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Effect of irrigation and nutrient on physical properties of safflower seeds

Maziar Feyzollahzadeh, Asaad ModaresMotlagh, and Ali M. Nikbakht*

Department of Agricultural Machinery, Urmia University, Urmia, Iran, 165

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A b s t r a c t. The effect of irrigation and nutrient treatments on physical properties of safflower seeds was investigated. Physical properties of safflower seeds were determined at a moisture content of 7% w.b. The parameters determined at different treatments were: size, geometric mean diameter, sphericity, surface area, mass, volume, bulk and true densities, porosity, and static and dynamic coefficient of friction. The results showed a better effect of the use of organic fertilizers in comparison with chemical ones. The results showed that nutrient and irrigation treatments had a significant effect on most of the physical properties of safflower seeds at p<0.01.

K e y w o r d s: safflower seeds, physical properties, irrigation, nutrient

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) oil has been produced commercially and for export for about 50 years, first as an oil source for the paint industry, now for its edible oil for cooking, margarine, and salad oil (Dajue and Mündel, 1996). Safflower has become an increasingly important crop in Iran and worldwide due to the rich nutritional value of its edible oil. It is a rich source of oil (35-40%) and linoleic acid content (75-86%). Currently, the estimated world production is about 636 000 t of safflower seed from an area of 772 700 ha land (FAO, 2010).The estimated Iran production is about 470 t of safflower seed over an area of 740 ha (FAO, 2010). Although Iran does not have a dominating share in the world production of safflower seed, areas under safflower seed cultivation have recently increased because oilseed crops are in extensive demand in Iran to meet the lack of country oil and biodiesel production. In dry land cropping systems, water is the most important limiting factor for crop production. One of the keys to irrigated crop production is correct crop choice to achieve a stable quality under drought stress.

There are many investigations on physical properties of different types of oil seeds, such as sunflower (Gupta *et al*., 2007); hazelnut (Kibar and Ozturk, 2009) and jatropha (Karaj and Muller, 2010). Safflower is an important oilseed crop particularly in arid and semi-arid regions of the world due to its cold, drought, and salinity tolerance (Weiss, 2000). The quantity and quality of crops, especially oilseeds, is influenced by soil fertility and nutrients. Synchronization of plant requirement with the nutrient supply is a problem, especially if the nutrient is supplied from a source whose cycle requires microorganism intermediation (Abbott and Murphy, 2007). With the advent of the Green Revolution, consumption of chemical fertilizers rose rapidly. Statistics shows that the annual consumption of nitrogen and phosphorus fertilizers is 85 and 15 mln t worldwide, respectively (Roy *et al*., 2006). However, replacement of chemical fertilizers with organic and biological fertilizers plays an important role in environment health (Chandrasekar, 2005). According to the problems that emerged due to indiscriminate use of chemical fertilizers, the use of biological fertilizers has been suggested as an essential component of sustainable development of agriculture (Alexandratos, 2003).

Determination of the physical properties of safflower seeds, like those of other grains, is essential for the design of equipment for handling, harvesting, aeration, drying, storing, dehulling, and processing. These properties are affected by numerous factors such as the size, form, superficial characteristics, and moisture content of the grain (Baumler, 2006). Also physical properties of crops are essential parameters in utilization, development of processing methods, and design of equipment (Bagherpour *et al*., 2010; Ogunsina *et al*., 2008). The axial dimensions of the seeds are important for a number of reasons. Determination of these dimensions

*Corresponding author e-mail: mazynas@gmail.com

is useful in determining orifice sizes in the design of grain handling machineries. The major axis, indicative of the natural rest position of the seeds, is useful in application of compressive force to induce mechanical rupture of the hull. The geometric mean of the axial dimensions is helpful in estimation of the projected area of a particle moving in the turbulent or near-turbulent region of an air stream. The projected area of the particle (seed) is generally indicative of its pattern of behaviour in a flowing fluid such as air, as well as the ease of separating extraneous materials from the particle during cleaning by pneumatic means.

The objective of this study was to investigate the effect of irrigation and nutrient treatments on chosen physical properties of the safflower seed.

