Appendix 5.21

Paper in press

Title: Domestication potential of Marula (*Sclerocarya birrea* subsp *caffra*) in South Africa and Namibia: 2. Phenotypic variation in nut and kernel traits

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Domestication potential of Marula (*Sclerocarya birrea* subsp *caffra*) in South Africa and Namibia: 2. Phenotypic variation in nut and kernel traits.

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ABSTRACT

As part of a wider study, twenty four ripe fruits were collected from each of 55 marula (*Sclerocarya birrea*) trees in Bushbuckridge, South Africa and from 63 trees from the North Central Region of Namibia. The South African trees were in farmers's fields (20), communal land (29) and natural woodland (14), at three sites: Acornhoek road, Allandale/Green Valley and Andover/Wits Rural Facility. The Namibian trees were all from farmers' fields in three areas: North east (20), North west (10) and West (25). The nuts were removed from the fruit flesh, sun dried and weighed. The kernels were then extracted, counted and their total mass determined. The identity of each nut and its kernels was maintained throughout the series of assessments. Analysis of this indicates the extent of the tree-to-tree variation found in the different traits, its frequency distribution and the patterns dry matter partitioning among the nut components of different trees.

Mean nut, shell and kernel mass were not significantly different between the two countries. There were highly significant differences in mean nut, shell and kernel mass, as well as kernel number, between sites in South Africa and in mean shell and kernel mass, between areas in Namibia, but not in fruit or nut mass. Mean kernel mass was significantly greater in fruits from farmers' fields than from communal land or natural woodland in South Africa. Within all sites, in both South Africa and Namibia, there was highly significant and continuous variation between individual trees in all the morphological traits of nuts and kernels that were measured.

The small and valuable kernels constitute a small part of the nut. There can be 4 kernels per nut, but even within the fruits of the same tree, kernel number can vary between 0-4, suggesting variation in pollination success. Nevertheless there is also clearly a genetic component to the kernel variation. The nuts and kernels of the Namibian trees were compared with the fruits from one superior tree ('Namibian Wonder').

INTRODUCTION

Sclerocarya birrea (A. Rich.) Hochst. subsp. *caffra* (Sond.) Kokwaro is one of the traditionally important indigenous fruits of southern Africa, which in recent years has also become commercially important as its fruits and other products have entered local, regional and international trade (Shackleton *et al*., 2002a; Wynberg *et al*., in press). The growing commercial importance of this traditionally valued fruit tree has led to several domestication initiatives in South Africa (Holtzhausen *et al.* 1990), Botswana (Taylor *et al*., 1995; 1996), and outside the region in Ben Gurion University in the Negev, Israel (Nerd and Mizrahi 1993; Mizrahi and Nerd, 1996). In addition, in 1995, the International Centre for Research in Agroforestry (ICRAF), now the World Agroforestry Centre, initiated germplasm collection and field trials, aimed at helping subsistence farmers to produce and grow improved planting stock (Maghembe, *et al*., 1995; 1998; Leakey and Simons, 1998). These collections provide material for conservation and future utilisation.

Initiatives in four regions of Africa are developing techniques and strategies for the domestication and commercialisation of agroforestry trees producing non-timber forest products (NTFPs) for integration into farmland. This is seen as an approach to poverty alleviation (Leakey and Simons, 1998; Poulson and Poole, 2001) and the environmental rehabilitation of degraded farmland (Leakey, 1999a; 2001). The present study, as part of a resource inventory, quantifies the phenotypic variation in fruit, nut and kernel traits in marula (*S. birrea* ssp. *caffra*), within the framework of a broader project examining the benefits and opportunities for domesticating and commercialising the fruits and kernel oil of marula in South Africa and Namibia. Chemical analysis of fruits and kernels has indicated the potential of marula nutritionally, and as a source of high quality oil, rich in tocopherol (Leakey, 1999b). Recent collections of marula fruits and nuts from individual trees in Makueni district of Kenya have been analysed for a wide range of nutritional compounds and minerals, and the kernels were rich (56-64%) in oils (Thiong'o *et al*., 2002). Kernels are traditionally used extensively in some areas in southern Africa (eg. Inhambane, Mozambique; Owambo, Namibia; KwaZulu-Natal, South Africa), but little used in other areas (eg. Kavango, Namibia; Northern Province, South Africa) as a nutritious food, a meat preservative and as a skin moisturizing agent (Shackleton *et al*., 2002a; Wynberg *et al*., in press). The oil is also starting to become important in the cosmetics industry (Wynberg *et al*., in press).

METHODS AND MATERIALS

Marula fruits fall from the tree just before they ripen. As reported for a study of marula fruit characterization (Leakey *et al*., in press a) ripe, unblemished fruits were collected from beneath the crown of marula trees in villages in Limpopo Province, South Africa (Bushbuckridge) and Namibia (North Central Region), between 21st January and 5th February 2002 (Table 1). In South Africa, marula trees were found in farmers' fields, in communal grazing land, and in natural woodland, while in Namibia, fruiting trees were only found in farmers' fields. In general, fruits were usually plentiful and so were collected at random sampling from four quadrants (6 fruits per quadrant), according to the procedures developed by Leakey *et al.* (2000). Fruits from each tree were separately bagged and labelled for use in the study of fruit characteristics (Leakey *et al*., in press a) and for the present study. As soon as possible (usually 2-3 days later), the nuts were soaked and scrubbed to remove the flesh before being set in the sun to dry for about 10 hours. When dry, the nuts were weighed and numbered still in the same order as for the study of fruit traits (Leakey *et al*., in press a) so that their identity was maintained for subsequent cracking and kernel removal. The kernels were then weighed using a laboratory (0.001g) balance (Mettler Toledo PB 3002) and packaged for later oil extraction. Shell mass was derived by difference (Nut – kernel = shell).

Table 1. Origins of trees sampled in South Africa and Namibia, by village and land use (for more details see Leakey *et al*., in press a).

	Natural woodland	Communal land	Farmers fields	Total
South Africa				
Bushbuckridge				
Acornhoek road		29 trees	6 trees	35 trees
Allandale			10 trees	10 trees
Green Valley			4 trees	4 trees
Andover	11 trees			11 trees
Wits Rural Facility	3 trees			3 trees
TOTAL	**14 trees**	**29 trees**	**20 trees**	**63 trees**
Namibia				
North west				
Omanjoshi, Omankango, Okamukwa			20 trees	20 trees
North east				
Onangwe, Oilyateko, Elope			10 trees	10 trees
West				
Tsandi, Onesi, Eunda, Ongosi			25 trees	25 trees
TOTAL			**55 trees**	**55 trees**

In addition, one fruit sample was collected from the Mhala Development Centre (MDC), a project of the Mineworker’s Development Agency in Bushbuckridge that is processing fruits for fruit juice and for kernel oil. A further sample from a superior tree (‘Namibian Wonder’) was analysed in the same way. The origin of this tree is not disclosed in order to protect the villagers’ rights to this germplasm.

Analysis of Variance, Duncan’s Multiple Range tests, and tests for skewness and kurtosis have been using SPSS 10.0 for Windows.

Oil extraction from the South African and Namibian kernels was done by Analytical Laboratory Services in Windhoek using a petroleum ether extract, according to the Deutsche Einheitsmethoden zur Untersuchung van Fetten, Fettprodukten, Tensiden und Verwandten Stoffen (Method code = DGF 8-15 (B7)) method.

RESULTS

Variation between sites

Comparison of mean values between South Africa and Namibia.
Mean nut, shell and kernel mass were not significantly different between the two countries (Table 2).

Comparison of mean values between sites in South Africa
There were highly significant differences in mean nut, shell and kernel mass, as well as kernel number, between sites in South Africa (Table 3). Fruits from Allandale were typically the largest. The trees from Acornhoek road were located in both farmer's field and communal land, while those from Allandale and Green Valley were only in farmer's fields. Trees from Andover and Wits Rural Facility were in natural woodland. An analysis by land use follows.

Comparison of mean values between land uses in South Africa
Mean kernel mass was significantly greater in fruits from farmers' fields than from communal land or natural woodland in South Africa (Table 4). The commercially undesirable trait of a large shell mass were also significantly greater in fruits from farmer's fields than in fruits from communal land, although not significantly different from those from natural woodland.

Comparison of mean values between sites in Namibia
There were significant differences in mean shell and kernel mass, between areas in Namibia (Appendix 1.4), but not in nut mass (Table 5).

Variation within sites
Within all sites, in both South Africa and Namibia, there was highly significant variation between individual trees in the morphological traits of nuts and kernels that were measured.

Nut and kernel mass
Tree-to-tree variation in nut mass was statistically significant in all landuses in South Africa (Figure 1a) and in all sites in South Africa and Manibia (e.g. Figure 1b), but was only weakly related to fruit mass (Figures 1a and b). The nuts of marula are mostly composed of shell, with the important kernels making up only 3.5-14.8% of the mass in South Africa and 2.8-16.0% in Namibia. Mean kernel mass per nut is the sum of the mass of between 1-4 individual kernels, and while there is continuous variation in mean kernel mass per nut, this is not matched by the number of kernels per nut (Figures 2a and b). The mean kernel mass of 'Namibian Wonder' was more than twice that of the mean kernel mass per nut of other trees. However, the nut mass:kernel mass ratio was similar to that of trees from the West district, but was less that that of trees from the North east and North west (Table 5). In South Africa, the nut mass:kernel mass ratio was greatest in the natural woodland population and least in farmers fields.

