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The Effects of physical parameters of the screw press oil expeller on oil yield from *Nigella sativa* L seeds

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Abstract: The effects of physical parameters of a screw press machine on oil yield of *N. sativa* seeds were studied using a KOMET Screw Oil Expeller. Different nozzle size (6, 10, and 12 mm), extraction speed (21, 54, 65 and 98 rpm) and diameter of shaft screw (8 and 11 mm) were applied in this study. Different nozzle size, diameter of shaft screw and rotational speed do effects the percentage of oil yield. By using shaft screw with diameter of 8 mm had resulted to the decrease of oil yield with the increase of nozzle size and rotational speed. While, by using the shaft screw with diameter of 11 mm had recorded the highest percentage of oil yield at 65 rpm when using nozzle with the size of 6 and 10 mm. However, when using nozzle with the size of 12 mm, the percentage of yield had recorded the same result pattern with the result of using shaft screw with diameter of 8 mm which is; the decreased of percentage of oil yield with the increase of rotational speed. The highest percentage of oil yield recorded was at the combination of shaft screw with diameter of 8 mm, rotational speed at 21 rpm and nozzle size of 6 mm. There was significantly different ($p<0.05$) between oil yield with heat temperatures. The oil yield was higher at 50°C (22.68%) and lower at 100°C (15.21%). Most of the results obtained (percentage of oil yield of *N. sativa* seeds recorded) was significantly different ($p<0.05$) in relation with the effect of physical parameters of machine screw press on the oil yield.

Keywords: Screw oil expeller, *N. sativa* seed, nozzle size, oil yield, shaft screw of screw press

Introduction

N. sativa originated from West Asia and grows up to 41-61 cm in tall. It has white and black flowers, sharp-cornered rectangle seeds (no more than 3 mm) and this part used for the products. These plants are now cultivated from Near East to India. Its seed had been used in the Middle East and Far East countries for centuries to treat diseases including bronchial asthma, bronchitis, rheumatism (Mahfouz and El-Dakhakhny, 1960; Soliman, 1978; Toppozada *et al*., 1965; Atta, 2003) and related inflammatory diseases (Khan *et al*., 1999; Ramadan, 2007), increase milk production in nursing mothers, to treat digestive disorders (Rajkapoor *et al*., 2002; Ramadan, 2007), to support the body's immune system, to promote digestion and elimination, and to fight parasitic attack (Ramadan, 2007). The seeds have been used to produce oil usually by using mechanical expression method, solvent extraction method, or both methods (Owolarafe *et al*., 2003; Oyinlola and Adekoya, 2004).

Mechanical pressing is the most common method for oil extraction which includes of different types of press such as hydraulic press, screw press and rolling press (Bamgboye and Adejuno, 2007). Solvent extraction is a method which is able to extract over 98% oil (Yoyock *et al*., 1988). However, this method has its own disadvantages such as the necessary equipment is high in cost, the process is quite dangerous in correlation with fire and explosion, and the solvent used requires specific process before further to the next process (Bargale *et al*., 1999; Ajibola *et al*., 2002). According to Fitch-Haumann (1997) and also Wiesenborn *et al*. (2001) said that screw press has much better safety features; environmental friendly and can extracts oil seeds from 8 kg to 45 kg per hour of raw material depending on type of expeller. One type of the screw press is the KOMET screw press which consists of different nozzle sizes, speed and diameter. Different accessories of this machine will probably generate a number of different types of seed oils. Some researchers have reported that the parameters that was used before and during pressing will affect oil pressing processes including particle size, heating temperature, heating time, moisture content, and applied pressure (Ajibola *et al*., 2000; Olayanju *et al*., 2006; Baryeh, 2001; Mwithiga and Moriasi, 2007). So far, there was no research evidence reported on the influence of three types of accessory factors of the screw machines which is nozzle size, speed and diameter of shaft screw press on the extraction of *N. sativa* seeds oils. Therefore, the purpose of this study

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is to examine the effect of these three factors on the production of oil yields of *N. sativa* seed and also effect of different temperatures on the production of oil yield.

