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INVESTIGATION OF THE EFFECTS OF IRRIGATION METHODS AND NUTRIENT TREATMENTS ON THE MECHANICAL PROPERTIES OF SAFFLOWER SEED

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Abstract

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A comprehensive investigation of effects of irrigation systems and nutrient treatments on mechanical properties of IL111 varieties of safflower seeds (*Carthamus Tinctorius L.*) have been fulfilled. Rupture force, deformation at rupture point, hardness, energy used for rupture and modulus of elasticity were measured in order to get an exact picture of the properties of seeds. Cutting off irrigation in the reproductive growth stage resulted in lower rupture point values while seeds grown with the conventional irrigation system were of more rupture point. The least value of modulus of elasticity was measured to be 66.53 MPa for no cutting off irrigation and combination of nutrient treatments. The similar trend was observed for hardness of seeds. It was proved that the application of organic fertilizers for safflower nutrient improved mechanical properties of seeds in comparison with the chemicals. Also, lower consumption of water in the several growth stages of the crop did not have negative effects on the mechanical attributes of seeds. This can be regarded promising due to the important effect of such attribute in machine designing.

Keywords: safflower; treatments; mechanical properties; rupture

Abbreviations: M - Moisture content (% d.b.); R_f - Rupture force (N); D_{rp} - Deformation at Rupture point (mm); H - Hardness (*N/mm*); E_r - Energy for rupture (J); m - unit mass of the seed (g)

Introduction

Safflower (Figure 1.a), is a member of the family Compositae or Asteraceae, thistle-like herbaceous annual or winter annual plant, with numerous spines on leaves and bracts mainly grown in dry hot climates as an oilseed or birdseed. Its flowers are usually used as dye sources and for medicinal purposes. The typically white achenes averaging from 0.030 to 0.045 g, are smooth (in some varieties varying amounts of pappus, tufts of hairs may be present on the end adjacent to the plant) and four-sided, with a thick pericarp. Traditionally, the crop was grown for its flowers, used for coloring and flavoring foods and making dyes, especially before cheaper aniline dyes became available. Oil has been produced commercially and for export for about 50 years, firstly as an oil source for the paint industry and nowadays for cooking, margarine and salad oil. Over 60 countries grow safflower while over half is produced in India (mainly for the domestic vegetable oil market). (Dajue and Mündel, 1996). Safflower has become an increasingly important crop in Iran and the world 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 653791 tonnes of seed from an area of 731 971 ha land (FAO, 2009). The estimated Iran production is about 500 tons of seed from an area of 1000 ha land (FAO, 2008). Safflower has lately gained importance because the seed oil has an important food-value, with high linoleic acid content. Knowledge of fracture char-

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Fig. 1. a) A view of safflower seeds, b) Compression test of safflower seed (not to scale)

acteristics of the seed is imperative for a rational design of efficient dehulling systems, as well as the optimization of the process and product parameters (Baumler, 2006).

Mechanical properties such as rupture force, deformation and energy used for rupturing nut and kernel are useful information in designing the seed shelling and kernel grinding machines. These properties are affected by numerous factors like variety and moisture content of the nut and kernel. The rupture force indicates the minimum force required for shelling the nut and grinding the kernel (Sirisomboon et al., 2007). The amount of deformation at rupture point can be used for the determination of the gap size between the surfaces to compress the nut for shelling. Therefore, the study of relationships between the forces on a single safflower seed is needed for a better understanding of milling while there are not considerable researches on the effect of agronomic treatment on mechanical properties. Therefore, the objective of this study was to investigate the effect of 21 different treatments on some mechanical properties of the safflower seeds typically cultivated in Iran. The measured parameters at different treatments at moisture content of 7% (dry basis) were rupture force, deformation at rupture point, hardness, energy used for rupture and modulus of elasticity.

Nutrients are important agricultural factors that have significant effect on the growth and development of the seed yield and quality of oily plants such as safflower. Since the mineral elements are identified as the cause of crop production enhancement, plant nutrition science is of major concern. Although water is abundant on earth, drought is the most limiting factor for a successful production of crop such as oilseed. Nutrient uptake by safflower plant is influenced by the amount of water in soil and drought stress causes a series of complex reactions that leads to changing in the cellular, physiological and plant growth. As drought is a serious phenomenon observed in many countries, the effect of drought stress on mechanical attributes of safflower seeds was studied. Such attributes are widely used in the processing systems including oil extraction machinery, extruders, dehulling and sorting facilities. Thus, an exact overview of the effect of cutting off irrigation systems is necessary. Thus, the main objective of this research was investigation of effect of drought and nutrient on engineering properties of safflower seeds.