MATERIALS AND METHODS

The field experimental design was a split-plot (2×4.4 m) arranged in a completely randomized design with three replications conducted from a farm at Urmia University, Iran during 2010. The main plot comprised three irrigation modes:

– no irrigation cut off (a),
– irrigation cut off in the vegetative stage (b),
– rrigation cut off in the reproductive growth stage (c),

The sub-plot included seven nutrient treatments:

– chemical (d),
– organic (HUMIX95) (e),
– biological (Nitroxin) (f),
– biological, (biosulfur) (g),
– compilation (d+e+f) (h),
– compilation (d+e+g) (i)
– control (j).

Nitroxin and biosulfur are organic fertilizers containing several microorganisms (Black, 2003). They enhance soil biological activity, which improves nutrient mobilization from organic and chemical sources and decomposition of toxic substances, promote mycorrhizal colonization, which improves P supply, and improve root growth due to better soil structure. They also increase the organic matter content of the soil, thereby improving the exchange capacity of nutrients, increasing soil water retention, promoting soil aggregates, and buffering the soil against acidity, alkalinity, salinity, pesticides, and toxic heavy metals. The fertilizers release nutrients slowly and contribute to the residual pool of organic N and P in the soil, reducing N leaching loss and P fixation; they can also supply micronutrients. They supply food and encourage the growth of beneficial microorganisms and earthworms and finally they help to suppress certain plant diseases, soil-borne diseases, and parasites (Chen, 2006; Rajendran and Devarj, 2004; Vessey, 2003).

After harvesting, the seeds were stored in the warehouse (12±1°C) to reach the equilibrium moisture content. They were manually cleaned to remove foreign materials and broken or immature seeds. The moisture content (MC) of the seeds was determined by the oven method (AOAC, 1980) and it was found to vary between 7 and 7.2% w.b. To determine the average size of the seeds, a sample of 60 seeds was randomly selected.

Three linear dimensions of the seeds, namely length, width, and thickness, were measured. The geometric mean diameter (GMD) of the seeds, seed mass, sphericity, surface area, bulk density, seed density, porosity, static coefficient of friction (SCF), and dynamic coefficient of friction (DCF) were calculated. All the properties were determined using standard methods. SCF and DCF of the seeds on polished wood, steel sheet, and aluminium surfaces were determined using the electro mechanical inclined plane apparatus designed in Urmia University. The tangent of the angle was reported as a SCF (Mohsenin, 1970).

All the experimental procedures were repeated three times for each applied treatment. Mean values were recorded as obtained data. The collected data were subjected to ANOVA using PASW STATISTICS 18 package.

RESULTS AND DISCUSSION

The mean length, width and thickness of the seeds varied within the ranges of 7.51-8.14, 4.31-4.58, and 3.56-3.87 mm, respectively. It was observed that all characteristics such as dimensions (x, y, z) and geometrical diameter within the treatments were significantly different at $p \leq 0.01$. However, the irrigation treatments had no significant effect on the width of seeds. The nutrient treatment and combined treatments had a significant effect on the width of the seeds only at $p<0.05$.The length of the seeds from the 'No irrigation cut off and Organic (Humix95)' (ae) treatment was higher than that in the other treatments (Fig. 1). This may have been caused by better performance of minerals in the presence of sufficient water levels. Similarly, the increase in the length may have been related to increased photosynthesis and plant production in full irrigation, which resulted in longitudinal growth of the seeds. Yet, the width, thickness and the geometric mean diameter (Fig. 2) of the seeds from the 'Irrigation cut off in the reproductive growth stage and Biological (Biosulfur)' (cg) treatment were higher than in the other treatments. This result showed that transversal growth of seeds was affected by the type of the treatment applied, and the same trend was observed for the thickness and width of the seeds. In fact, the effect of the treatments on seed growth in the direction perpendicular to the longitudinal axis of the seeds was consistent. Applying the (ae) treatment also increased the transversal growth of the seeds; since this treatment required full irrigation, in order to prevent excessive consumption of water, the (cg) treatment is recommended if the objective is to produce spherical seeds and with more thickness. On the other hand, the (ae) treatment resulted in higher length and width, which yielded bigger seeds in comparison with the other treatments. The length, width, thickness, and geometric mean