Number of kernels
There was significant variation between trees in the mean number of kernels per nut (Figures 2a and b). Kernel number per nut also varied within individual tree fruit samples from 0 to 4 kernels per fruit (Figures 3a and b). Nuts with a high proportion of 0 kernels were among those with the lowest mean kernel mass per fruit, while those with 4 kernels were among those with the highest mean kernel mass. Nuts with 2-3 kernels were the most common. In both South African and Namibian fruits the mean

mass of individual kernels declined, the greater the number of kernels per nut (Figures 3a and b). The mean mass of quadruple kernels in South African trees was greater than for other groups, but the sample size was n=2, and consequently, can be ignored. In ‘Namibian Wonder’, the mean mass of individual kernels was constant, regardless of the number of kernels per nut (Figure 3b).

Oil content

The percentage oil content of both South African and Namibian kernels were not significantly different between land uses or site (South African range = 44.7-72.3%; Namibian range = 50.2-63.8%). The oil content of ‘Namibian Wonder’ kernels was not dissimilar to that of other trees.

In South Africa, the oil yield per fruit (% oil content x kernel mass) was significantly greater in fruits from farmers’ fields (Figure 4a), while in Namibia it was significantly greater in fruits from West district than in those from the North east (Figure 4b). The oil yield of ‘Namibian Wonder’ was very much greater than from any other tree (Figures 4a and b).

A few kernel samples have been sent for analysis of their fatty acid profiles to determine whether there are qualitative differences in oil samples from different trees. The results have not been received yet.

Frequency distribution

The data for nut and kernel mass of each tree in each site displayed considerable variance about its mean. The frequency distribution of the South African site data sets, and of the overall country mean were close to a normal distribution (Table 6). However, when the nut and kernel data for South African trees were aggregated by land use, the frequency distributions for natural woodland remained close to normality (skewness = -0.03 to 0.83), but that for communal lands and farmers fields had a tendency towards being positively skewed (Figures 5a and b), the latter also having some bi-modality (especially kernel mass). In the Namibian data, the distribution pattern of the same traits had similar distributions (Table 6), but the kernel mass in populations from the West had a small number of large kernels (Figure 6b).

DISCUSSION

This study quantifies the variation in dry matter partitioning between constituent parts of marula nuts for the first time, and provides good fundamental knowledge about the range of variation in several important traits across geographically separated, as well as environmentally and culturally different sites, as well as across different landuses in South Africa. Unlike the skin, flesh and juice components of marula fruits (Leakey *et al.*, in press a), the mean nut, shell and kernel mass were similar in South Africa and Namibia. However, there were differences in kernel mass between all sites and landuses, and differences in nut and shell mass between sites in South Africa and in just shell mass in Namibia, which may reflect differences in the environment, in anthropogenic activity or evolutionary responses to different survival/regeneration pressures.

Evidence from the frequency distribution data of marula nut and kernel mass suggests that as in west African indigenous fruits (Leakey *et al.*, in press b), subsistence farmers have initiated the domestication process. However, in marula, the process does not seem to be well advanced, although several data sets (eg. nut and kernel mass from the West of Namibia and from trees in farmers' fields in South Africa) are positively skewed (with a tendency to bimodality). This suggests that farmers, through truncated selection over several generations, have achieved at least the second stage of domestication (Leakey *et al.*, in press b).

The very considerable tree-to-tree variation in nut and kernel characteristics in marula mirror those found in the fruit traits (Leakey *et al.*, in press a) and are consistent with results on nut and kernel traits from other indigenous fruit trees, such as *Irvingia gabonensis* (Atangana *et al.*, 2001; 2002; Anegbeh *et al.*, in prep). There is, however, one major difference in that *I. gabonensis* typically has a single kernel within the nut, while marula has up to four kernels per nut. Nevertheless, there was extensive phenotypic variation in dry matter allocation to kernels in both species, that is probably genetic in origin. Interestingly, the mean kernel mass of 'Namibian Wonder' was more than twice that of the mean kernel mass per nut of most other trees, indicating the potential for individual tree selection for cultivar development.

In marula, the number of kernels per nut greatly affected the total kernel mass per nut/fruit, with an indication that although individual kernel mass is relatively constant, there is a slight reduction in mean kernel mass as the number of kernels per nut increases. This was particularly clear in the Namibian data set (in the South African case only 2 nuts had four kernels and so the mean is not comparable with that for nuts with 1-3 kernels). Competition between kernels for assimilates is suggested by this declining mean mass of individual kernels as the number of kernels per nut increases (Figures 3a and b). The constant mean mass of individual kernels in 'Namibian Wonder', regardless of the number of kernels per nut (Figure 3b), indicates that potentially, all kernels can have the same mass and that the partitioning of dry matter does not have to be limited by competition. Clearly this would be a desirable trait in any domesticated cultivars. The finding that nuts with single kernels do not have much larger kernels than nuts with more kernels indicates that selection for nuts with a single kernel is not an appropriate strategy.

The varying number of kernels per nut (0 to 4 kernels per fruit) within individual tree fruit samples, indicates that this trait is affected by some environmental factors and is not only a genetic trait. A possible explanation for this variability in kernel number per nut is that not all ovules were successfully pollinated, perhaps because of a lack of pollinators, excessive distances between trees, or inappropriate weather for pollinator activity. If poor pollination success is the cause of low kernel numbers, then the siting of beehives in male marula trees might be advantageous.

Typically kernel mass is about 10% of nut mass (Wynberg *et al.*, in press), but this study found a range from 2.8 - 16% between individual trees. Ideally, in developing marula as a nut crop, selection would seek to increase the partitioning of dry matter from shell to kernel, with the additional benefit of perhaps making the nut easier to crack. However, there was little evidence from this study to suggest that shell mass can be greatly reduced, although the shell:kernel ratio of nuts from the West and of 'Namibian Wonder' was considerably lower (8.0) than in nuts from the North west

(15.4), offering some hope that shell mass could be reduced to some extent. The similarity in nut:kernel ratio between 'Namibian Wonder' and many other trees, despite its abnormally large fruit is interesting as it demonstrates that 'Namibian Wonder' is normal in terms of the relative partitioning of dry matter between different components of the nut.

When the marketable product is only a small proportion of the overall production (ie. represents a low Harvest Index) it is important to maximize its value, or to derive a number of different products from the crop at the same time. In marula, both the fruit pulp and the kernels are marketable, and while the fruits (pulp, juice, shell and kernel) are fairly small, they can be numerous when grown in farmers' fields (up to 128610 fruits have been recorded from a single tree – Shackleton *et al*, 2002b). The fruit pulp (skin and juice) is used to make local beer (Shackleton et al. ???), and is being marketed as a fruit juice and fermented as an ingredient in 'Amarula' liqueur (Mander ???). Prices of kernels ?? A parallel study (Leakey *et al*., in press) has examined the tree-to-tree variation in fruit traits and found very extensive variation and, thus, the potential for genetic selection. This study has identified equivalent variation in kernel production. Kernels are both a nutritious local food additive, rich in proteins, and a source of oils for a variety of uses from cooking to cosmetics. This study has determined that there is considerable tree-to-tree variation in oil content of kernels (Namibia = 50 - 64%: South Africa = 45 - 72%), which when combined with the variation in kernel mass (0.147- 1.144g) results in large differences in oil yield per fruit (0.01 – 0.71g). The superiority of 'Namibian Wonder' in oil yield indicates the opportunity for genetic selection, an opportunity which could be further improved by increasing the mean number of kernels per nut, through better pollination, as described above. Currently, in the cosmetics industry kernel oil is priced at ….. (US$?), but there may be a premium for oil quality, thus it is now important to determine whether or not there is tree-to-tree variation in the fatty acid and … compositions of the oils.

To meet the evident potential of developing cultivars of marula, it is not yet clear to what extent cultivar development in marula needs to be separately focussed on selection for fruit and kernel traits, as in *I. gabonensis* from west Africa (Leakey *et al*., 2000; Atangana *et al*., 2002), or whether selection could be on the basis of the combination of fruit and kernel traits. This will be examined elsewhere (Leakey, in preparation).

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FIGURE LEGENDS

Figure 1a. Nut (shell + kernel) mass (g) of marula (*Sclerocarya birrea*) by landuse in Bushbuckridge, South Africa (in order of increasing fruit mass)

Figure 1b. Nut (shell + kernel) mass (g) of marula (*Sclerocarya birrea*) by site in North Central Region, Namibia (in order of increasing fruit mass)

Figure 2a. Number of kernels per nut in marula (*Sclerocarya birrea*) in Bushbuckridge, South Africa (in order of increasing kernel mass/nut)

Figure 2b. Number of kernels per nut in marula (*Sclerocarya birrea*) in North Central Region, Namibia (in order of increasing kernel mass/nut)

Figure 3a. Mean total and individual kernel mass in nuts of marula (*Sclerocarya birrea*) with 1-4 kernels per nut, in Bushbuckridge, South Africa

Figure 3b. Mean total and individual kernel mass in nuts of marula (*Sclerocarya birrea*) with 1-4 kernels per nut, in North Central Region, Namibia

Figure 4a. Oil content (%) and yield per nut of marula (*Sclerocarya birrea*) by landuse in Bushbuckridge, South Africa (in order of increasing oil content)

Figure 4b. Oil content (%) and yield per nut of marula (*Sclerocarya birrea*) by site in North Central Region, Namibia (in order of increasing oil content)

Figure 5a. Frequency distribution (%) of nut mass of marula (*Sclerocarya birrea*) by landuse in Bushbuckridge, South Africa.

