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Research Paper

Development and performance evaluation of a walnut kernel oil extractor

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ABSTRACT

Walnut is known because of its high polyunsaturated fatty acid content, reduce blood pressure, LDL cholesterol and help to prevent some cancers. China is a leading walnut producer in the world with annual production of 1.786 million tonnes (MT). India ranks 11th with production of 33000 tonnes per year. Total estimated area and production during 2018-2019 under walnut cultivation in the Union Territory of Jammu & Kashmir was 84777 ha and 0.279 MT, respectively. In walnut oil production, it is very important to find appropriate parameters to extract the oil efficiently from kernels. In this study, walnut oil was obtained through the combination of mechanical and manual energy. The development was targeted to achieve maximum oil yield, high extraction efficiency, quality oil at minimum cost. The effects of moisture content (3.0, 5.0 and 7.0 %) of walnut kernels, clearance (6.0, 8.0 and 10.0 mm) reduction unit and motor rpm (200, 250 and 300 rpm) in present experiments were evaluated. The response surface methodology was used for optimization of process parameters for oil yield, extraction efficiency and specific energy. The optimum conditions were experimentally validated. The maximum and minimum oil yield was 43.5 ml and 22.5 ml per 100 grams, respectively. The results stated that the maximum oil yield was obtained at 3% moisture content, 6.0 mm clearance and 250 rpm while as minimum was found at 7%, 10 mm and 250 rpm, respectively.

Key words: Extraction efficiency, oil yield, specific energy, walnut oil, walnut

There are three different methods for oil extraction possible, including pressing, solvent extraction, and a combination of pressing and solvent extraction. Enzymes or carbon dioxide are often used to improve the efficiency of these methods. Walnut kernels have a high oil content (polyunsaturated fatty acids, monounsaturated fatty acids, and saturated fats) which varies from 52 to 72 % as compared to almonds (25 to 50 %) (Poggetti *et al.*, 2017). Walnut kernel is well known because of its high polyunsaturated fatty acids (PUFA) content (Crews *et al.*, 2005, Mehmet 2009). Adding walnut oil to diet may fight chronic inflammation, which has been linked to heart disease, some cancers, and other health issues. Oil from walnut kernel can be obtained in three ways, mechanical extraction (pressed oil), chemical or solvent extraction and supercritical CO_2 extraction (Singh and Bargale 2000). The major advantage of the Soxhlet process is solvent recycling during extraction (Martinez *et al*., 2013). However, disadvantages of the *Soxhlet* method include high solvent requirement, time, and energy consumption as well as sample being diluted in large volumes of solvent. The benefits of screw pressing are to produce high-quality oil containing bioactive compounds, without using organic solvent. Screw pressed method have low investment costs for equipment compared with super critical fluid extraction method. Benefits of screw pressing is providing a simple and reliable method of processing small batches of seed, (Tehand Birch 2013, Martinez *et al.*, 2008). The extraction of oil from walnut kernels in Kashmir Valley is done traditionally, no mechanized method is used (Shaheen and Ali, 2020). Keeping in view this and need for a mechanical device for the extraction of walnut oil, the modifications in manual juicer were carried out to develop the existing manual fruit juicer for extraction of walnut oil and to study the performance evaluation of the developed walnut oil extractor

MATERIALS AND METHODS

Development of the extractor: An angle bar iron was used to develop a frame of size 25×25×2 mm. The choice of angle bar iron was based on its moderate strength with good weldability. The frame serves as the skeleton for other parts, and a means of coupling the other parts together. The frame has four legs of 630 mm each, horizontal frame support of 250×180 mm. A circular ring of diameter 80 mm was welded on the frame support in which the cylinder was fitted. A flat iron of dimensions 25×2 mm was welded on the top of frame at a gap of 50.5 mm through which screw and plate go down into the cylinder. A metal sheet of dimensions 180× 110 × 2mm was welded on the frame support to hold the flask for collecting walnut kernel oil.

A Kalsi juicer of silver colour made of aluminum material was installed on the frame. The dimensions of the juicer are 200 × 180 × 140 mm (L× W × H). The juicer has an inlet of 80 mm. This juicer was manufactured by an internationally reputed Kalsi brand recognized firm since 1970. This is a hand operated juicer used for production of real pure and unadulterated juice of lime, orange, pomegranate, apple at home for the entire family friends and kitties. So, modifications were incorporated in this fruit juicer to convert it into low-cost walnut kernel oil extraction machine (Fig A and Fig B).

