Determining The Best Form Factor Equation for Some Tree Species Commonly Used in Egypt to Fit The Actual Volume

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ABSTRACT

The best form factor of three fast growing tree species *Corymbia citriodora, Khaya senegalensis* and *Casuarina equisetifolia* growing in Serapium Plantation, Ismailia Governorate, Egypt *were* calculated. Real form factor (*ƒ*r) was calculated and its value was statistically compared to values of Natural (*ƒ*0.1), Artificial (*ƒ*0.5), Hohenadl's (*ƒ*h), Girard (*ƒ*g), and Absolute (*ƒ*a) form factors using a paired t-test analysis . Also, real volume was measured and compared to volume calculated with different form factors. Results showed that (*ƒ*r) can be replaced by (*ƒ*h) , (*ƒ*0.1) and (*ƒ*a) in *Corymbia citriodora* and *Khaya senegalensis*. Whereas, (*ƒ*0.1) and (*ƒ*a) form factors can be used instead of (*ƒ*r) in *Casuarina equisetifolia.* In addition, results showed no significant differences between real volume and volumes derived from different form factor equations.

Key words: *Corymbia citriodora, Khaya senegalensis, Casuarina equisetifolia,* form factor equations and tree's volume.

INTRODUCTION

Corymbia citriodora, Khaya senegalensis and *Casuarina equisetifolia* are fast growing and commonly used species in different plantations located in Egypt. Serapium plantation is an example of successful plantation and the volume of these species were 31.6, 102.5 and 25.0 m^3/ha, respectively (FAO, 2012).

In order to calculate real form factor, trees should be cut down and their real volume should be calculated with measuring of pieces volume, the real form factor is calculable using real volume of trees (Khoshnava, 2006).

So, real form factor is explained as the real volume of the tree divided by the volume of a cylinder having the basal area equivalent to the tree's basal area at breast height and the same height of the tree (Zobeiri, 2000). To calculate the real form factor, the tree should be cut down and its precise volume should be measured. This is would need a time and costly. As a result, forest researchers have proposed a variety of form factor formulas other than real form factor, notably those formulated by Girard (1933) and Hohenadl (1936).

Calculation of real form factor isn't possible forever (because of its high cost) and relations of different form factors are presented with real form factor by many researchers, thus with comparison of aforementioned form factor with real form factor, it is possible for selection of its nearest and replacement of real form factor. Mexner (2000), Haghverdi (2002), Khoshnava (2006), Lnoue (2006), Socha and Kulej (2007) and Rahim Nejad (2008) obtained the same results in relation to applicable of different form factors instead of real form factor. Thus, precision of different form factors based on the site, age, and species. For instance Bruchwald and Grochowski (1977) and Bonyad and Rostami (2005) reported following form factor investigation of *Pinus elliottii* stands in 25, 27, and 30 year-ages, no significant difference was observed amongst *ƒ*0.1, *ƒ*0.5, and *ƒ*r . Thus, they proposed the application of *ƒ*0.5, instead of *ƒ*r in tree's volume assessment.

Standard volume equations are often used to estimate tree volume as a function of tree diameter and height for both routine forest measurement and for forest research purposes. One way to simplify the volume estimating procedure and at the same time improve accuracy of tree volume estimates is to make the standard volume equation sensitive to variation of stem form (Gerald, 1985). For the construction of the volume prediction model, a theoretical structure was developed using the relationship of volume with form factor, basal area and total height (Philip, 1994).

Schmid-Haas and Klemens (1981) found that volume functions using only diameter at breast height provided volume estimates with standard deviations 30 to 110 percent higher than volume functions with form included when the same instruments were used for both. It is clear that including a form variable increases the precision of tree volume equations

The aim of this study is to determine the best form factor that replace real form factor for the species under study also, to calculate volume for stand trees using form factor according to this formula (V=g×h×f), instead of cutting trees down . For that, volume of trees (m^3) was calculated using different form factors for each tree species.

MATERIALS AND METHODS

Study Area:

Serapium plantation located in Northeastern Egypt 30º, 29', 15.55" N, and 32º,14',25.43" E, within the Governorate of Ismailia, roughly 16 km. south of the town of Ismailia and next to the Suez Canal and Serapium village .Plantation area is 373.3 feddans, planted with 10 tree species (FAO, 2012) . This assessment was carried out in 2013 on three tree species are common and wildly planted in Egypt: *Corymbia citriodora* , *Khaya senegalensis* and *Casuarina equisetifolia*, which aged 5,11and 7 years old, respectively .