Materials and Methods

Safflower seeds were collected from a research farm at Urmia University, Iran during 2010. The irrigation and nutrient treatments are summarized and indexed in Table 1. From Table 1 it can be stated that two categories of fertilizers, chemicals and organic based materials, were applied as treatments. Nitroxin contains nitrogen stabilizer bacteria and phosphate solubilizer. Biosulfur has sulfur-oxidizing microorganisms and HUMIX organic fertilizer is composed of 12% Folic acid, 68% Potassium and 15-13% Humic acid. After harvesting, the seeds were stored in the warehouse (12 ± 1ºC) to reach the equilibrium moisture content. They were manually cleaned to remove foreign materials, broken or immature seeds. The moisture content (M) of the seeds was determined by the oven method (Official Method 14003, AOAC, 1980) and was found to vary between 7% and 7.2% db.

Laboratory compression tests were carried out by using a compression tester (HOUNSFIELD H5KS) and data was acquired and processed by SPSS statistical package. The device was equipped with a load cell of 5000 N. Safflower seeds were placed on the fixed platform and pressed with the probe up to the seed rupture point at the strain rate of 1 mm/min. It

Table 1
Numbering order of the applied treatments

Treatments		
Irrigation Methods		Nutrients
		d. Chemical
a. No cutting off irrigation		e. Organic (HUMIX95)
		f. Biological (Nitroxin)
b. Cutting off irrigation in vegetative stage		g. Biological (Biosulfur)
		h. Combination (d+e+f)
c. Cutting off irrigation in reproductive growth stage		i. Combination (d+e+g)
		j. Control

was assumed that rupture occurred at the bio-yield point i.e. the point where there is a sudden decrease in force against deformation. As soon as the bio-yield point was detected, the experiment was stopped. Data collection was stopped at the moment of rupturing which is of great emphasis in the design of processing machinery.

Three replications of safflower seeds from each of the 21 treatments were tested in seed relaxation position (Figure 1.b). Considering the compression speed and time, the safflower seed deformation was computed and force-deformation curve was plotted. Rupture force and deformation were measured directly from the plotted force–deformation curve. Energy absorbed (E_R) by the seed at rupture point was determined by calculating the area under the force-deformation curve. Rupture force, deformation at rupture point and energy used for rupture were measured at a speed of 1-1.25 mm/min, which is suitable for highly oil content materials (Olaniyan and Oje, 2002).

The rupture force, R_F (N) is the minimum force required to break the sample. Deformation at rupture point, D_{RP} (mm) is the deformation at loading direction. Hardness, H (N/mm) is the ratio of rupture force and deformation at rupture point. It was calculated as follows:

$$H = \frac{R_F}{D_{RP}}$$

Energy for rupture, E_R (J) is the energy required to rupture the seed (Figure 2), which could be determined from the area under the curve between the initial point and the rupture point. The area was measured by using compression tester software.

Safflower seeds were subject to compression up to shell failure in order to determine the force-deformation behavior at different treatments. The dimensions of each seed were determined prior to loading. The results were processed by the SPSS (Version 18.0.0). Analysis of variance (ANOVA) and GLM test were used to analysis the results.