A heavy duty (Make: Hero) sewing machine with motor of 50 watts was installed on the frame to give power to screw of the juicer. The maximum speed of motor is 8600 RPM with 200/230 volts. It is made of aluminum cast iron, copper. The motor is of 1/12 HP with full aluminum winding heavy duty 50 watt and 3 pin plug long regulator wire with 1 belt 2 extra bush, 1 base plate and all fitting parts. The gears (spur and worm gear) of polylactic acid or polylactide (PLA) material were constructed by designing them in auto cad and printed via 3D printer. 3D printing is the construction of a three-dimensional object from a CAD model or a digital 3D model. The term "3D printing" can refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three-dimensional object with material being added together (such as plastics, liquids or powder grains being fused together), typically layer by layer. All the parts were finally assembled in a sequenced manner to get the best possible and result oriented design. The machine was tested several times to overcome all the drawbacks which resulted during the operation of machine (Table 1). The drawbacks were checked and corrected accordingly which led to the successful operation of the machine.

Determination of RPM: A KUSAM-MACO contact type digital tachometer was used to determine the RPM of the rotating shaft. The tachometer was placed in contact with the rotating shaft and the corresponding readings were taken. The RPM was varied and the desired RPM of 200, 250 and 300 were obtained with the help of a Variable Frequency Device (VFD) variable.

Determination of electrical energy: The electric input for an electric motor was determined from the following formula:

E = RHP × 0.746 × hours of use × efficiency (Pillai *et al.*, 2020)

E = Electricity input (kWh)

RHP = Rated Power of the electric motor (hp)

Efficiency of motor = 84%

Determination of specific energy: The specific energy was calculated using the following formula Specific energy (SE) = Electric energy + Manual energy

Where,

Manual energy of human = 1.96MJ/h

Determination of torque on rotating shaft

$$T = \frac{63000\,hp}{n}$$

Where,

hp = Horsepower of motor ; n = motor RPM

Table 1: Specifications of the developed walnut oil extractor

Capacity (g/h)	600
Speed range (RPM)	100-300
Screw thread thickness (mm)	5
Threaded section (mm)	110
Clearance (mm)	6
Internal diameter of extraction chamber (mm)	80
Height of extraction chamber (mm)	165

Walnut Kernels: Walnut kernels were procured from local market of Shalimar, Srinagar, India. Walnut kernels contained 69.2% oil (Dry Basis: DB) and 3.24% seed moisture content (SMC), (Wani, 2021). The walnut oil was obtained by pressing of 100 g sample of walnut kernels per each experiment using different process conditions/parameters.

Dried walnut kernels were put into the size reduction unit and the kernels were crushed by the screw which was driven by the belt and pulley connected with worm and wheel mechanism. The crushed material was collected in a vertical cylinder through an outlet. This crushed material was pressed manually, resulting extraction of oil. Then oil was collected at the bottom of the cylinder into a flask with the help of a funnel. Experiments were performed using 100 g samples of dried kernels, the quantity of extracted oil was measured under different variable parameters (Fig B and Fig C).

Determination of Moisture Content: A HE53 moisture meter/analyzer was used to determine the moisture content of walnut kernels. A sample of weight 25.8 g was taken. The moisture meter was set up and the sample prepared and placed on the meter accordingly. The moisture content of walnut kernels as determined by moisture meter varied depending on the different process conditions of the kernels. The moisture as determined by moisture meter ranged between 3.0 to 7.0 %.

