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GARLIC POWDER PRODUCTION USING A HAMMER MILL

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ABSTRACT

This research was carried out at El Mansoura Laboratory of soil fertility in Mansoura sity, Dakahlia Governorate, during 2001 season to mill two garlic cultivers (Balady and Sides-40) after slicing the cloves and drying the slices. The aim of garlic milling is producing garlic powder which is considered as the most effective commercial preparation for securing all health benefits of garlic. To achieve this aim, a laboratory swinging beaters hammer mill powered with a 0.20 kW motor was used. Factors studied were three hammer tip speeds (13.82, 18.43 and 23.04 m/sec), two feeding rates (27.00 and 43.20 kg/h), two screen hole diameters (1 and 2 mm) and two drying methods (natural and artificial). The performance of the mill was evaluated according to the actual milling capacity, milling efficiency, weight reduction ratio, energy requirements and oil content garlic powder.

The obtained results are summarized as follows:

1- The highest milling capacity of 7.10 kg/h was obtained by milling artificially dried garlic sides-40 variety at 23.04 m/sec hammer tip speed, 43.20 kg/h feeding rate and 2 mm screen holes diameter.
2- The highest milling efficiency (99 %) obtained by milling naturally dried garlic balady variety at 13.82 m/sec hammer tip speed, 27.00 kg/h feeding rate and 2 mm screen holes diameter.
3- The least specific milling energy of 39.76 MJ/Ton was obtained by milling artificially drying garlic sides-40 variety at 13.82 m/sec hammer tip speed, 43.20 kg/h feeding rate and 2 mm screen holes diameter.
4- The least specific powder production energy was 46.92 MJ/Ton was obtained by milling artificially dried garlic sides-40 variety at 13.82 m/sec hammer tip speed, 43.20 kg/h feeding rate and 2 mm screen holes diameter.
5- The highest weight reduction ratio of 1.35 was obtained by milling artificially dried garlic sides-40 variety at 23.04 m/sec hammer tip speed, 43.20 kg/h feeding rate and 1 mm screen holes diameter.
6- The highest oil content in garlic powder of 12.51 % was obtained by milling artificially dried garlic sides-40 variety at 23.04 m/sec hammer tip speed, 43.20 kg/h feeding rate and 1 mm screen holes diameter.

Analysis of variance indicated that there was high significant effect on oil content in garlic powder due to the interaction among levels of garlic hardness degree, hammer tip speed and screen holes diameter. The following regression formula represents the relation between oil content in garlic powder (Y), garlic hardness degree (X_1), hammer tip speed (X_2) and screen holes diameter (X_3).

$$Y = 1.47 + 0.48\ X_1 + 0.04\ X_2 - 0.04\ X_3$$

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INTRODUCTION

Garlic has been cultivated all over the world on account of its culinary and medicinal properties. The medical studies showed that garlic contains more than 100 biologically useful chemicals, including substances such as alliin, alliinase, allicin, S-allylcysteine, diallyl sulfide and allyl methyl trisulfide. Garlic health benefits involve lowering blood pressure, lowering cholesterol, lowering or helping to regulate blood sugar, helping to prevent blood clots from forming, helping to prevent cancer, preventing certain tumors from growing larger and reducing the size of certain tumors and helping to remove heavy metals such as lead and mercury from the body. Garlic is a potent natural antibiotic, it has anti-fungal and anti-viral properties and it has anti-oxidant properties and is a source of selenium (Pai and Platt, 1995; Sundaram and Milner, 1996; Khanum et al., 1998; Iqbal and Athar, 1998; Berthold et al., 1998; Ariga et al., 2000; Tsao et al., 2001 and Wu et al., 2001).

Garlic powder is the most effective of the commercial preparation for obtaining all the health benefits of garlic. Garlic cloves are sliced, dried and then ground into powder before the allicin is formed. A little allicin is formed when the cloves are sliced, but most of the cells are unbroken when dried and the alliin and allinase remain separate. This powder is put into capsules or made into pills and given an enteric coating to prevent it from dissolving until after it is swallowed. When the pill is dissolved in the stomach or intestines, the allicin is then formed. This process seems to be a good way to get the benefits of both the allicin and the sulphides with a minimum of resultant odor (Gara et al., 2000).