Figure 5b. Frequency distribution (%) of kernel mass of marula (*Sclerocarya birrea*) by landuse in Bushbuckridge, South Africa.

Figure 6a. Frequency distribution (%) of nut mass of marula (*Sclerocarya birrea*) by site in North Central Region, Namibia

Figure 6b. Frequency distribution (%) of kernel mass of marula (*Sclerocarya birrea*) by site in North Central Region, Namibia

Table 2. Comparison of marula (*Sclerocarya birrea*) nut traits between South Africa and Namibia

Trait	South Africa	Namibia	Probability
Nut mass	3.96	4.06	P=0.040
Kernel mass	0.34	0.36	P=0.027
Shell mass	3.62	3.68	P=0.212
No of kernels	1.54	1.50	P=0.286

Table 3. Comparison of marula (*Sclerocarya birrea*) nut traits across South African sites

Trait	Site				Probability
	Acornhoek road	Andover and Wits Rural Facility	Allandale	Green Valley	
Nut mass	3.8 b	4.2 a	4.2 a	3.6 b	P = <0.001
Kernel mass	0.31 c	0.32 c	0.45 a	0.38 b	P = <0.001
Shell mass	3.5 b	3.9 a	3.7 a	3.2 c	P = <0.001
No of kernels	1.4 b	1.4 b	1.8 a	1.8 a	P = <0.001

Table 4. Comparison of marula (*Sclerocarya birrea*) nut traits across land use systems in South Africa

Trait	Site			Probability
	Farmer's fields	Communal land	Natural woodland	
Nut mass	4.18 a	3.68 b	4.20 a	P = <0.001
Kernel mass	0.42 a	0.30 b	0.32 b	P = <0.001
Shell mass	3.78 a	3.39 b	3.87 a	P = <0.001
No of kernels	1.81 a	1.40 b	1.44 b	P = <0.001

Table 5. Comparison of marula (***Sclerocarya** birrea*) nut traits across Namibian sites

Trait	Site			Probability
	North west	North east	West	
Nut mass	4.11 a	4.02 a	4.04 a	P=0.666
Kernel mass	0.25 c	0.32 b	0.45 a	P = <0.001
Shell mass	3.86 a	3.55 b	3.59 b	P=0.002
No of kernels	1.21 b	1.68 a	1.68 a	P = <0.001
Shell:kernel ratio	15.4	11.1	8.0	

Table 6. Frequency distributions of marula (*Sclerocarya birrea*) nut trait data from different sites and land uses in South Africa and Namibia

Skewness / Kurtosis = 0 = normality (+ skewness = a long tail of high values - skewness = a long tail of low values
+ kurtosis = tails longer than normality - kurtosis = tails shorter than normality)

SOUTH AFRICA

	Allandale and Green Valley				**Andover and WRF**				**Acornhoek Rd**			
	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis
Nut mass	4.04	0.06	0.59	0.33	3.82	0.04	0.82	1.78	4.20	0.08	0.83	0.65
Kernel mass	0.43	0.01	0.28	0.21	0.31	0.07	0.55	0.52	0.32	0.01	0.31	-0.38
Shell mass	3.60	0.05	0.28	0.50	3.53	0.04	0.79	1.87	3.88	0.07	0.93	0.79
Kernel No	0.43	0.01	0.28	0.21	1.45	0.03	0.05	-0.49	1.44	0.05	-0.03	-0.79

	Farmers fields				**Communal land**				**Natural woodland**			
	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis
Nut mass	4.18	0.05	1.10	2.16	3.68	0.04	0.41	0.37	4.20	0.07	0.83	0.65
Kernel mass	0.42	0.01	0.41	0.26	0.30	0.01	0.42	0.17	0.32	0.01	0.31	-0.38
Shell mass	3.78	0.05	1.00	2.54	3.39	0.04	0.38	0.47	3.87	0.07	0.83	0.89
Kernel No	1.81	0.04	-0.13	-0.64	1.40	0.03	0.06	-0.47	1.44	0.05	-0.03	-0.79

NAMIBIA

	Namibia NE				**Namibia NW**				**Namibia W** (excluding Namibian Wonder)			
	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis
Nut mass	4.02	0.08	0.26	-0.68	4.11	0.05	0.41	-0.21	3.77	0.05	1.22	1.56
Kernel mass	0.32	0.01	0.70	0.89	0.25	0.01	0.54	-0.07	0.43	0.01	0.64	0.97
Shell mass	3.55	0.08	0.30	-0.77	3.86	0.05	0.48	-0.17	3.34	0.05	1.25	1.61
Kernel No	1.68	0.05	0.30	-0.59	1.21	0.04	0.26	-0.64	1.63	0.03	-0.17	0.09

SOUTH AFRICA AND NAMIBIA

	South Africa				**Namibia**				**South Africa and Namibia**			
	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis	Mean	SE	Skewness	Kurtosis
Nut mass	3.96	0.03	0.80	1.33	4.06	0.04	1.96	6.66	4.01	0.03	1.58	5.50
Kernel mass	0.34	0.01	0.06	0.13	0.36	0.01	1.12	2.75	0.35	0.004	0.86	1.95
Shell mass	3.62	0.03	0.80	1.57	3.68	0.04	1.86	5.95	3.65	0.02	1.50	4.96
Kernel No	1.54	0.02	-0.02	-0.61	1.50	0.02	-0.02	-0.26	1.52	0.02	-0.02	-0.46

Figure 1a

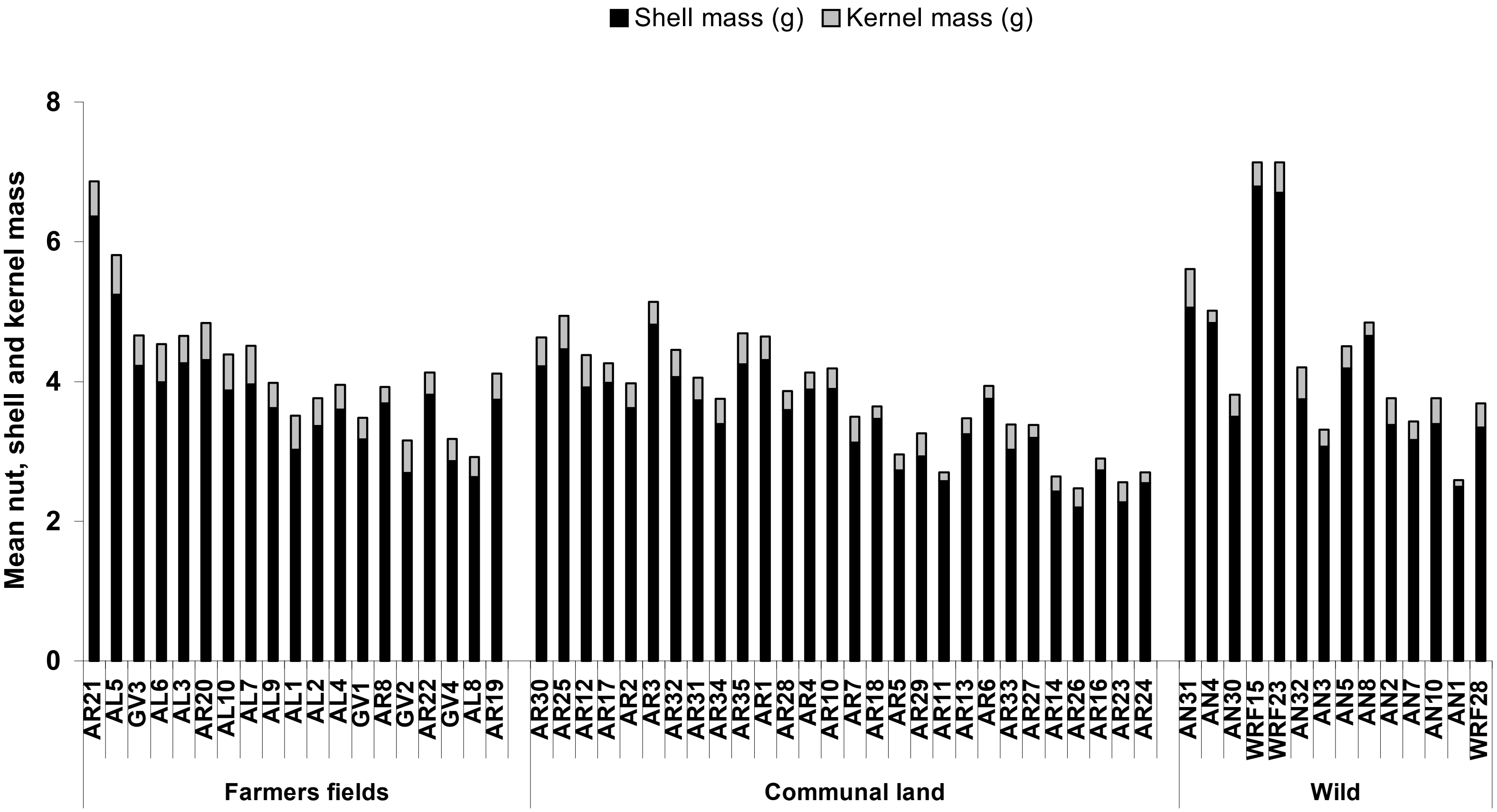

■ Shell mass (g) ▨ Kernel mass (g)
Mean nut, shell and kernel mass
0
2
4
6
8
AR21
AL5
GV3
AL6
AL3
AR20
AL10
AL7
AL9
AL1
AL2
AL4
GV1
AR8
GV2
AR22
GV4
AL8
AR19
AR30
AR25
AR12
AR17
AR2
AR3
AR32
AR31
AR34
AR35
AR1
AR28
AR4
AR10
AR7
AR18
AR5
AR29
AR11
AR13
AR6
AR33
AR27
AR14
AR26
AR16
AR23
AR24
AN31
AN4
AN30
WRF15
WRF23
AN32
AN3
AN5
AN8
AN2
AN7
AN10
AN1
WRF28
Farmers fields
Communal land
Wild