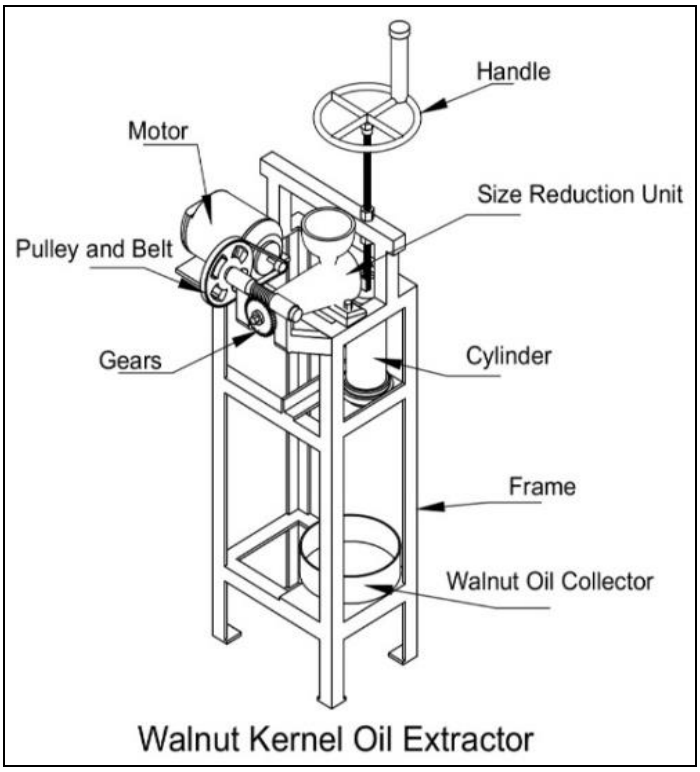

Fig A. Conceptual design of walnut oil extractor

Statistical analysis: The three independent variables of study viz. RPM of shaft, moisture content of walnut kernels and clearance of screw were selected for extraction of oil from walnut kernels. The response surface methodology (RSM) was used to decrease the number of experimental runs without affecting the accuracy of the findings and to evaluate the interaction effects of process variables on the response variables. The combinations of process variable levels in each experiment were decided by the Box Behnken Design (BBD). The plan consisted of total 18 experiments in each group with first 12 experiments in the factorial part and the remaining 6 experiments at the central point. Levels of variables were decided through literature and preliminary experiments on the walnut kernel oil extraction machine.

Total no of experimental runs $N = 2^K + (2K-1) + Cp$

Where K is the number of factors and Cp is the number of central point experiments.

Fig. (B) Developed prototype of walnut kernel oil extractor and (C) walnut oil sample extracted

RESULTS AND DISCUSSION

Fitness of models: Analysis of variance **(**ANOVA) given in Table 2 indicates that the models developed for all the product responses (oil yield, extraction efficiency and specific energy) were significantly ($p<0.05$) affected by independent variables viz. clearance (A) and moisture content (B). The coefficient of determination computed for all the selected parameters were highly desirable (R^2 ranged between 0.93 and 0.99), which indicates the reasonable fit of empirical models with actual data. The predicted and adjusted R^2 values for all the product responses were in sound agreement with each other. In addition, the lower coefficient of variation (% CV) obtained for all the models confirms accuracy, reliability and reproducibility of results. Models for all the parameters (oil yield, extraction efficiency and specific energy) showed non-significant lack of fit which indicates that the second order polynomial models correlated well with the measured data. Adequate precision computed for the models of all parameters were much higher than 4, which indicates highly desirable validation of models.

Table 2: ANOVA for the fit of data to Response Surface Model

Responses	**Regression**						
	R^2	**Adjusted R^2**	**Predicted R^2**	**Adequate precision**	**C.V**	**p-value**	**Lack of fit**
Oil Yield	0.9912	0.9812	0.9248	39.256	2.58	<0.05	NS
Extraction Efficiency **(%)**	0.9910	0.9809	0.9221	38.831	2.60	<0.05	NS
Specific Energy	0.9365	0.8651	0.2574	13.149	4.99	<0.05	NS

p-value = Probability value, C.V = Coefficient of variation; NS = not-significant

It is imperative to mention here that for each of the dependent variable; only those independent variables have been included in the models, which had significant effect as was depicted from ANOVA results.

Effect of process parameters on product responses

Effect of clearance and moisture content on oil yield (OY): From an economic point of view, oil yield is an important aspect of extraction process. The oil yield (OY) ranged between 22.5 ml to 43.5 ml. The regression equation obtained for OY is given below as equation (1)

$$OY=32.42 - 6.81A - 5.06B \quad \text{---------------} \ (1)$$

Where, A is the clearance, B is the moisture content.

