Technical and economical evaluation of abrasive peeling machine and its effect on nutritional characteristics of quinoa

Mohammad Shaker[1*], Akbar Jokar[2] , Dadgar Mohammadi[3]

(1. Department of Agricultural Engineering Research, Fars Research and Education Center for Agriculture and Natural Resources, AREEO, Shiraz, Iran. postal code: 7155863511;
2. Department of Agricultural Engineering Research, Fars Research and Education Center for Agriculture and Natural Resources, AREEO, Shiraz, Iran. postal code: 7155863511;
3. Department of Instructor, Economic, Social and Extension Research, Fars Research and Education Center for Agriculture and Natural Resources, AREEO, Shiraz, Iran. postal code: 7155863511)

Abstract: The objective of this study was to evaluate the abrasive peeling machine from technical, economical and quinoa nutritional characteristics point of view. A factorial experimental design based on completely randomized experimental with three replications was used for this study. For technical evaluation, effects of two factors including inlet valve opening (IVO) and linear speed (LS) of the machine axis on grain breakage, machine capacity and grain weight loss were investigated. In order to select the most economic treatment, partial budgeting technique was used. Values of saponin, protein, fat, fiber, dry matter, zinc, magnesium and ash were measured to assess changes in quinoa nutritional characteristics. The results showed that the most suitable treatment for peeling machine was treatment involving LS of 11.91 m s^{-1} and IVO of 20 mm. In this setting, the highest amount of machine working capacity (0.38 tons per hour) and the lowest amount of quinoa weight loss (12.7%) was achieved. This treatment had also a reasonable amount of grain breakage (2.4%). From the economic point of view, the highest added value and beneficial were obtained in treatment 9. In this setting, the amount of input quinoa saponin before and after peeling was recorded equal to 3.18% and 0.25%, respectively.

Keywords: quinoa, saponification, abrasive peeler, nutritional value.

Citation: Mohammad Shaker, Akbar Jokar and Dadgar Mohammadi. 2022. Technical and economical evaluation of abrasive peeling machine and its effect on nutritional characteristics of quinoa. Agricultural Engineering International: CIGR Journal, 24(3): 214-225.

1 Introduction

Quinoa is a pseudocereal crop that adapts to different climatic conditions. It has great potential to increase production as a new product in other parts of the world including North Europe, North America, Asia and Africa. Due to its exceptional nutritional properties, quinoa is very useful and significant in humans as well as in animal nutrition (Bilalis et al., 2019).

Removing saponin is the first essential step in using quinoa as a food product. Saponins as well as solanine (in potato) which belongs to the family of saponins, in addition to being bitter, have many anti-nutritional effects such as breaking down hemoglobin, inhibiting the activity of trypsin and chymotrypsin, reducing the absorption of nutrients and energy, weight loss and so on (Egbuna and Ifemeje, 2015).

In a study using a abrasive disk mill, quinoa was milled eight times for 1 minute. After each milling step, the milled seeds and their parts were examined. The results showed that with increasing milling time, seeds

Received date: 2021-09-29 **Accepted date:** 2022-03-07

***Corresponding author: Mohammad Shaker,** Assistant Professor, Fars Research and Education Center for Agriculture and Natural Resources, AREEO, Shiraz, Iran. postal code: 7155863511, email: m.shaker1348@gmail.com.

protein, fat and ash content decreased, while glucose concentration increased. The final protein, fat and ash content were 3.35, 1.37 and 0.33%, respectively (D'Amicoa et al., 2019).

Eleven samples of quinoa grain with different peeling rates were evaluated using a light abrasive mill. In this study, the relationship between peeling rate and nutrient composition of quinoa grain was determined. The results showed that with increasing the rate of peeling, the ratio of protein, fat, fiber and ash decreased. With the peeling rate of 8.6%, 11.72% protein, 7.57% fat, 4.72% starch, 28.9% total dietary fiber, 45.5% soluble dietary fiber, 48.58% saponin, 26.18% flavonoid and 42.25% total phenolic were lost in dehulled quinoa grain. Therefore, in order to maintain the maximum nutritional and phytochemical content in quinoa and to maintain the integrity of quinoa grain, it is necessary to limit the quinoa peeling rate to less than 8.6% (Wu et al., 2020).

In a study, quinoa seeds were evaluated for the effect of degree of milling (DOM) on the content of saponins, free and bound phenols, and their antioxidant activity through oxygen radical absorbance capacity (ORAC) and ferric reducing power (FRAP). The results showed that saponins cause a bitter taste and their anti-nutritional effects can be eliminated from quinoa during the milling process. With increasing DOM from 0% to 27.23%, the total saponin content decreased by 41.8%, while the total phenol and flavonoid content decreased by 31.5% and 41.4%, respectively. Total ORAC and FRAP antioxidant activities also decreased by 39.6% and 40.7%, respectively (Han et al., 2019).

The milling process causes the loss of phenolics along with their antioxidant activity. In a study found that the phenolics contents, including flavonoids, were higher in bran than milled quinoa seeds (Hemalatha et al., 2016). Liu et al. (2015) reported that increasing DOM significantly reduced content of total phenolic and antioxidant activity of brown rice.

A simple rice peeler was modified and used to peel quinoa. This device is very suitable for personal and ordinary use. Depending on the size and weight of the peeler, they changed it to be portable and affordable for every user (Murty et al., 2016).

The content of phenolic compounds and carotenoids in quinoa seeds was investigated at different drying temperatures. Five drying temperatures (room temperature, 40 ℃, 50 ℃, 60 ℃ and 70 ℃) were tested to achieve a dry matter content of 94%-95%. The results showed that the process performed at 70 ℃ provided the highest recovery of total phenolic compounds, 994 ± 28 mg kg^{-1} (Multari et al., 2018).