Materials and Methods

Raw material

The samples of *N. sativa* seeds, from India were procured from supplier Abdul Ghafar Enterprise, Malaysia. The *N. sativa* seeds were sieved to remove dust, sand, stone, small weed seeds and other foreign matter. It is important to remove it before extraction (Ohlson, 1976). The samples were kept in vacuum plastic and stored at room temperature until processing.

Oil extraction procedure

Physical treatment of screw press with combination nozzle size, diameter of shaft screw and speed

The samples of *N. sativa* seeds were pressed in KOMET screw oil expeller DD 85 G- D 85- 1G (IBG Monforts Oekotec GmbH & Co.KG, Germany) at 60^{0}C. KOMET oil expellers feature a special cold pressing system with a single conveying screw to squeeze the oils from various oil-bearing seeds. The machines operate on a gentle mechanical press principle that does not involve mixing and tearing of the seeds (Ferchau, 2000). Figure 1 shows the diagram of laboratory KOMET oil expeller for pressing operation. One kilogram of each combined treatment from *N. sativa* seeds was filled into feeding hopper and pressed by screw press R8 and R11 (diameter shaft screw of 8 mm and 11 mm), with nozzle sizes of 6, 10, and 12 mm and with rotational speeds of 21, 54, 65 and 98 rpm. The extracted oil was kept away from light, placed in a dark container (wrapped with aluminum foil) and stored in a chiller (4^{0}C) to allow foreign materials to settle down. After 48 hours, the oil was filtered to remove other fine particles. The oil was weighed and the percentage of oil yield was calculated using the following formula:

$$oil\ yield\ (\%) = \frac{mo}{ms} x100 \qquad (1)$$

Where: m_0 – weight of oil extract, m_s – weight of sample.

Oil extraction procedure at different temperatures

After the suitable combination of screw press parameters used to produce optimum oil yield had been obtained, the samples was extracted using that combination (which is nozzle sizes of 6 mm, diameter shaft screw of 8 mm and rotational speed at 21 rpm) and for this time, the samples were pressed at six different temperatures (50°, 60°, 70°, 80°, 90° and 100°C).

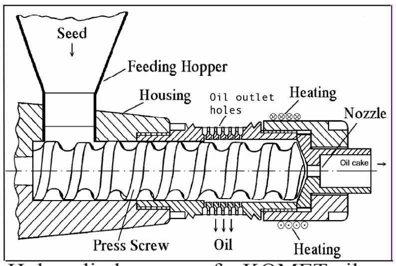

Figure1. Hole cylinder press of a KOMET oil expeller (Ferchau, 2000)

The screw press was first run for 30 minutes by heating it using electrical resistance-heating ring that attached around the press head to ensure the screw press work at 100±3^{0}C without seed. A digital thermometer with a type T thermocouple was used to measure the temperature between the heating ring and the press head. Then, 350 g seed was pressed for 4 to 5 min to rinse the screw press before the samples were run in order to achieve a steady flow of oil and meal extraction. Upon achieving steady operation, triplicate 3000 g sample was poured into the hopper, and was pressed at different temperatures (100±3^o, 90±3^o, 80±3^o, 70±3^o, 60±3^o, and 50±3^{o}C). The oil that had been produced was stored away from light in a dark container (wrapped with aluminum foil), in a chiller (4^{O}C) for 48 hours to let the foreign materials in the oil settle. After 48 hours, the oil was filtered to remove other fine particles in the oil, and the percentage of oil yield was calculated using formula (1).

Statistic analysis

Physical treatment of the screw press machine was carried out at nozzle sizes of 6, 10 and 12 mm, diameter of shaft screw of 8 and 11 mm and four level speeds of rotation machine at 21, 54, 65 and 98 rpm using 3 x 2 x 4 factorial experimental design with twice replication. The data was analyzed using two-way ANOVA (SPSS 12) by Univariate with Tukey's Multiple Range test to indicate the differences among means ($p<0.05$) expressed as Mean ± Standard Deviation (M±SD).