The select of the proper mill is much greater important to obtain high quality of garlic powder. Review of agricultural and medical literature showed that there is a lack in the information about garlic milling. On the other hand, many researches were published in the agriculture engneering literature concering cereal grains milling, using different mill types such as Appel (1987), Rothwell et al. (1991), Fang et al. (1997), El-Hadidi et al. (1997) and Laskowski et al. (1998). These researches concluded that the hammer mill achieved higher performance and consumed lower energy among the other types. In this study, the authors carried out a trial to explore the possibility of using a laboratory hammer mill for garlic milling and assessment of the quality of finished product. Also, this study aimed to determine the effect of mill operational parameters and garlic physical properties on milling capacity, milling energy and milled product quality.

MATERIALS AND METHODS

Experimental procedure:

This study was carried out at Mansoura soil fertility laboratory, in Mansoura sity, Dakahlia governorate, during 2001 season. This study was conducted in two stages as follows:

1- premilling stage: two garlic cultivars (Balady and Sides-40) were selected to apply this study. These cultivars were planted during the winter season 2000 at the experimental farm of El-Baramon Horticultural Research Station, Dakahlia Governorate. The standard agricultural practices were applied according to the recommendations of the Ministry of Agriculture, district authority for these cultivars.

The fresh cloves were shelled and sliced into small pieces of 1mm thickness. The garlic pieces were dried naturally and artificially until a constant weight. They were dried naturally at ambient room temperature of 26 °C ± 1. Also, they were dried artificially using an electric oven at 65 °C according to Pezzutti and Crapiste (1997).

Moisture content and hardness degree of garlic pices were determined as follows:

A- Samples were weighed before and after drying. Moisture content % (w.b.) was calculated according to AOAC (1996).

B- The hardness degree of dried garlic pieces was measured using a digital hardness meter model (FGC-20). Each garlic piece was put on the device bottom plate, and the manual cross head was moved down until failure occurred. The hardness value of each piece was recorded in Newton. The hardness degrees, moisture contents and drying times are presented in table (1).

Table 1: Hardness degrees, moisture contents and drying times of dried garlic cultivars.

Garlic cultivers	Drying method	Hardness degree, N	Moisture content, % (w.b.)	Drying time, h
Balady	Natural	14.93	65.14	85
	Artificial	16.93	66.39	8
Sides-40	Natural	18.20	65.99	93
	Artificial	21.16	68.12	10

2- Milling stage: the used laboratory mill in this study is shown in Fig. (1). The specifications of the mill are presented in table (2). The mill is directly driven by an electric motor. Hopper, with dust-proof cover is fixed on the top of the mill. Mill grinding chamber is a chromium-plated steel block. There are three swinging hammers which rotate on a horizontal rotor in a strong housing, which has into it sharp edges of high-grade tool steel around the internal periphery of the chamber. At the point close to the hammer's periphery, there is a semi-circular screen. As the material is fed from the feed hopper into the mill, the hammers strike and pulverize it. Due to the constant hammering action, the material gets disintegrated till it becomes finer than the screen to pass through the holes.

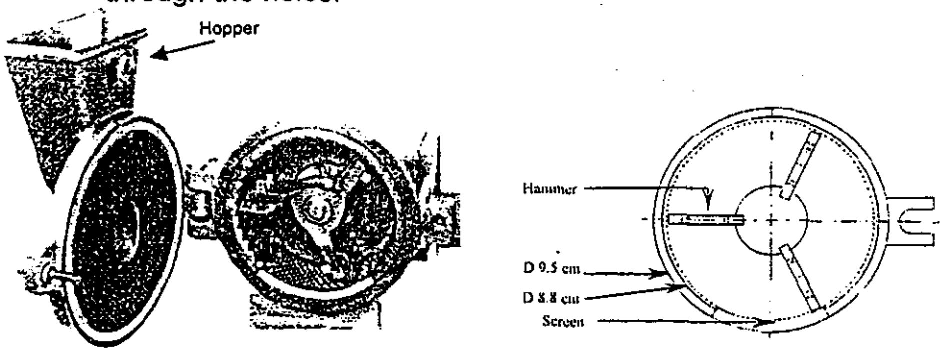


Fig. 1: The used laboratory hammer mill.

Table 2: Specifications of laboratory hammer mill.

Specifications	Hammer mill
Manufacture country	Germany
Type	Swinging beaters hammer mill
Model	MFC 180-220 V
Overall length, mm	450
Width, mm	150
Height, mm	220
Grinding chamber diameter, mm	95
Rotor diameter, mm	28
Rotor speed, rpm	5000
Hammer tip speed, m/sec	23.04
Number of hammers,	3
Hammer length, mm	30
Power source	single phase electric motor
Ac motor, kW	0.20

During this study the following parameters of the mill were tested: three hammer tip linear speeds (13.82, 18.43 and 23.04 m/sec) corresponding to peripheral speeds of 3000, 4000 and 5000 rpm respectively, two feeding rates 27.00 and 43.20 kg/h and two screens 1 and 2 mm round holes diameter.