Considering the importance of quinoa and saponin removal requirement from quinoa grain, the purpose of this study was evaluation and determination the optimal conditions for using abrasive peeling machine to remove saponin from quinoa grain, based on technical, economical, and Quinoa nutritional characteristics.

2 Materials and methods

2.1 Site specifications

The research was conducted in Marvdasht region of Fars province (Southern Iran, 30°94′E, 52°48′N, average annual rainfall of 365 mm, maximum temperature of 41 ℃, minimum temperature of 9 ℃, and 1620 m above sea level) from 2019 to 2020.

2.2 Abrasive peeling machine

The abrasive peeling machine was installed after two sieves and a stone separator in series Therefore, quinoa was transferred to this machine using an elevator after passing from sieves and stone separator (Figure 1). The inlet valve was at the top and the outlet valve was at the bottom of the machine. To start the machine, power from a 11-kilowatt (15 hp) three-phase electromotor was transmitted to the machine axis by pulley and belt. There were some abrasive rubbers on this rotational axis to remove saponin from the outer layer of quinoa grains when passing through this machine. The powdered saponin was taken out of the area using a fan. In order to grade the peeled quinoa, grains were transferred from the outlet of the machine to the final sieve by an elevator. On this machine, only two adjustments were applicable, the opening of the inlet valve and the linear speed of the axis.

2.3 Experimental design and treatments

The research was conducted using a factorial experiment based on a completely randomized experimental design with three replications and nine treatments. Treatments were opening of peeling machine inlet valve in three levels (10, 15, and 20 mm) and the linear speed of peeling machine axis in three levels (10.07, 10.99 and 11.91 m s^{-1}).

Adjusting the inlet valve to 10 mm and linear speed of 11.91 m s^{-1} was considered as control treatment. The dominant quinoa cultivar (TTKK) in Fars province was used in this experiment. The moisture content was measured in an oven at 75 Celsius degree (AOAC, 1998). The moisture content of quinoa grain at the time of entering to the peeling machine was about 7% to 8% (wet based). Product moisture was measured before and after treatments.

Figure 1 The abrasive peeling machine

To adjust the peeling machine inlet valve, a blade attached to the valve (on which a pice of a tape meter was installed) was used to indicate the opening of the valve and a pulley was used to adjust the opening of the valve (Figure 2). By rotating the pulley, the blade was moving out or into the chamber so that when the inlet valve was closed, the gauge blade was showing number 1.5. Similarly, for 10, 15, and 20 mm valve opening, gauge blade numbers were 2.5, 3, and 3.5, respectively.

Figure 2 Blade connected to the machine inlet valve and its adjusting pulley

To change the linear speed of the peeler axis, the linear speed of the electromotor shaft was changed by an 11-kilowatt Yulico inverter (Figure 3). The electromotor speed change was performed by changing the input electrical frequency using inverter. An optical tachometer was used to determine and record the rotational speed of the peeler axis (Figure 4). This type of tachometer has a glossy label that is mounted on the pulley and when the pulley is rotating, it shows revolutions per minute (rpm) by reflecting light. According to the diameter of the peeler axis pulley, which was equal to 35 cm, its linear speed was calculated in m s^{-1}.

Figure 3 Three-phase electromotor and inverter installed on the peeling machine

Figure 4 Using an optical tachometer (model Pantec DTM 30) to determine the rotational speed of the machine axis

After performing the initial tests, it was found that at frequency of 50 Hz, the linear speed of the peeler axis was 11.91 m s^{-1}. At 45 and 41 Hz, the linear speeds of peeler axis were 10.99 and 10.07 m s^{-1}, respectively (the frequency of the electric current entering the inverter was adjustable from zero to 50 Hz by a button on the inverter).

The amount of 30 kg of quinoa in each experiment was peeled. Having 9 treatments and 3 replications (a total of 27 tests), total of 810 kg quinoa was used. First, quinoa impurities were separated and cleaned by sieving and stone separator devices. Then 27 samples of 30 kg quinoa were poured into plastic bags after weighing. In each experiment, the electromotor frequency and the machine axis linear speed were adjusted first and then three treatments of inlet valve openings (10, 15 and 20 mm) were adjusted and performed in three replications.

At the end of each experiment, factors of peeling time and weight of the output were measured. A 1 kg sample was also taken from the input and output of the peeling machine to measure the quinoa nutritional properties.

2.4 Parameters measurements

To determine the percentage of quinoa breakage three samples of 10 g (as three replicates) were taken from output quinoa of peeling machine in each experiment. Then, using Damavand laboratory sieve with mesh 18, whole grains were separated from the broken ones. Because separation accuracy of the above mentioned sieve was about 70% to 80%, the samples were re-examined using a magnifier. Finally, this factor was obtained according to Equation 1 (Wimberly, 1983).

$$B = \frac{Wa}{Wb} \times 10 \quad (1)$$

Where *B* is breakage (%), *Wa* is weight of broken grains (g), and *Wb* is total weight of whole and broken grains (g).

The capacity of peeling machines was expressed in terms of mass of peeled material per unit time, so this factor was measured and calculated in terms of tons per hour according to Equation 2 (Chakraverty and Paul Singh, 2001).

$$C = \frac{Wt}{T} \quad (2)$$

Where *C* is machine capacity (tons hr^{-1}), *Wt* is weight of peeled quinoa (tons), and

T is time required for peeling (hr).

Equation 3 was used to calculate the percentage of quinoa weight loss (Chakraverty and Paul Singh, 2001).

$$WL = \frac{W1-W2}{W1} \times 100 \quad (3)$$

Where *WL* is quinoa weight loss (%), *W1* is weight of input (kg), and *W2* is weight of output (kg).