Data of percentage of oil yield pressed at six different temperatures (50°, 60°, 70°, 80°, 90° and 100°C) was analyzed using one-way ANOVA (SPSS 12) with triplicate data. The differences among means were analyses using Tukey's Multiple Range test to indicate differences among means ($p<0.05$) expressed as M±SD (Pallant, 2005).

Result and Discussion

Physical parameters of screw press

The average percentage of oil yield of *N. sativa* seeds that was extracted using screw press between different nozzle sizes, diameter of shaft screw and rotational speeds are shown in Table 1.Based on the result (can be seen in Table 1), it showed that, the percentage of oil yield recorded the highest one at the combination of nozzle with the size of 6 mm, shaft screw with diameter of 8 mm and rotational speed at 21 rpm which is about 22.27%. The lowest oil yield recorded is about 8.73% which is at combination of nozzle size of 10 mm, diameter of shaft screw of 11 mm and rotational speed at 21 rpm. Both results (the highest and the lowest percentage of oil yield) were significantly different ($p<0.05$) with other results.

Table 1. Percentage of oil yields from *N. sativa* seed pressed at 60°C with different nozzle sizes, diameter of shaft screw and speed of screw press machine

No	Nozzle size (mm)	Diameter shaft screw (mm)	Speed rotational (rpm)	Oil yield (%) M±SD
1	6	R8	21	22.27±0.18^{n}
2	6	R8	54	19.2±0.23^{m}
3	6	R8	65	17.85±0.04^{klm}
4	6	R8	98	15.62±0.03^{ghi}
5	6	R11	21	13.01±0.68^{cd}
6	6	R11	54	17.84±0.41^{klm}
7	6	R11	65	17.92±0.10^{klm}
8	6	R11	98	17.67±0.74^{klm}
9	10	R8	21	18.58±0.37^{lm}
10	10	R8	54	16.21±0.42^{hij}
11	10	R8	65	17.13±0.02^{jkl}
12	10	R8	98	14.72±0.35^{efg}
13	10	R11	21	8.73±0.76^{a}
14	10	R11	54	11.45±0.49^{b}
15	10	R11	65	14.17±0.24^{def}
16	10	R11	98	12.02±0.29^{bc}
17	12	R8	21	18.37±0.33^{klm}
18	12	R8	54	17.79±0.18^{klm}
19	12	R8	65	16.94±0.24^{ijk}
20	12	R8	98	15.88±0.42^{ghij}
21	12	R11	21	19.05±0.66^{m}
22	12	R11	54	15.47±0.02^{fgh}
23	12	R11	65	14.96±0.08^{fgh}
24	12	R11	98	13.46±0.31^{cde}

Results represent means of duplicate with standard deviations. Different common superscript in the same row represent significant different ($p<0.05$).

Using shaft screw with diameters of 8 mm

The percentage of oil yield had showed significantly different results when using the shaft screw with diameter of 8 mm for each nozzle sizes and at all different speed of rotation machine. The combination of this shaft screw (diameter of 8 mm) with nozzle size of 6 mm shown significantly different ($p<0.05$) of oil yield between speed 21 rpm with 54, 65 and 98 rpm. However, the oil yield at speed 54 rpm is not significantly different ($p<0.05$) with the speed of 65 rpm. Based on the experiment, it had showed that, the percentage of oil yield was decreased with the increase of the speed machine. Similar result had been observed on the combination of shaft screw with diameter of 8 mm with nozzle size of 10 and 12 mm at each different speed, where the percentage of oil yield also reduced with the increase of speeds rotation machine. The percentage of oil yield at combination of this shaft screw with diameter of 8 mm with nozzle size of 12 at speed 21 and 54 rpm had showed significant different ($p<0.05$) oil yield with the speed of 98 rpm.

