International Journal of Theoretical & Applied Sciences, **5**(1): 37-46 (2013)
ISSN No. (Print): 0975-1718
ISSN No. (Online): 2249-3247

Introducing Jojoba in the Arabian Desert:1. Agronomic Performance of Nine Jojoba Clones Selected in Makkah Area in Northern and Western Saudi Arabia

Hussein E. Osman and Atalla A. Abohassan
College of Meteorology, Environmental Science and Arid land Agriculture,
King Abdul Aziz University, P.O. Box 80208, Jeddah 21589, Saudi Arabia

(Received 05 February, 2013, Accepted 02 March, 2013)

ABSTRACT: Jojoba is a potential industrial crop in the Arabian Desert. In Saudi Arabia, preliminary efforts were made to initiate the commercial production of jojoba seed and wax but they were soon abandoned due to the absence of adapted cultivars. For this reason, a selection program that is intended to identify high yielding genotypes adapted to western and north regions of the country was initiated. This work examines the performance of jojoba clones and uses some agronomical and chemical traits as descriptors for discrimination and selection of jojoba clones. The field trials were carried out at three planting sites in Makkah, Al Madinah and Hail districts. Nine promising individual mother plants were selected from a heterogeneous seed stock planted in Makkah area on the basis of plant habit, consistency in seed yield and wax production. The selected mother plants were vegetatively propagated and planted in three experimental farms western and northern Saudi Arabia. Significant differences were found among the clones in most of the evaluated parameters in Al Madinah area but limited variations were observed at Hail and Makkah areas. High significant correlations were observed among most of the studied traits. Data on individual seed weight, seed yield and seed wax content in addition to number of floral buds, node length and plant height (one parameter at a time) were used to make selection indices (SI). The results obtained in this work indicate that there is a moderate genetic variability among jojoba clones established in western and northern Saudi Arabia which could permit utilization of some of the evaluated clones in establishing commercial plantations for seed and wax in areas north of latitude 24°N. At lower latitudes, the fast growth of the jojoba bush will permit its utilization in sand stabilization, landscaping, desertification, open natural range lands and national parks projects.

Key words: Jojoba; Agronomy; Selection; Saudi Arabia; Oil; Yield

I. INTRODUCTION

Jojoba (*Simmondsia chinensis* [Link] Schneider) is a dioecious, long-lived perennial evergreen shrub that grows wild in the semi-arid region of the Sonoran desert in Northern Mexico and Southwestern USA. Its natural distribution falls between latitudes 25 and 34°N (Gentry, 1958). The jojoba plant has economic value because its seeds contain about 50% of a light yellow, odorless wax ester commonly referred to as jojoba oil, which is extensively used in the cosmetic industry due to dermatological properties. In addition, the seed de-oiled cake is rich in protein and can be used as livestock feed and as a source of commercial enzymes. The plant exhibits tremendous variability in male: female ratio in a given population, with male plants generally outnumbering female plants, leading to low yields as expected due to heterogeneity in the population (Purcell and Purcell, 1988; Ramonet-Razon,1988).

The reproductive cycle in jojoba is very complex as it begins with formation of the primordial cell a year and a half before the complete maturity and harvest of the fruits (Dunstone ,1988). According (Gentry,1958 and Benzioni,1999), the floral buds are continuously produced at all stages of vegetative growth. however, the timing of anthesis is affected by radiation level and availability of nutrients in the soil (Dunstone ,1988, Benzioni and Nerd, 1989; Ferriere *et al.* , 1989) and temperature and irrigation regimes(Benzioni *et al*.,1992). In this respect, dormancy of jojoba flower buds is broken by exposure to temperatures between 5 and 20C (Dunstone, 1980). Buds released from dormancy will complete morphogenesis and proceed to anthesis only if water is available and plants have accumulated a sufficient heat sum (Benzioni and Dunstone, 1985; Ferriere *et al*., 1989). Prolonged periods with temperatures above 36/31°C, would be harmful to the development of jojoba seed that grows best, as many subtropical species, at an optimum temperature of (33/28°C). This extensive existing variability in the physiological responses to environmental factors coupled with the ability to withstand extended periods of drought permit the selection of a range of jojoba cultivars to be cultivated as a crop in several semi-arid and arid regions of the world.

High yielding genotypes have been selected from experimental plantations, vegetatively propagated to provide genetically uniform, known sex plants to boost yields (Benzioni, 1997).