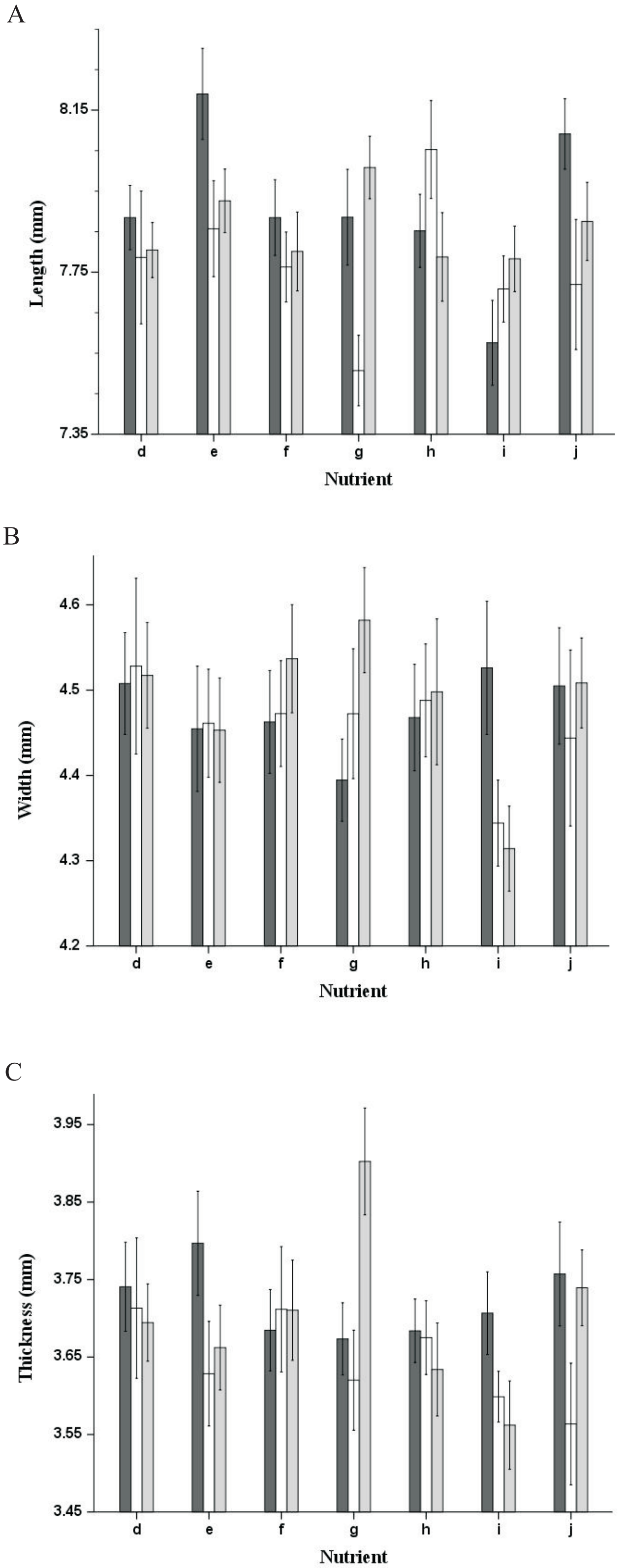

Fig. 1. Effect of nutrient and irrigation treatments on: A – length, B – width, and C– thickness of safflower seed. ■ a – no irrigation cut off, □ b – irrigation cut off in the vegetative stage, ■ c– irrigation cut off in the reproductive growth stage, error bars indicate the standard deviation.

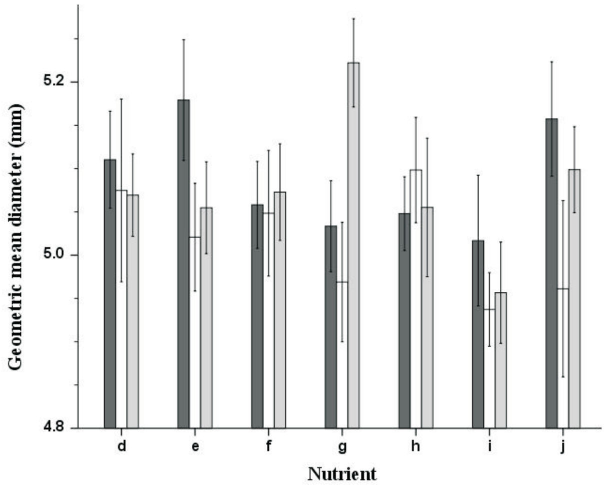

Fig. 2. Means of safflower geometric mean diameter (GMD) at various treatments. Explanations as in Fig. 1.