Tree's measurements:

10 trees of *Corymbia citriodora*, 9 trees of *Khaya senegalensis*, and 8 trees of *Casuarina equisetifolia* were randomly selected and cut down into . Total height , diameter at base, breast height (1.3 m), 10%, 30%, 50%, 70%, 90% of total height, were measured .

Tree's volume:

Each tree was cut into logs at 10%, 30%, 50%, 70%, 90% of tree's total height.

- Volume of each log was calculated with Smalian equation according to next formula:

$$V = \frac{g_1 + g_2}{2} h$$

Where: g_1, g_2 is lower and upper log base area (m^2), h is log's height (m) (Gray, 1956).

- Upper part of stem was calculated as a cone according to next equation:

$V = (1/3)\, \pi\, r^2\, h$

Where: h is log's height (m), r is log base radius.

- Calculated volume was done by this equation:

V=g×h×f

Where V is calculated volume (m^3), g is base area at dbh (m^2), h is tree's total height(m) and f is form factor (Philip, 1994).

Form factor equations

Six form factor equations were used as following:

1-Real form factor (fr)

This form factor was calculated according to next equation:

$$f_r = \frac{v}{g1.3h}$$

Where: ν is real volume (m^3), g1.3: base area at dbh (m^2) and h is tree's total height (m), (Zobeiri, 2000).

2-Artificial form factor (f0.5)

$$f_{0.5} = \frac{(d0.5)2}{(d1.3)2}$$

Where: (d0.5) is the diameter at the half total tree's height (cm), and (d1.3) is the diameter at breast height (cm), (Zobeiri, 2000).

3-Hohenadl's form factor (fh)

$$f_h = 0.2[1 + \frac{d^2 0.3}{d^2 0.1} + \frac{d^2 0.5}{d^2 0.1} + \frac{d^2 0.7}{d^2 0.1} + \frac{d^2 0.9}{d^2 0.1}]$$

Where (d 0.1, d 0.3 …. , d0.9) are tree diameters at 0.1, 0.3 …0.9 of tree's height (cm) from the bottom to top, respectively (Zobeiri, 2000).

4-Natural form factor (f0.1)

$$f_{0.1} = \frac{v}{g0.1h}$$

Where: (v) is the tree real volume (m^3), (g0.1) is the tree base area at 0.1of its total height (m^2), and (h) is tree's total height (m) (Philip, 1994).

5- Girard form factor (fg)

$$fg = \frac{D.I.b \text{ at top of First 16th F. log}}{DBH \ (o.b.)}$$

Where: D.I.b is diameter inside bark, o.b. outside bark (Girard, 1933).

6-Absolute form factor (fa)

$$fa = \frac{DOB\ (at \frac{1}{2}H + 1.3m)}{DBH}$$

Where: DOB is diameter outside bark (Lewis *et al*, 1976).

Statistical analysis:

A paired t-test statistical analysis was used to test mean's value of (fr) and other form factors. As will as a simple regression analysis was used to predict calculated volume values (Snedecor and Cochran 1974).

RESULTS

1-Form factor:

Real volume of each tree species was calculated. Real form factor (fr), Natural (f0.1), Artificial (f0.5), Hohenadl's (fh), Girard (fg), and Absolute (fa) form factors were calculated. A paired t-test analysis was done between real form factor and other form factors as shown in Table (1) to determine which form factor can be used instead of real form factor. Results showed a highly significant differences at probability level α = 0.01, between *Crombya citredora* real form factor (0.54) and both of Artificial (0.47), Girard (0.51) form factors. Whereas, Hohenadl's form factor (0.77), Natural (0.47), and, Absolute form factor (0.58) were not significant. Real form factor of *Khaya senegalensis* showed the same trend as *Crombya citredora*. So, real form factor of Khaya *senegalensis* (0.55) displayed highly significant differences with Artificial form factor (0.45) at probability level α = 0.01 and significant at probability level α = 0.05 with Girard form factor (0.66). While, Hohenadl's (0.47), Natural (0.52), and Absolute (0.53)

Form Factors showed no significant differences with real form factor. Whereas, the mean of real form factor of *Casuarina equisetifolia* (0.47) showed highly significant differences at probability level α= 0.01 with Artificial (0.34) and Girard (0.59) form factors, significant at probability level α = 0.05 with Hohenadl's form factor (0.41) and showed no significant differences with Natural (0.45) and Absolute (0.43) form factors, Table (2) presented means of form factors.

