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Performance of Some Female Jojoba (*Simmondsia chinensis*) Genotypes Irrigated with Primary Treated Wastewater

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Abstract: The present study was carried out on six years old sexually propagated female jojoba genotypes irrigated with primary treated wastewater (domestic and industrial) to investigate the effect of genotype on vegetative growth, flowering, fruiting, seed characteristics and seed oil percentage. As well as the impact of washing seeds with running water on oil and defatted meal (jojoba mill by-product) heavy metals contents (Cadmium, Nickel and Lead). Results revealed significant differences between the tested jojoba genotypes in the studied characteristics, genotype 1 significantly exceeded the others in seed and oil yields. Cd, Ni and Pb concentrations exceeded the permissible limits in soil, irrigation water, jojoba oil and defatted meal. Washing seeds with running water proved to be significantly effective just for Cd reduction in jojoba oil while, it was significantly sufficient in lowering Cd, Ni and Pb contents in jojoba defatted meal. Therefore, it can be concluded from the present study that jojoba oil is not likely to be used in cosmetics industry, while it is likely to be used as a biofuel to ensure the recycling of water resources resulting from cities and industry. Also, the cultivation of jojoba can be used in minimizing soil contamination with heavy metals. Jojoba meal after washing was under limits for Pb content but above limits for Cd, so is not supposed to be used as livestock feed or fertilizer.

Key words: *Simmondsia chinensis* · Jojoba · Flowering · Yield · Seed oil · Defatted meal · Primary treated wastewater · Heavy metals · Washing seeds

INTRODUCTION

Jojoba (*Simmondsia chinensis*, (Link) Schneider), the only member of family Simmondsiaceae is a wax-yielding shrub (commercially oil). Jojoba oil is composed almost completely (97%) of wax esters of monounsaturated, straight-chain acids and alcohols. Jojoba seed oil is not easily oxidized and remains chemically unchanged for years. It also remains essentially unchanged when heated repeatedly to temperatures above 285°C [1]. So it is used for lubrication of aircraft engines and heavy machinery as well as the production of biofuel. Jojoba oil differs from the other vegetable oils (high triglyceride content). The stability shown by jojoba oil makes it especially useful for cosmetic applications. The potential therapeutic uses of jojoba oil include the treatment of acne, cold sores and skin diseases such as psoriasis [2]. Once jojoba seed defatted (meal), the rest of the seed is composed of protein rich meal (32%) that can be used for animal feed [3]. Also, jojoba residue is rich in metals and contains high percentage of antioxidants. It is introduced in a variety of medical products [4]. Recently, jojoba wax was reported to be a food additive and an edible oil rich in all sorts of vitamins and minerals [5, 2].

The current available water resources in Egypt are limited and there is a big gap between the total water supply and the total current water demands due to urbanization and population growth. The water resources in Egypt are surface water from Nile about 55.5 Billion cubic meter (BCM)/Y. Effective rains 1.6 BCM/Y. About 2.4 BCM/Y from non-renewable deep ground water in the western desert of Sinai and from shallow ground water 6.5 BCM/Y. The total water supply is 66 BCM/Y and the total water demands in several activities is 79.5 BCM/Y. The agriculture sector is the biggest consumer of freshwater 80 % of the total demands. To satisfy the Egyptian water demands, the shortage of 13.5 BCM/Y of

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water should be accomplished through non-confidential water resources such as indirect wastewater reuse and agriculture wastewater reuse of good quality. The expected total water shortage in 2025 would be 26 BCM/Y [6].

Primary treated wastewater has been in use since 1922 in Al-Gabal-Al-Asfar farm (1, 200 ha) about 30 km from Cairo which was established to dispose of the city wastewater [7, 8]. In Egypt, reuse of treated wastewater (domestic and industrial) is considered an effective saving measure. Primary use of treated wastewater in Egypt is for irrigation of green areas (landscape development) and irrigation of non-food agriculture [9]. The volume of discharged wastewater (treated) is increasing for Egypt (with 57 % wastewater treated) but the wastewater volume which is used is too low [10]. Produced municipal wastewater was estimated at 7, 078 million m^3 in 2012. Around 92 % of this amount is collected and 4, 013 million m^3, is treated [11]. In 2010, 35, 500 ha are directly using treated wastewater [12]. Wastewater irrigation creates both opportunities and problems. The opportunities of wastewater irrigation are that it provides convenient disposal of waste products and adds valuable plant nutrients and organic matter to soils and crops [8]. However, there are risks such as health risks resulting from human exposure (workers, agricultural products processors and consumers) to pathogens as well as contamination of soils, ground water and plants [7]. Kinuthia *et al*. [13] reported that, Cadmium toxicity leads to damages of respiratory, renal, skeletal and cardiovascular systems as well as development of cancers. The disadvantageous effects of nickel on health may include dermatitis, allergy, organ diseases and respiratory system cancer. Lead poisoning damages the kidneys, liver, heart, brain, skeleton and the nervous system.