Figure 1b

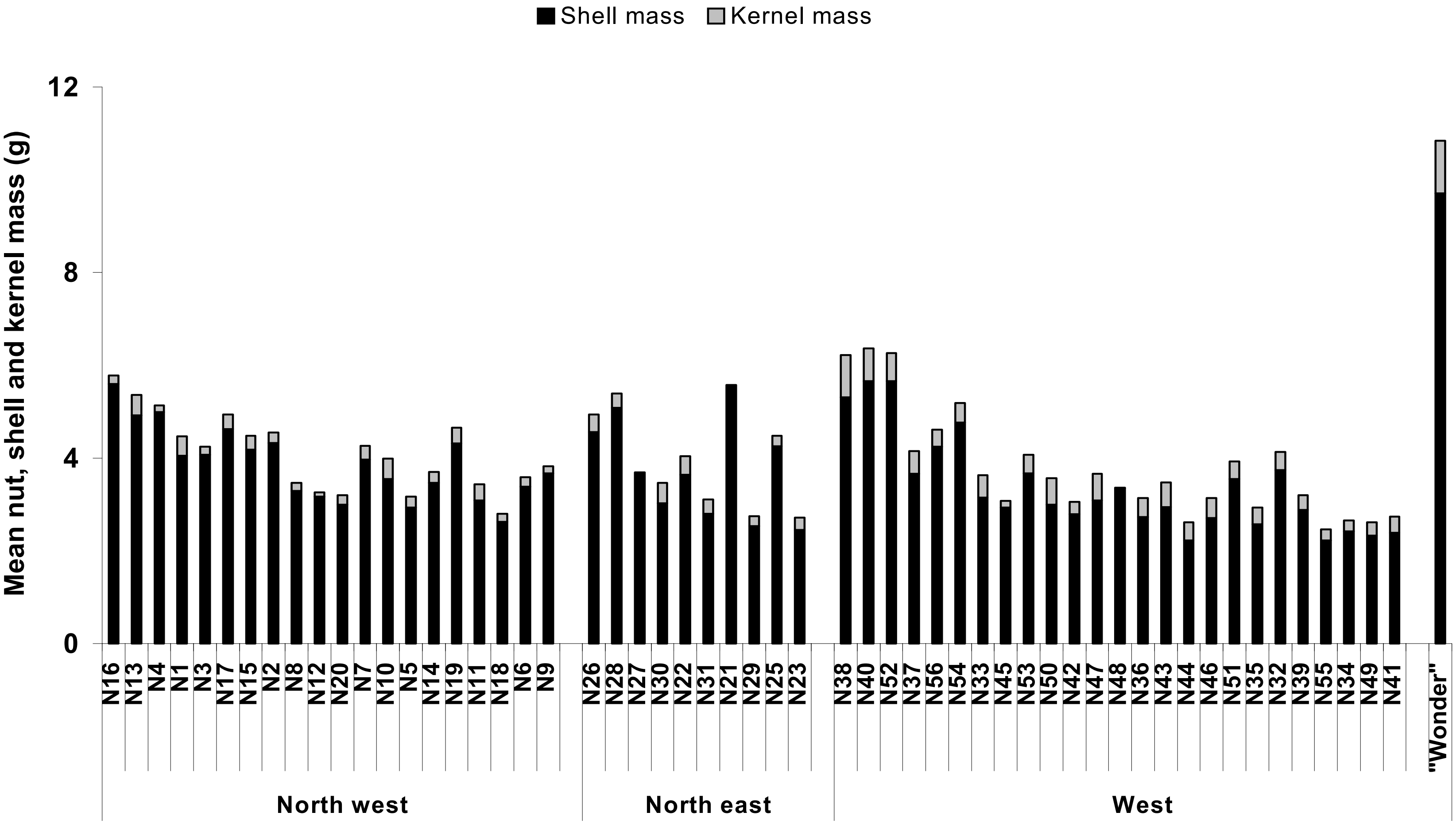
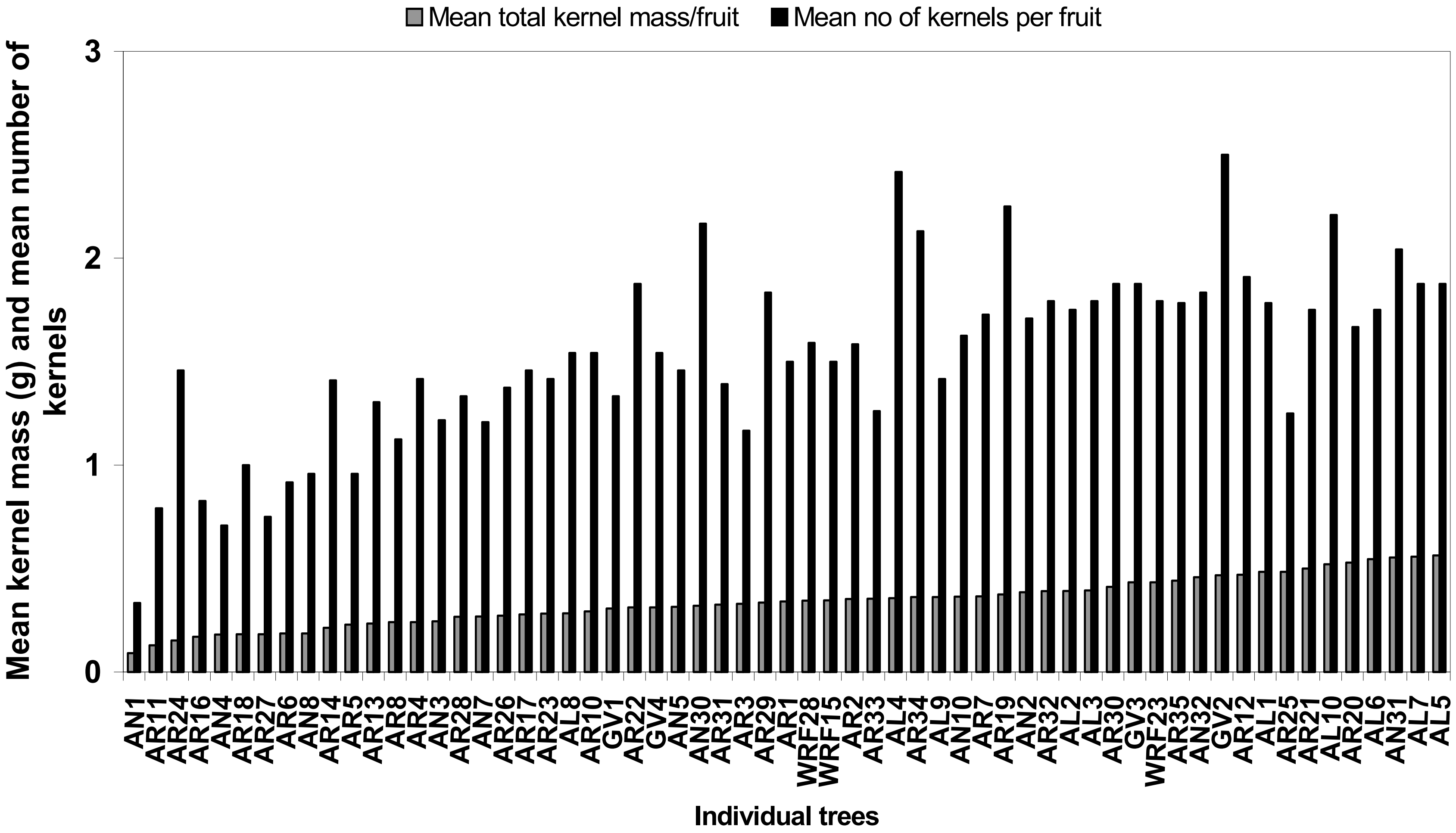
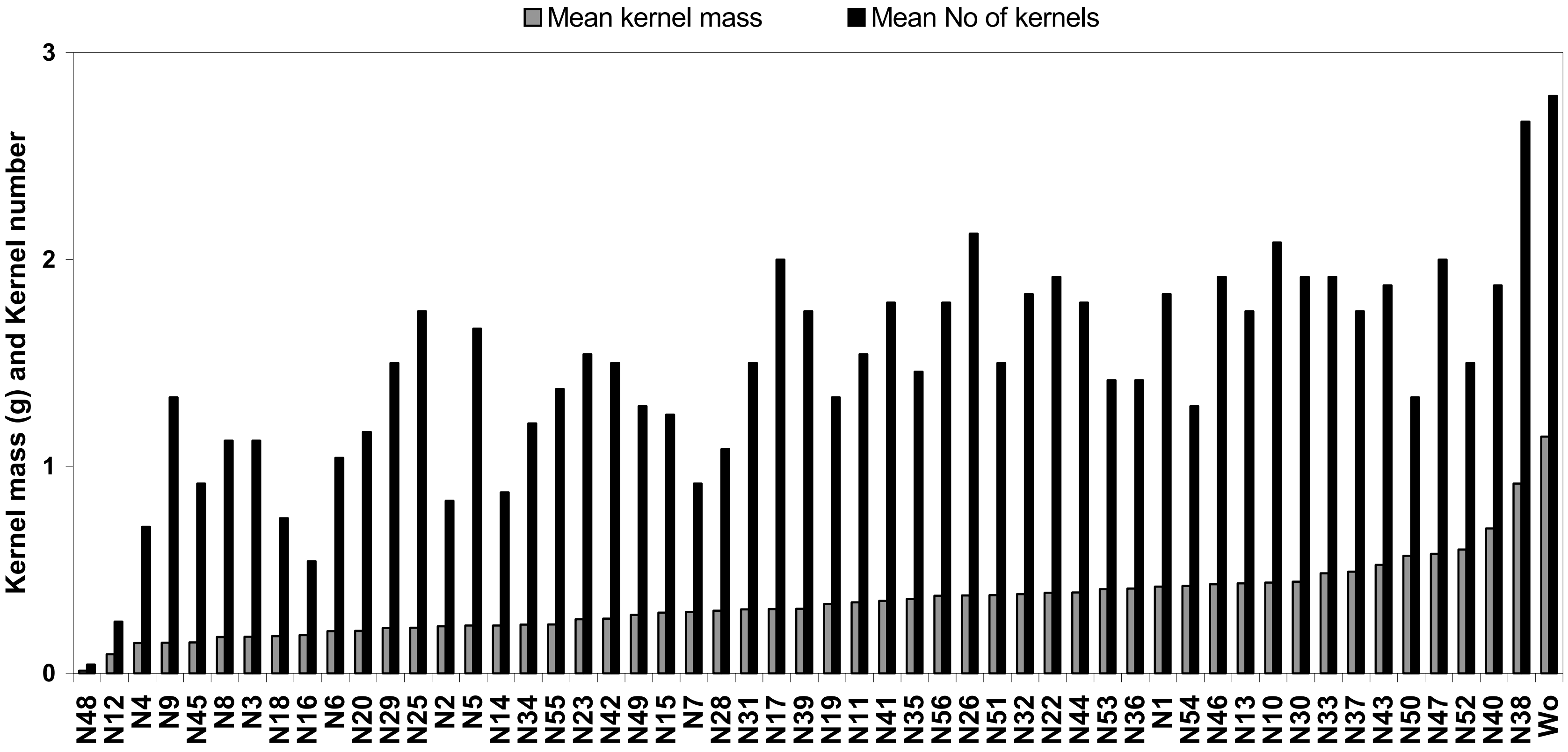