In order to select the most economic treatment, partial budgeting technique was used. This method is used when the manager of a production unit makes a slight change in the method of production management. The purpose of partial budgeting is to organize and setting information so that a specific decision can be made in the management of production affairs.

To select the most beneficial treatment, the added value created by each treatment was calculated. In this regard, non-shared benefits and costs for the tested treatments were estimated. The benefits of each treatment were calculated by multiplying the amount of whole and broken peeled quinoa by their price. Costs were calculated based on the value of the amount of unpeeled quinoa plus the cost of peeling the incoming quinoa. The price of each kilogram of unpeeled and whole peeled quinoa according to the information obtained from the Organization of Agriculture - Jahad Fars Province was 0.77 and 1.92 $, respectively, and the price of each kilogram of broken quinoa was 0.92 $. The cost of Quinoa peeling was estimated at 0.15 $ for amounts above one ton and 0.19 $ per kilogram for amounts below one ton based on information received from the Laser Boresh Company.

To measure the nutritional values of quinoa, 500 g samples were taken from inlet and outlet of peeling machine in each experiment and grinded using a Retsch model grinder (Figure 5). Then100 g samples were prepared in zipped plastic from the grinded quinoa and transferred to the laboratory with labeling and numbering for each treatment.

Figure 5 Retsch model grinder machine for quinoa flour

The saponin content in quinoa, was evaluated by spectrophotometry and microwave extraction methods according to procedures (Goel et al., 2012; Vongsangnak et al., 2004).

The percentage of saponification was calculated according to Equation 4.

$$S = \frac{S1-S2}{S1} \times 100 \quad (4)$$

Where *S* is saponification (%), *S1* is amount of saponin in the input quinoa (g), and

S2 is amount of saponin in output quinoa (g).

To evaluate changes in nutritional properties, minerals, protein, fat, moisture, and quinoa fiber were measured. Protein, fat, moisture and minerals (zinc, magnesium) were measured by Macroceldal, Soxhlet, 100 degree oven and atomic absorption methods according to AOAC standard method (AOAC, 1998). Neutral detergent fiber was measured according to the AACC, 32-20.01 standard method (AACC, 2000).

2.5 Statistical analysis

One-way ANOVA analysis were applied to the data collected from the experiments using SAS software and Duncan's multiple range tests was used to compare the treatments means.

3 Results and discussion

3.1 Quinoa grain breakage

Variance analysis of quinoa grain breakage data, quinoa grain breakage in different axis linear speed and valve openings, and interaction effect of linear speed and valve openings on quinoa grain breakage are shown in Tables 1, 2, and 3 and Figure 6, respectively. The results presented in Table 1 showed that the effect of linear speed and valve opening on of quinoa breakage was not significant. While the interaction effect of linear speed and valve opening on quinoa grain breakage was significant at 5% probability level.

The results of Tables 2 and 3 indicated that there was no significant difference between quinoa grain breakage means in different linear speed and valve opening and they were statistically in the same group. The results of Fig. 6 showed that the highest percentage of quinoa grain breakage (4.5%) occurred in treatment 3 (linear speed of 10.07 m/s and valve opening of 20 mm) and the lowest percentage of quinoa grain breakage (1.3%) was related to the treatment 1 (linear speed of 10.07 m s^{-1} and valve opening of 10 mm).

Table 1 Variance analysis of quinoa grain breakage data in peeling machine

Row	Sources of change	Degree of freedom	Sum of squares	Mean of squares	f value	Probability level
1	Linear speed	2	2.0896	1.0448	1.36	0.2821 ^{ns}
2	Valve opening	2	4.2274	2.1137	2.75	0.0908 ^{ns}
3	Interaction of speed and valve	4	12.7615	3.1904	4.15	0.0149 *
4	Error	18	13.8400	0.7689		

Note: ^{ns}: Non-significant; *: significant at *p*<0.05; **: significant at *p*<0.01.

Table 2 Comparison of the means of linear speed effect on quinoa grain breakage in peeling machine

Linear speed (m s^{-1})	Breakage (%)
S_1 = 10.07	2.8000 ^{a}
S_2 = 10.99	2.1333 ^{a}
S_3 = 11.91	2.5889 ^{a}

Note: Similar letters indicate that there is no significant difference.

Table 3 Comparison of the means of valve opening effect on quinoa grain breakage in peeling machine

valve opening (mm)	Breakage (%)
C_1 = 10	2.2111 ^{a}
C_2 = 15	2.2444 ^{a}
C_3 = 20	3.0667 ^{a}

Note: Similar letters indicate that there is no significant difference.