There are no available scientific researches dealing with the effect of wastewater irrigation on jojoba oil and defatted meal (jojoba mill by-product) until the completion of this study. Jojoba oil extraction in Egypt is done without seeds washing and it's a routine procedure because seed drying is a time consuming operation. The aim of this investigation was to identify the impact of primary treated wastewater irrigation (domestic and industrial) polluted with heavy metals on the selected six female jojoba genotypes vegetative growth, flowering, fruiting and seed physical characteristics. As well as, the effect of seed washing with running water on the heavy metals content of jojoba oil and defatted meal.

MATERIALS AND METHODS

Biological Materials and Experimental Design: The present study was carried out on six years - old sexually propagated six female jojoba genotypes (*Simmondsia chinensis*, (Link) Schneider) during two consecutive (2017 and 2018) experimental seasons, in a private farm near Cairo-Al Wahat Al Baharia road which is known for heavy traffic, in the Green belt area, Giza Governorate, Egypt. Jojoba healthy genotypes were planted in sandy loamy soil spaced at 4 × 2 m. Plants drip irrigation procedure is totally depending on primary treated wastewater (domestic and industrial) resulted from 6^{th} of October city, Giza Governorate. Only 500 g each of compost, super phosphate and sulfur were added for each genotype per year as the genotypes receive most of their mineral nutrition through wastewater irrigation.

Plant Materials: Since the six female jojoba shrubs (genotypes) which were chosen for this investigation were not previously evaluated so the upcoming data were recorded:

- Vegetative growth characteristics: Twelve shoots were selected/genotype (4 shoots and each were represented by 3 replicates) for estimation of the followings:

Shoot length (cm), leaves density (No./m), leaf length (cm, from the middle of the shoot), leaf width (cm) and No. of laterals/m of the selected shoots were estimated at the end of July 2017 and 2018 seasons.

- Flowering, fruiting and yield characteristics: At the end of February; flowering density (No. of flowers/m,) and No. of fruits/m at the end of April were estimated (three replicates). Yield as Kg/genotype was weighted at the end of June.
- Transformed oil percentage was determined by extracting the oil from the dried and crushed seed samples (three replicates for each genotype) by means Soxhlet extraction apparatus [3] using petroleum ether (60–80°C) as solvent. Oil percentage was transformed to angle value before statistical analysis.
- Oil yield (Kg) was estimated using the formula:

Oil yield = [(seed sample before extracting – seed sample after extracting) / seed sample before extracting] *seed yield.

- Seed physical characteristics: after harvesting, seed length, width and thickness (cm) and weight (g) were measured (three replicates/genotype, 10 seeds per each).

Soil and Irrigation Water Samples Analysis: Soil samples (3 replicates, then mixed) at depth 0-60 cm of soil surface were taken and air dried. Soil pH (was measured using a glass electrode) and electrical conductivity (EC) was measured in 1:2.5 and 1:5 soil: water extract, respectively at 25°C.

Soil organic matter percentage was estimated using Walkley and Black method outlined by Jackson [14]. Calcium carbonate content percentage of the soil samples using Collins calcimeter was measured according to Piper [15]. Soluble cations and anions in soil were analyzed in (1:5) extracts according to Cottenie *et al*. [16] as shown in Table (4).