In Saudi Arabia, Osman and Abohassan (1997) reported that jojoba in Western Saudi Arabia, as in its original habitat, maintained positive growth under high drought stress. Limited jojoba production trials were initiated recently in a small scale in Makkah, Al Madinah and Hail areas. However, as these fields were initiated from seed stocks, they were soon abandoned and no further efforts were taken to introduce jojoba as a productive crop in the country. The present work is intended to introduce jojoba as a commercial crop in the country on scientific basis. Superior clones selected from a heterogeneous seed stock were planted in targeted areas and evaluated for agronomical and seed characteristics with the purpose of selecting superior jojoba genotypes.

II. MATERIALS AND METHODS

A. Materials

An open pollinated seed stock was introduced from Arizona in 1993 and planted in a five hectare area in a nursery field at the Experimental Research Farm of King Abdul-Aziz at Hada al Sham (longitudes 39° 40' E. and latitudes 21° 48' N), 25 km west of Makkah al Mokaramah. At a later date (June 1999). 50 individual plants were tagged in the nursery field and evaluated on the basis of high seed yield, consistency in production, wax content and plant habit as suggested by Ayerza (1996) and Benzioni *et al.* (1996). Based on this selection criterion, nine most promising mother plants were propagated by stem cuttings and planted in replicated field's trials.

B. Field experiments

Three field experiments were conducted in Hada al Sham Experimental Farm , Al Alyotamah Agricultural Farm,75 km south of AL Madinah al Monwarah (latitude: 24 28' 07"N, longitude : 39 36' 51" E) and in Algbreen Agricultural Project Farm or AGPF (latitude: 27° 30' 59" N, longitude: 41° 41' 48" E.) , 140 east of Hail city, from March 2001 to October 2007). Monthly maximum, minimum and mean temperature, representing the experimental sites is shown in Table 1. Each of three trials was executed in a randomized complete block design in three replicates. The acclimatized clones were transplanted on 20/3/2001. 28/3/2001 and on 28/8/2003 at Hada al Sham, Alyoutamah and Algbreen agricultural farms, respectively. Three experimental rows (5 plants each) were assigned for each clone in each replication. Distances between rows and within plants in rows were 4 and 2 m. respectively. Plants (mixed males and female seedlings) derived from the open population, as a source of pollen, were repeated one row every six female (clone) rows. Additional border mixed seedling rows were planted around each replication and no free space was left between rows within each replication to ensure homogeneity within each replication. Before sowing the field was ploughed and appropriate planting holes prepared and a drip irrigation system was installed in the experimental areas. Weed control and irrigation were done as necessary but no fertilizers were applied in the course of the study.

Table 1: Maximum, minimum and mean monthly temperatures representing the prevailing temperatures at the three jojoba experimental sites.

	Hada al Sham Lat: 21° 46' N Long: 39° 39' 31"E			Alyotamah Lat : 24 27' 37"N, Long : 39 36' 51"E			Hail Lat:27° 30' 59" N, Long: 42° 41' 48" E		
Month	Max	Min	Mean	Max	Mim	Mean	Max	Mim	Mean
1	35	12	23.5	31	4	17.5	26	-1.,5	12.3
2	35	11	23.0	32	4	18.0	29	0.5	18.0
3	38	15	26.5	33	5	19.0	35	5	19.0
4	44	17	30.5	40	7	23.5	38	9	23.5
5	52	18	35.0	44	14	29.0	41	13	29.0
6	47	21	34.0	43	17	30.0	44	15	30.0
7	44	21	32.5	42	17	29.5	45	21	29.5
8	43	27	35.0	48	19	33.5	49	21	33.5
9	44	26	35.0	43	20	31.5	44	19	31.5
10	44	22	33.0	40	17	28.5	41	12	28.5
11	42	17	29.5	33	8	20.5	29.9	9	20.5
12	37	14	25.5	25	7	16.0	26.5	1	16.0

C. Parameters

1. Fruiting branch characteristics: Data on fruiting or terminal branches from each of the field trials was recorded from the most inner three plants in the middle row of each experimental plot. Data included total number of branches, nodes, leaves, floral buds and developing or mature fruits per a 50 cm terminal fruiting branch. Data on terminal branches was recorded during the first week of December, February and April to coincide with the active reproductive stage of jojoba.