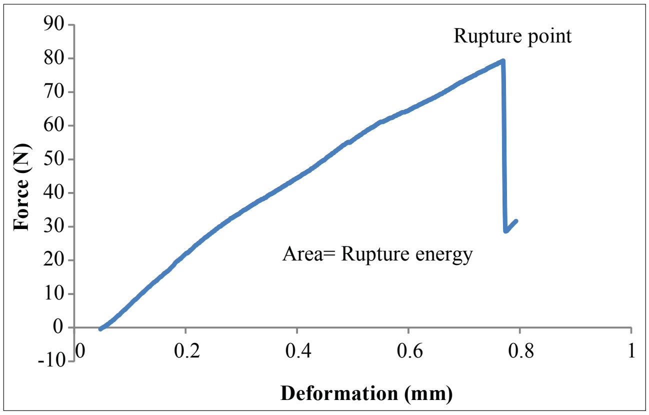

Fig. 2. Typical force-deformation curve for a compressed seed

Results and Discussion

It was observed that mature or larger sized seeds may require higher force to fracture with respect to immature or smaller seeds. This was also reported for sunflower by Subramanian et al. (1990). Furthermore, it was observed that the heavier seeds require higher force to fracture and hardness of seeds increased with the seed mass. It is well known that the dehulling efficiency of seeds is highly correlated with the rupture force. As a consequence, seeds needing less force to rupture would of better choice for processing units. Additionally, a classification based on seed mass (m) is required since wrong grading might allow small seeds pass uncracked through the dehulling equipment and larger seeds might be broken into small fragments instead of being dehulled as already observed in other seeds and grains (Ashes and Peck, 1978; Karaj and Muller, 2010).

As indicated in Figure 3, rupture force of “Cutting off irrigation in reproductive growth stage” treatment at all levels of nutrient had a higher value in comparison with the “No cutting off irrigation” treatment. It was probably because of softer texture of seed and softening impact of irrigation on the seed structure. Whereas it was observed that applying “Cutting off irrigation in reproductive growth stage” with “Organic (HUMIX95)” nutrient had opposite effect on rupture force in comparison with others. This was probably because of softening effect of “organic” nutrient, that composed of 12% Folic acid, 68% Potassium and 15-13% Humic acid in result of water lacks. When the combinations of organic, chemical and biological (Nitroxin) nutrients were applied, rupture force diminished significantly with irrigation, i.e. cutting off irrigation caused harder seeds to be produced. However, it was observed that applying “Cutting off irrigation in vegetative stage” irrigation with “combination of organic, chemical and biological (biosulfur)” or “Control” nutrient had the same effect. This means that we can gain the same yield on safflower cultivation by consuming less water. The highest value of rupture force was obtained to be 88.56 with applying “Cutting off irrigation in reproductive growth stage” irrigation with “combination of organic, chemical and biological (biosulfur)” nutrient. This feature may not be desirable for oil extraction, because it results in harder seed hull and hence more force required. On the other hand, it might be useful if the target is storing seeds. The similar trend was observed for “Cutting off irrigation in vegetative stage” with Organic (HUMIX95) or Biological, (biosulfur) nutrient.

Results showed that applying of “Combination (d + e + f)” nutrient at all levels of irrigation has caused diminished rupture forces. This shows that the treatment causes seed hull to become softer and can be easily separated from kernel by conventional processing and oil extraction machinery. Applying “Combination (d + e + f)” and “Cutting off irrigation in reproductive growth stage” resulted in brittleness of the hull and reduction in required rupture force. Therefore, according to Figure 3 and Figure 4, it can be shown that applying “Combination (d + e + f)” and “Cutting off irrigation in reproductive growth stage” treatments will lead to reduction of processing costs. Besides, using “Combination (d + e + f)” and “No cutting off irrigation” treatments caused the lowest rupture force and caused highest deformation at rupture point as well. This means that seeds have been more flexible, or in other words, the gap size between the compression plates of hulling equipment should be increased. “Cutting off irrigation in vegetative stage” treatment had a different impact on rupture force in a way that it caused the minimum rupture force in some nutrient treatments and maximum on others. Obviously, this might be due to interaction between “Cutting off irrigation in vegetative stage” and nutrient treatments.

In general, it was observed that deformation at rupture point in “Cutting off irrigation in reproductive growth stage” was lower than “No cutting off irrigation” treatment (Figure 4). It can be due to brittle structure of safflower seeds i.e. “Cutting off irrigation in reproductive growth stage” treatment was applied. Also there was not a significant difference between “Cutting off irrigation in reproductive growth stage” and “Cutting off irrigation in vegetative stage” treatments at $p < 0.05$, except when combinations of organic, chemical and biological (Nitroxin) nutrients were applied. There was an inverse relationship between force and deformation i.e. increase in force, result in a dramatic fall in deformation. Minimum value obtained with performing “Cutting off irrigation in reproductive growth stage with combinations of organic, chemical and biological (Nitroxin) nutrients” and “No cutting