From the regression equation (1), it was evident that all of the independent variables significantly ($p<0.05$) affected OY. The negative coefficients of linear terms of clearance (A) and moisture content (B) showed that with decrease in A and B oil yield increased. The increase in OY with decrease in clearance is due to less gap between kernels and size reduction unit which leads to fine crushing of kernels. This less clearance also applies more pressure on the walnut kernels leading to easy separation of oil from kernel particles and hence more oil yield. The effect of clearance and moisture content on oil yield showed, that moisture content affected oil yield significantly ($p<0.05$). The negative coefficient of regression equation shows that with decrease in moisture content oil yield increases and vice versa. This was also in agreement with (Nnam Raphael et al- 2020) who stated thatthe negative or inverse effect of moisture content (B) on oil yield could be due to the level of diffusivity of the solvent towards the surface which is dependent on the moisture content of the seed as moisture blocks the diffusivity of solvent to the seed surface thereby stopping the extraction of the bio-active compounds present in the seed as oil.

Farsie and Singh (1985) reported that the seed kernels with higher moisture content yielded less oil as compared to those with lower moisture content. They reported maximum oil recovery for sunflower seeds expressed at 6% moisture content, however with the increase in moisture content to 14%, oil recovery was found to decrease by 16%.

The interactive effect of all the independent variables was significant ($p<0.05$) and a significant ($p<0.05$) negative interactive effect was shown by clearance and moisture content (equation 1).

From the regression equation (1), it was further evident that the linear effect of moisture content (B) was dominant amongst all the three independent variables viz. clearance (A), moisture content (B) and RPM (C).

Effect of clearance and moisture content on extraction efficiency (EE): Extraction efficiency is also an important parameter in extraction process. The extraction efficiency ranged between 35% to 72.5%. The regression equation (2) obtained for extraction efficiency is given below:

$$EE = 54.00-11.35A-8.35B \ \text{--------------------} \ (2)$$

Where, A is the clearance and B is the moisture content.

From the regression equation (2), it is observed that with decrease in clearance, extraction efficiency increased and vice versa. This is because the mean particle size has a critical impact on the extraction efficiency. The effect of particle size on the extraction yield was assessed using mean particle sizes. An increase of particle size is accompanied by a decrease in solubility and extraction rate (Salgin and Salgin 2006).

From the above equation it is seen that with decrease in moisture content, extraction efficiency increased and vice versa. These results are in agreement with Farsie and Singh (1985) who reported that the seed kernels with higher moisture content yielded less oil as compared to those with lower moisture content and hence decreased the extraction efficiency and vice versa.

Effect of clearance and moisture content on specific energy (SE): Specific energy is the energy per unit mass. To save some energy this parameter should be as less as possible. The specific energy ranged between 199.3 MJ/L and 353.5 MJ/L. The regression equation (3) obtained for specific energy is given below:

$$SE = 239.87 + 36.51B \quad \text{--------------------} \ (3)$$

This equation shows that the specific energy has positive or direct relation with moisture content (B) that means with increase in moisture content, specific energy also increases and vice versa. If the moisture content of walnut kernels is high, more mechanical energy is required to crush the walnut kernels and more labour energy is required to extract oil. The relationship of the specific energy to the kernel moisture content was described by means of linear equation. However, clearance did not show any significant effect on specific energy.

Optimization and model validation: The optimum condition was obtained by employing the desirability function method. The desirability value obtained was 0.962. For the optimum formulation, the final condition would be considered optimum if the oil yield, extraction efficiency value was as high as possible while specific energy value is as low as possible. According to the optimized-dependent parameters, clearance will be 6.037mm, moisture content will be 3%, and RPM will be 278. The predicted response values and the actual obtained response values were within 4% of the predicted values. At the optimized condition, product responses were oil yield: 43.56ml; extraction efficiency: 72.50%; specific energy: 219.380 MJ/ml (Table 3).

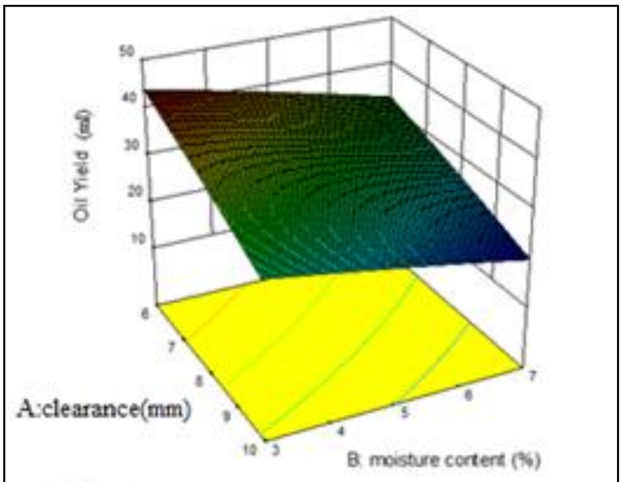

Fig 1: Effect of clearance and moisture content on oil yield (OY)