2. Plant habit characteristics. Shrub characteristics (height. diameter and volume) were recorded prior to harvest from three shrubs randomly selected in each experimental plot once a year.

3. Seed yield and seed related traits. Seeds were harvested from three individual plants in each experimental plot by hand at full maturity. They were cleaned, dried and weighed. Individual seed weight (100 seed weight) and oil content of the seeds were recorded after harvest on plot basis and seed wax was extracted using n-hexane (one extraction 12 h) in a Soxhlet apparatus. Wax content was quantified according to AOCS method (1992), using a sample of 50 randomly picked seeds.

D. Statistical analyses

Data on fruiting branches at individual dates in each of the three years at each of experimental sites was analyzed as for a randomized block design. On the basis of the Bartlett's homogeneity of variances test (Snedecor and Cochran, 1983), overall means of the sampling dates in each year and means for individual years (plant habit and yield related traits) were used in analyzing the data. Statistical differences among jojoba clones (all traits) were estimated from ANOVA test. Whenever ANOVA test indicated significant difference between clones, least significant differences (LSD) were estimated for comparing yearly means. All analyses of variance were computed using the SAS program (2006). Correlation analysis was performed employing Pearson's test (Zar, 1984).

III. RESULTS AND DISCUSSION

A. Fruiting branch characteristics

Fruiting branch characteristics (number of branch tips, leaves, buds and fruits, leaf length and internode length), apart from those recorded at Alyotamah planting site, presented limited significant variation among jojoba clones (Tables 2 to 3) and they were generally, with a few exception, significantly correlated with one another and with seed yield per plant (Table 4). At Alyotamah experimental site (Table 2), clones HD3 attained significantly the highest number of branch tips (9.1branch tips), the highest number of leaves (111 leaves) per unit branch length and the longest leaf type (3.8 cm). Clones HD8 and HD9 (16.4cm, each), HD 7 (27.5 buds) and HD4 (6.5 fruits) had respectively the longest node, the highest number of floral buds and the highest number of developing fruits per unit branch length, respectively (Table 3). In Israel, number of branch tips ranged from 6.4 to 11.4 tips per a one meter branch length (Benzioni *et al*., 1999); whereas node density ranged between 31 and 55 nodes per meter branch length. Positive relationships between numbers of branch tips along the stem segment, numbers of nodes (halve the number of leaves) and numbers of flowers per branch, as in this study, were reported in Arizona (Ravetta and Palzkill, 1993). The highly significant negative correlations of node length with all fruiting branch traits, apart from those with numbers of fruits (Table 4), indicate the importance of short internodes in improving jojoba seed yields. Apparently, the absence of significant positive correlation between number of developing fruits and number of floral buds (r = 0.200) indicates that not all buds that are produced had a chance to mature into fruits. This may be attributed to the complexity of the reproductive cycle in jojoba (Dunstone ,1988) and the lack of synchronization between the onset of flowering (anthesis) and availability of pollen. According to Benzioni *et al*. (1999), clones that flower early are more likely to reach anthesis during unfavorable weather conditions : whereas clones that begin flowering very early and flower gradually afterwards or those that flower late usually have a good fruit set, since they have a better chance of escaping bad weather. Coates and Ayerza (2008) reported that application of supplemental pollen reduced the number of aborted capsules and increased jojoba yields in Arizona.

B. Plant habit

Plant habit (height, diameter and volume) presented moderate significant variation among jojoba clones (Tables 5-7). On the average, highest estimates for plant height (1.5-2.1 cm), crown diameter (1.7-1.9 cm) and plant volume (1.2-2.10m^3) across years and locations were attained at Hada al Sham planting site (Tables 5-7). Similar trends were recorded for plant height and volume in Argentina (Tobares *et al*., 2004) but lower ranges were recorded for plant height in northern Saudi Arabia (Al-Soqeer, 2010) Data in Table 8 showed that plant height was highly significantly correlated with crown diameter and plant volume both of which were positively correlated to seed yield. Similarly, Tobares *et al.* (2004) reported that plant height and plant volume were positively correlated.

Table 2. Number of branches, number of leaves and leaf length of nine jojoba clones at three experimental sites.