Measurements

To fulfill the objective of this study, each treatment was milled three times and there average was calculated. The following measures were determined to evaluate the mill as follows:

1- Actual milling capacity: it is defined as the actual rate of powder production and calculated by dividing the total production by time of operation.

2- Milling efficiency (η_m): it was calculated according to El-Hadidi et al. (1997) as follows:

$$\eta_m\ \% = \frac{\text{Theoretical milling capacity (kg/h)}}{\text{Actual milling capacity (kg/h)}} \times 100$$

Notes;

- Theoretical milling capacity is the rate of productivity if the mill performed 100 % of the instant time.
- Acual milling capacity is the actual rate of productivity by the amount of actual time consumed in operation (lost + productive time).

3- Energy requirements: Fig. (2) shows a digital vip MK3 energy analyzer meter Italian made. It measures the line current and the potential difference value. The energy (kW.h) is measured directly. The useful milling energy (energy with load – energy without load) for each treatment was calculated, then the specific milling energy (SME) and the specific powder production energy (SPPE) are calculated as follows:

$$\text{SME (MJ/Ton)} = \frac{\text{Useful milling energy}}{\text{Original sample weight}}$$

$$\text{SPPE (MJ/Ton)} = \frac{\text{Useful milling energy}}{\text{Powder weight}}$$

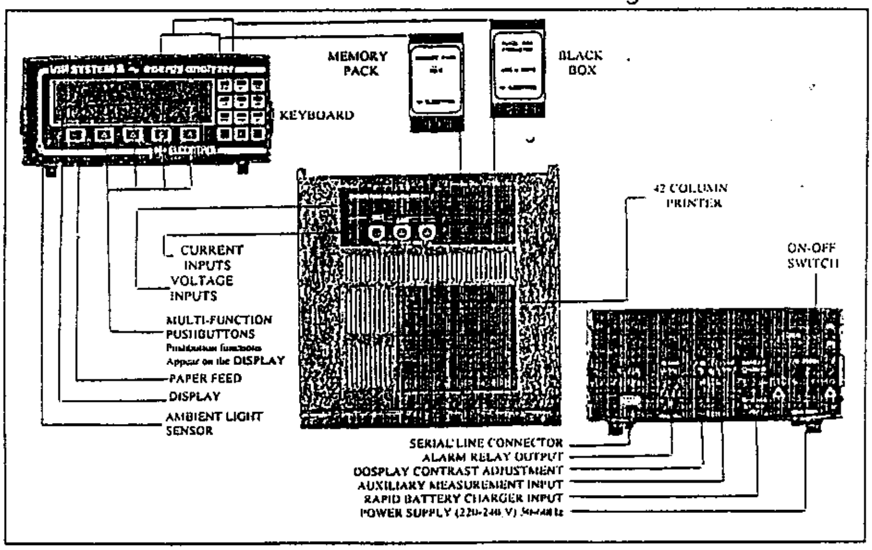


Fig. 2: Digital vip MK3 energy analyzer meter.

4- Weight reduction ratio: as cited by Fang et al. (1997), the weight reduction ratio was defined as the ratio of original sample weight to the sample weight of the ground material.

5- Oil content in garlic powder: a sample of 2 g is taken after milling to represent each treatment. The oil content of each sample is determined gravitationally using soxhlet apparatus and petroleum ether as a solvent. The oil content in milled sample (%) is calculated according to AOAC (1996).

$$\text{The oil content in milled sample \%} = \frac{\text{Weight of oil (g)}}{\text{Weight of sample (g)}} \times 100$$

Statistical and mathematical analysis:

The obtained data of oil content in garlic powder are analyzed statistically as a completely randomized factorial experimental design in three replications (Steel and Torrie, 1960). The multiple regression and simple correlation analysis are carried out using Microstat computer program.

RESULTS AND DISCUSSION

1- Actual milling capacity and milling efficiency:

Fig (3) indicates that the milling capacity is related positively to the garlic pieces hardness degree. This phenomenon is due to the effect of the moisture content on the hardness degree. At relatively lower moisture content levels, the garlic pieces dimensions decrease. Consequently, the hardness degree increases. So, the hammer ability to pulverize garlic pieces increases. Then, the rate of garlic powder production per unit time increases.