The effect of difference speeds to the percentage of oil yield is related with the duration of pressing process. Slow speed would probably extend the pressing process and result to the increase of heating process in the machine (Evangelista, 2009). This condition might result to the oil yield to flow easily and also increased (Lutanda ltd, 1988). The size of the nozzle also related with the pressing process. Smaller size of nozzle might add pressure to the seed which thus promote heat to be produced by the result of the collision between the shaft screws and the seeds and also between the seeds themselves.

This statement was supported by Singh and Bargale (2000) which had stated that, the oilseeds that were placed into feeding hopper of the screw press are compressed by the shaft screw and nozzle under high pressure to break the cell wall. The oil will come out through the slits provided along the barrel length (Figure 1). The oil actually was contained inside the cells of the oilseed at different places together with other components such as protein, globoids and nucleus where they are covered by the cells wall. This oil will come out in the form of oil globules (Singh *et al*., 1990)

Khan and Hanna (1983) stated that pressure will break the cells wall of the seed and release more oil. Adeeko and Ajibola (1990) stated that, in mechanical pressing, there were some factors which can influence the quality and level of the oil yield such as particle size, heating temperature, heating time, applied pressure and duration of pressing oil.

According to Harmanto *et al*. (2009), they found that, the highest oil yield of Jatropha seeds is at rotational speed of 45 rpm and nozzle size of 6 mm using screw press. Their results showed that oil yield decreased with the increased of nozzle size and rotational speed. This result do support the result obtained from this experiment which is; smaller nozzle size and rotational speed result to the increase of the oil yield. While, according to Singh and Bargale (2000), diameter of shaft screw also involved in compression of sample using the screw press in order for the production of oil yield, while the other components such as pitch, helix angle of the screw and barrel diameter were kept constant (Singh and Bargale, 2000). It is means that, all three types of physical parameters of screw press which is nozzle size, diameter of shaft screw and speed rotational do influenced the production of oil yield.

Using shaft screw with diameter of 11 mm

The combinations of shaft screw with diameter of 11 mm with nozzle size of 6, 10 mm, at all four different speeds (21, 54, 65 and 98 rpm) had showed an increase of the percentage of oil yield with the increase of speed rotation of the screw press. The percentage of oil yield recorded using this shaft screw with diameter of 11 mm with nozzle size of 6 mm and at rotational speed of 21 rpm showed significantly different ($p<0.05$) with other rotational speeds and nozzle sizes except at rotational speed of 65 and 98 rpm with nozzle size of 10 mm and also at rotational speed of 98 rpm with nozzle size of 12 mm, where it recorded no significant different with those results (refer to Table 1).

From the experiment, it had showed that, the percentage of oil yield recorded using shaft screw with diameter of 11 mm with nozzle sizes of 6 and 10 mm applied at the lowest rotational speed (21 rpm) until the highest rotational speed (98 rpm) had showed a pattern of an increase of oil yield percentage at 21 rpm to 65 rpm of rotational speed, followed by a decrease of percentage of oil yield which is from 65 rpm to 98 rpm. The combination of shaft screw with diameter of 11 mm with nozzle size of 12 mm showed a similar result pattern with the percentage of oil yield recorded when using shaft screw with diameter of 8 mm with combination of all nozzle sizes and at all different rotational speed; which the result showed a decreased on the percentage of oil yield with the increase of rotational speed.

Based on the result obtained above, it is seemed that, the best rotational speed to be used in order to obtain highest percentage of oil yield is at 65 rpm when using nozzle size of 6 and 10 mm. This might be due to closer to the theoretic maximum oil yield, which reduced it with increase of nozzle sizes and it increased again when increasing nozzle size (Beerens, 2007). The relation to the properties of shaft screw with diameter of 11 mm is suitable with the rotational speed that is not too high or too low (which is in this case, 65 rpm was the best one) when using the nozzle size of 6 and 10 mm. Therefore, it indicated that rotational speed of 65 rpm is seemed to be the best speed for give optimum pressure towards the seeds and produce optimum percentage of oil yield when using shaft screw of 11 mm and with nozzle size of 6 and 10 mm.