	Number of branches			Number of leaves			Leaf length (cm)		
Clone	Hada al Sham	Alyotamah	Hail	Hada Al Sham	Alyotamah	Hail	Hada Al Sham	Alyotamah	Hail
1	7.9	5.0	1.7	94	66	54	3.4	2.3	3.5
2	8.3	3.5	1.7	95	67	41	3.6	2.4	3.3
3	9.8	9.1	2.0	121	111	47	3.8	3.8	3.4
4	5.2	5.8	1.8	76	69	48	3.6	2.6	3.5
5	8.3	5.8	1.5	81	73	41	3.7	3.7	3.6
6	7.8	3.8	1.8	86	57	46	3.6	2.5	3.5
7	6.2	3.4	1.7	86	48	36	3.6	2.4	3.5
8	8.3	0.5	1.5	74	33	37	3.7	1.2	3.4
9	8.7	6.2	1.8	70	89	47	3.5	4.5	3.6
Mean	7.8	4.8	1.7	87	68	44	3.6	2.8	3.5
LSD(5%)	N,S	0.75*	N,S	N,S	6.6	N.S	N.S	1.3	N,S

Table 3. Node length, number of floral buds and number of developing flowers of nine jojoba clones at three experimental sites.

Clone	Node length (cm)			Number of floral buds			Number of fruits		
	Hada Al Sham	Alyotamah	Hail	Hada Al Sham	Alyotamah	Hail	Hada Al Sham	Alyotamah	Hail
1	11.5	12.3	12.1	14.0	12.5	8.8	1.2	4.8	1.1
2	12.0	11.0	11.5	18.2	19.7	9.5	0.0	1.0	2.0
3	12.0	15.4	11.8	16.5	20.1	10.9	0.8	3.8	1.4
4	12.0	12.0	12.5	14.4	16.3	9.1	0.8	6.5	2.5
5	12.5	14.5	12.1	16.2	15	7.9	2.4	5.4	2.1
6	12.5	11.9	11.7	18.2	13.5	12.7	1.3	5.5	1.8
7	12.0	11.9	12.7	16.0	27.5	12.7	0.0	3.5	1.8
8	12.5	16.4	12.5	13.5	12.7	12.3	0.3	0	1.5
9	12.5	16.4	11.9	15.0	11.4	9.4	2.0	3.7	2.2
Mean	12.2	13.5	12.1	15.8	16.5	10.4	1.0	3.8	1.8
LSD (5 %)	N,S	0.10	N,S	N,S	1.47	N,S	N,S	0.79	N,S

Table 4. Simple correlation coefficients among six fruiting branch characteristics and seed yield in nine clones growing in three experimental sites.

Trait	Number of leaves	Node length	Leaf length	Number of floral buds	Number of developing fruits	Seed yield
Number of branches	0.177	- 0. 417**	0.202	0.562**	- 0.393**	0.563**
Number of leaves		--0.692**	0.468**	0.602**	0.421**	-0.015
Node length			--0.469**	- 0.754**	- 0.104	- 0.292**
Leaf length				0.461**	0.057	0.078
Number of floral buds					0.200	0.347**
Number of floral fruits						-0.201

** Significant at the 1 % level.

Table 5. Plant height (m) of nine jojoba clones at Hada three experimental sites.

	Hada al Sham			Alyotamah			Hail		
Clone	2003/04	2005/06	2006/07	2003/04	2005/06	2006/07	2003/04	2005/06	2006/07
1	1.5	2.1	2.2	1.2	1.2	1.0	0.70	1.3	1.4
2	1.3	1.7	1.8	1.1	1.0	1.3	0.58	1.0	1.2
3	1.4	1.7	2.0	1.3	1.2	1.1	0.62	1.1	1.2
4	1.7	1.9	2.1	0.9	1.1	1.2	0.69	1.3	1.2
5	1.5	1.8	2.3	1.1	1.1	1.0	0.55	1.1	1.3
6	1.6	2.0	2.2	1.6	1.3	1.3	0.48	1.4	1.4
7	1.6	2.1	2.2	1.2	0.8	1.0	0.61	1.1	1.4
8	1.6	2.0	2.3	1.5	1.0	0.9	0.63	1.1	1.5
9	1.7	2.2	2.2	1.5	1.3	1.0	0.67	1.3	1.4
Mean	1.5	1.9	2.1	1.2	1.1	1.1	0.61	1.2	1.3
LSD(5%)	N.S	0.28*	N.S	N.S	N.S	N.S	N.S	0.21	N.S

Table 6. Crown diameter (m) of nine jojoba clones at three experimental sites.