diameter of the seeds from the 'Irrigation cut off in the vegetative stage and Biological, (Biosulfur)' (bg), 'Irrigation cut off in the reproductive growth stage and Compilation (d+e+g)' (ci), 'Irrigation cut off in the reproductive growth stage and Compilation (d+e+g)' (ci), and 'Irrigation cut off in the vegetative stage and Compilation (d+e+g)' (bi) treatments were lower than those in the other treatments, respectively. This shows the negative effect of the 'Irrigation cut off in the vegetative and reproductive growth stage' treatment on longitudinal growth and the geometric mean diameter of the seeds. The results also show a negative effect of the 'compilation (d+e+g)' treatment on the width, thickness, and geometric mean diameter of the seeds, which may have been caused by the interaction effect of minerals on the cellular growth of seeds. As a result, application of the organic fertilizer increased seed size, while the use of compilation fertilizers increased the volume of the plant stem and bush size. Similar results were found by (Bulluck *et al.*, 2002). There was no significant difference between the 'Chemical, Compilation (d+e+f), and Control' treatments on the width and geometric mean diameter, whereas a significant effect of the 'organic, (Humix95)' and 'biological, (Biosulfur)' nutrient on the length and thickness of seeds was observed.

The mean unit mass of each safflower seed was found to fall into the range of 0.040-0.055 g. It was observed that unit mass within the treatments was significantly different at $p \leq 0.01$. There was a significant effect of the 'Irrigation cut off in the reproductive growth stage' treatment on mass. The highest value was recorded for the 'Irrigation cut off in the reproductive growth stage and Biological (Biosulfur)' (cg) treatment. In contrast, the 'No irrigation cut off' treatment had a negative effect on the mass, and the lowest value was obtained for the 'No irrigation cut off and Biological

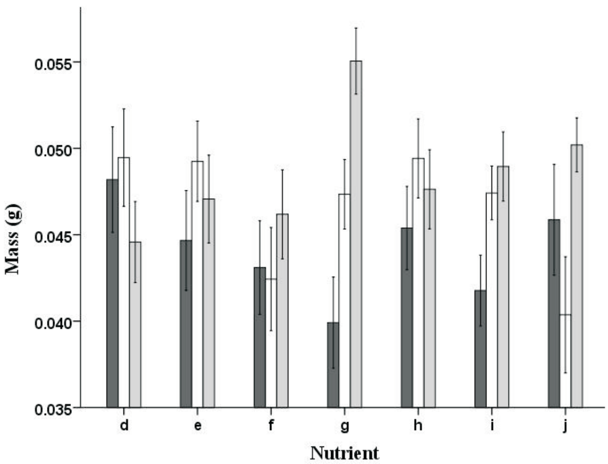

Fig. 3. Safflower mass at various treatments. Explanations as in Fig. 1.

(Biosulfur)' (ag) treatments. This was probably due to lack of solid material when the 'No irrigation cut off' treatments were applied. The results showed that seed size had a direct effect on mass. In contrast, Istanbulluoglu *et al.* (2009) reported that the highest yield was observed in the fully irrigated control, and the highest total water use efficiency was obtained in the treatment irrigated only at the vegetative stage, while the lowest value was observed when the crop was irrigated only at the yield stage. Biological fertilizer (Biosulfur) accelerates oxidation of granular organic sulphur, changing the pH of the soil and providing ideal conditions for different plants to uptake micro and macro nutrients in calcareous and alkaline soils. Ashrafi and Razmjoo (2010) reported that a proper irrigation regime throughout the life of the plant may cause small reduction in the total oil content, but it dramatically increases the quality of the oil composition of safflower seeds. This means that proper irrigation reduces safflower seed mass, which is consistent with the results obtained. Also, the results showed that the performance of Biosulfur was reversed depending on the type of irrigation. Thus, under the 'No irrigation cut off' treatment the lowest seed mass was obtained, whereas application of the 'Irrigation cut off in the reproductive growth stage' treatment yielded the highest mass (Fig. 3).