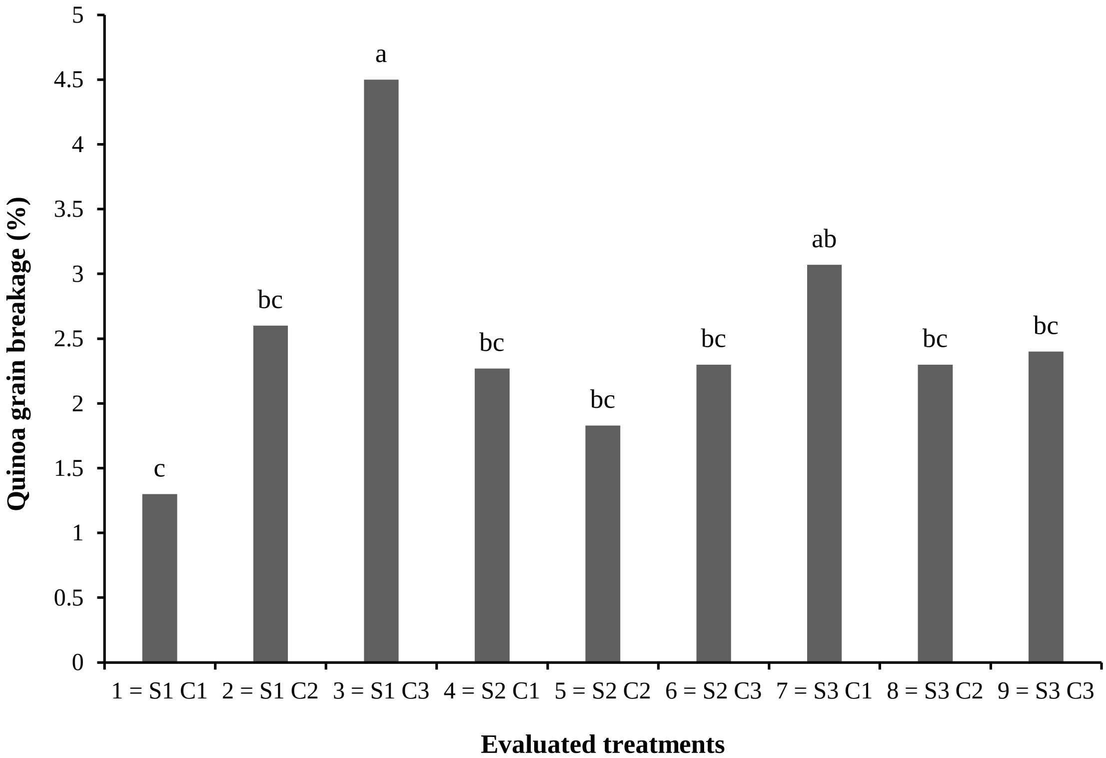

Figure 6 Comparison of means of speed and valve interaction on quinoa grain breakage in peeling machine

S_1 = Linear speed 10.07 m s^{-1}; S_2 = Linear speed 10.99 m s^{-1}; S_3 = Linear speed 11.91 m s^{-1} C_1 = valve opening 10 mm; C_2 = valve opening 15 mm; C_3 = valve opening 20 mm

In treatment 3, the quinoa sample used was related to the end of the separating sieve and the fine grains in this sample were more than the other samples. Therefore, differentiating between treatment effect and sample error in this treatment was difficult. It seemed some of the quinoa grain breakage in this treatment was due to the fine grains existing in the entering sample. On the other hand, interaction effect of linear speed and valve opening on the grain breakage was also affected by this bias in sampling. In the other words, result of this treatment could be considered as a bias result. In treatment 1 (linear speed of 10.07 m s^{-1} and valve opening of 10 mm), because the inlet valve opening of the peeling machine was at its minimum position, the quinoa was fed to the machine with a lower capacity, and at the linear speed of 10.07 m s^{-1} fewer mechanical impacts were applied to the quinoa grains, the lowest grain breakage was occurred in this treatment.

3.2 Machine capacity

Variance analysis of machine capacity data, machine capacity in different axis linear speed and valve openings, and interaction effect of linear speed and valve openings on machine capacity are shown in Tables 4, 5, and 6 and Figure 7, respectively. The results of Table 4 showed that the effect of linear speed on machine capacity was significant at the 1% probability level; while, the effect of valve opening and the interaction effect of linear speed and valve opening on the machine capacity was not significant.

The results presented in Table 5 showed that the maximum amount of machine capacity was obtained at the linear speeds of 10.99 and 11.91 m s^{-1} with 0.3556 and 0.3496 tons h^{-1} and the lowest amount of machine capacity was related to the linear speed of 10.07 m s^{-1} with 0.3015 tons h^{-1}. The results of Table 6 showed that there was no significant difference between the means of machine capacity at different valve opening and they were statistically in the same group. In Figure 7, the maximum amount of machine capacity occurred in treatment 9 (linear speed of 11.91 m s^{-1} and valve opening of 20 mm) with a value of 0.38 tons h^{-1} and the lowest value of machine capacity was related to the treatment 1 (linear speed of 10.07 m s^{-1} and valve opening of 10 mm) with a value of 0.28 tons h^{-1}.

It seems that in treatment 9, due to the highest linear speed and the highest amount of the inlet valve opening of the peeling machine, the amount of quinoa fed to the machine was at its maximum amount, so the maximum capacity of the machine was obtained from this treatment. This factor has reached its minimum value in treatment 1 due to the lowest linear speed and the least amount of opening of the machine inlet valve, and therefore the lowest machine capacity has occurred in this treatment.

Table 4 Analysis of variance of peeling machine capacity data

Row	Sources of change	Degree of freedom	Sum of squares	Mean of squares	f value	Probability level
1	Linear speed	2	0.0158	0.0079	6.92	0.0059 **
2	Valve opening	2	0.0058	0.0029	2.54	0.1070 ns
3	Interaction of speed and valve	4	0.0074	0.0018	1.61	0.2154 ns
4	Error	18	0.0206	0.0011		

Note: ns: Non-significant; *: significant at $p<0.05$; **: significant at $p<0.01$.

Table 5 Comparison of the means of linear speed effect on peeling machine capacity

Linear speed (m s^{-1})	Machine capacity (t h^{-1})
S_1 = 10.07	0.3015 b
S_2 = 10.99	0.3556 a
S_3 = 11.91	0.3496 a

Note: Similar letters indicate that there is no significant difference.

Table 6 Comparison of the means of valve opening effect on peeling machine capacity

valve opening (mm)	Machine capacity (t h^{-1})
C_1 = 10	0.3151 a
C_2 = 15	0.3430 a
C_3 = 20	0.3486 a

Note: Similar letters indicate that there is no significant difference.