Using bigger diameter of shaft screw (which is in this case 11 mm), will result to the space where the seeds were filled to be pressed was increased. In comparing between shaft screws with diameter of 11 mm with the shaft screw with diameter of 8 mm, it can be seen that, the shaft screw with diameter of 8 mm provided much smaller space for the seeds to be filled to be pressed compared to shaft screws with diameter of 11 mm. This smaller space provided actually help in increase the pressure towards the seeds. Therefore, it is means that, shaft screw with diameter of 11 mm which having bigger space provided for the seeds to be filled will give less pressure towards the seeds to be pressed. Since the pressure provided by shaft screw of 11 mm was less, therefore, lower rotational speed is not enough to give optimum pressure towards the seeds, thus result the percentage of oil yield to be low (for nozzle size of 6 and 10 mm).

The reason of why the percentage of oil yield getting decrease when the rotational speed is over 65 rpm (which is 98 rpm) is might be due to the pressure that was applied under this speed was too high or over the optimum pressure, which might increase the production of heat as the result of higher collision occurred among the seeds and also between the seed and screw press. The increase of heat to a certain level will reduce the moisture content of the seeds, thus result the water content to be reduced. The low level of water content will not be able to help in breaking or cracking the cell wall of the seeds, which thus result the percentage of oil yield to be decreased.

This result can be supported by Felycia *et al.* (2008) which had stated that increasing of heating temperature would decrease the oil yield of Neem seeds. Faborode and Favier (1996) stated that, the increase of temperature might reduce the water content of the seeds. This low level of water is not be able to break or crack the cells walls of the seeds in order to ooze out the oil, and thus result the oil yield to become decreases. While, Baryeh (2001) stated that not always increase in heat will increase the oil yield. That depends to the quality and moisture content of the seeds and also the design of screw press (Baryeh, 2001).

As been mentioned above, the percentage of oil yield recorded when using shaft screw with diameter of 11 mm with nozzle sizes of 12 mm had showed similar result pattern with the results recorded when using the shaft screw with diameter of 8 mm, where the percentage of oil yield was decreased as the rotational speed getting increased. This might be due higher speed would reduced residence time and thus less chance for oil to flow from between the seeds (Beerens, 2007).

Actually, different type of seeds (i.e coconut seeds, olive seeds, etc) having different properties that making them to be suitable to certain conditions of physical parameters of the screw press in order to produce optimum oil yield. Not only that, different diameter of shaft screw also having its own properties which making them to be suitable to be used to certain types of seeds (whether soft seeds or hard seeds) in order to produce optimum percentage of oil yield. Therefore, it can be said here that, this *N. sativa see*ds also having its own properties (in term of moisture content, types of the seeds; whether soft or hard, etc), where this properties will produce different effects of the percentage of oil yield when been applied with different combination of physical parameters of screw press used.

Effects of temperatures on the yield of N. sativa *seed oil*

From the result that had been obtained (which can be seen in Table 1) , it shows that the optimum percentage of oil yield of *N. sativa* seed oil recorded was at combination of nozzle with the size of 6 mm, diameter of shaft screw of 8 mm and at rotational speed of 21 rpm. Second experiment involved the pressing of *N. sativa* seed at six different temperatures using that combination of screw press machine. The percentages of oil yield are 22.68% (50°C), 22.16% (60°C), 20.02% (70°C), 17.97% (80°C), 16.35% (90°C) and 15.21% (100°C), respectively. It can be seen from Figure 2 that, as the temperature getting increase, the percentage of oil yields getting decrease. The reduction of the percentage of oil yield is obviously at the temperature of 70°C until 100°C. The oil yield that had been extracted from N. sativa seed showed significant decrease ($p<0.05$) between the lowest temperature (50°C) with the highest temperature (100°C) which can be seen in figure 2. This shows that the heating temperature for extract *N. sativa* seed oil should not be above 70°C. This is because, using the temperature above 70°C just result to a waste since the oil yield is just low in level, and also required extra cost (in term of electrical used because high temperature required more heating, etc), where it lastly not necessarily improve yield and extraction efficiency (Baryeh, 2001).