Sphericity is quite important in the design of hoppers and dehulling equipment. The values of sphericity were calculated individually using the data on the geometric mean diameter and the major axis of the seed; the results obtained are illustrated in Fig. 4a. There was no significant effect of the irrigation treatment on sphericity at $p \leq 0.05$. In contrast, nutrient supply had a significant effect at $p \leq 0.01$. The mean values of seed sphericity ranged from 0.629 to 0.663. Baumler *et al.*, (2006) reported values of safflower seed sphericity from 0.58 to 0.62, which is close to the results of this investigation. The sphericity of the safflower seeds was lower than the reported values of 0.764-0.805 for soybean grain (Davies and El-Okene, 2009).The mean sphericity of the 'No irrigation cut-off and Compilation (d+e+g)' (ai) treatment was higher than the others, and it was the lowest in the 'Irrigation cut-off in the vegetative stage and Compilation (d+e+g)' (ci) treatment. In fact, the results showed that the performance of the 'Compilation (d+e+g)' treatment depended on the type of irrigation. Thus, the highest sphericity was recorded under the 'No irrigation cut-off' treatment and the lowest sphericity was obtained under the 'Irrigation cut-off in the reproductive growth stage' treatment (Fig. 4). The results indicate that the safflower seed is quite far from the shape of a sphere and this means that a sieving or separating machine with circular holes will not easily let seeds through its holes. During unloading, the seeds will not roll away too far from the intended unloading spot.

It was observed that the surface area within the treatments is significantly different at $p \leq 0.01$. The 'Irrigation cut off in the vegetative stage' treatments had a negative effect on the surface area. The results showed that there was no significant difference between the 'no irrigation cut off' and 'irrigation cut off in the reproductive growth stage' treatments. Also, the result showed a negative effect of the 'compilation (d+e+g)' treatment on the surface area, but no significant effect of the other nutrients on the surface area was observed. The surface area of safflower seed from the "Irrigation cut off in the vegetative stage and Compilation (d+e+g)"(bi) treatment was the lowest, and the highest for the 'Irrigation cut off in the reproductive growth stage and Biological (Biosulfur)' (cg) treatments (Fig. 4b). There was a significant correlation between the dimensions and surface area of the safflower seed. The mean values of the surface area of the seeds ranged from 76.66 to 86.19 mm^2. Such a result was predictable because the surface area was a function of the geometric mean diameter and the greater the geometric mean diameter, the even greater the surface area. The surface area was closely related to the mass of the seeds. As can be seen from the coefficient of determination between the surface area and mass ($R^2 = 0.9034$) of safflower seed, these results suggest that the mass of the safflower seed can be predicted from the surface area. Similar results were obtained for tomato fruit (Zhiguo *et al.*, 2011). Geometric properties of grains are fundamental because they determine interactions between and among particles, and with the surrounding air. These interactions influence almost all the engineering properties of grains that must be considered in the design and evaluation of grain storage and handling systems.

The gravimetric and density characteristics exert an impact on the amount of product yield and efficiency of processing machines and machine throughput. Volume and density play an important role in processing methods and product quality estimation. It was observed that bulk density within the treatments is significantly different at $p \leq 0.01$. The bulk density of the safflower seed was found to be in the