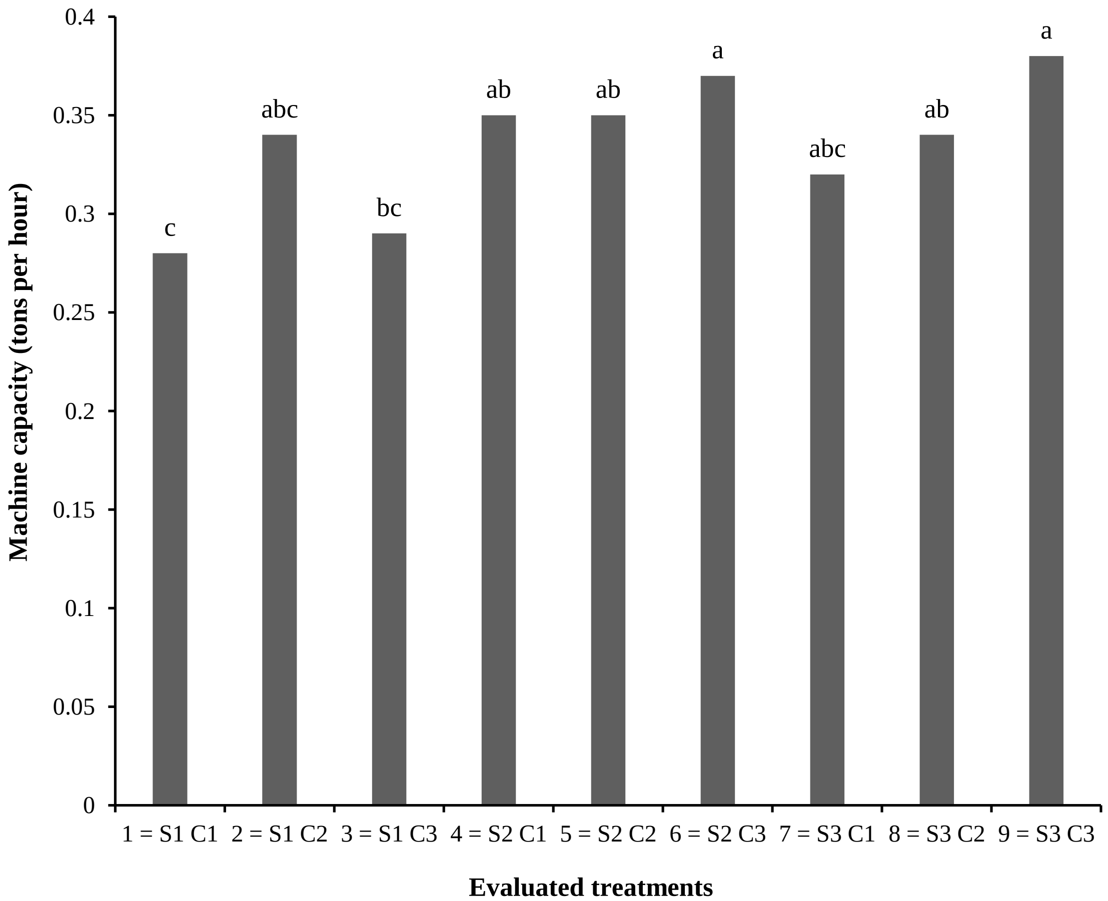

Figure 7 Comparison of means of speed and valve interaction on peeling machine capacity

S_1 = Linear speed 10.07 m s^{-1}; S_2 = Linear speed 10.99 m s^{-1}; S_3 = Linear speed 11.91 m s^{-1} C_1 = valve opening 10 mm; C_2 = valve opening 15 mm; C_3 = valve opening 20 mm

3.3 Quinoa weight loss

Variance analysis of quinoa weight loss data, quinoa weight loss in different axis linear speed and valve openings, and interaction effect of linear speed and valve openings on quinoa weight loss are shown in Tables 7, 8, and 9 and Figure 8, respectively. The results of Table 7 showed that the effect of linear speed on quinoa weight loss was significant at 1% probability level; while, the effect of valve opening and the interaction effect of speed and valve on quinoa weight loss was not significant.

Table 7 Analysis of variance of quinoa weight loss data in peeling machine

Row	Sources of change	Degree of freedom	Sum of squares	Mean of squares	f value	Probability level
1	Linear speed	2	28.6308	14.3154	7.16	0.0051 **
2	Valve opening	2	6.1524	3.0762	1.54	0.2414 ns
3	Interaction of speed and valve	4	3.5171	0.8793	0.44	0.7781 ns
4	Error	18	35.9676	1.9982		

Note: ns: Non-significant; *: significant at p<0.05; **: significant at p<0.01.

Table 8 Comparison of the means of linear speed effect on quinoa weight loss in peeling machine

Linear speed (m s^{-1})	Weight loss (%)
S_1 = 10.07	15.2224 a
S_2 = 10.99	13.2450 b
S_3 = 11.91	12.8776 b

Note: Similar letters indicate that there is no significant difference.

Table 9 Comparison of the means of valve opening effect on quinoa weight loss in peeling machine

valve opening (mm)	Weight loss (%)
C_1 = 10	14.3967 a
C_2 = 15	13.2331 a
C_3 = 20	13.7152 a

Note: Similar letters indicate that there is no significant difference.

The results of Table 8 showed that the highest amount of quinoa weight loss was at 10.07 m s^{-1} with 15.22% and the lowest amount of quinoa weight loss was at 11.91 m s^{-1} with 12.88%. The results of Table 9 showed that there was no significant difference between the means of quinoa weight loss at different valve openings and they are statistically in the same group. Figure 8 showed that the highest amount of quinoa weight loss occurred in treatment 1 (linear speed of 10.07 m s^{-1} and valve opening of 10 mm) with a value of 16.32% and the lowest amount of quinoa weight loss was related to the treatment 8 (linear speed of 11.91 m s^{-1} and valve opening of 15 mm) with 12.68%.