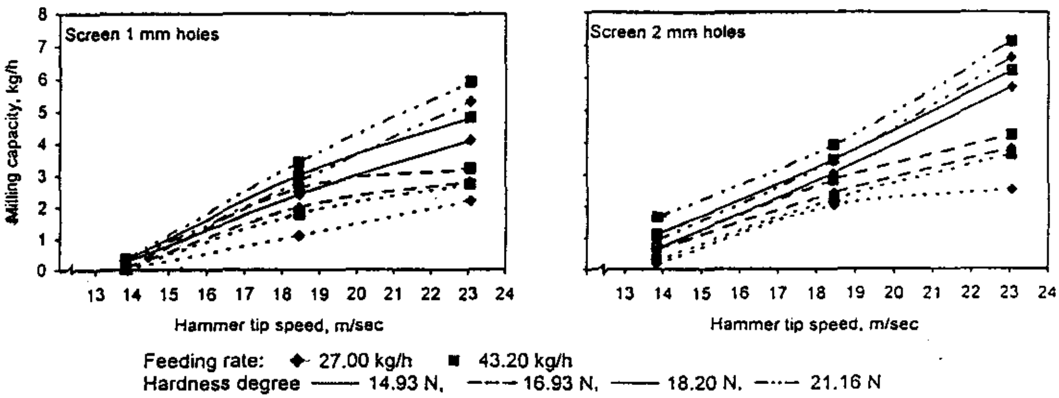
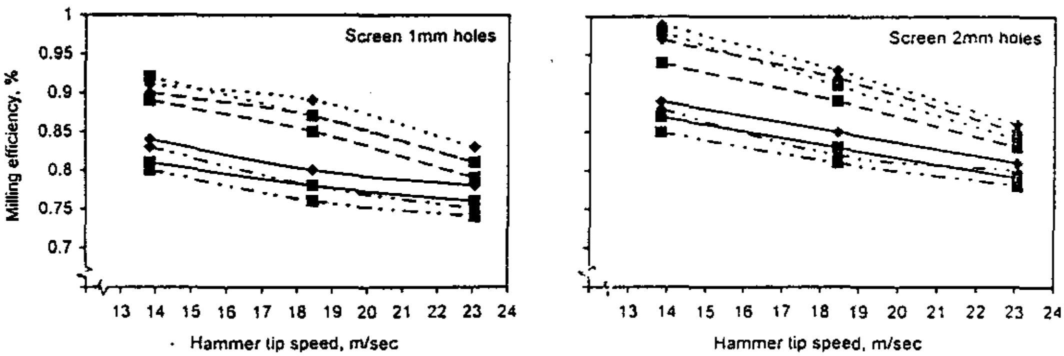


Fig. 3: Effect of hammer tip speed, feeding rate, screen holes diameter and garlic hardness degree on milling capacity.

Data in Fig. (3) shows that there are positive relations between milling capacity and each of hammer tip speed, feeding rate and screen holes diameter. To illustrate these relations, an explanation of how the mill pulverizes the garlic pieces may be introduced. The hammer mill is assumed to reduce the size by impact. The high speed of the hammer produces kinetic energy that is dissipated within the material, causing it to disintegrate. The material is beaten and hammered until it is small enough to pass through the screen. As the hammer tip speed increases, the number of hammer impacts per unit time increases. The increased hammering action produces more pulverized material per unit time which continues to disintegrate till its particles become finer than the screen holes to pass through. As the screen holes diameter increases, they allow longer particle size to pass through, the residing time decreases and the consumed time for pulverizing and disintegrating the same weight of material becomes less. Hence the milling capacity increases with larger screen holes diameter. The milling capacity tends to increase as the feeding rate increases. In case of the increased feeding rate, more amount of the material was objected to the hammer action per unit time. So, it is logic that the increased material feeding rate produce more amount of milled product per unit time to a certain limit.

The obtained data of milling efficiency are presented in Fig. (4). The results show that there is no loss in actual milling time except the time spent for refilling the hammer hopper. As the milling capacity increases, the loss in refilling time for refilling the hammer hopper increases, consequently, the milling efficiency decreases. Hence, the milling efficiency takes the opposite trend of the milling capacity with hardness degree, hammer tip speed, feeding rate and screen holes diameter.



Feeding rate: ◆ 27.00 kg/h ■ 43.20 kg/h
Hardness degree ······ 14.93 N, – – – 16.93 N, —— 18.20 N, –··– 21.16 N

Fig. 4: Effect of hammer tip speed, feeding rate, screen holes diameter and garlic hardness degree on milling efficiency.