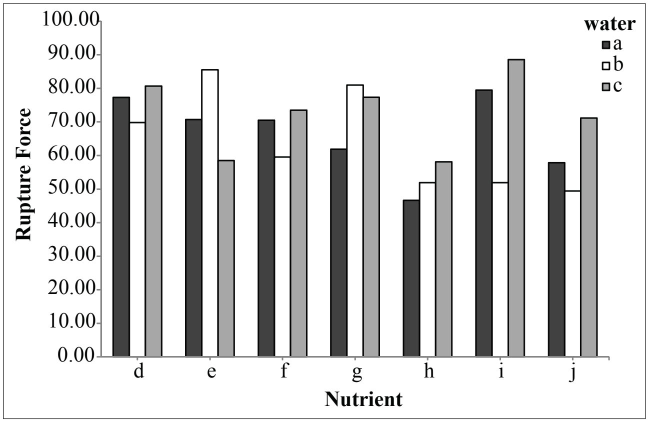

Fig. 3. Means plot of the safflower seed rupture force at various treatments

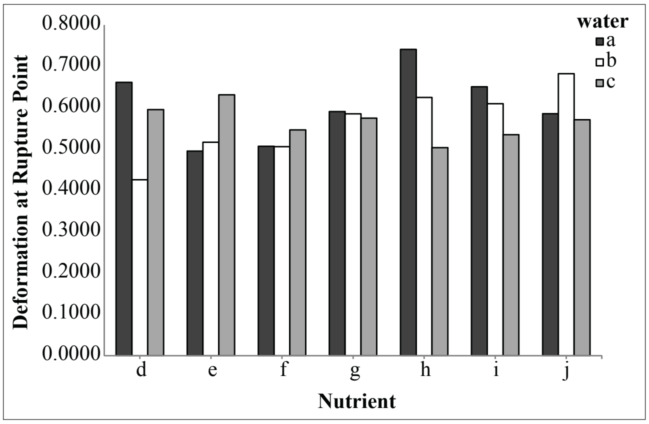

Fig. 4. Means plot of the safflower seed deformation at rupture point at various treatments

off irrigation with Biological (Nitroxin)". Therefore, the latter was beneficial, because of lower water consumption and nutrient. Knowing deformation at the rupture point can be basically useful for the determination of the gap size between the dehulling plates in the processing machinery.

In most cases, the required energy to rupture the seed was higher for "Cutting off irrigation in reproductive growth stage" treatment in contrast to "No cutting off irrigation" treatment (Figure 5). This means that further energy will be required to break the brittle seeds. In addition, there was not observed a significant difference between "Cuttings off irrigation in vegetative stage" with other treatments at $p < 0.05$. As indicated in Figure 5, applying "Combination (d + e + f)" and "Cutting off irrigation in reproductive growth stage" caused lowest rupture energy which means lower energy and costs required to process the seeds. As a result, this treatment will be considerably beneficial. Maximum value obtained with applying "Cutting off irrigation in vegetative stage with biological fertilizer (biosulfur), "Cutting off irrigation in reproductive growth stage with Organic (HUMIX95)" and "Cutting off irrigation in reproductive growth stage with Biological (biosulfur)" treatments. Inasmuch as these treatments need higher energy for rupture, we must refuse to use them to reduce the costs.

The hardness of seeds increased with the seed mass at all treatments. Similar results were obtained by Karaj and Muller (2010). Hardness of the seeds was generally higher than that of kernels. This can be explained by the hard hull of seeds in contrast to the soft texture of the kernels. Similar results were reported by Sirisomboon et al. (2007). As indicated in Figure 6, hardness was higher for "Cutting off irrigation in reproductive growth stage" treatment in comparison with "No cutting off irrigation" treatment.