It seems that in treatment 1, due to the lowest linear speed and opening of the machine inlet valve, quinoa grains were exposed to peeling for a longer time (about 6 minutes) and therefore the maximum amount of quinoa weight loss occurred in this treatment. In treatment 8, quinoa grains were exposed to peeling in less time (about 4.6 minutes), so the lowest amount of this factor occurred in treatment 8.

Summary of technical evaluation results showed that in terms of quinoa grain breakage, except for treatments 3 (linear speed of 10.07 m s^{-1} and valve opening of 20 mm) and 7 (linear speed of 11.91 m s^{-1} and valve opening of 10 mm), all other treatments were in same statistical group and there was no significant difference between them. In terms of machine capacity, the maximum capacity of the machine was related to the treatments 6 (linear speed of 10.99 m s^{-1} and valve opening of 20 mm) and 9 (linear speed of 11.91 m s^{-1} and valve opening of 20 mm) and there was no significant difference between them. In terms of quinoa weight loss, treatments 8 (linear speed of 11.91 m s^{-1} and valve opening of 15 mm) and 9 (linear speed of 11.91 m s^{-1} and valve opening of 20 mm) had the lowest amount of quinoa weight loss, and there was no significant difference between them. According to the results of this study, the most suitable option for the peeling machine was treatment 9 (linear speed of 11.91 m s^{-1} and valve opening of 20 mm), because the highest capacity of the machine and the lowest amount of quinoa weight loss occurred in this treatment. In terms of quinoa grain breakage, this treatment had also a reasonable amount of quinoa grain breakage and there was no significant difference between this treatment the others from grain breakage point of view.

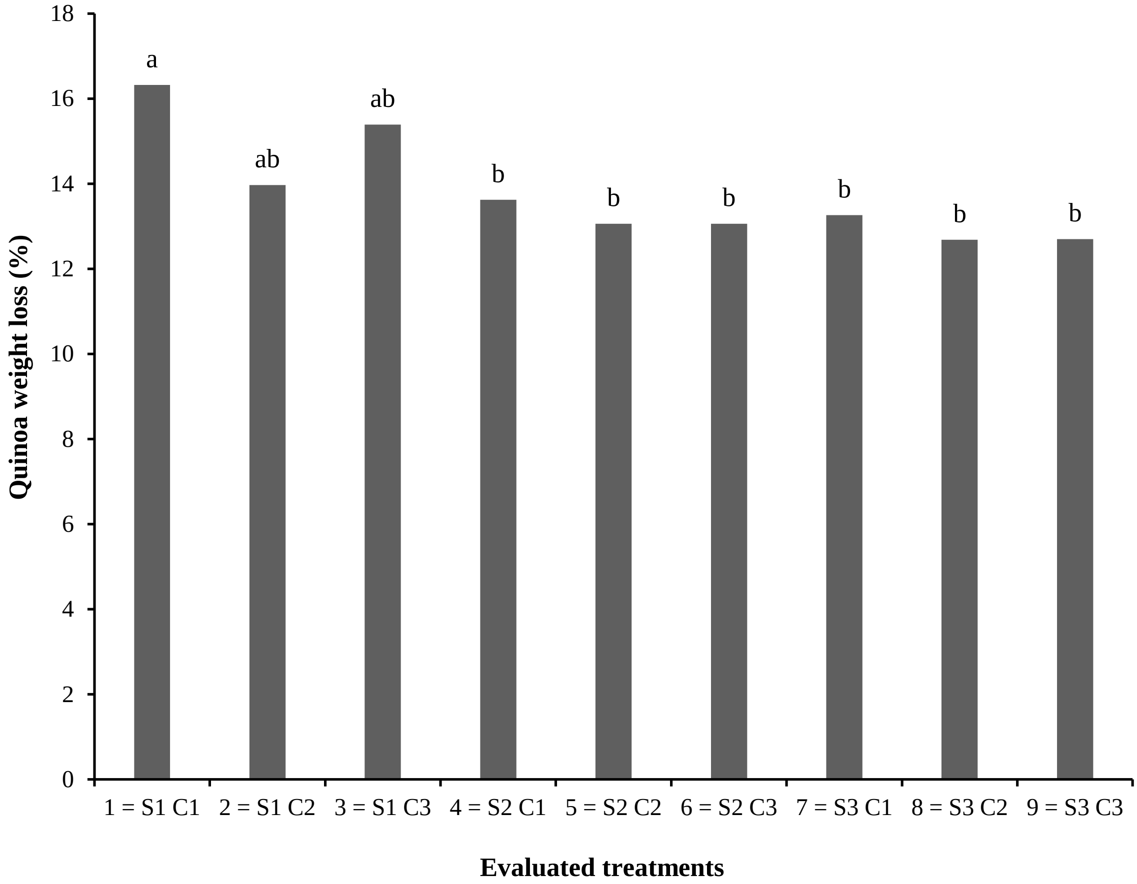

Figure 8 Comparison of means of speed and valve interaction on quinoa weight loss in peeling machine

S_1 = Linear speed 10.07 m s^{-1}; S_2 = Linear speed 10.99 m s^{-1}; S_3 = Linear speed 11.91 m s^{-1} C_1 = valve opening 10 mm; C_2 = valve opening 15 mm; C_3 = valve opening 20 mm

3.4 Cost analysis

In Table 10, non-shared benefits and costs in different treatments was listed. In order to take time into account, the value of peeled quinoa per hour was estimated. The results presented in Table 11 showed that based on the added value created in one hour by different treatments, treatment 9 (linear speed of 11.91 m s^{-1} and valve opening of 20 mm), had the highest added value and was the most economically beneficial treatment.