2- Energy requirements:

a- Specific milling energy:

Fig. (5) reveals that specific milling energy is related inversely to the garlic pieces hardness degree. This finding is due to the fact that the static friction coefficient increases as the material moisture content increases. Increasing material surface moisture content would increase material coefficient of kinetic friction on metal surface of grinding chamber and among particles. Consequently, the energy increases with the reduction in hardness degree.

Plotted data in Fig. (5) shows that there is a considerable positive relation between specific milling energy and hammer tip speed. The greater energy at higher speed is mainly due to the increased hammer impacts per unit time, resulting in: a- greater required force for striking and hitting garlic pieces and b- increased kinetic friction coefficient of garlic pieces against the metal surface of grinding chamber.

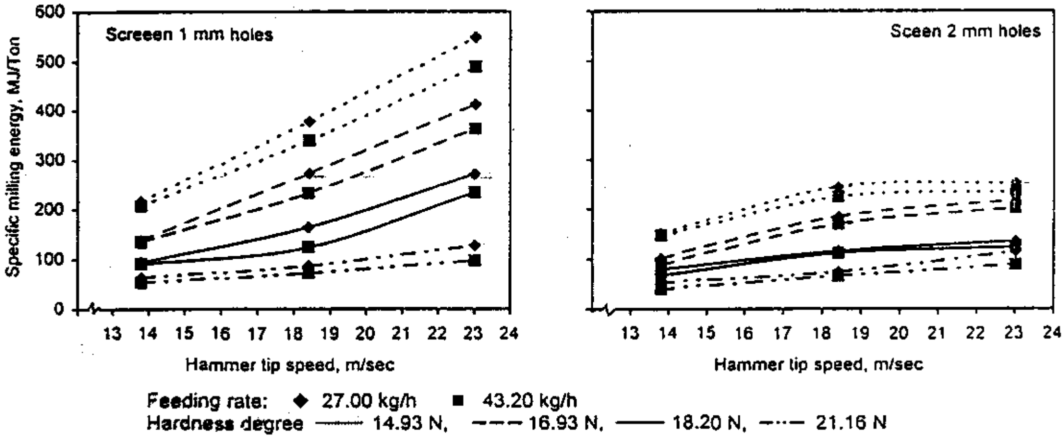


Fig. 5: Effect of hammer tip speed, feeding rate, screen holes diameter and garlic hardness degree on specific milling energy.

Fig (5) indicates that specific milling energy is inversely related to both feeding rate and screen holes diameter. At the higher feeding rate, the required energy for milling a unit weight was less than the corresponding one of the lower feeding rate. Using smaller screen holes diameter increases the consumed time for milling the material per unit weight, consequently the specific milling energy increases.

b- Specific powder production energy:

As shown in Fig. (6), the specific powder production energy relates positively to the hammer tip speed. While, it relates inversely to garlic pieces hardness degree, feeding rate and screen holes diameter. The curves in the figure indicates that the specific powder production energy values are more than the corresponding values of the specific milling energy. It is because the milled sample weight is less than original sample weight as a result of the moisture content loss during the milling process.