2- Tree's volume:

Tree's volume (m^3) were calculated using different form factors for each tree species. Means of tree's true volume were measured and compared with tree's volume derived by different form factors as presented in Table (3). True volume (m^3) of *Crombya citredora* (0.1) differs significantly at probability level α = 0.01 with volume's derived from artificial (0.09) and Girard (0.15) form factors , but was not significant with volumes derived from Hohenadl's (0.09), natural (0.1), and, absolute (0.11) form factors.

Also, true volume (m^3) of *Khaya senegalensis* (0.14m^3) showed a highly significant differences with volumes derived from artificial form factor (0.12 m^3), significant differences with volume derived from both Hohenadl's (0.13 m^3) and Girard (0.20 m^3) form factors but there were no significant differences between true volume and that derived by natural (0.15 m^3), and, absolute (0.14 m^3) form factors.

While, true volume of *Casuarina equisetifolia* (0.12m^3) showed highly significant differences with the volume calculated by Artificial form factor (0.09 m^3), and significant differences for volume calculated by Girard form factor (0.17 m^3). Moreover, result showed no significant differences between volume derived from Hohenadl's (0.11 m^3), natural (0.12 m^3), and absolute (0.12 m^3) form factors. Table (2) presents means of volumes derived by different form factors.

Volume prediction equation:

Fig.(1, 2, 3) presented volume prediction equation using form factors that can precisely predict the true form factor for tree species under study.

So that, for *Crombya citriodora* real volume (m^3) can be predicted using volume derived by Hohenadl's , natural and absolute form factors with R^2 0.72, 0.68 and 0.89, respectively (Fig.1). While, in case of *Khaya senegalensis* real volume (m^3) can be predicted using both of volume calculated by natural and absolute form factors, since it displayed, R^2 of 0.96 and 0.98, respectively, (Fig. 2). Also, volume derived from Hohenadl's, natural, and, absolute form factors used for real volume prediction with R^2 0.91, 0.93 and 0.94, respectively for *Casuarina equisetifolia* (Fig. 3).

DISCUSSION

Results indicated that real form factor is 0.54, 0.55 and 0.47 for *Crombya citriodora*, *Khaya senegalensis* and *Casuarina equisetifolia*, respectively. This result matches with FAO (1981) that use 0.52 form factor value for *Eucalyptus citriodora*. Also, Botman (2010) mentioned that 0.51 is commonly used for Eucalyptus species growing in Southern Africa. While, Clément (1982) used 0.77 as a form factor for *Khaya senegalensis* , and El-Osta *et al*, (1992) who investigated *Casuarina equisetifolia* and used 0.39 as a form factor value.

While, results of the best form factor indicated that we can replace real form factor of *Crombya citriodora* aged 5 years and *Khaya senegalensis* aged 11 years by Hohenadl's, Natural and Absolute form factor , but in *Casuarina equisetifolia* that aged 7 years natural and absolute form factor can be used as a real form factor. This result is combatable with Fadaei ,*et al*. (2008) for Hohenadl's form factor, who found that no significant difference between real form factor and both of artificial and Hohenadl's form factors in *Pinus taeda* . Also, for tree's volume he found no significant difference can be observed between the real volume and the estimated volumes derived from Hohenadl and Artificial form factor at %5 level of probability. In addition, Hassan Kalantari, *et al* (2012), found that real from factor can be replaced by natural form factor in *Cupressus sempervirence*.

The important point is that several form quotients defined by Hohenadl's method are highly correlated with volume (Heger 1965, Pollanshiitz 1966, Assman 1970). On the other hand, Pollanschultz (1966) examined form functions and volume equations derived from them. He used the variables DBH, total height, and stem diameters at "0.1, 0.3, 0.5, D.7 and D.9 of total height. He found also that combinations of these primary variables effectively reduce standard deviation of form-function equations. Schmid-Haas and Klemens (1981) found that including upper stem diameter is very important for tree volume estimation. So, it is clear that including a form variable increases the precision of tree volume equations.

Anyway, the degree of accuracy to substitute real form factor by another one vary according to many factors, such as, site, age and species. So, form factor equation capability to replace the real form factor doesn't match its preference at the trees during all growth levels and ages. Therefore, results in this research are restricted to studied area, species and age. That's because of tree shape highly varies due to its growth nature (Zobeiry, 2000; Zobeiry and Najarian , 2002 and Namiranian 2007).