	Hada al Sham			Alyotamah			Hail		
Clone	2003/04	2005/06	2006/07	2003/04	2005/06	2006/07	2003/04	2005/06	2006/07
1	1.8	1.9	2.0	1.4	1.6	1.3	0.57	1.2	1.3
2	1.7	1.9	2.2	1.4	1.3	1.6	0.85	1.1	1.2
3	1.8	1.7	1.8	1.5	1.5	1.6	0.51	1.1	1.2
4	1.8	1.6	1.9	1.3	1.4	1.3	0.59	1.3	1.2
5	1.6	1.6	1.9	1.2	1.2	1.5	0.47	1.1	1.2
6	1.9	1.6	1.7	1.5	1.4	1.3	0.52	1.2	1.3
7	1.6	1.7	2.2	1.3	0.8	1.3	0.55	1.0	1.0
8	1.6	1.7	1.8	1.3	1.0	1.2	0.51	1.1	1.2
9	1.9	1.8	1.8	1.5	1.2	1.3	0.48	1.1	1.3
Mean	1.7	1.7	1.9	1.4	1.3	1.4	0.57	1.1	1.2
LSD (5%)	N.S	N.S	N.S	N.S	0.30	N.S	N.S	0.21	N.S

Table 7. Tree volume (m^3) of nine jojoba clones at three experimental sites.

	Hada al Sham			Alyotamah			Hail		
Clone	2003/04	2005/06	2006/07	2003/04	2005/06	2006/07	2003/04	2005/06	2006/07
1	1.30	1.92	2.31	0.65	0.80	0.44	0.06	0.466	0.538
2	0.99	1.54	2.38	0.61	0.48	0.94	0.111	0.298	0.456
3	1.26	1.27	1.72	0.72	0.73	0.76	0.042	0.349	0.461
4	1.37	1.37	2.16	0.38	0.60	0.68	0.063	0.551	0.551
5	0.99	1.28	2.13	0.43	0.40	0.62	0.0316	0.33	0.36
6	1.48	1.35	1.72	0.98	0.72	0.64	0.0342	0.5	0.509
7	1.05	1.54	2.81	0.51	0.16	0.41	0.048	0.289	1.855
8	1.01	1.57	1.98	0.67	0.26	0.34	0.044	0.369	0.499
9	1.50	1.92	1.76	0.84	0.58	0.52	0.04	0.388	0.481
Mean	1.20	1.50	2.10	0.64	0.52	0.59	0.045	0.394	0.653
LSD(5%)	N.S	N.S	N.S	N.S	0.32	N.S	N.S	0.14	N.S

Table 8. Simple correlation coefficients among plant habit traits, seed yield and seed yield related traits in nine jojoba clones growing in three experimental sites.

Trait	Plant diameter	Tree volume	Oil content	Seed weight	Seed yield
Plant height	0.724**	0.745**	0.083	0.003	0.589**
Plant diameter		0.682**	0.025	-0.07	0.451**
Tree volume			-0.010	-0.015	0.555**
Oil content				0.041	0.011
Seed weight					-0.016

** Significant at the 1 % level**.**

The later was either linearly correlated to potential seed yield (Benzioni, 1988) or not (Tobares *et al*., 2004). Apparently, relatively higher temperatures prevailing in Makkah area (Table 1) encouraged vegetative growth; whereas relatively lower temperatures prevailing at Hail and Madinah areas did not.

C. Seed yield and seed related traits

Mean Seed yield and its direct components (seed size and wax content and individual seed weight) varied greatly across years and location (Tables 9-11) but they were not significantly correlated to one another (Table 8) as reported by Tobares *et al*. (2004). Average seed yield across locations and years varied from 0.92 to 1.22 kg per plant at Hada al Sham and from 0.18 to 0.59 kg per plant at AGPF (Table 9). At Hada al Sham, clones HD 4 (1.67 kg) and HD 7 (1.66 kg) attained significantly the highest seed yield per plant in season 2003/2004 but they failed to fruit in season 2006/2007 and onwards. This may be attributed to the complexity of the reproductive cycle in jojoba (Dunstone, 1988) and to the inability of the plants to accumulate a sufficient heat sum to meet their chilling requirements (Benzioni and Dunstone, 1985; Ferriere *et al*., 1989) at the lower latitudes. Average individual seed weight was highest (0.87-0.89 g) at Hada al Sham and lowest (0.57-0.58 g) at AGPF (Table 10). Seed yield, among 14 clones evaluated in Argentina, ranged from 0.36 kg to 1.35 kg per plant; whereas individual seed weight varied between 0.66 and 1.38 g. It was noteworthy that some clones (HD1, HD 4 and HD 7), at Hada al Sham, amply exceeded the ranges of seed yield recorded in Argentina (Tobares *et al.*, 2004). The liquid wax content of jojoba seeds among clones (Table 11) ranged from 39.9 to 56.9 % at Hada al Sham and from 37.9 to 49.0 % at Al Medinah and from39.2 to 56.9% at AGPF and all of the clones, except HD5, were included in the ranges obtained with seeds produced in commercial plantations as reported elsewhere (Benzioni *et al*., 1999; Ulger *et al*., 2002, Tobares *et al*., 2004).