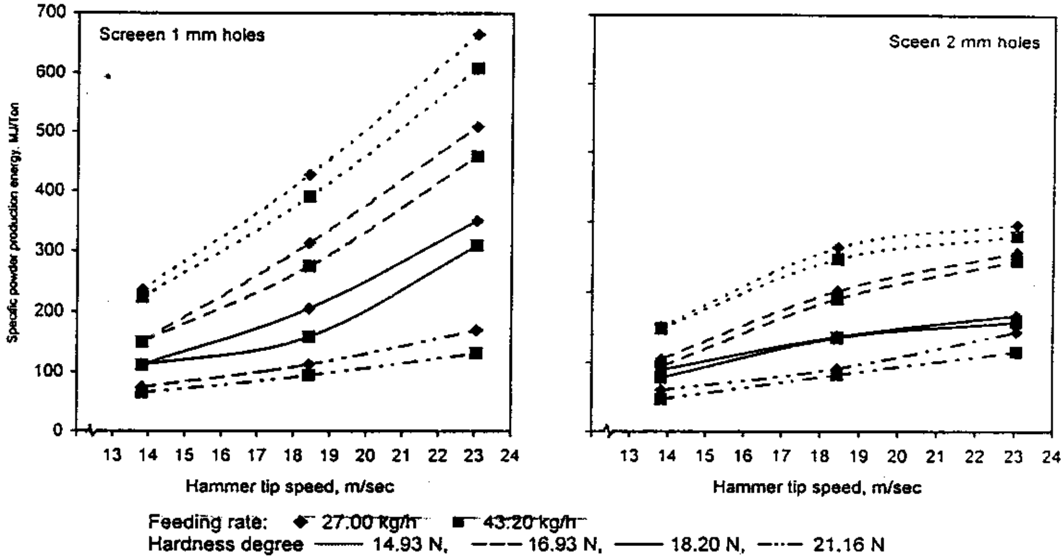


Fig. 6: Effect of hammer tip speed, feeding rate, screen holes diameter and garlic hardness degree on specific powder production energy.

3- Weight reduction ratio:

Fig. (7) shows that the weight reduction ratio is affected positively by garlic pieces hardness degree. This is attributed to the increased garlic brittleness at lower moisture contents which results in more pulverized material, accompanied with more losses in material moisture content. This process may reduce the milled product weight, consequently, the weight reduction ratio increases.

The figure demonstrates the relations between weight reduction ratio and both hammer tip speed and feeding rate. There is a trend towards increasing weight reduction ratio with hammer tip speed. At the higher speed, the increased centrifugal force produces excessive pulverized material with lower weight as a result of losing more moisture content, consequently, the weight reduction ratio increases. The relation between weight reduction ratio and feeding rate seemed to be positively proportional. At the higher feeding rate, hammer impacts strikes more weight material per unit time, producing lower weight product, resulting in higher weight reduction ratio.

Data in Fig. (7) shows that there is a reversible relation between weight reduction ratio and screen holes diameter. It is attributed to the more pulverized material with lower product weight, resulting in higher weight reduction ratio when using smaller screen holes diameter.

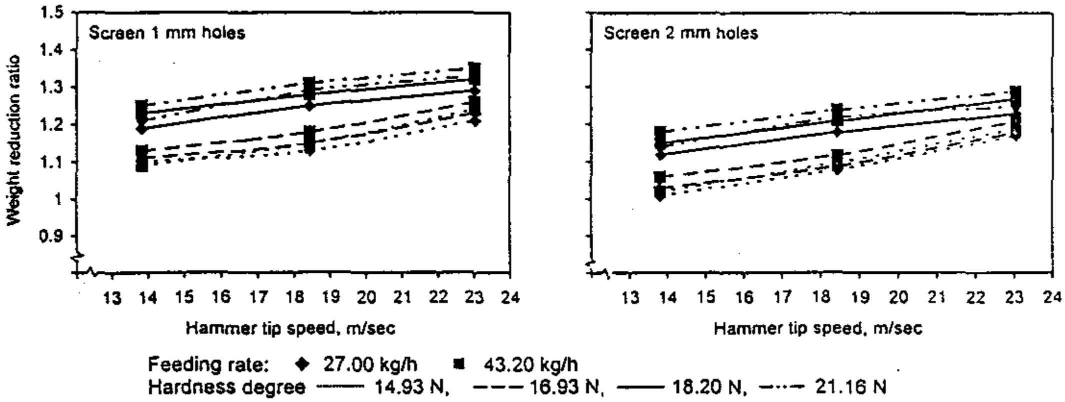


Fig. 7: Effect of hammer tip speed, feeding rate, screen holes diameter and garlic hardness degree on weight reduction ratio.

4- Oil content in garlic powder:

As shown in Fig. (8), the percentage of garlic oil content is influenced positively by garlic pieces hardness degree. The higher hardness degree makes garlic pieces easy to disintegrate, resulting in more pulverized particles having larger specific surface area which attributed to larger quantity of garlic oil content.