Table 1: A paired t-test analysis of real and different form factors for the three species

Tested Pairs	Degree of Freedom	Mean difference	Std. Dev.	Standard error	Minimum	Maximum	t Value	Pr > |t|
				Corymbia citriodora				
fr-f_{05}	9	0.071	0.0446	0.0141	0	0.13	5.04	0.0007
fr-fh	9	0.076	0.1129	0.0357	-0.02	0.38	2.13	0.0621
fr-f_{01}	9	0.027	0.1269	0.0401	-0.08	0.37	0.67	0.5181
fr-fg	9	-0.224	0.0602	0.019	-0.33	-0.1	-11.76	<.0001
fr fa	9	-0.031	0.0725	0.0229	-0.09	0.16	-1.35	0.2093
				Khaya senegalensis				
fr-f_{05}	8	0.1078	0.071	0.0237	0.02	0.25	4.55	0.0019
fr-fh	8	0.0889	0.1617	0.0539	-0.08	0.5	1.65	0.1377
fr-f_{01}	8	0.0244	0.1723	0.0574	-0.19	0.45	0.43	0.6817
fr-fg	8	-0.106	0.1422	0.0474	-0.27	0.15	-2.23	0.0566
fr fa	8	0.03	0.0614	0.0205	-0.03	0.16	1.46	0.1811
				Casuarina equisetifolia				
fr-f_{05}	7	0.135	0.06	0.0212	0.03	0.2	6.36	0.0004
fr-fh	7	0.0675	0.0696	0.0246	-0.07	0.15	2.74	0.0289
fr-f_{01}	7	0.0113	0.0669	0.0236	-0.12	0.09	0.48	0.6486
fr-fg	7	-0.115	0.0941	0.0333	-0.29	0.02	-3.46	0.0106
fr fa	7	0.0463	0.0721	0.0255	-0.11	0.12	1.81	0.1125

Table 2: Means of different form factors and volumes for the three species

Tree species	No. of trees	Tree's age	Mean of total height (m)	Mean of Dbh (cm)	Mean of form factor						Mean of tree's volume (m^3)					
					fr	*f0.5*	*fh*	*f0.1*	*fg*	*fa*	Vr	V0.5	Vh	V0.1	Vg	Va
Cromlya citriodora	10	5	15	12.5	0.54	0.47	0.47	0.51	0.77	0.58	0.1	0.09	0.09	0.1	0.15	0.11
Khaya senegalensis	9	11	11.75	16.5	0.55	0.45	0.47	0.52	0.66	0.53	0.14	0.12	0.13	0.15	0.20	0.14
Casuarina equisetifolia	8	7	12.35	15.4	0.47	0.34	0.41	0.45	0.59	0.43	0.12	0.09	0.11	0.12	0.17	0.12

Table 3: A paired t-test analysis of real volume and volumes derived by different form factors for the three species

Tested Pair	Degree of Freedom	Mean difference	Std Dev	Standard error	Minimum	Maximum	t Value	Pr > |t|
				Corymbia citriodora				
Vr – V0.5	9	0.0129	0.009	0.0028	0.0015	0.0291	4.53	0.0014
Vr - Vh	9	0.0136	0.0254	0.008	-0.007	0.0842	1.69	0.1258
Vr – V0.1	9	0.0041	0.0287	0.0091	-0.023	0.0827	0.46	0.6595
Vr - Vg	9	-0.047	0.0305	0.0096	-0.104	-0.015	-4.84	0.0009
Vr - Va	9	-0.006	0.016	0.0051	-0.025	0.0357	-1.09	0.3038
				Khaya senegalensis				
Vr – V0.5	8	0.0304	0.0232	0.0077	0.0023	0.0643	3.92	0.0044
Vr - Vh	8	0.0161	0.016	0.0053	-0.01	0.0465	3.02	0.0165
Vr – V0.1	8	-0.001	0.0197	0.0066	-0.026	0.0421	-0.16	0.8803
Vr - Vg	8	-0.047	0.0567	0.0189	-0.127	0.014	-2.50	0.0368
Vr - Va	8	0.006	0.0129	0.0043	-0.01	0.0311	1.41	0.1969
				Casuarina equisetifolia				
Vr – V0.5	7	0.0298	0.0172	0.0061	0.0091	0.0562	4.91	0.0017
Vr - Vh	7	0.0131	0.0245	0.0087	-0.034	0.0514	1.51	0.1750
Vr – V0.1	7	-0.002	0.0266	0.0094	-0.062	0.0279	-0.16	0.8770
Vr - Vg	7	-0.043	0.0523	0.0185	-0.156	0.0017	-2.33	0.0529
Vr - Va	7	0.0046	0.0251	0.0089	-0.056	0.0215	0.52	0.6185