■ Shell mass ▨ Kernel mass
Mean nut, shell and kernel mass (g)
12
8
4
0
N16
N13
N4
N1
N3
N17
N15
N2
N8
N12
N20
N7
N10
N5
N14
N19
N11
N18
N6
N9
N26
N28
N27
N30
N22
N31
N21
N29
N25
N23
N38
N40
N52
N37
N56
N54
N33
N45
N53
N50
N42
N47
N48
N36
N43
N44
N46
N51
N35
N32
N39
N55
N34
N49
N41
"Wonder"
North west
North east
West

Figure 2a



Mean total kernel mass/fruit
Mean no of kernels per fruit
Mean kernel mass (g) and mean number of kernels
0
1
2
3
AN1
AR11
AR24
AR16
AN4
AR18
AR27
AR6
AN8
AR14
AR5
AR13
AR8
AR4
AN3
AR28
AN7
AR26
AR17
AR23
AL8
AR10
GV1
AR22
GV4
AN5
AN30
AR31
AR3
AR29
AR1
WRF28
WRF15
AR2
AR33
AL4
AR34
AL9
AN10
AR7
AR19
AN2
AR32
AL2
AL3
AR30
GV3
WRF23
AR35
AN32
GV2
AR12
AL1
AR25
AR21
AL10
AR20
AL6
AN31
AL7
AL5
Individual trees

Figure 2b



▨ Mean kernel mass
■ Mean No of kernels
Kernel mass (g) and Kernel number
3
2
1
0
N48
N12
N4
N9
N45
N8
N3
N18
N16
N6
N20
N29
N25
N2
N5
N14
N34
N55
N23
N42
N49
N15
N7
N28
N31
N17
N39
N19
N11
N41
N35
N56
N26
N51
N32
N22
N44
N53
N36
N1
N54
N46
N13
N10
N30
N33
N37
N43
N50
N47
N52
N40
N38
Wo

Figure 3a

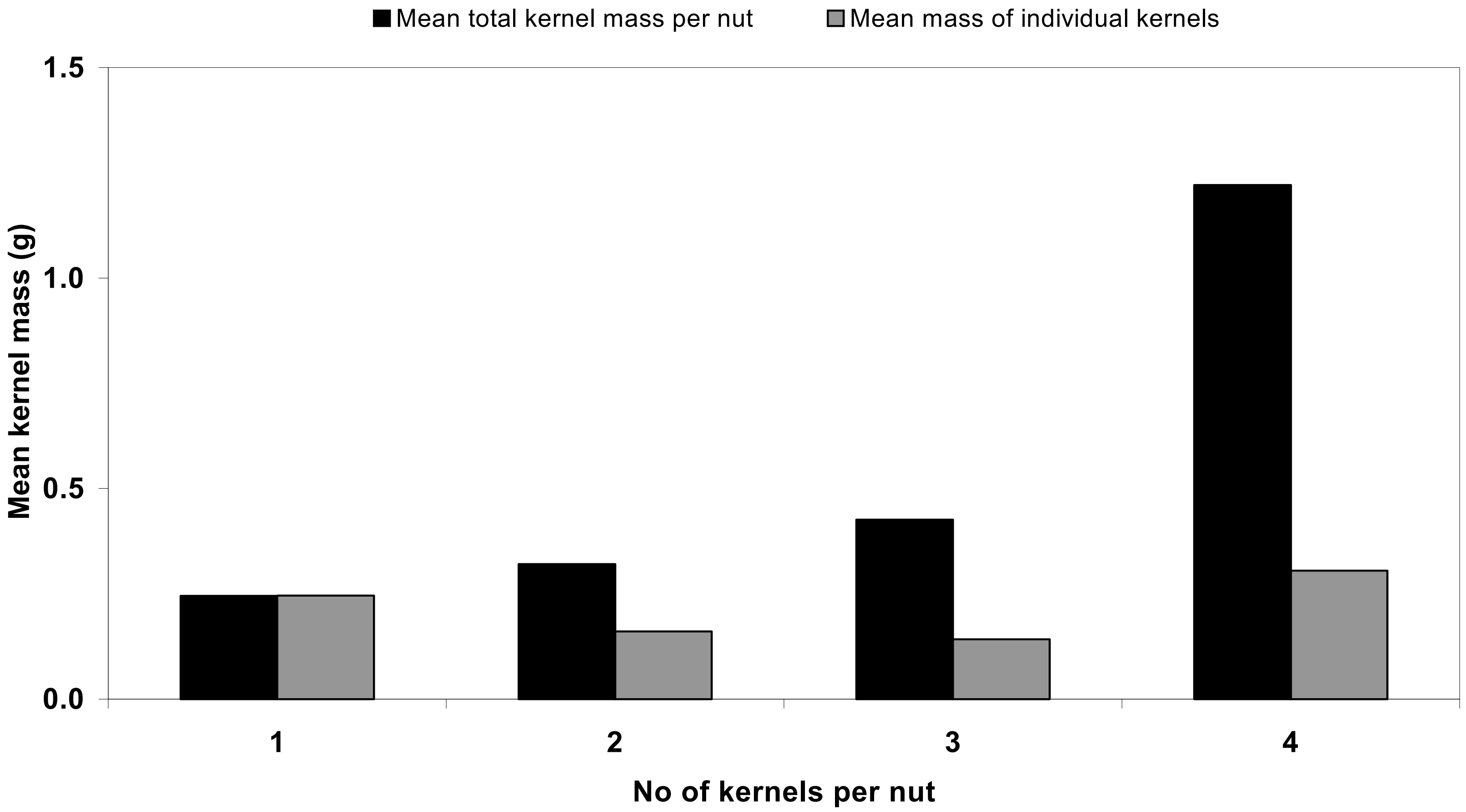
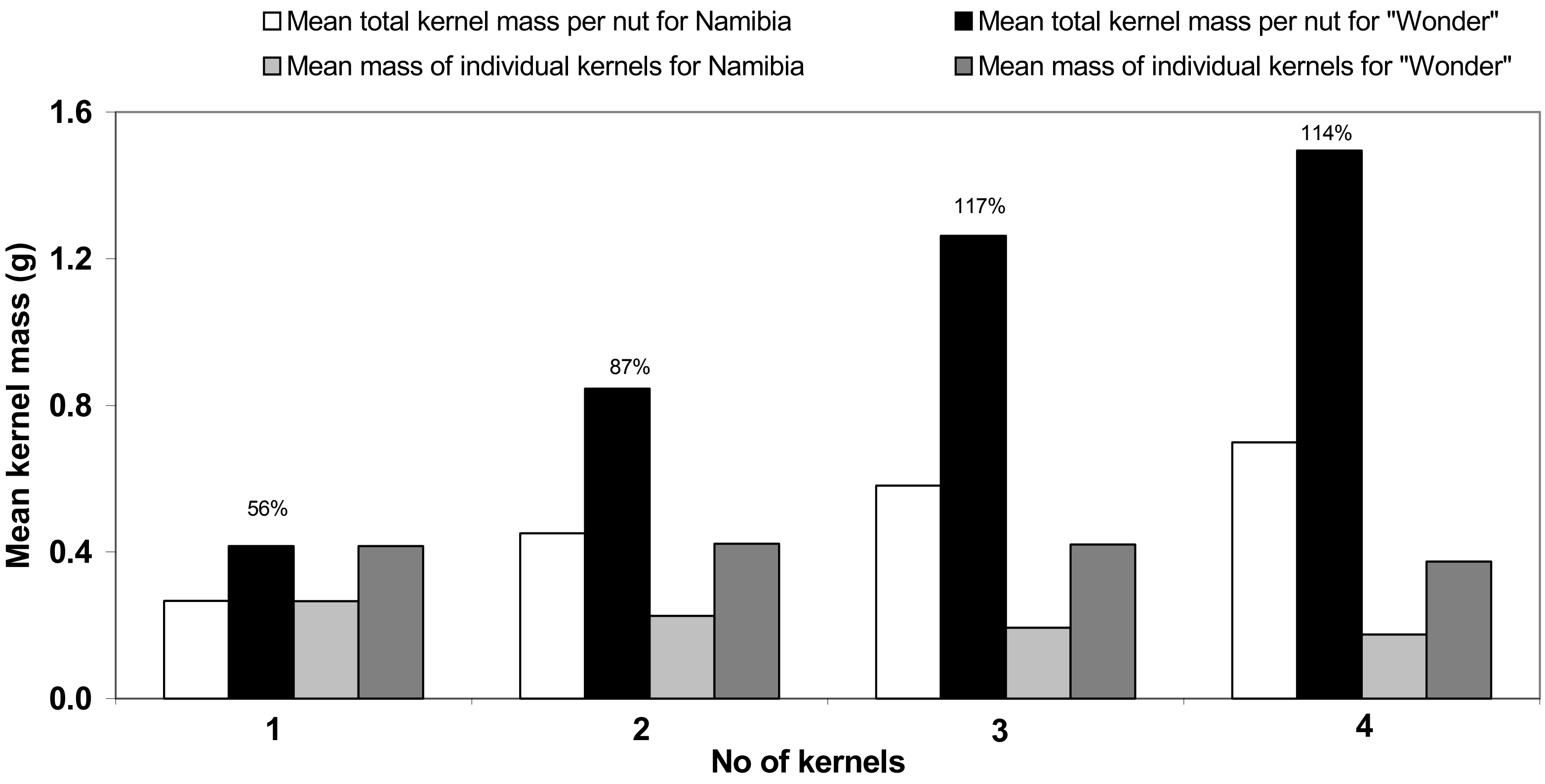