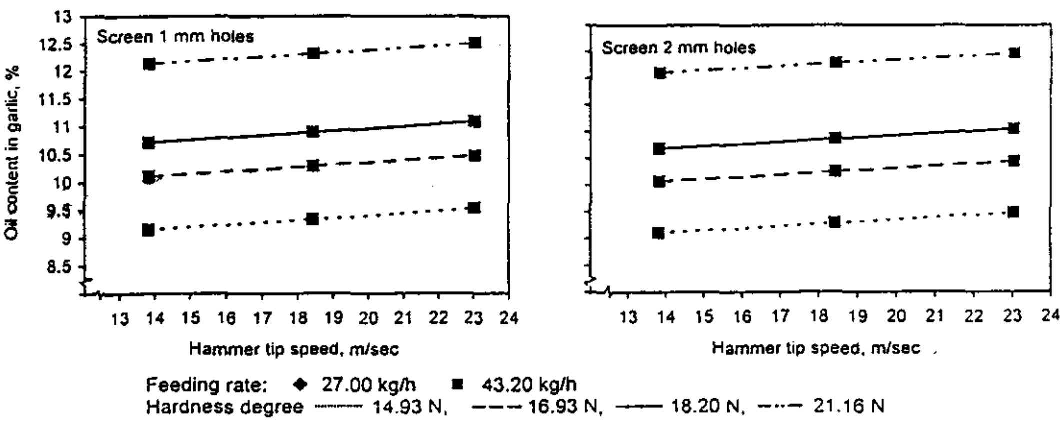


Fig. 8: Effect of hammer tip speed, feeding rate, screen holes diameter and garlic hardness degree on oil content in garlic powder.

The figure reveals that the percentage of oil content in garlic powder increases with the hammer tip speed. At higher speed, the more frequent hammer impacts produce finer product which produces excessive garlic oil amounts because of the larger specific surface area of the finer particles. The figure indicates that the garlic oil content percentage increases slightly with feeding rate. It is due to the fact that the different feeding rates (at the same screen holes diameter) give approximate weight reduction ratios, leading to produce the same amounts of garlic oil content.

The inverse effect of screen holes diameter on oil content percentage in garlic powder is indicated in Fig. (8). This inverse relation is attributed to the effect of screen holes diameter on the product fineness. Using smaller screen holes diameter produces finer product particles, resulting in the increased garlic oil content percentage.

Analysis of variance indicates that there are high significant effect on oil content in garlic powder due to the following sources of variation:

Garlic hardness degree levels, hammer tip speed levels, screen holes diameter levels, interaction among levels of garlic hardness degree and hammer tip speed, interaction among levels of garlic hardness degree and screen holes diameter, interaction among levels of hammer tip speed and screen holes diameter, and interaction among levels of garlic hardness degree, hammer tip speed and screen holes diameter.

L.S.D. test shows that the highest oil content in garlic powder was obtained due to the interaction among garlic hardness degree of 21.16 N, hammer tip speed of 23.04 m/sec and screen holes diameter of 1 mm.

The relation between oil content in garlic powder (Y), garlic hardness degree (X_1), hammer tip speed (X_2) and screen holes diameter (X_3) could be represented by the following formula:

$$Y = 1.47 + 0.48\ X_1 + 0.04\ X_2 - 0.04\ X_3$$

The simple correlation coefficients were determined as follows:

$r_{yx_1} = 0.94$, $r_{yx_2} = 1.00$, and $r_{yx_3} = -1.00$

SUMMARY AND CONCLUSION

Garlic powder was produced using a laboratory hammer mill. The tested parameters were hammer tip speed, feeding rate, screen holes diameter ano garlic hardness degree. The obtained results could be summarized as follows:

1- The actual milling capacity was affected positively by hardness degree of garlic pieces, hammer tip speed, feeding rate and screen holes diameter. The highest value of milling capacity (7.10 kg/h) was obtained after milling garlic of hardness degree 21.16 N at hammer tip speed of 23.04 m/sec, feeding rate of 43.20 kg/h and screen holes diameter of 2 mm.

2- The milling efficiency was related inversely with hardness degree, hammer tip speed, feeding rate and screen holes diameter. The highest value of milling efficiency was 99 %. It was obtained by milling garlic of hardness degree 14.93 N at hammer tip speed of 13.82 m/sec, feeding rate of 27.00 kg/h and screen holes diameter of 2 mm.

3- Both specific milling energy and specific powder production energy were related inversely to each of hardness degree, feeding rate and screen holes diameter. While, they increased with hammer tip speed. Milling one ton garlic of hardness degree 21.16 N at hammer tip speed of 13.82 m/sec, feeding rate of 43.20 kg/h and screen holes diameter of 2 mm expended lowest specific milling energy and lowest specific powder production energy of 39.76 and 46.92 MJ respectively.

4- Weight reduction ratio was affected inversely by screen holes diameter and positively by hardness degree, hammer tip speed and feeding rate. The highest value of weight reduction ratio was 1.35. It was obtained by milling garlic of hardness degree 21.16 N at hammer tip speed of 23.04 m/sec, feeding rate of 43.20 kg/h and screen holes diameter of 1 mm.