Table 9. Individual seed weight (g) of nine jojoba clones at three experimental sites.

	Hada al Sham		Alyotamah		Hail	
Clone	2003/2004	2004/2005	2004/2005	2006/2007	2004/2005	2006/2007
1	0.94	0.68	0.80	0.92	0.55	0.67
2	0.95	0.93	0.81	0.52	0.53	0.45
3	1.21	1.01	0.85	0.84	0.65	0.58
4	0.76	0.95	0.56	0.72	0.62	0.61
5	0.81	0.86	0.69	0.64	0.56	0.57
6	0.86	0.78	0.85	0.57	0.56	0.65
7	0.86	0.99	0.99	1.00	0.59	0.53
8	0.74	1.25	1.06	1.11	0.6	0.56
9	0.70	0.58	0.79	0.90	0.49	0.58
Mean	0.87	0.89	0.82	0.80	0.57	0.58
LSD (5%)	0.47	0.31	0.17	0.16	N.S	0.11

Table 10. Seed yield (kg/plant) of) of nine jojoba clones at three experimental sites.

	Hada al Sham		Alyotamah			Hail		
Clone	2003/2004	2004/2005	2004/2005	2005/2006	2006/2007	2004/2005	2005/2006	2006/2007
1	1.33	1.87	0.57	0.24	1.10	0.28	0.62	0.62
2	1.28	0.68	0.20	0.37	0.28	0.17	0.43	0.35
3	0.85	0.42	0.51	0.31	0.64	0.17	0.50	0.67
4	1.67	0.78	0.41	0.18	0.48	0.17	0.37	0.52
5	0.94	0.95	0.14	0.36	0.68	0.23	0.68	0.65
6	1.15	1.00	0.19	0.63	0.58	0.23	0.60	0.70
7	1.66	0.95	0.22	0.10	0.40	0.12	0.90	0.62
8	0.98	0.94	0.20	0.15	0.40	0.18	0.72	0.38
9	1.10	0.66	0.18	0.56	0.92	0.11	0.53	0.42
Mean	1.22	0.92	0.29	0.32	0.61	0.18	0.59	0.55
LSD (5%)	0.48	N.S	0.28	0.15	0.26	0.12	0.18	N.S

Table 11. Oil content (%) of jojoba clones at Hada al Sham experimental site.

	Hada		Alyotamah		Hail	
Clone	2003/2004	2004/2005	2004/2005	2006/2007	2004/2005	2006/2007
1	46.9	53.6	41.9	42.0	53.6	56.7
2	42.8	49	45.0	45.2	49.0	47.7
3	47.2	56.9	39.6	40.0	56.9	53.8
4	43.2	45.7	37.9	38.1	45.7	53.2
5	41.6	39.2	38.6	39.0	39.2	46.5
6	41.4	46.2	44.9	45.0	46.4	49.4
7	49.6	50.9	48.6	49.0	50.9	46.9
8	45.2	44	41.4	41.5	44.0	44.2
9	42.5	41	45.2	45.7	41.0	41.5
Mean	44.5	47.4	42.6	42.8	47.4	48.9
LSD (5%)	N.,S	N.S	6.5	6.6	5. 8	4. 9