■ Mean total kernel mass per nut
▨ Mean mass of individual kernels
1.5
1.0
0.5
0.0
Mean kernel mass (g)
1
2
3
4
No of kernels per nut

Figure 3b



□ Mean total kernel mass per nut for Namibia
■ Mean total kernel mass per nut for "Wonder"
▨ Mean mass of individual kernels for Namibia
▨ Mean mass of individual kernels for "Wonder"
Mean kernel mass (g)
1.6
1.2
0.8
0.4
0.0
56%
87%
117%
114%
1
2
3
4
No of kernels

Figure 4a

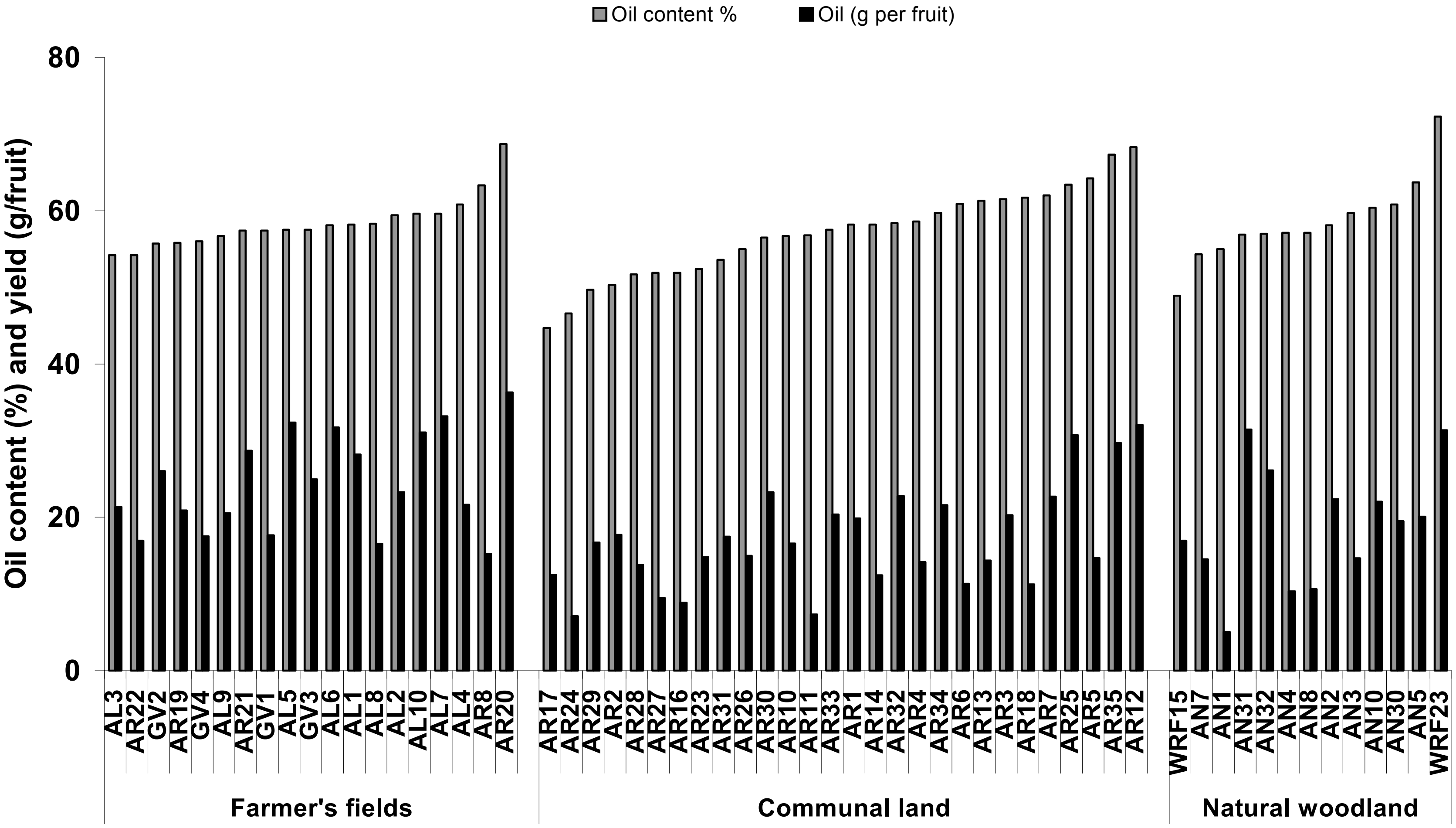

■ Oil content %
■ Oil (g per fruit)
Oil content (%) and yield (g/fruit)
80
60
40
20
0
AL3
AR22
GV2
AR19
GV4
AL9
AR21
GV1
AL5
GV3
AL6
AL1
AL8
AL2
AL10
AL7
AL4
AR8
AR20
AR17
AR24
AR29
AR2
AR28
AR27
AR16
AR23
AR31
AR26
AR30
AR10
AR11
AR33
AR1
AR14
AR32
AR4
AR34
AR6
AR13
AR3
AR18
AR7
AR25
AR5
AR35
AR12
WRF15
AN7
AN1
AN31
AN32
AN4
AN8
AN2
AN3
AN10
AN30
AN5
WRF23
Farmer's fields
Communal land
Natural woodland