5- Oil content in garlic powder was affected positively by hardness degree and hammer tip speed. It was related inversely to screen holes diameter. While, the feeding rates did not affect the oil content amount. The highest percentage of oil content was 12.51. It was derived from the garlic powder which was produced by milling garlic pieces of 21.16 N hardness degree at hammer tip speed of 23.04 m/sec and screen holes diameter of 1 mm.

The obtained results mean that the used hammer was useful for producing garlic powder.

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الملخص العربى

إنتاج مسحوق الثوم بإستخدام مطحنة ذات مطارق

د. صفيه مصطفى الجيار* د. أسامه طه بهنس*

أجرى هذا البحث فى معمل خصوبة التربة بالمنصورة خلال موسم ٢٠٠١ لطحن صنفى الثوم (بلدى، سدس-٤٠) بعد التقطيع إلى شرائح ثم التجفيف وذلك للحصول على مسحوق الثوم الذى يعتبر أفضل منتج تجارى للحصول على كل فوائد الثوم الصحية. وقد إستخدمت مطحنة معملية ذات مطارق متحركة قدرتها ٠,٢ كيلووات وتم إختبار ثلاث سرعات للمطارق (١٣,٨٢، ١٨,٤٣، ٢٣,٠٤ م/ث) ومعدلين للتغذية (٢٧,٠، ٤٣,٢ كجم/ساعة) وغربالين ذوى فتحات بقطر (١، ٢ مم) وتم تجفيف صنفى الثوم بطريقتين (صناعى وطبيعى).

وتم تقييم أداء المطحنة بناء على سعة المطحنة وكفاءة الطحن ونسبة الإنخفاض فى الوزن والطاقة النوعية للطحن والطاقة النوعية لإنتاج مسحوق الثوم والنسبة المئوية لمحتوى الزيت فى مسحوق الثوم. وتتلخص أهم النتائج فيما يأتى:

١-كانت أعلى سعة للمطحنة ٧,١ كجم/ساعة بعد طحن ثوم سدس-٤٠ مجفف صناعى عند سرعة مطارق ٢٣,٠٤ م/ث ومعدل تغذية ٤٣,٢ كجم/ساعة وغربال ذى فتحات بقطر ٢ مم.

٢-كانت أعلى كفاءة للطحن ٩٩ % عند طحن ثوم بلدى مجفف طبيعى عند سرعة مطارق ١٣,٨٢ م/ث ومعدل تغذية ٢٧,٠ كجم/ساعة وغربال ذى فتحات بقطر ١ مم.

٣-كانت أقل طاقة نوعية للطحن ٣٩,٧٦ ميجاجول/طن بعد طحن ثوم سدس-٤٠ مجفف صناعى عند سرعة مطارق ١٣,٨٢ م/ث ومعدل تغذية ٤٣,٢ كجم/ساعة وغربال ذى فتحات بقطر ٢ مم.

٤-كانت أقل طاقة نوعية لإنتاج مسحوق الثوم ٤٦,٩٢ ميجاجول/طن بعد طحن ثوم سدس-٤٠ مجفف صناعى عند سرعة مطارق ١٣,٨٢ م/ث ومعدل تغذية ٤٣,٢ كجم/ساعة وغربال ذى فتحات بقطر ٢ مم.

٥-كانت أعلى نسبة إنخفاض فى الوزن ١,٣٥ بعد طحن ثوم سدس-٤٠ مجفف صناعى عند سرعة مطارق ٢٣,٠٤ م/ث ومعدل تغذية ٤٣,٢ كجم/ساعة وغربال ذى فتحات بقطر ١ مم.

٦-كانت أعلى نسبة مئوية لمحتوى الزيت فى مسحوق الثوم ١٢,٥١ % بعد طحن ثوم سدس-٤٠ مجفف صناعى عند سرعة مطارق ٢٣,٠٤ م/ث ومعدل تغذية ٤٣,٢ كجم/ساعة وغربال ذى فتحات بقطر ١ مم.

وقد أظهرت نتائج التحليل الإحصائى وجود فرق معنوى جداً فى محتوى الزيت فى مسحوق الثوم نتيجة للتداخل بين درجة صلابة الثوم وسرعة المطارق وقطر فتحات الغربال ومعادلة الإنحدار الآتية توضح العلاقة بين محتوى الزيت فى مسحوق الثوم (Y) ودرجة صلابة الثوم (X_1) وسرعة المطارق (X_2) وقطر فتحات الغربال (X_3).

$$Y = 1.47 + 0.48\ X_1 + 0.04\ X_2 - 0.04\ X_3$$

* باحث بمعهد بحوث الهندسة الزراعية - مركز البحوث الزراعية - الجيزة.