The primary treated wastewater sample was taken to determine the EC (dSm^{-1}) and pH, soluble cations (Ca^{++}, Na^{+}, Mg^{++} and K^{+}) and soluble anions (CO_3^-, HCO_3^-, Cl^- and $SO_4^{=}$) in water samples were analyzed according to the methods described by Jackson [14]. Heavy metals content in the soil were determined using $HCl\text{-}HNO_3$ digestion method as recommended by Cottenie *et al*. [16] while, heavy metals Cadmium (Cd), Nickel (Ni) and Lead (Pb) were determined after filtration using cellulose filter paper in irrigation water and were measured by atomic absorption (model Perkin Elmer 400) and expressed as ppm.

Sodium adsorption ratio (SAR) was calculated in primary treated irrigation water using the equation.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Sodium, calcium and magnesium concentrations are expressed in mEq/L (Table 5).

Effect of Washing on Heavy Metals Content in Seed Oil and Defatted Meal

Samples Preparation: Clean seeds were collected from the soil surface under the six selected jojoba shrubs (50 gm/ genotype) and then mixed all together. Samples were re-cleaned using a dry towel to remove dust and divided into two groups of equal weight: the 1st group was left dry (unwashed) and the 2nd one was washed with running water for approx. 5 minutes. Seed samples were oven dried at 70°C till a constant weight and then grounded. Oil extractions were done separately for each group using manual hydraulic press and the resulted oil was kept in clean brown glass bottles with tight lids. After extraction, the defatted meals were collected from each group and were kept in clean petri dishes with lids.

Heavy Metals Content: Oil sample digestion was carried out by Microwave Equipment. Jojoba oil and meal were digested with di-acid mixture as described by Chapman and Pratt [17]. The determination of Cd, Ni and Pb metals of jojoba oil and defatted meal (unwashed and washed samples) were done in each season using atomic absorption (model Perkin Elmer 400) in Land Resources Evaluation and Mapping Laboratory, National Research Center.

Statistical Analysis: Data recorded in 2017 and 2018 seasons were subjected to analysis of variance (ANOVA) in a Randomized Complete Block Design according to Snedecor and Cochran [18] and the means were distinguished according to Duncan Multiple Range test at the level of probability 5% [19].

RESULTS AND DISCUSSION

Vegetative Growth Characteristics: According to the collected data in Table (1) that, the maximum leaf density values (No. of leaves/m) have been displayed by genotypes 4, however Genotype 4 showed the minimum records of shoot length (cm), leaf length and width (cm) and No. of laterals/m. Whereas, the highest values of shoot length (2nd season) and leaf length (cm) and the lowest ones of leaf density were obtained in genotype 3, this was true in both seasons under study. Genotype 6 transcend the others in leaf width (both seasons) and No. of laterals/m (2nd season).

Similarly, significant differences were observed between seven female jojoba genotypes regarding leaves density/m, leaf length and leaf width [20] and between 15 female jojoba genotypes concerning shoot length, leaves density/m and No. of laterals/m as described by Eltaweel *et al.* [21].

Flowering, Fruiting, Yield and Oil Percentage Characteristics

Flowering Density (No. of Flowers/m): In both seasons of study (Table, 2), genotype 4 significantly surpassed the others giving the highest flowers No./m. Similar result was found by Al-Soqeer [20] and Eltaweel *et al.* [21].

Table 1: Vegetative growth parameters of six female jojoba genotypes irrigated with wastewater (primary treated(in 2017 and 2018 seasons

	Shoot length (cm)		Leaf density/m		Leaf length (cm)		Leaf width (cm)		No. of laterals/m	
Genotype No.	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
1	32.00A	33.04B	80.86D	78.66E	3.34B	3.43B	1.23B	1.26B	7.00C	5.67C
2	24.79C	27.13C	87.87B	82.86C	2.78C	2.83D	1.14C	1.20B	8.64B	8.22A
3	30.83B	34.17A	60.26E	57.58F	3.74A	3.84A	1.20BC	1.24B	3.62D	4.35D
4	22.75D	24.83E	102.30A	94.41A	2.41D	2.50E	1.00D	1.08C	2.62E	1.65F
5	24.54C	25.18D	82.56C	85.16B	2.99C	3.13C	1.18BC	1.22B	8.95AB	7.12B
6	24.42C	25.42D	81.19D	79.69D	3.29B	3.33B	1.30A	1.40A	9.35A	4.17E

Means designated with the same letter within column in each season is not significantly different according to Duncan's Multiple Range Test (DMRT) at 0.05 level of probability.