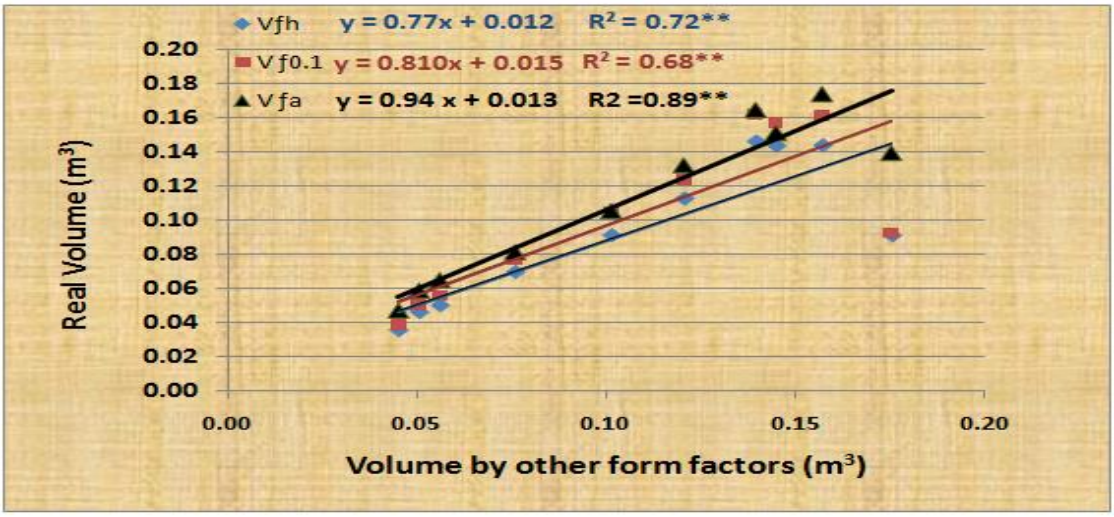

Fig. 1: Relation between real volume(m^3) and volume by other from factors in *Crombya citredore*

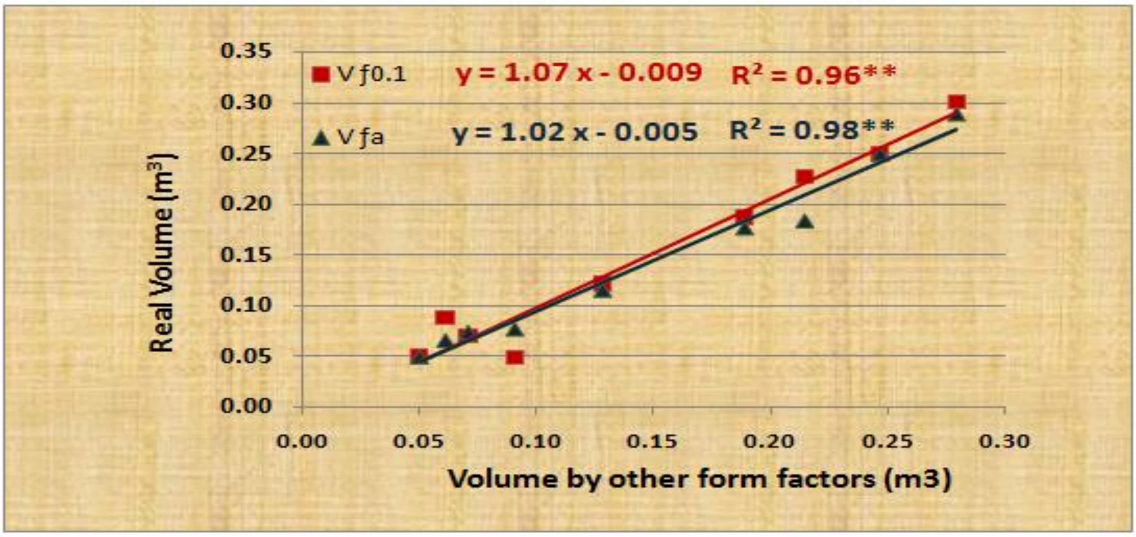

Fig. 2: Relation between real volume(m^3) and volume by other from factors in *Khaya senegalensis*

