauhou, but there was no obvious difference from Own Choice.

Besides, among all the trial varieties, crude fat content of kernel from mature fruit was more than 72% (water content was around 1.5%), up to the standard of high-quality kernel abroad.

Wind resistance analysis

Macadamia is a fruit tree poor in wind resistance. The orchards would be damaged under the wind velocity of the Beaufort force scale higher than 7. The wind resistance of *Macadamia* varieties was examined under the wind velocity scaled 7 to 11 (Table 5). It was shown that Keauhou was the weakest, following by Makai, Ikaika and Kau, and Own Choice was the strongest.

Under the condition of wind velocity of the Beaufort force scale higher than 12, *Macadamia* orchards would suffer destructive calamity (Table 6), although the wind resistance of varieties tested indicated no obvious difference from each other.

DISCUSSION

Ikaika (333) is a strong variety of *Macadamia* introduced and grew in our country back to 1970s. It has already been 30 years since *Macadamia* was first planted on the trail basis. The trunk height, canopy diameter, and truck diameter of Ikaika short of 5-year-old had no obvious distinction with those of Own Choice, Keauhou, Kau or Makai. The findings of investigation in Yunnan and Guangxi also accorded with it. In addition, the results also showed in nature condition without any culture technique or management, the growth period before yield of Ikaika was the same as that in the main producing area in other

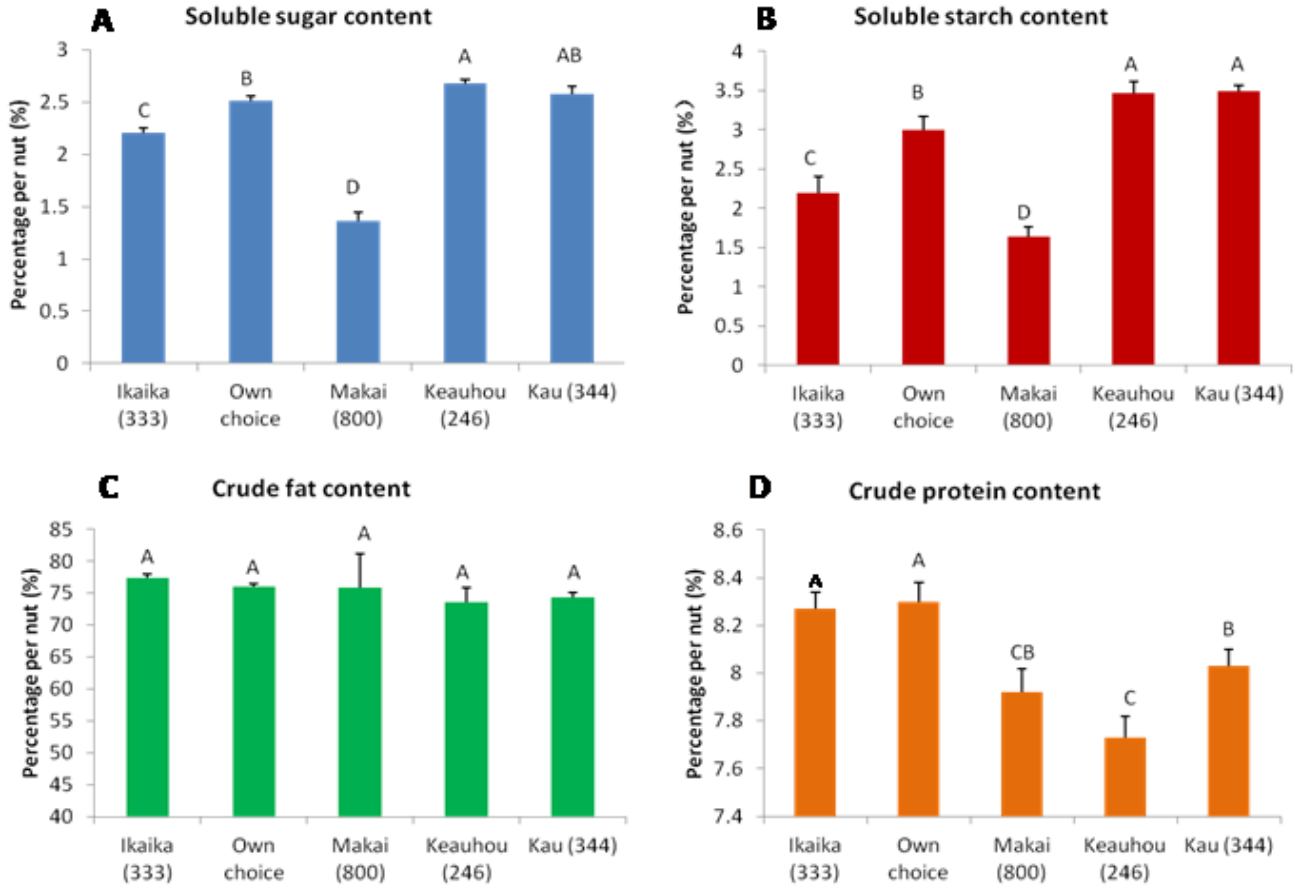

Figure 2. Quality analysis of nuts in different *Macadamia intergrifolia*. (A) Soluble sugar content. (B) Soluble starch content. (C) Crude fat content. (D) Crude protein content. Different characters above the bars indicate the results of Q test between samples were significant at the P = 0.05 level.