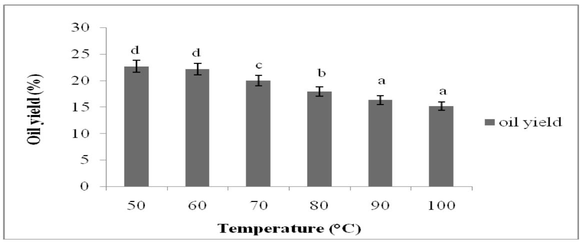

Figure 2. Means of percentage oil yield from *N. sativa* seed pressed at six different temperatures. Means in the column with different letters are significantly different ($p<0.05$) N= 3

Theoretically, oil yield would be increased with the increase of heating temperature and pressure extraction. However, under a certain level, the increase of heating temperature and pressure extraction will probably decrease the amount of oil yield (Adeeko and Ajibola, 1990; Hamzat and Clarke, 1993; and Baryeh, 2001). The reason of why the percentage of oil yield get reduced at higher temperature might be due to the change of moisture content and structure of the seeds during the heating process which this condition actually related to the production of oil. (Ogunsina *et al*., 2008). The moisture content of the meal cake of *N. sativa* seed was decreased with the increased of heating temperatures (data was not shown).

This statement was supported by Felycia *et al.* (2008), where based on their study, they had found that, the moisture content was decreased from 4.6% to 2.6% with the increased of heating temperature from 40°C to 80°C , while the oil yield also decreased from 32% to 18%. Heating could also promote binding between oil and proteins within the seed structures which making the oil to attach more towards the seeds and result the oil to not be able to flow out from the seedbed. The folk center stated that, moisture content that is suitable for screw press are commonly within 7-8% for oil seed (Ferchau, 2000; Owolarafe *et al*., 2003; and Ogunsina *et al.*, 2008). Cake residue from oil extraction of *N. sativa* seeds can be used as animal feed because the seed contained with high protein, fiber, and antioxidant which can improve the nutrient quality of animal feed and also can be as an alternative to replace soybean meal (Zeweil *et al*., 2008) which usually been used as rabbit feed. The soybean meal is quite expensive, therefore, the introduction of *N. sativa* cake residue which is cheaper than soybean meal is seemed to be as an advantages especially for the improved of economic efficiency (El-Ayek *et al*., 1999; Abdel-Magid *et al*., 2007). Bargale *et al.* (1999) stated that, standard level nutrients of animal feed must be low in fat (<5%) and protein rich (>50% protein) of soybean meal. From here, it indicates that, the oil extraction of *N. sativa* seed was not suitable to be pressed at high temperature since at a very high temperature, all those nutrients can be reduced or the worst case; it will be destroyed, which thus might result the expressed oil and deoiled cake that had been produced for not having good quality of food (Mrema, 1979).

Conclusions

The study found that optimum condition for cold press of *N. sativa* seeds oil is using 6 mm of nozzle size, 8 mm of diameter shaft screw and pressing at speed 21 rpm. The highest amount of oil yield is 22.27% on diameter shaft screw 8 mm and 19.05% on diameter shaft screw 11 mm. The percentages of oil yield decreased with increasing of nozzle sizes, diameter screw, speed and temperatures. The effect of all combined physical parameters of screw press oil expeller was significant different ($p<0.05$) on oil yield of *N. sativa* seeds oil. There was significantly different ($p<0.05$) between oil yield with heat temperatures. The oil yield was higher at 50°C (22.68%) and lower at 100°C (15.21%). The optimum condition and effect temperatures will be used for further research to observe the quality and antioxidant properties of *N. sativa* seeds oil and meal.

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