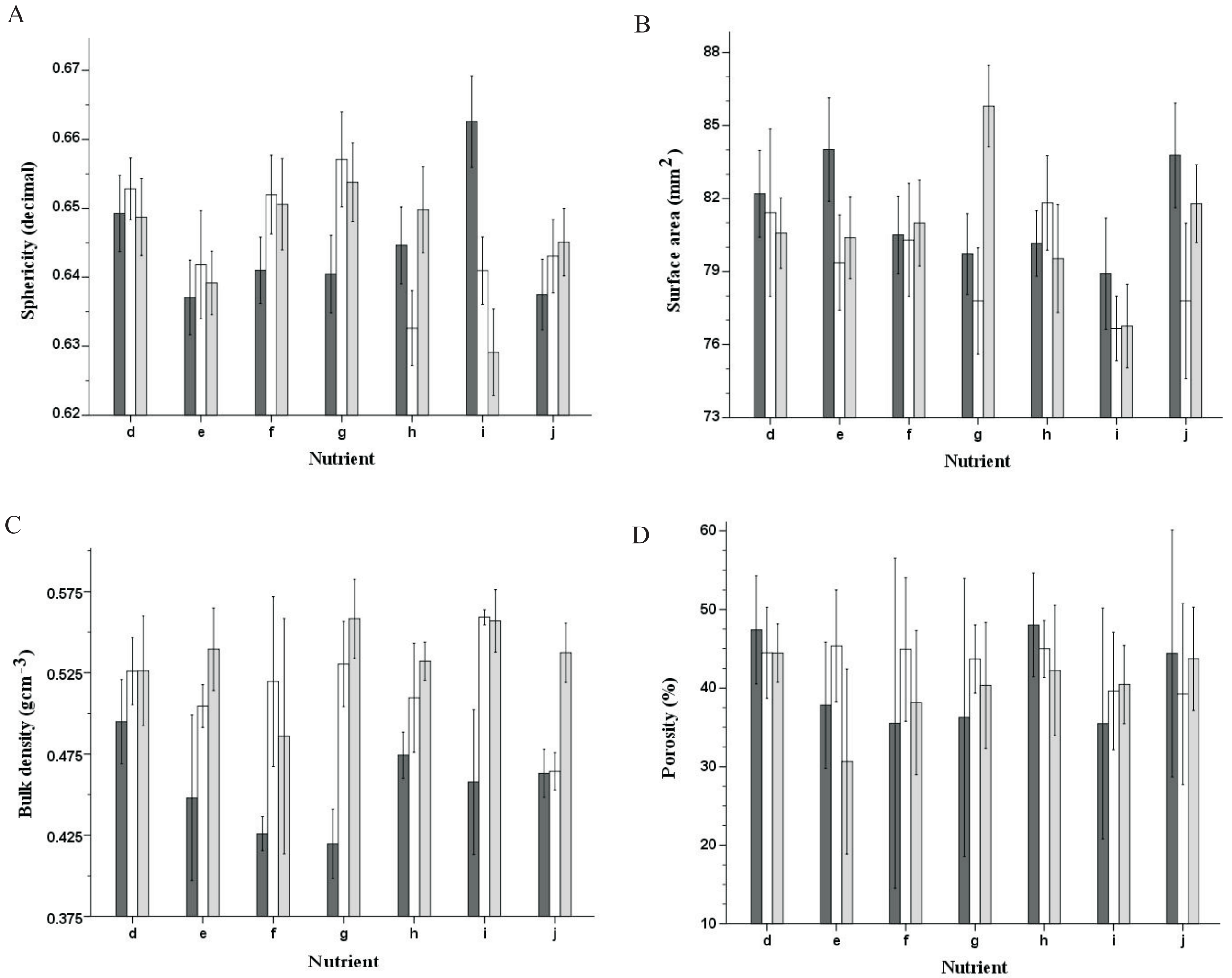

Fig. 4. Safflower: A – sphericity, B – surface are, C – bulk density, D – porosity at various treatments. Explanations as in Fig. 1.

range of 419.7-559.1 g m^{-3}. Maximum and minimum values of bulk density were obtained for the 'Irrigation cut off in the vegetative stage and Compilation (d+e+g)' (bi) and 'No irrigation cut off and Biological (Biosulfur)' (ag) treatments, respectively. Additionally, the results showed that there was no significant difference between the cg, bi and ci treatments. This means that these treatments can be replaced together for similar purposes. There was a significant effect of the irrigation treatment on bulk density. It was observed that the 'Irrigation cut off in the reproductive growth stage' treatment resulted in the highest value of bulk density, while the 'No irrigation cut off' treatment had an opposite effect (Fig. 4c). Also, the effect of the nutrient treatments was significant, while the 'compilation (d+e+g)' treatment had a positive impact and the 'Biological (Nitroxin)' treatment had a negative effect on bulk density. However, there was an interaction between the irrigation and nutrient treatments, which may have been related to the impact of irrigation on mineral and organic materials in changing the cell structure and growth of the seeds.

Porosity is considered as an important parameter in the study of heat and mass transfer and air flow between the mass of seeds. In addition, together with moisture content, volume, density, and ε are essential parameters for studying, drying, and storage of agricultural products. As seen from (Fig. 4d), the increases in ε of safflower seed were found to range from 30.65 to 48.04%. The highest values of ε (48.04%) were recorded for the 'No irrigation cut off and Compilation (d+e+f)' (ah) treatment and the lowest values (30.65%.) were recorded for the 'Irrigation cut off in the reproductive growth stage and Organic (HUMIX95)' (ce) treatment The ε of the safflower seed was in the range of the reported values for jatropha seed (Karaj and Muller, 2010). Bulk density and ε affect the structure loads.