Table 2: Flowering, fruiting, yield and seed transformed oil percentage of six female jojoba genotypes irrigated with wastewater (primary treated) in 2017 and 2018 seasons

	No. of flowers/m		No. of fruits/m		Yield (Kg)		Transformed oil %		Oil yield (Kg)	
Genotype No.	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
1	10.15F	13.84E	9.62D	13.46C	2.00A	2.63A	39.32E	39.66E	0.79A	1.04A
2	17.37B	17.92B	14.11B	15.26B	1.00D	1.30D	42.56D	43.23C	0.43D	0.56D
3	10.57E	10.69F	8.73F	9.45F	1.25C	1.60C	39.85E	42.00D	0.50C	0.67C
4	18.48A	18.59A	17.05A	17.22A	1.50B	1.82B	44.36C	46.10B	0.67B	0.84B
5	15.75C	17.02C	12.65C	12.91D	0.75E	1.12E	47.56A	48.50A	0.36E	0.54DE
6	12.21D	15.55D	9.03E	12.43E	0.75E	1.05E	46.13B	47.61A	0.35E	0.50E

Means designated with the same letter within column in each season is not significantly different according to Duncan's Multiple Range Test (DMRT) at 0.05 level of probability

No. of Fruits/m: Table (2) gives a clear evidence that genotype 4 was significantly superior in this concern. Similarly, Eltaweel *et al.* [21] confirmed that No. of fruits of jojoba genotypes under study ranged 2.61-12.67 fruits.

Yield (Kg): Genotype 1 (Table 2) significantly produced the maximum values in this regard. Al-Soqeer [20] and Eltaweel *et al.* [21] belayed that significant variations in yield among female jojoba shrubs.

Transformed Oil Percentage Content (%): Transformed oil (%) significantly differed between selected genotypes (Table 2). The richest two genotypes in seed oil content were 5 and 6. Likewise, Al-Soqeer *et al*. [3], Eltaweel *et al.* [21] and Agarwal *et al*. [22] reported that highly significant differences among the jojoba genotypes were found in oil content.

Oil Yield (Kg): Data shown in Table (2) revealed that Genotype 1 significantly exceeded the others in oil yield, whilst genotype 6 recorded the minimum values in both seasons.

Seed Physical Characteristics: In this regard, according to the collected data in Table (3) and Fig. (1), there was a clear significant differences between the studied genotypes. It is apparent that genotype 1 surpassed the others in terms of seed width (cm), weight (g) and thickness (cm). Genotype 3 was the superior in seed length (cm). Whereas, genotype 4 produced seeds have the least quality (length, width, weight and thickness). Similarly, Al-Soqeer [20] reported that significant differences were clear regarding seed weight in 3 seasons study. The above results are in agreement with Eltaweel *et al.* [21] who found that seed physical characteristics ranged 1.42-2.10 cm, 0.90-1.30 cm, 0.83-1.52 g for seed length, width and weight, respectively of 15 female jojoba shrubs. Moreover, Agarwal *et al*. [22] reported similar results concerning seed length (1.582-1.847 cm), width (0.923-1.090 cm), weight (0.760-0.977 g) and thickness (0.817-0.955 cm).

In this investigation, extreme variations were observed between the jojoba genotypes regarding vegetative growth, flowering, fruiting, seed and oil yields, oil percentage and seed characteristics due to propagation by seed which resulted in great diversity between genotypes. Similarly, it was concluded that the outbreeding in jojoba has resulted in highly heterogeneous seeds that provide a wide range of hybrid vigor and fertility [3].

Table 3: Seed physical characteristics of six female jojoba genotypes irrigated with wastewater (primary treated) in 2017 and 2018 seasons

	Seed length (cm)		Seed width (cm)		Seed weight (g)		Seed thickness (cm)	
Genotype No.	2017	2018	2017	2018	2017	2018	2017	2018
1	1.60CD	1.58C	1.11A	1.12A	1.04A	1.06A	1.08A	1.09A
2	1.53D	1.54C	1.04A	1.07B	0.78CD	0.79CD	1.01B	1.02B
3	1.96A	1.97A	0.94B	0.95C	0.81C	0.82C	0.87E	0.89E
4	1.55D	1.57C	0.81C	0.82D	0.52E	0.53E	0.78F	0.79F
5	1.68BC	1.70B	0.92B	0.94C	0.74D	0.75D	0.93D	0.93D
6	1.74B	1.76B	1.09A	1.08AB	0.98B	0.97B	0.98C	0.99C