D. Selection index

It is evident from the results of the present study that high seed yielding clones at Hada al Sham and Alyotamah planting sites had generally heavy individual seed weight. This coupled with related studies (Ayerza (h), 1996: Botti *et al*., 1998: Benzioni et al., 1999 and Purcell et al., 2000) indicate that seed production and seed weight (or seed size) appear to be the two major criteria for selecting jojoba clones. High-yielding plants with larger seeds appeal to jojoba plant selectors because larger seeds are easier to harvest and handle. Because the wax is the main product of jojoba, its content in the seed is also an important factor for selection. Based on these considerations, a selection index (SI) basic formula was proposed by Tobares *et al*. (2004) and defined as follows:

SI = seed yield (kg/tree) × individual seed weight (g) × seed oil content (%)

According to Tobares *et al*. (2004), Seed weight was selected instead of seed size because it is a simple parameter to measure. However, as the results of this study revealed that number floral buds per unit primary branch length, node length (short internodes) and plant height were significantly correlated to seed yield and that they can easily be used at to assess jojoba populations at earlier stages of plant growth, they were also included as additional parameters (0ne character at a time) in the basic formula of the selection index and presented in Table 12. It is evident from this data that clones HD1, HD3, HD6 and HD7 offer good production prospects and may be recommended for commercial production in regions under conditions similar to those of Makkah, Al Madinah and Hail areas in Saudi Arabia.

Table 12. Selection index (SI) and rank of 9 jojoba clones growing at three experimental sites.

Clone	Basic equation	Node length Cm)	Number of floral buds	MeanPlant height (cm)
1	21.34(1)a	51.07(1)	251.10(3)	24.18(1)
2	9.73(9)	22.38(9)	153.75(6)	10.02(9)
3	19.62(2)	51.26(2)	310.58(1)	21.32(2)
4	10.98(8)	26.71(8)	145.64(9)	11.69(9)
5	12.79(7)	33.33(7)	166.67(6)	13.11(7)
6	15.83(4)	38.10(4)	234.28(4)	19.73(3)
7	16.04(3)	39.13(3)	300.40(2)	16.33(4)
8	13.01(6)	35.92(5)	167.02(7)	14.38(6)
9	13.07(5)	35.55(6)	155.96(8)	15.62(5)

*(a) : rank of a clone according to SI value.

This study indicates that jojoba oil and seed can be produced reasonably well under irrigated conditions in the arid ecosystem of northern and western Saudi Arabia. However, further studies are needed to determine factors affecting seed yields, including potential interactions of genotype × environment on seed per tree production and failure to break flower dormancy at lower latitudes and economic potentials of jojoba as a new crop for the region. However, we need to emphasize that the fast growth rates attained by the shrub at lower latitudes will allow the utilization of jojoba in in sand stabilization, landscaping, desertification, open natural range lands and national parks projects.

ACKNOWLEDGEMENTS

The authors acknowledge financial support provided by King Abdulaziz City for Science and Technology or KACST (Grant At-14-25).

REFRENCES

[1]. Al-Soqeer, A., 2010. Establishment and early growth of some Jojoba clones in Al-Qassim Region. J Agron, 9: 157-162.

[2]. American Oil Chemist Society (AOCS), 1992. Recommended methods for the determination of jojoba oil quality and purity. In: Sampling and Analysis of Commercial Fats and Oils, US AOCS Recommended Practices, pp. 1–91.

[3]. Ayerza, R(h)., 1996. Evaluation of eight jojoba clones for rooting capacity, plant volume, seed yield and wax quality and quantity. In: Princen, L.H., Rossi, C. (eds.), Proceedings of the Ninth International Conference on Jojoba and its Uses, 25–30 September 1994. Catamarca, Argentina, pp. 1–3.

[4]. Benzioni, A., Dunstone., R.L., 1986. Jojoba: Adaptation to environmental stress and the implications for domestication. *The Q. Rev. Boil.*, **61**: 177-199.

[5]. Benzioni, A. Nerd, A., 1986. Effects of irrigation and fertilization on vegetative growth and yield in jojoba in relation to water status of the plants. In: Zabisky, Y., J. Wisnial, J.(eds.), *Proceedings of the Sixth International Conference on Jojoba and its Uses, Ben Gurion Univ., Beer Sheva, Israel*, pp. 201-212.

[6]. Benzioni, A., Nerd, A.,1989. Effect of water status, genetic background and fertilizer on flowering in jojoba. Adv. *Hort Sci.*, **2**: 48-51.

[7]. Benzioni, A., 1988. Water status and its control in jojoba (*Simmondsia chinensis* L.). In: Baldwin, A.R. (ed.), *Proceedings of the seventh International Conference on Jojoba and its Uses. American Oil Chemist Society, Champaign*, IL, USA,pp. 20–35.