The seed density of the safflower seed varied between 705.5 and 955.5 kg m^{-3}. This shows that the seeds are lighter than water and this characteristic can be used to design a separation or cleaning process for seeds since heavier fractions will sink. The statistical analysis of the experimental data showed that, related to seed density, only the relationship between irrigations (p≤0.01) was highly significant but the relationship between the nutrients as well as the interaction between irrigation and nutrients was not highly significant. It was observed that 'no irrigation cut off' reduced the seed density. Also, there was no significant difference between the 'Irrigation cut off in the vegetative stage' and 'Irrigation cut off in the reproductive growth stage' treatments (Table 1). Furthermore, there was a significant difference between the 'chemical' and 'compilation (d+e+f)' treatments with the 'biological (Nitroxin)' treatment. The 'chemical' and 'compilation (d+e+f)' treatments resulted in the highest seed density, while the 'biological (Nitroxin)' treatment yielded the lowest seed density (Table 1). Besides nitrogen stabilization and balancing absorption of macro and micro nutrients needed for plants, the bacteria in the Nitroxin (biological fertilizer) undertake secretion of amino acids and antibiotics. They also contribute to growth and development of roots and aerial parts of the plants and increase production (Gilik *et al*., 2001).The seed density of the safflower seed was lower than the reported values of 1 225 kg m^{-3} for sorrel seed (Omobuwajo *et al*., 2000) and 1 257-1 311 kg m^{-3} reported for gram (Dutta *et al*., 1988).

T a b l e 1. Combined analysis of variance for seed true density as affected by irrigation and nutrient treatment

Treatment	D.F.	M.S.	F	Pr>F
Irrigation	2	0.170	6.10	**
Nutrient	6	0.057	2.03	*
Irrigation x Nutrient	12	0.044	1.59	ns

D.F. – degree of freedom, M.S. – mean of square. Significant at: *p< 0.05, **p<0.01; ns – not significant.

It was observed that the friction coefficient in the treatments was significantly different at p≤0.01. The mean static coefficients of friction (SCF) on aluminium, steel sheet, and polished wood were found for each treatment. The results of determination of the static coefficients of friction of safflower seeds on various surfaces were compared. As shown