Means designated with the same letter within column in each season is not significantly different according to Duncan's Multiple Range Test (DMRT) at 0.05 level of probability

Fig. 1: Seed physical characteristics of the six female jojoba genotypes

Soil Chemical Properties and Heavy Metals Content: Regarding soil reaction, soil pH recorded 7.20 as shown in Table (4). Similar result was confirmed by Farrag *et al.* [23] who reported that soil pH values varied between 6.82 and 8.88 and using sewage water in irrigation showed more decrease in the soil (pH) of the studied area in Luxor Governorate, Egypt as well as Abd-Elwahed [24] who mentioned that pH of the surface soil ranged from 6.8 to 7.8 for the whole study area in Elgabal Elasfar farm. Wastewater-irrigated soils contained higher organic nitrogen and carbon contents, which could promote micro-organism activity to break up organic nitrogen molecules into inorganic nitrogen and H^+. Also, wastewater itself may carry H^+ into irrigated soils too. These two aspects could result in lower pH values of wastewater-irrigated soils [25].

Concerning electrical conductivity (Table 4), EC of experimental soil samples was 0.25 dS/m which indicated low salinity (EC_e < 4dS/m) as mentioned by Farrag *et al*. [23], they also found that under the drip irrigation systems, the long-term use of sewage water showed lower EC_e values. Similarly, Nawaz *et al*. [26] declared a significant decrease in EC of soil, with the application of industrial effluents in culture areas of rice in Pakistan. The above result is in line with Elgharably and Allam [27] who found that EC of collected soil of ElMadabegh area, Assiut, Egypt was 0.23 ± 0.01 (dS m^{-1}).

The texture of the soil was sandy loam. Sandiness of soil suggests easy leaching of heavy metals and nutrients to ground water. As mentioned by Onweremadu [28], increased bio-toxicity occurs in lesser clay content soils as clay surfaces are negatively charged thereby attracting cationic heavy metals. Also, Sherene [29] belayed that, clay is an important adsorption medium for heavy metals in soils. The clay soils retain a high amount of metals when compared to sandy ones.

Taking into consideration $CaCO_3$ %, soil samples recorded 4.00 % (Table 4). Farrag *et al*. [23] reported that $CaCO_3$ content ranged 0.2-11.51 % and the average value was 5.64 % of four studied sites.

The organic matter content of the studied samples was 1 % as shown in Table (4) and this result go perfectly with Farrag *et al*. [23] who found that organic matter content of the studied soils varied from 0.0 to 1.84 %. According to Khafagi *et al*. [30] and Farrag *et al*. [23] prolonged irrigation with sewage water resulted in an increase in the soil organic matter compared to those irrigated with ground water and Nile water, indicating that, irrigation with sewage water helps improving the fertility status of the soil. In the present study, Jojoba genotypes maintained their normal growth, flowering and fruiting without any symptoms of minerals shortage despite of the low fertilizers application. Similarly, Hegazi *et al*. [31] reported that sewage water provided macro and micro nutrients to Navel orange trees.

Table 4: Chemical properties and heavy metals content (Cd, Ni and Pb) of the tested soil samples collected from the experimental area

mEq/L.											
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	So_4^{--}	pH (1:2.5)	EC dSm^{-1} (1:5)	$CaCO_3$ %	Organic matter %
1.10	0.50	0.70	0.03	-	0.60	1.20	0.53	7.20	0.25	4.00	1.00
Heavy metals content (ppm)				Cd		Ni		Pb			
				0.072		0.314		0.372			

Permissible limits of Cd, Ni and Pb were 0.003, 0.050 and 0.100 ppm, respectively [13].