Figure 4b

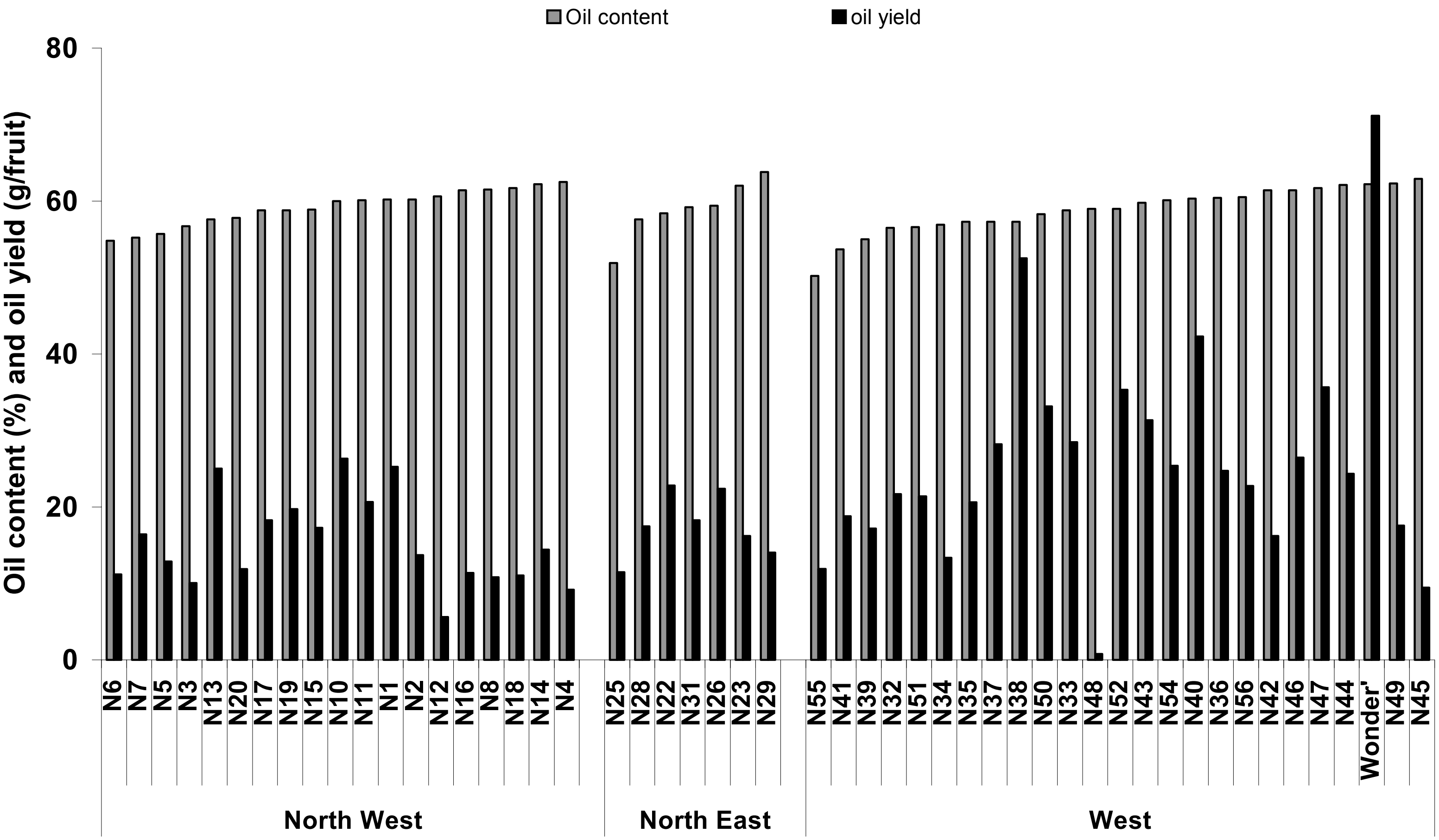

Oil content
oil yield
80
60
40
20
0
Oil content (%) and oil yield (g/fruit)
N6
N7
N5
N3
N13
N20
N17
N19
N15
N10
N11
N1
N2
N12
N16
N8
N18
N14
N4
N25
N28
N22
N31
N26
N23
N29
N55
N41
N39
N32
N51
N34
N35
N37
N38
N50
N33
N48
N52
N43
N54
N40
N36
N56
N42
N46
N47
N44
Wonder'
N49
N45
North West
North East
West

Figure 5a

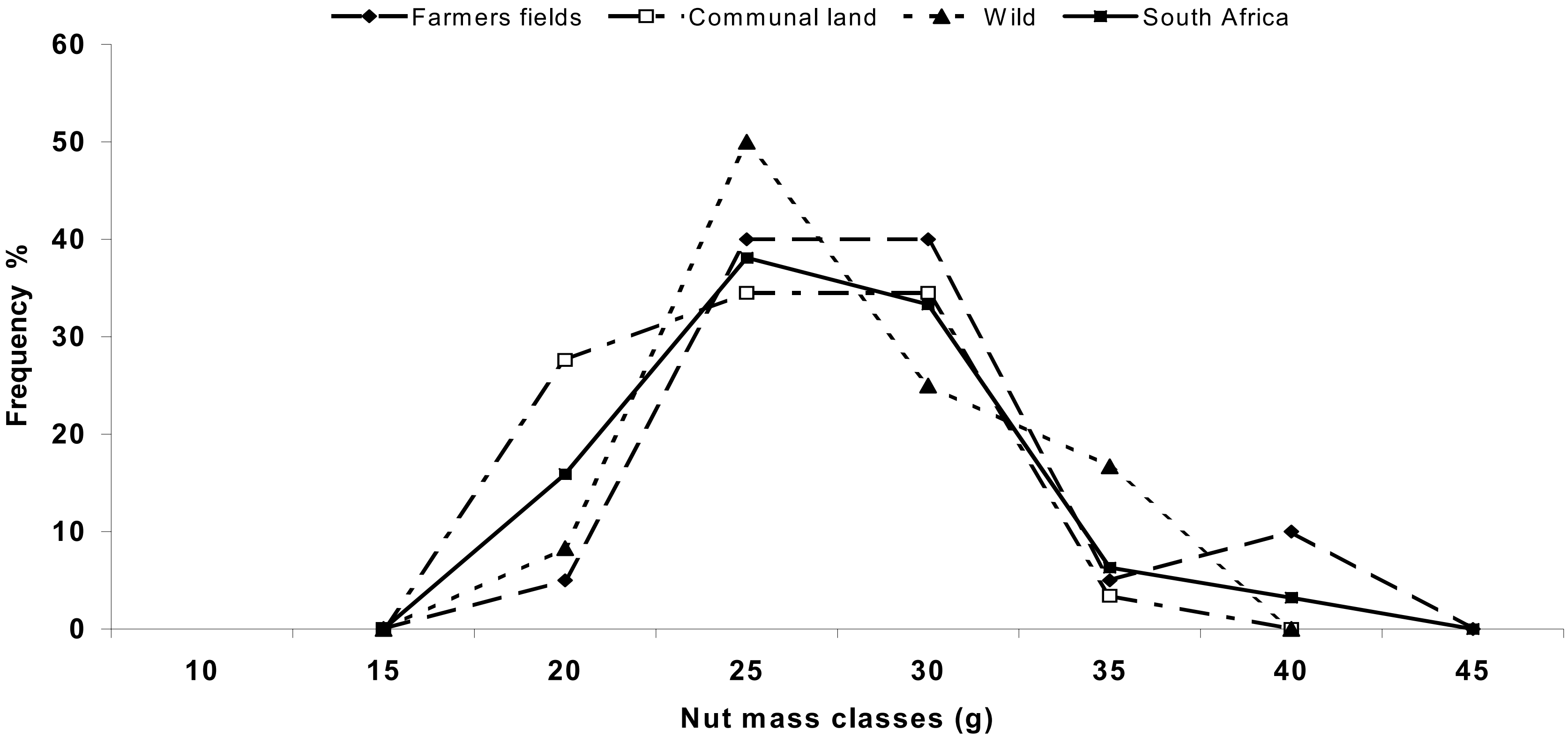

Farmers fields
Communal land
Wild
South Africa
60
50
40
30
20
10
0
Frequency %
10
15
20
25
30
35
40
45
Nut mass classes (g)