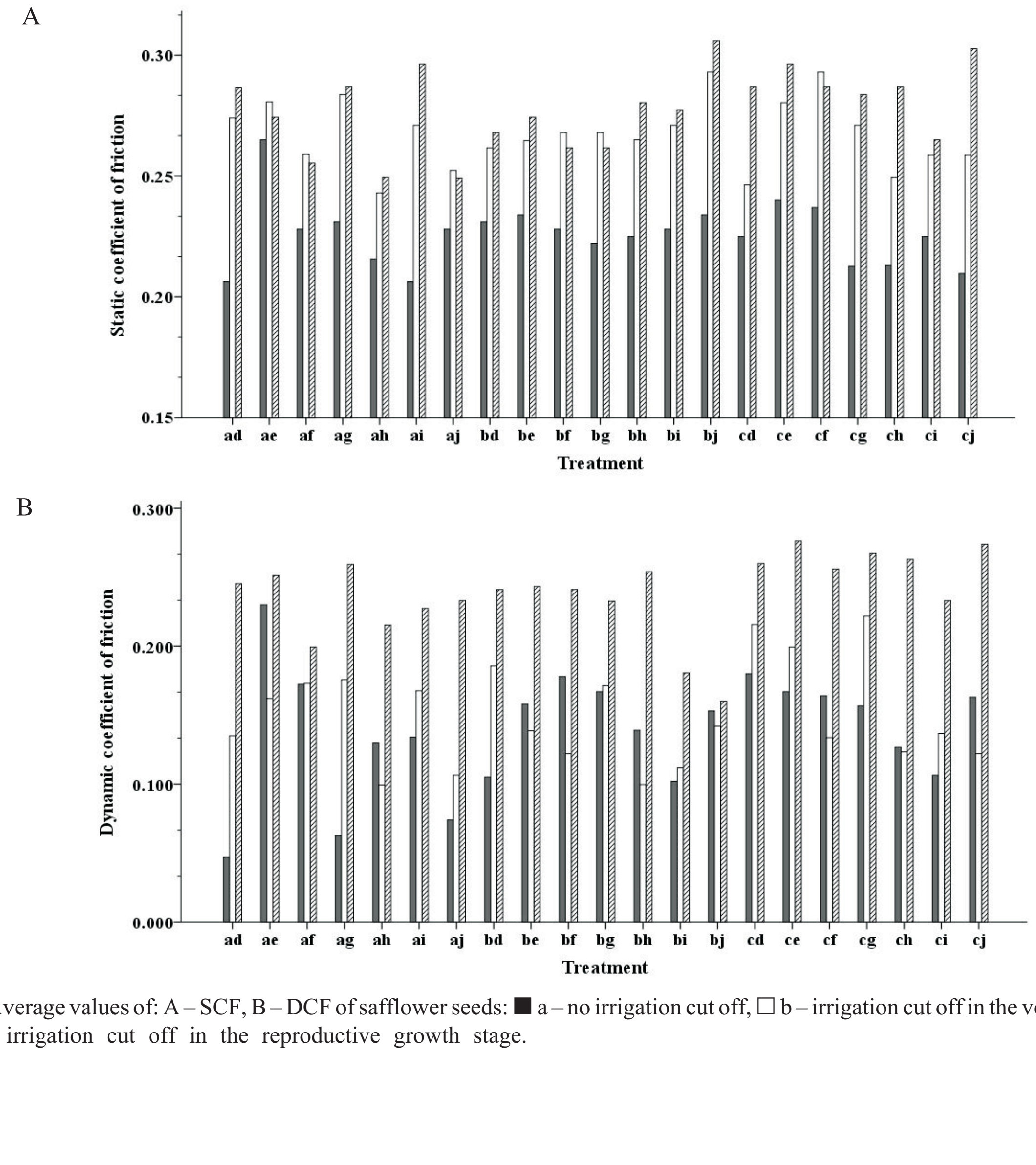

Fig. 5. Average values of: A – SCF, B – DCF of safflower seeds: ■ a – no irrigation cut off, □ b – irrigation cut off in the vegetative stage, ▨ c – irrigation cut off in the reproductive growth stage.

in (Fig. 5A), regardless of the treatment type, the SCF had the highest value on aluminium and the lowest value on polished wood. The SCF of the 'Irrigation cut off in the vegetative stage and control' (bj) treatment was the highest on aluminium and steel sheet; in the 'No irrigation cut off and organic (HUMIX95)' (ae) treatment, it was the highest on polished wood. A significant effect of the 'Irrigation cut off in the reproductive growth stage' treatment on the SCF of aluminium was observed, but there was no significant effect of irrigation on the SCF of the other materials. Among the contact surfaces, the highest (0.306) and lowest (0.206) mean SCF values were found for aluminium and polished wood, respectively. The results obtained on the aluminium surface are lower than those found for jatropha seed (Garnayak *et al*., 2008). The dynamic coefficients of friction of safflower seeds on various surfaces were compared. As shown in (Fig. 5B), regardless of the treatment type the DCF had the highest value on aluminium. However, this trend was not observed for the metal sheet and polished wood surfaces. Among the contact surfaces, the highest (0.276) and lowest (0.047) mean DCF values were reported for aluminium and polished wood, respectively. A significant effect of the 'Organic (HUMIX95)' treatment on the SCF and DCF on polished wood, steel, and aluminium was observed. The seeds had a smooth surface, which allowed them to move easily on the studied surfaces. The coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting, and storing structures.

CONCLUSIONS

1. The results showed a positive effect of the use of organic fertilizers in comparison with chemical fertilizers. Application of organic fertilizers increases seed size.

2. A negative effect of the 'irrigation cut off in the vegetative stage' treatment on longitudinal and transversal growth of seeds was observed. A significant effect of the 'organic, (HUMIX95)' and 'biological, (biosulfur)' nutrient treatment on seed length and thickness was observed.

3. The highest value of the coefficient of friction of the seeds was recorded on the aluminium surface.

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