Referring to heavy metals content in soil samples as presented in Table (4), Cd, Ni and Pb scored 0.072, 0.314 and 0.372 ppm, respectively. The previously mentioned concentrations are above the permissible limits (0.003, 0.050 and 0.100 ppm, respectively) for agricultural soils of WHO [13]. Hegazi *et al*. [32] studied the effect of different locations in Egypt on Ni, Pb and Cd content in soil samples and they found that the concentrations in Esmalia were 0.156, 0.096 and 0.003 µg/ml, respectively, while in El Sadat they were 2.167, 0.013 and 0.133 µg/ml, respectively and in El Saff they were 0.136, 0.016 and 0.166 µg/ml respectively. Elgharably *et al*. [33] proved that the agricultural soils of Assiut under investigation are contaminated with Pb, Cd and Ni. The metal concentrations in soils of the studied areas exceeded the limited values recommended by several studies. Nasr *et al*. [4] concluded that soil samples of jojoba plants (longest cultivation and irrigation period) have the highest heavy metal concentrations. The above results are in line with Abd-Elwahed [24] who reported that mean concentrations of heavy metals showed this trend Pb > Ni > Cd at the south and middle sections of Elgabal Elasfar area, Egypt. The mean concentration ± SE (standard error) of heavy metals in soil samples irrigated with wastewater in Nairobi, Kenya was highest for Pb and lowest for Hg in an ascending sequence of Hg < Tl < Cd < Ni < Cr < Pb [13].

Irrigation Wastewater Samples Analysis: Chemical properties and heavy metals of primary treated wastewater samples are shown in Table (5). The pH value of investigated water source was 6.71 which falls in the safe limits reported by Egypt Decree 92/2013 Indirect wastewater reuse [34]. Similarly, Farrag *et al*. [23] reported that sewage water has a lower pH value compared to Nile water and ground water in Luxor Governorate, Egypt and Abd-Elwahed [24] in Elgabal Elasfar area, Egypt.

Electrical Conductivity and SAR of irrigation water recorded 1.57 dSm^{-1} and 4.56 which indicated slight to moderate salinity and considered within the permissible limit [36].

Concerning heavy metals content in the tested irrigation water (primary treated wastewater), Cd, Ni and Pb concentrations were 0.042, 0.600 and 0.012 ppm, respectively (Table 5) exceeding WHO limits reported by Kinuthia *et al*. [13] who mentioned that WHO permissible limits of Cd, Ni and Pb and they were 0.003, 0.02 and 0.01 ppm, respectively. However, ECP 501 [35] reported that maximum concentrations of Cd, Ni and Pb elements in irrigation water to be 0.01, 0.20 and 5.00 ppm, showing that Pb of the studied irrigation water didn't exceed the recommended maximum limits. Several scientists studied wastewater content of heavy metals, Cd, Ni and Pb concentrations were 0.06, 0.27 and 1.28 mg/L, respectively in El-Sadat city, Minufiya Governorate, Egypt [37], < 0.01, - and 0.05 mg/L of raw wastewater [4], N D (not detected), 0.13 and 4.21 mg/L in the south section, N D, 0.12 and 4.02 mg/L in the middle section as well as N D, 0.12 and 3.91 mg/L in the north section of Elgabal Elasfar area, Egypt [24]. In the previously mentioned area, there was a potential transfer of heavy metals using raw sewage water to Navel orange trees. The transfer continues to increase in response to the increase in the irrigation period. The transfer of such pollutants to the food chain represent a health hazard to human as reported by Hegazi *et al*. [31]. Moreover, Lone *et al*. [38] gave evidence that sewage water irrigation leads to the accumulation of heavy metals in crop plants and may cause harmful effects on animals and plants. Long term application of sewage water may cause accumulation of heavy metals in surface and subsurface soils, which proved to be harmful to plants and consumers of the harvested crops.

Considering, Ca^{++}, Mg^{++}, Na^{+}, K^{+}, CO_3^{--}, HCO_3^{-}, Cl^{-} and So_4^{--} contents as shown in Table (5) were in the usual range of irrigation water [36].

Environmental pollution resulting from using sludge, sewage water, some industrial composts as well as from the heavy metal containing aerosols falling from the atmosphere and fuel burning and factories cause the contamination of soil and plants [39]. Despite the contaminated soil, water and the heavy traffic, jojoba

Table 5: Chemical properties and heavy metals content (Cd, Ni and Pb) of the tested primary treated wastewater samples collected from the experimental area

mEq/L.										
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	So_4^{-}	pH	EC dSm^{-1}	SAR
4.00	2.00	7.90	0.20	-	2.10	6.00	6.00	6.71	1.57	4.56
Heavy metals content (ppm)				Cd		Ni		Pb		
				0.042		0.600		0.012		

WHO permissible limits of Cd, Ni and Pb and they were 0.003, 0.02 and 0.01 ppm, respectively [13] as well as 0.01, 0.20 and 5.00 ppm, respectively [35].

genotypes in the present study thrived well without showing any apparent symptoms of toxicity, so they may be used to mitigate the contaminated sites.