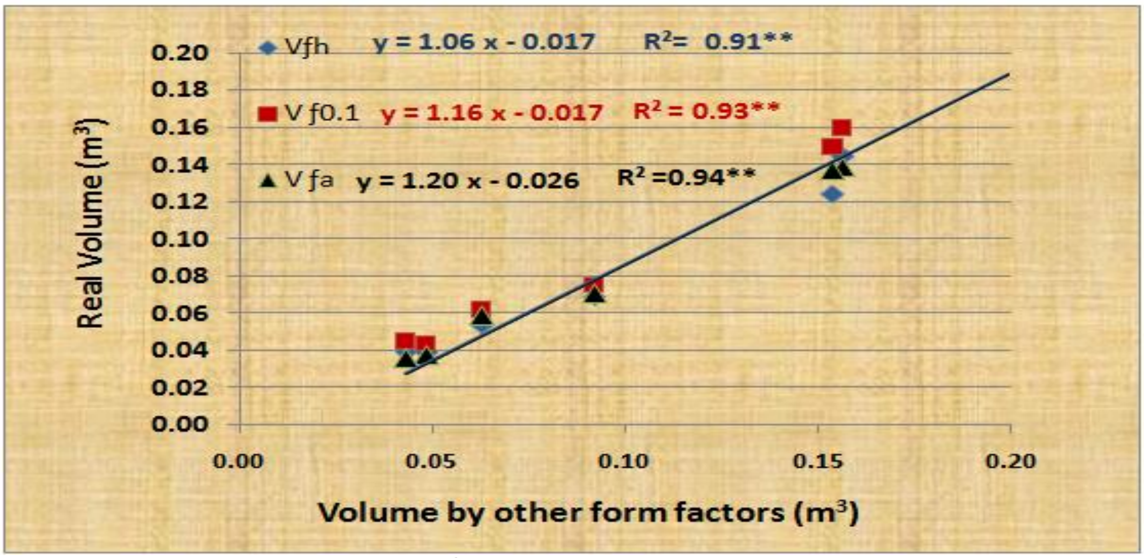

Fig. 3: Relation between real volume(m^3) and volume by other from factors in *Casuarina equisetifolia*

CONCLUSION

For this study, we can conclude that real form factor is 0.54, 0.55 and 0.47 for *Crombya citredora*, *Khaya senegalensis* and *Casuarina equisetifolia*, respectively. Whereas, the best form factor equation that can be replaced real form factor of *Crombya citredora* aged 5 years and *Khaya senegalensis* aged 11 years is (fh), (f0.1) and (fa) form factors. But, for *Casuarina equisetifolia* aged 7 years (f0.1) and (fa) form factors can be used.

In addition, results showed that volumes yielded from (fh), (f0.1) and (fa) in *Crombya citriodora* and *Casuarina equisetifolia*, volume derived by (f0.1) and (fa) for *Khaya senegalensis* were not significantly different with the real volume.

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الملخص العربى

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اسكندرية– جمهورية مصر العربية

تم حساب معادلة افضل معامل شكل لثلاثة انواع شجرية سريعة النمو والمزروعة فى غابة سيرابيوم وهى الكافور الليمونى, كايا سينجالينسيس والكازوارينا ذيل الحصان. تم تقدير معامل الشكل الحقيقى(*f*r) ومقارنة متوسطه احصائيا مع متوسطات كلا من معامل الشكل الطبيعى(*f*0.1), الصناعى(*f*0.5), هوهندال(*f*h), جيرالد(*f*g), والمطلق(*f*a)٠ ايضا تم تقدير الحجم الحقيقى ومقارنته مع متوسطات الحجوم المحسوبة بمعاملات الشكل المختلفة. وقد اظهرت النتائج ان معامل الشكل الحقيقى لكل من الكافور الليمونى والكايا سينجالينسيس يمكن استبداله بكلا من (*f*h), (*f*0.1), (*f*a). بينما يمكن استبدال معامل الشكل الحقيقى للكازوارينا ذيل الحصان بكلا من(*f*a), (*f*0.1). واظهرت النتائج انه لا يوجد اختلافات معنوية بين الحجم الفعلى للانواع تحت الدراسة والاحجام المحسوبة باستخدام معاملات الشكل المختلفة.

الكلمات الدليلية: الكافور الليمونى, الكايا, كازوارينا ذيل الحصان, معادلات معامل الشكل والحجم الشجرى.