Table 5. Investigation of the impact of tropical cyclone No. 3 and No. 19 in 1994 on different *Macadamia intergrifolia*.

Variety	Tropical cyclone signal	Total number of trees	Number of trees in the damaged scale					*d*	Significant difference
			Grade 0	Grade 1	Grade 2	Grade 3	Grade 4		
Ikaika (333)	No.3	26	9	0	12	3	2	50.55	bc
	No.19	41	19	0	18	4	0		
Own Choice	No.3	31	18	0	8	3	2	31.88	d
	No.19	38	32	0	5	1	0		
Keauhou (246)	No.3	30	3	0	17	6	4	66.36	a
	No.19	43	10	2	20	11	0		
Makai (800)	No.3	85	20	0	49	12	4	54.75	b
	No.19	82	36	0	32	14	0		
Kau (344)	No.3	32	9	0	14	8	1	45.70	c
	No.19	33	23	0	5	5	0		

Tropical cyclone No. 3 arose on June 8th, 1994. The average wind velocity was of the Beaufort force scale 7 to 9 and the gust was of scale 10 to 11. And tropical cyclone No. 19 arose on August 28th, 1994. The average wind velocity was of the Beaufort scale 8 and gust was of scale 9. *d* represents values replaced via arc sine processing, using analysis of variance and then analysed by F and multiplex Q test. P = 0.05.

Table 6. Investigation of the impact of tropical cyclone No. 15 in 1996 on different *Macadamia intergrifolia* in the test field.

Variety	Group 1	Group 2	Group 3	Group 4	*d*	Significant difference
Ikaika (333)	87.50	100.00	62.50	100.00	75.43	a
Own Choice	100.00	100.00	100.00	100.00	90.00	a
Keauhou (246)	100.00	87.50	85.00	100.00	79.13	a
Makai (800)	100.00	100.00	60.00	100.00	80.19	a
Kau (344)	100.00	100.00	100.00	100.00	90.00	a

The wind velocity of tropical cyclone No. 15 in 1996 was 57m/s and the gust was of Beaufort force scale more than 12. *d* represents values replaced via arc sine processing, dealt with analysis of variance and then analyzed by F and multiplex Q test. P=0.05.

parts of the world. Ikaika tree began to bear fruits and yield at the age of 5. Alternatively if the orchard is under good management, it will yield the first harvest in the 4th year.

By investigation of test field and domestic trial planting orchards over large area, the yield of Ikaika at its early years was higher or remarkably higher than Keauhou, Kau and Makai, but was unable to compare with the instable yield of Own Choice. Furthermore, results show that the yield of Ikaika varied wildly in different regions and orchards. In general, the yield of orchards in Yunnan was higher than that in Guangxi and Guangdong under the same level of orchard management. And the output of orchards was greatly higher under regular management than those under less management.

Compared with the major producing areas abroad, the average yield of Ikaika per tree in China was fewer than that in America and Australia. On the contrary, domestic planting density was much higher. Therefore, the total yield per hm^2 in our country was remarkably higher than that in South Africa, basically the same to Australia, and a little lower than Hawaii. Besides, quality analysis indicated that the average weight of Ikaika kernel was lower than that of Choice, Kau, Makai and Keauhou. However, its weight of kernel and kernel ratio were approaching to the average levels in Hawaii and Australia. With 1.5% water content in kernel, the crude fat content of Ikaika was 77.34%, which is higher than Choice, Kau, Makai and Keauhou, up to the standard of high-quality kernel abroad.

The main root of *Macadamia* is not rich or strong, for the root system shallowly distributes and thus its wind resistance is weak. Under the average wind velocity of the Beaufort force scale 7 to 9 and the gust of scale 10 to 11, the orchards were heavily damaged. The damaged degree of trees of age 5 to 7 ranged from 31 to 67%. For wind velocity of tropical cyclone was 57 m/s and the gust was of Beaufort force scale more than 12, the orchards met ruinous destruction and 95% trees slanted or evenlaid flat to the ground. Though *Macadamia* has weak wind resistance, it has certain resistance against monsoon. In this case, *Macadamia* need to be planted in location protected from the wind with mild climate and shelterbelts and its yield can be considerable, which has been proved in Yunnan.

Conclusion

Ikaika (333) has a rounded crown in dark green color with big leaves and reddish-brown nut covering grainy surface. It was planted in Guangdong, Guangxi and Yunnan province at an earlier time. It grows and adapts well and the good yield can be harvested at its early years.

In the Ikaika orchards in southern China, the kernel with nutshell and without shell weighed 6.46 and 2.21 g respectively while kernel ratio and crude fat content were 34.2 and 77.34% accordingly, resulting to reach the quality levels in other main producing areas abroad like Hawaii and Australia.

Ikaika is a fruit tree poor in wind resistance. The Ikaika orchards would be heavily damaged under the average wind velocity of the Beaufort force scale more than 7. For wind velocity of tropical cyclone scales 12, the orchards would meet ruinous destruction.

Consequently, the good integrated characters of Ikaika (333) enable its extensive planting in orchards with few typhoons in southern China like Yunnan, Guangxi and Guangdong province.

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