Heavy Metals Content

Oil Heavy Metals Content (ppm): Cadmium, Nickel and Lead contents in jojoba oil are presented in Table (6). In both seasons of study washing treatment dramatically reduced Cd contents in oil (less than 1/3 in the 1st season and more than 1/3 in the 2nd season). Maximum permissible concentration of Cd in oil is 0.05 mg/Kg as reported by Angelova *et al*. [40]. Milled jojoba capsules (conc. 1%) recorded 34.8 % Cd adsorption from Abu Zaabal industrial area wastewater at 24h contact times [41].

In 2017 season a clear significant difference was shown between unwashed and washed treatments concerning Ni content (0.93 and 0.42 ppm, respectively) while, in 2018 season insignificant difference was observed. In comparison to edible oils (soybean, hazelnut, sunflower, almond and olive), Ni content is high in jojoba oil [22].

Regarding Pb content in jojoba oil (Table 6), insignificant reduction between treatments in 2017 season was observed, however in 2018 season, washing led to a significant reduction (2.17 and 0.95 ppm, respectively). El Kinawy *et al.* [42] showed that jojoba oil (20 mg/L) has the ability to remove heavy metals ions (Cu^{++} and Pb^{++}) with the same efficiency several times after its regeneration. Angelova *et al*. [40] reported that maximum permissible concentration of Pb in oil is 0.10 mg/Kg. Agarwal *et al.* [22] declared that Pb contamination showed negative effects on human health either by respiration or by skin absorption. The specification for crude jojoba seed oil includes less than 0.8 ppm elemental lead (Pb). The Expert Panel expressed concern regarding pesticide residues and heavy metals that may be present in botanical ingredients, including jojoba derivatives. They stressed that the cosmetic industry should continue to use the necessary procedures to limit these impurities in the ingredients before blending into cosmetic formulations [1]. In our study, Pb content in oil in 2018 season exceeded the Cosmetic Ingredient Review [1] limits, so using skin care products based on contaminated jojoba oil with high Pb concentration may result in health side effects.

Our results are in line with El-Hamidi and Zaher [43] who announced that jojoba oil, may also has promise in the treatment of industrial wastewater and toxic heavy metals recovery. They also added that jojoba oil can be used as a protective coating, pesticides and plant hormones carrier. As concluded from our study, using of contaminated jojoba oil in the previously mentioned usages may lead to heavy metals contaminated food. The quantities of Pb and Cd in rapeseed oil, obtained from rapeseed, grown 0.5 km away from the Non-Ferrous-Metal Works (NFMW) and Pb in the oil from sunflower, grown in the region of the NFMW, were higher than the accepted maximum permissible concentrations and could be hazardous for the people to consume it [40].

It is worthy to mention that Hegazi and Hegazi [44] proved that olive oil is free from Cd, Ni and Pb contents. This contradiction with our results may be due to the difference in composition between jojoba and olive oil as the first composed of wax esters but the last constitute of high triglyceride content or resulted from the using of domestic and industrial wastewater. The significant effectiveness reduction of heavy metals by washing was not approved (except for Cd content) in jojoba oil and this may be because mobilization of heavy metals needs an aqueous media while oil molecule is greatly hydrophobic [44].

Defatted Meal Heavy Metals Content (ppm): Table (7) presents heavy metals contents in jojoba defatted meal. The same trend of increased Cd content in unwashed samples was observed in both seasons of study (8.20 and 8.30 ppm, respectively) with significant differences with washed ones (1.90 and 2.20 ppm, respectively). It was reported that maximum Cd^{+2} uptake of 9.89 mg/g was achieved at jojoba residue concentration of 5 mg/ml and Cd^{+2} ion concentration of 25 ppm [45]. Milled jojoba capsules (conc. 1%) recorded 34.8 % Cd adsorption from Abu Zaabal industrial area wastewater at 24h contact time [41].