Figure 5b

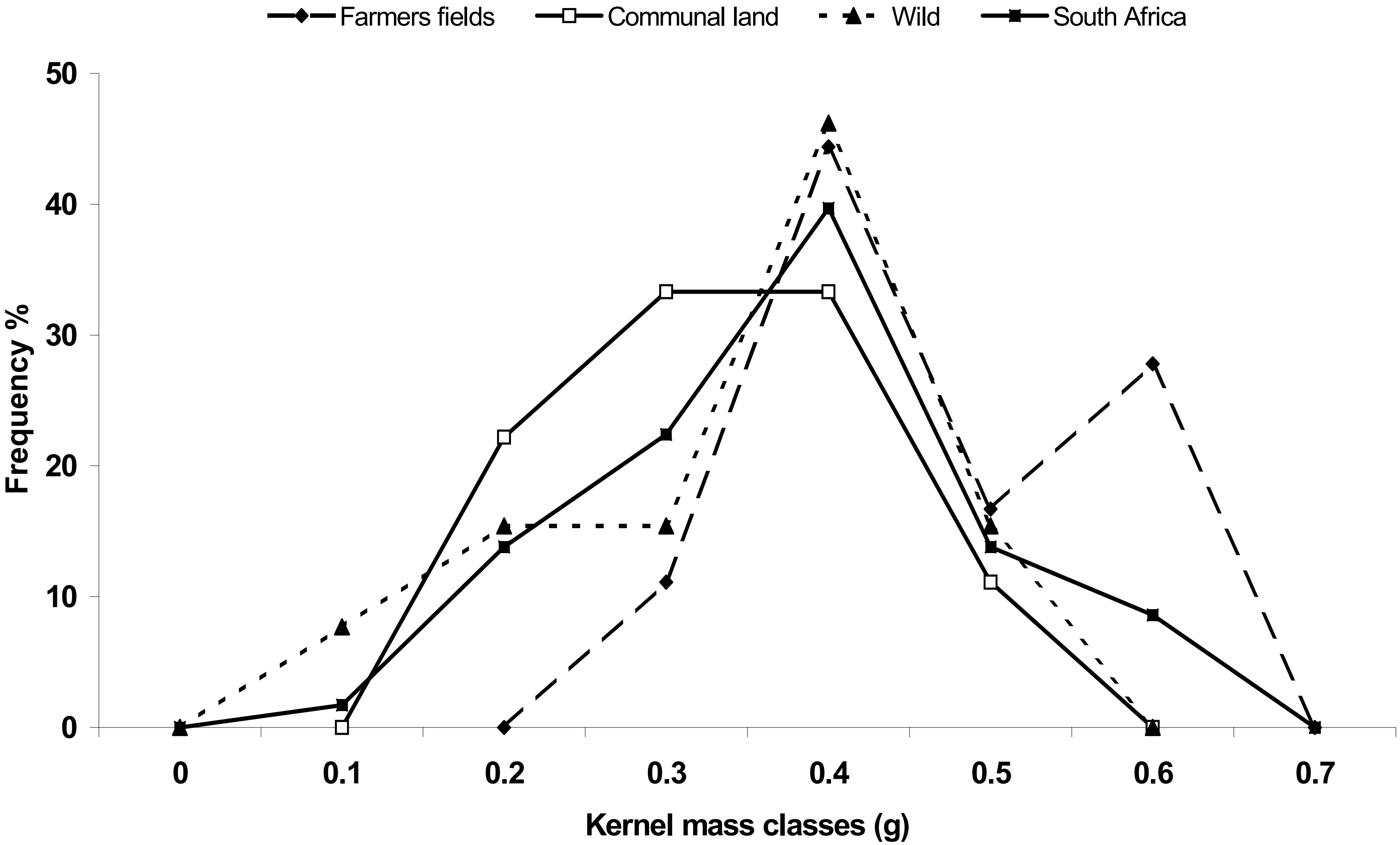

Farmers fields
Communal land
Wild
South Africa
Frequency %
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Kernel mass classes (g)

Figure 6a

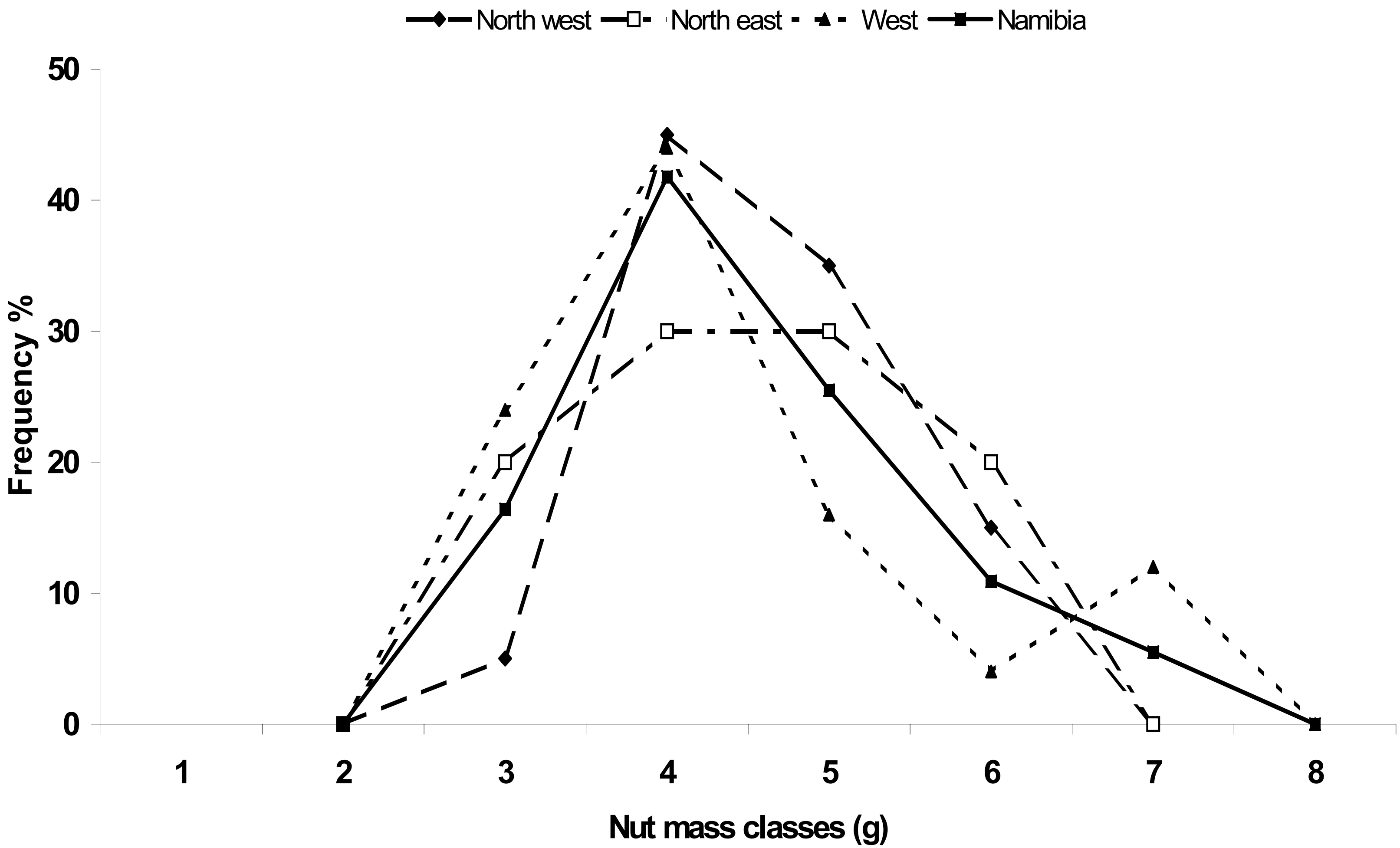
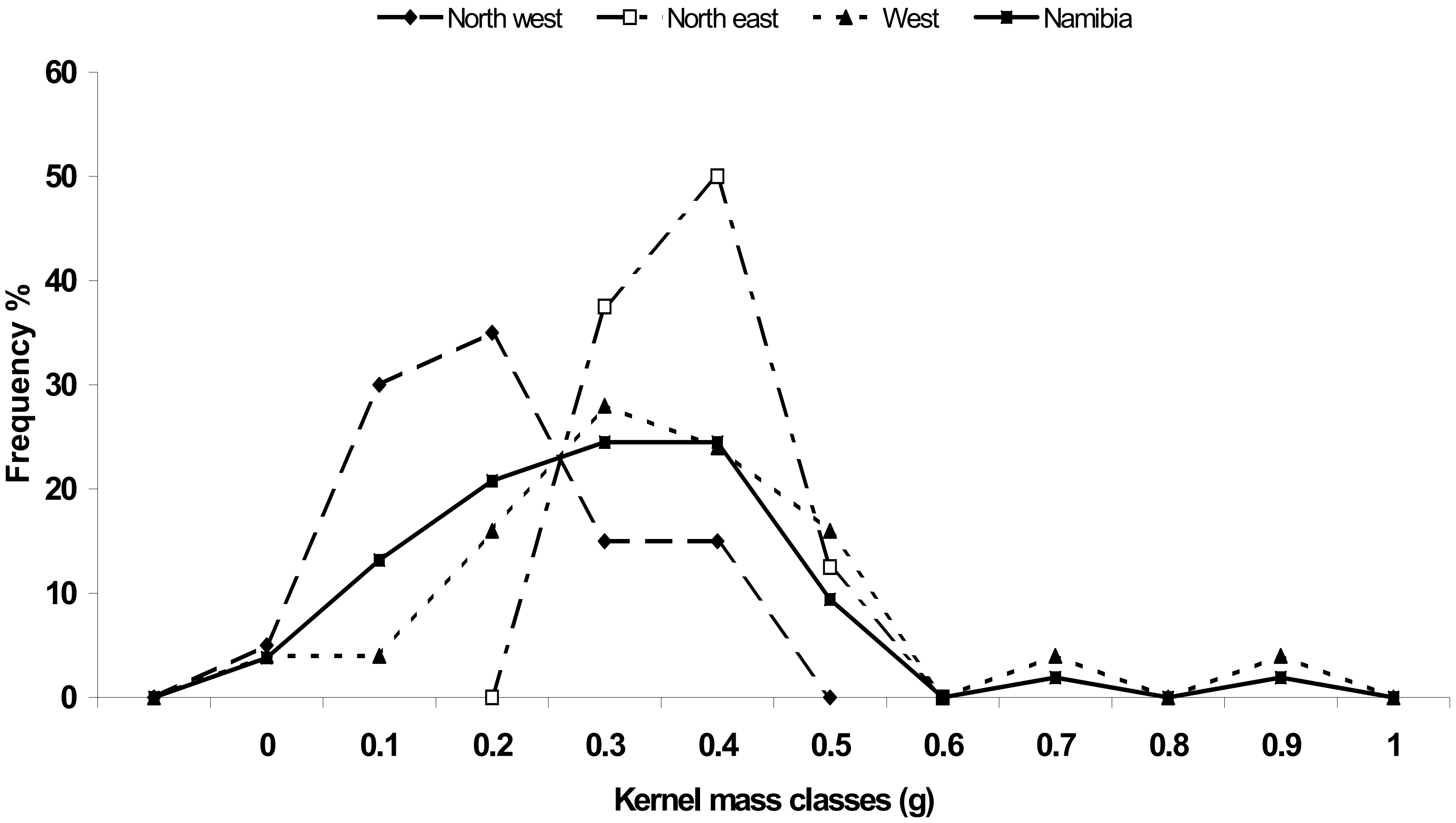

North west
North east
West
Namibia
50
40
30
20
10
0
Frequency %
1
2
3
4
5
6
7
8
Nut mass classes (g)

Figure 6b


North west
North east
West
Namibia
Frequency %
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Kernel mass classes (g)