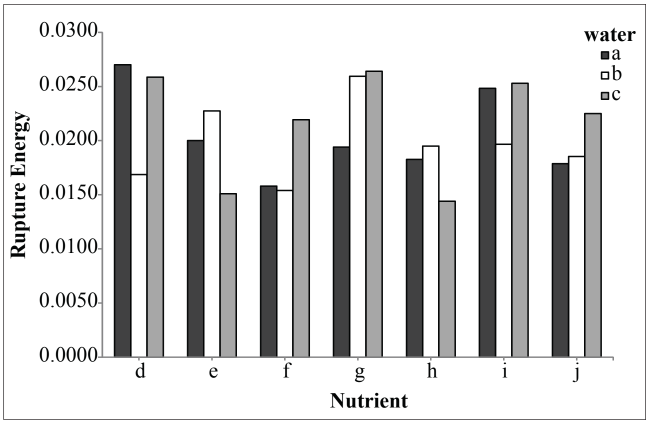

Fig. 5. Means plot of the safflower seed rupture energy at various treatments

Modulus of elasticity can be used in the simulation of seeds for machine design purposes. Finite element analysis (FEA) can used to model the mechanical behavior of the safflower seed hull after the seed impact. Modulus of elasticity was significantly different between "No cutting off irrigation" and "cutting off irrigation in the reproductive growth stage" irrigation treatment at $p < 0.05$. Also there wasn't a significant effect of nutrient on modulus of elasticity in some treatments (Figure 7).

Conclusions

Mechanical properties such as rupture force, deformation at rupture point; hardness and energy required for rupture were reported. It was observed that there was a significant effect of irrigation on some mechanical properties at $p < 0.05$.

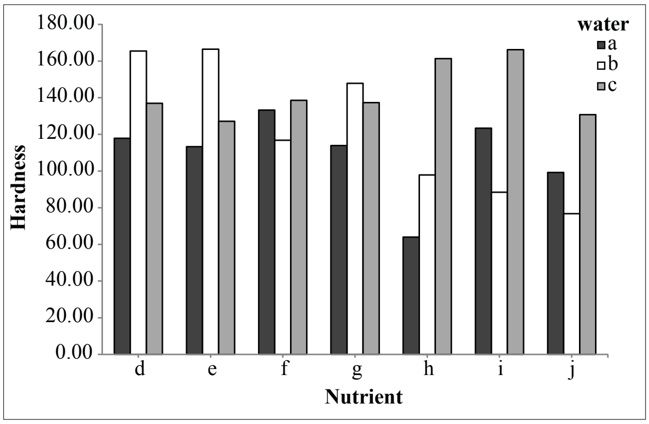

Fig. 6. Means plot of the safflower seed hardness at various treatments

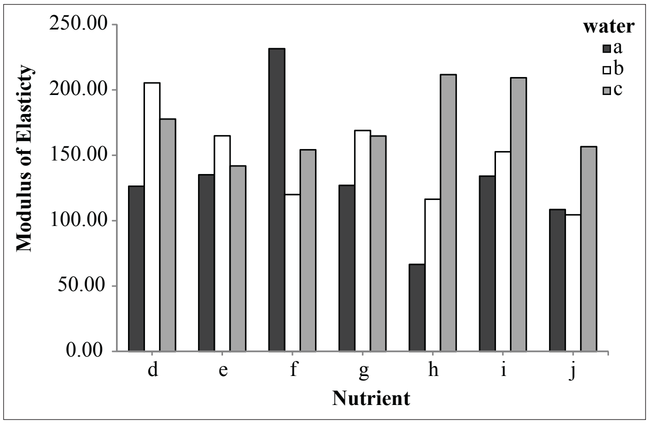

Fig. 7. Means plot of the safflower seed modulus of elasticity at various treatments

Nutrient had significant effect on some mechanical properties at $p < 0.05$. Mean values of rupture force, deformation at rupture point, energy for rupture, modulus of elasticity and hardness of seeds varied within the ranges of 46.65-88.56 (N), 0.389-0.741 (mm), 0.0144-0.0817 (J), 66.53-231.60 (MPa) and 63.95-252.13 (N/mm) respectively. Minimum value of deformation at rupture point and energy for rupture were observed in cutting off irrigation in reproductive growth stage while seeds grown with the conventional irrigation system were of more rupture point. Modulus of elasticity was measured to be 66.53 MPa, its least value, for no cutting off irrigation and combination of nutrient treatments. The similar trend was observed for hardness of seeds. It was proved that the application of organic fertilizers for safflower nutrient improved mechanical properties of seeds in comparison with the chemicals. Seed structure became brittle as "Cutting off irrigation in reproductive growth stage" was applied. There was a significant difference between "Cutting off irrigation in reproductive growth stage" and "No cutting off irrigation" on rupture force and rupture energy. Applying "Combination (d + e + f)" and "Cutting off irrigation in reproductive growth stage" were beneficial compared to other treatments. Organic fertilizers can substitute the chemical fertilizers, whereas organic fertilizers are more beneficial than chemical fertilizers emphasizing that they do not contaminate environment as much as chemicals do.

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