[8]. Benzioni, A., Shiloh, E., Ventura, M., 1996. Performance and characteristics of some Israeli jojoba clones: growth, flowering and yields. In: Princen, L.H., Rossi, C. (eds.), *Proceedings of the Ninth International Conference on Jojoba and its Uses, Catamarca, Argentina*, pp. 30–36.

[9]. Benzioni, A., Shiloh,E., Ventura, M.,1999. Yield parameters in young jojoba plants and their relation to actual yield in later years. *Ind. Crops Prod*, **10**: 85–95.

[10]. Botti, C., Prat, L., Palzkill, D., Cánaves, L.,1998. Evaluation of jojoba clones grown under water and salinity stresses in Chile. *Ind. Crops Prod.*, **9**: 39 –45.

[11]. Coates, W. ,Ayerza, A.,2008. Supplemental pollination-increasing Jojoba (*Simmondsia chinensis* L. Schneider) seed yields in the Arid Chaco environment. *Ind Crops Prod*, **27**: 364–370.

[12]. Dunstone, R.L., 1980. Jojoba flower buds: Temperature and photoperiod effects in breaking dormancy. *Austral. J. Plant Physiol*., **31**: 727-737.

[13]. Dunstone, R.L., 1982. Jojoba flower buds: Effect of preconditioning temperature. *Aust. J. Agric. Res*., **33**: 649-656.

[14]. Dunstone, R.L.,1988. The reproductive cycle of jojoba. In: A.R. Baldwin (ed.), *Proceedings of the Seventh International Conference on Jojoba and its Uses, American Oil Chemist Society, Champaign*, IL, USA, pp.50-59.

[15]. Gentry, H.S.,1958. The natural history of jojoba (*S. chinensis*) and its cultural aspects. *Econ. Bot.*, **12**: 261-295.

[16]. Milthorpe, P.L., Dunstone, R.L., 1989. The potential of jojoba (*Simmondsia chinensis*) in New South Wales. 2. Some factors affecting yield. *Austral. J. Expt. Agr.*, **29**: 389-395.

[17]. Osman, H.E., Abo-Hassan, A.A., 1997 . Jojoba (*Simmondsia chinesis* (Link) Scheinder): A potential shrub in the Arabian Desert: II. Effect of drought stress on vegetative growth and nutritive value. *JKAU, Met. Env., Arid Land Agric.*, **8**: 97-107.

[18]. Purcell H.C, Abbott, T.P., Holser, R.A., Phillips, B.S. 2000. *Simmondsia* and wax ester levels in 100 high-yielding jojoba clones. *Ind Crops Prod.*, **12**: 151–157.

[19]. Purcell, H.C., Purcell II, H.C., 1988. Jojoba crop improvement through genetics. In: Baldwin, A.R. (ed.), *Proceedings of the Seventh International Conference on Jojoba and its Uses, American Oil Chemist Society*, Champaign, IL, USA, pp. 69–85.

[20]. Ramonet-Razon, R., 1988. Selection criteria and evaluation procedures for jojoba plant improvement. In: A.R. Baldwin (ed.). *Proceedings of the Seventh International Conference on Jojoba and its Uses Amer. Oil. Chem. Soc. Champaign*, IL., USA, pp. 60-68.

[21]. Ravetta, D.A., Palzkill, A., 1993. Variation and broad sense heritability of branching frequency of jojoba. In: J. Janick and J.E. Simon (eds.), New Crops, Wiley, New York, USA, pp. 358-359.
[22]. Snedecor, G.W., Cochran, W.G. ,1989. Statistical Methods, 8th ed., Iowa State University Press.
[23]. Tobares, L., Frati, M., Guzman, C., Maestri, D., 2004. Agronomical and chemical traits as descriptors for discrimination and selection of jojoba (*Simmondsia chinensis*) clones. *Ind Crops Prod*, **19**: 107-111.
[24]. Ulger, S., Akdeur, O., Baktir, U. , 2002. Selection of promising jojoba (*Simmondsia chinensis* link schneider) types in terms of yield and oil content. *Turk. J. For. Agric.* , **26**: 319-322.
[25]. Zar, J.H., 1984. Biostatistical Analysis, second ed., Prentice-Hall, Englewood Cliffs.