Table 6: Heavy metals content of jojoba oil (unwashed and washed samples) in 2017 and 2018 seasons

	Cd (ppm)		Ni (ppm)		Pb (ppm)	
Treatments	2017	2018	2017	2018	2017	2018
Unwashed sample	0.58A	0.82A	0.93A	0.95A	0.65A	2.17A
Washed sample	0.18B	0.28B	0.42B	0.88A	0.53A	0.95B

Means designated with the same letter within column in each season is not significantly different according to Duncan's Multiple Range Test (DMRT) at 0.05 level of probability. Maximum permissible concentration of Cd and Pb are 0.05 and 0.10 mg/Kg [40].

Table 7: Heavy metals content of jojoba defatted meal (unwashed and washed samples) in 2017 and 2018 seasons

	Cd (ppm)		Ni (ppm)		Pb (ppm)	
Treatments	2017	2018	2017	2018	2017	2018
Unwashed sample	8.20A	8.30A	11.30A	26.80A	40.30A	40.70A
Washed sample	1.90B	2.20B	3.20B	6.60B	3.29B	7.70B

Means designated with the same letter within column in each season is not significantly different according to Duncan's Multiple Range Test (DMRT) at 0.05 level of probability. Maximum tolerable/tolerance level for Cd and Pb in (complete) feed are 0.50 and 30 ppm [47]

Ni content in unwashed sample is more than triple in washed one in 2017 season and increased to more than four times in 2018 season with significant differences (Table, 7).

Lead (Pb) contents of jojoba meal were severely and significantly reduced by washing from 40.30 to 3.29 ppm and 40.70 to 7.70 ppm in the 1st and the 2nd seasons, respectively (Table, 7).

Similarly, heavy metals accumulated in fruits of olive cultivars and higher heavy metals content of seeds than oil of rapeseed and sunflower plants was reported [44, 46, 40].

Association of American Feed Control Officials (AAFCO) [47] reported that the current maximum tolerable/tolerance level for Cd and Pb in (complete) feed is 0.50 and 30 ppm, respectively. In this study either washed or unwashed samples of Cd content were above the limits so it’s not suitable for livestock feed. No limits for Ni content in jojoba meal were available.

Washing was reported to remove or reduce heavy metals content, as reported by WHO [48] on leafy vegetables, Banerjee *et al*. [49] on several fruits and vegetables and Yamada and Wu [50] on polished rice.

Our results didn’t support many suggestions of wastewater irrigation of jojoba shrubs as an industrial oil seed crop [8, 7, 4] due to heavy metals accumulation in oil and meal which may contaminate cosmetic products or interfere in food chain. Our results are in agreement with El-Arby and Elbordiny [37] who found that jojoba surpassed other plants in accumulation of heavy metals and the accumulation percentage by jojoba shrubs could be arranged in the following order: Co> Pb > Ni > Cu> Fe=Zn> Mn. Jojoba shrubs accumulated both Co and Pb more than other trees. Moreover, Shukry *et al*. [51] concluded that Cu, Mn, Cd and Pb accumulated in jojoba plant planted in crude oil contaminated soil. Finally, Khafagi *et al*. [30] reported that jojoba could be considered as a hyper accumulator for one or more of the tested heavy metals.

CONCLUSION

In view of the above results, it can be concluded that:

- The tested jojoba genotypes showed great diversity in their vegetative growth, flowering, fruiting, seed and oil yields, transformed oil percentage and seed characteristics. Genotype 1 recorded the highest seed and oil yields.
- Irrigation with primary treated wastewater (domestic and industrial) increases heavy metals content in soil and jojoba genotypes are biosorpant of Cd, Ni and Pb metals.
- Extracted oil from jojoba genotypes irrigated with primary treated wastewater is not suitable for cosmetic and pharmaceutical industries, protective coating of fruits as well as carrier oil for pesticides or plant hormones but it’s highly recommended to be used as a biofuel or an additive to engine lubricants to ensure the recycling of water resources resulted from cities and industry and to reduce soil contamination with heavy metals.
- Jojoba defatted meal is not supposed to be used as livestock feed or fertilizer due to its higher content of Cd.
- Washing samples proved to be significantly effective just for Cd reduction in jojoba oil while, it was significantly sufficient in lowering Cd, Ni and Pb contents in jojoba defatted meal.

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