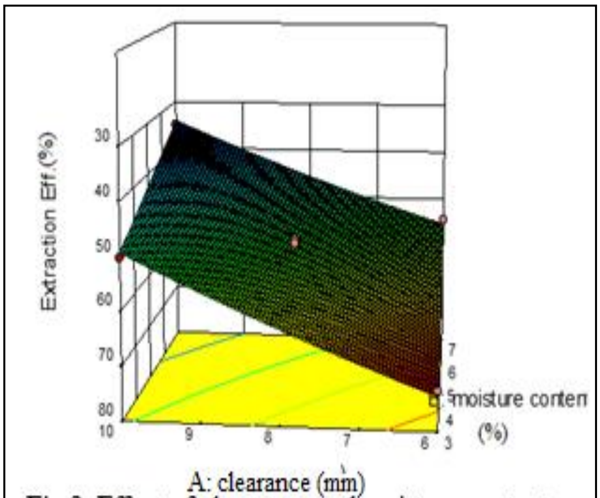

Fig 2: Effect of clearance and moisture content on extraction efficiency (EE).

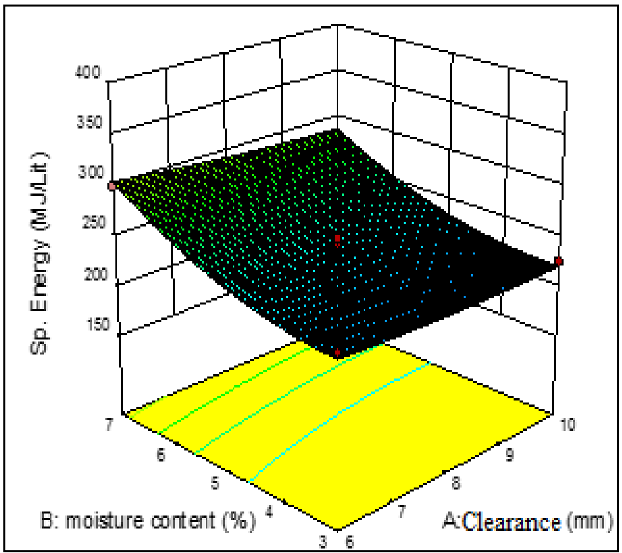

Fig 3: Effect of clearance and moisture content

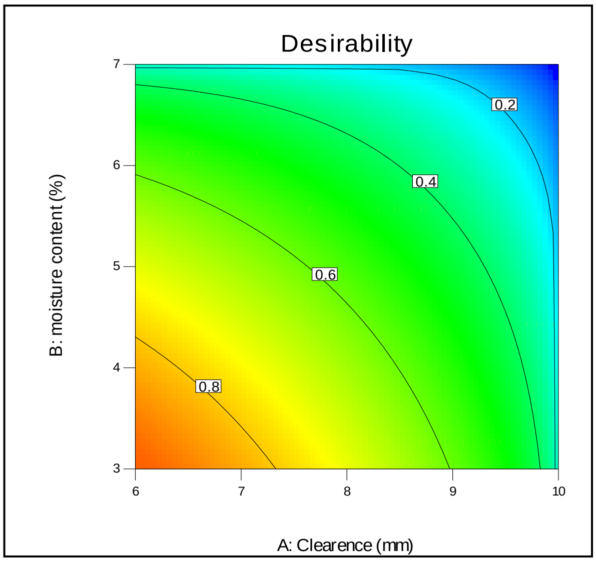

Fig 4: Desirability on specific energy (SE)

Table 3. Predicted response verses actual response

Values	Responses		
	Oil Yield (ml)	Extraction efficiency (%)	Specific energy (MJ/ml)
Predicted	43.56	72.50	219.38
Actual	42.24	71.2	214.5
Variation (%)	3.03	1.79	2.2

CONCLUSION

The findings of this investigation indicate that the optimal combination of extraction parameters is having 3.0 % moisture content, 6mm clearance of screw press and 278 RPM. Using these process settings, it is possible to achieve the highest oil yield of more than 400 ml of oil per kilogram of walnuts kernels. The obtained results can be used in commercial practice for optimizing the pressing process for pressing of oil from walnuts kernels.

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