Treatments 6 (linear speed of 10.99 m s^{-1} and valve opening of 20 mm), 8 (linear speed of 11.91 m s^{-1} and valve opening of 15 mm), 5 (linear speed of 10.99 m s^{-1} and valve opening of 15 mm), 4 (linear speed of 10.99 m s^{-1} and valve opening of 10 mm), 2 (linear speed of 10.07 m s^{-1} and valve opening of 15 mm), 7 (linear speed of 11.91 m s^{-1} and valve opening of 10 mm), 1 (linear speed of 10.07 m s^{-1} and valve opening of 10 mm), and 3 (linear speed of 10.07 m s^{-1} and valve opening of 20 mm) took the second to ninth places, respectively from the economic added value point of view. Calculation of added value changes compared to the control treatment indicated that treatments 9 (linear speed of 11.91 m s^{-1} and valve opening of 20 mm), 6 (linear speed of 10.99 m s^{-1} and valve opening of 20 mm), 8 (linear speed of 11.91 m s^{-1} and valve opening of 15 mm), 5 (linear speed of 10.99 m s^{-1} and valve opening of 15 mm), 4 (linear speed of 10.99 m s^{-1} and valve opening of 10 mm), and 2 (linear speed of 10.07 m s^{-1} and valve opening of 15 mm) had higher added value changes compared to the control treatment; while, treatments 1 (linear speed of 10.07 m s^{-1} and valve opening of 10 mm) and 3 (linear speed of 10.07 m s^{-1} and valve opening of 20 mm) had lower added value changes compared to the control treatment.

Table 10 Estimation of benefits and costs in the tested treatments

Treatment	Weight of whole peeled quinoa (Kg)	Value of whole peeled quinoa ($)	Amount of broken quinoa (Kg)	Value of broken quinoa ($)	Total benefits created per treatment ($)	Non-shared costs per treatment ($)
1 = S_1 C_1	24.715	47.83	0.390	0.36	48.19	29.03
2 = S_1 C_2	25.030	48.44	0.780	0.72	49.16	29.03
3 = S_1 C_3	23.034	44.58	1.350	0.13	45.83	29.03
4 = S_2 C_1	25.234	48.83	0.680	0.63	49.47	29.03
5 = S_2 C_2	25.533	49.41	0.550	0.51	49.92	29.03
6 = S_2 C_3	25.391	49.14	0.690	0.64	49.78	29.03
7 = S_3 C_1	25.102	48.58	0.920	0.85	49.43	29.03
8 = S_3 C_2	25.507	49.36	0.690	0.64	50.00	29.03
9 = S_3 C_3	25.470	49.29	0.720	0.67	49.96	29.03

Source: Research Findings

Table 11 Ranking of the tested treatments based on the added value created in each treatment

Treatment	Total benefits created per treatment ($)	Total non- shared costs per treatment ($)	Added value created per treatment ($)	Added value created in one hour ($)	Rank Treatments	Added Value changes of treatments compared to the control ($)
9 = S_3 C_3	49.96	29.03	20.93	298.07	1	50.57
6 = S_2 C_3	49.78	29.03	20.75	255.62	2	38.11
8 = S_3 C_2	50.00	29.03	20.97	239.98	3	22.47
5 = S_2 C_2	49.92	29.03	20.89	238.65	4	21.15
4 = S_2 C_1	49.47	29.03	20.44	237.81	5	20.30
2 = S_1 C_2	49.16	29.03	20.13	225.77	6	8.26
7 = S_3 C_1	49.43	29.03	20.41	217.51	7	0.00
1 = S_1 C_1	48.19	29.03	19.16	175.87	8	-41.63
3 = S_1 C_3	48.83	29.03	16.80	154.16	9	-63.35

Source: Research Findings

3.5 Quinoa nutritional properties

Results of variance analysis of quinoa saponin, protein, fat, and fiber data in Table 12 showed that the effect of linear speed, valve opening and the interaction effect of linear speed and valve opening on the nutritional properties was not significant. The amount of input quinoa saponin (before peeling) was 3.18%. After peeling by machine, the amount of output quinoa saponin reached to 0.25% on average; therefore, quinoa saponin decreased by 92.1% during peeling proces. The mean values of protein, fat and fiber of quinoa were 16.08%, 5.19% and 48.89%, respectively.

Reichert et al. (1986) found that the reduction in amount of saponin in the abrasive peeler was between 85% and 95%, which was consistent with the results of the present study. This amount of saponin in the output quinoa (0.25%) is higher than the standard amount (0.12%) (Bhargava and Srivastava, 2013) and it is necessary to adjust or optimize the peeling machine to approach the standard value.

Table 12 Analysis of variance of quinoa saponin, protein, fat and fiber data in peeling machine

Row	Sources of change	Degree of freedom	Mean of squares			
			saponin	protein	fat	fiber
1	Linear speed	2	0.001 ^{ns}	0.508 ^{ns}	0.051 ^{ns}	20.222 ^{ns}
2	Valve opening	2	0.000 ^{ns}	0.07 ^{ns}	0.247 ^{ns}	1.388 ^{ns}
3	Interaction of speed and valve	4	0.000 ^{ns}	0.185 ^{ns}	0.152 ^{ns}	10.138 ^{ns}
4	Error	9	0.001	0.421	0.233	6.888

Note: ^{ns}: Non-significant.

Table 13 Analysis of variance of quinoa dry matter, zinc, magnesium and ash data in peeling machine

Row	Sources of change	Degree of freedom	Mean of squares			
			dry matter	zinc	magnesium	ash
1	Linear speed	2	0.7039 ^{ns}	0.67 ^{ns}	0.0009 ^{ns}	0.000005 ^{ns}
2	Valve opening	2	0.4606 ^{ns}	0.17 ^{ns}	0.0004 ^{ns}	0.00007 ^{ns}
3	Interaction of speed and valve	4	0.2931 ^{ns}	0.58 ^{ns}	0.0001 ^{ns}	0.00002 ^{ns}
4	Error	9	0.5322	3.11	0.0003	0.00002

Note: ^{ns}: Non-significant.

Results of variance analysis of quinoa dry matter, zinc, magnesium, and ash data in Table 13 indicated that the effect of linear speed, valve opening and the interaction effect of linear speed and valve opening on the abovementioned factors were not significant. The mean values of dry matter, zinc, magnesium, and ash factors were 94.17%, 16.33%, 0.21% and 0.016%, respectively.

4 Conclusion

Results of this study showed that the most suitable treatment for the quinoa peeling was (linear speed of 11.91 m s^{-1} and valve opening of 20 mm), because of the maximum amount of machine capacity (0.38 tons h^{-1}) and the lowest amount of quinoa weight loss (12.7%). This treatment had also a reasonable grain breakage (2.4%) and there was no significant difference between this treatment and the others. From the cost analysis of view, the highest added value was also related to the linear speed of 11.91 m s^{-1} and valve opening of 20 mm. Also, this treatment had the higher added value changes compared to the control treatment (linear speed of 11.91 m s^{-1} and valve opening of 10 mm). There was no significant difference between the treatments in terms of saponin content and nutritional properties of quinoa (protein, fat, fiber, dry matter, zinc, magnesium and ash); therefore, none of treatments had priority from the nutritional factors point of view.

Acknowledgements

The authors would like to acknowledge the financial support extended by the Agricultural Organization of Fars province. Technical supports from Laser Boresh Company and colleagues in the Department of Agricultural Engineering Research during the experimental works are also appreciated.

References

AACC. 2000. Approved Methods of AACC. Methods: 08-1, 10-05, 32-20.1, 38-10, 38-12A, 54-10, 54-21, 56-81B. 10th ed. St. Paul, Minn., USA: American Association of Cereal Chemists.

AOAC. 1998. Official Methods of Analysis of the Association of Official Analytical Chemists. 16th ed. Washington, DC: Association of Official Analytical Chemists.

Bhargava, A., and S. Srivastava. 2013. Quinoa: Botany, Production and Uses. Wallingford: CABI Publishing.

Bilalis, D., I. Roussis, I. Kakabouki and A. Folina. 2019. Quinoa (Chenopodium quinoa Willd.) crop under Mediterranean conditions: a review. Ciencia e Investigacion Agraria, 46(2): 51-68.

Chakraverty, A., and S. R. Paul. 2001. Postharvest Technology: *Cereals, Pulses, Fruits and Vegetables*. Science Publishers, Inc., Enfield, USA.

D'Amico, S., S. Jungkunz, G. Balasz, M. Foeste, M. Jekle, S. Tömösközi, and R. Schoenlechner. 2019. Abrasive milling of quinoa: study on the distribution of selected nutrients and proteins within the quinoa seed kernel. *Journal of Cereal Science*, 86: 132-138.

Egbuna, C., and J. C. Ifemeje. 2015. Biological functions and anti-nutritional effects of phytochemicals in living system. IOSR Journal of Pharmacy and Biological Sciences, 10(2): 10-19.

Goel, N., S. K. Sirohi, and J. Dwivedi. 2012. Estimation of total saponins and evaluate their effect on in vitro methanogenesis and rumen fermentation pattern in wheat straw based diet. Journal of Advanced Veterinary Research, 2(2): 120-126.

Han, Y., J. Chi, M. Zhang, R. Zhang, S. Fan, L. Dong, F. Huang, and L. Liu. 2019. Changes in saponins, phenolics and antioxidant activity of quinoa (Chenopodium quinoa willd) during milling process. LWT-Food Science and Technology, 114: 108381.

Hemalatha, P., D. P. Bomzan, B. V. Sathyendra Rao, and Y. N. Sreerama. 2016. Distribution of phenolic antioxidants in whole and milled fractions of quinoa and their inhibitory effects on α-amylase and α-glucosidase activities. Food Chemistry, 199: 330-338.

Liu, L., J. Guo, R. Zhang, Z. Wei, Y. Deng, J. Guo, and M. Zhang. 2015. Effect of degree of milling on phenolic profiles and cellular antioxidant activity of whole brown rice. Food Chemistry, 185: 318-325.

Multari, S., A. Marsol-Vall, M. Keskitalo, B. Yang, and J. P. Suomela. 2018. Effects of different drying temperatures on the content of phenolic compounds and carotenoids in quinoa seeds (*Chenopodium quinoa*) from Finland. Journal of Food Composition and Analysis, 72: 75-82.

Murty, V. S., P. Padhi, D. Padhi, and D. Padhi. 2016. A modified dehulling machine for abrasive dehulling of quinoa version 2.0. International Journal of Agriculture, Forestry and Plantation, 3: 13-15.

Reichert, R. D., R. T. Tyler, A. E. York, D. J. Schwab, J. E. Tatarynovich, and M. A. Mwasaru. 1986. Description of a product model of the tangential abrasive dehulling device and its application to breeder's samples. Cereal Chemistry, 63(3): 201-207.

Vongsangnak, W., J. Gua, S. Chauvatcharin, and J. Zhong. 2004. Towards efficient extraction of notoginseng saponins from cultured cells of Panax notoginseng. Biochemical Engineering Journal, 18(2): 115-120.

Wimberly, E. 1983. Paddy rice postharvest industry in developing countries. Los Banos, Laguna, Philippines: International Rice Research Institute.

Wu, L., A. Wang, R. Shen and L. Qu. 2020. The effect of slight milling on nutritional composition and morphology of quinoa (Chenopodium) grain. *International Journal of Food Engineering*, 16(11): 20190371.