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CONTENTS

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Ergonomic evaluation of manually-operated peanut butter mills

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Previous studies showed that the manually-operated peanut butter mills available on the market had technical problems related to the design and operation of the machines. One such problem was that the mills were too heavy for women to operate, resulting in limited operational time and ultimately, low total output. An ergonomic study of the original and modified versions of the mills was conducted at the University of Zimbabwe to verify the previously identified problems and develop appropriate and lighter mills for manual operation. A body discomfort assessment and heart rate measurement were used to determine stress endured by 12 women, as a result of operating the mills. Medium to high levels of discomfort were experienced in the lower back, neck, chest, lower arm, upper arm and shoulder. The heart rate readings showed that the mills currently available on the market were highly stressful (138 beats/minute), exceeding guidelines for safe manual operations. The modified mills, incorporating variable feed control devices, can be adjusted to ensure that stress levels are within recommended levels. The ergonomic study also established that for feed rates of 1.1 and 1.5kg/hour, the mills produce peanut butter of acceptable fineness to the subjects, in one pass without overstressing the operator. In a separate field experiment using the same subjects, extremely high stress levels (150 beats/minute) were recorded with the traditional stone-mill.

Keywords: Ergonomics, groundnuts, peanut butter mill, peanut butter, heart-rate meter, body discomfort chart.

Introduction

Groundnuts are an important crop in the smallholder farming sector of Zimbabwe with at least 160 000ha being put to the crop per annum (Anonymous, 2001). However, this crop is traditionally considered a woman's domain, often cultivated on small pieces of land, basically to meet household food requirements. Groundnuts are used as a source of food in various ways but are mainly processed into peanut butter. Peanut butter is an essential source of both protein and fat in the diet of most Zimbabwean families. Processing of peanut butter is normally practised by women as individuals, organized clubs or formal cooperatives. Most of the women use the indigenous method of stone-mill grinding. This method is extremely arduous, unhygienic and time-consuming. The overall throughput is also very low, although no data are available.

Manually-operated peanut butter processing machines were introduced in Zimbabwe in the mid 1990's. Of the various designs available on the market, the Omega IV (Compatible Technology Incorporated, St. Paul, United States of America) is the only purpose-built mill. Versions of the imported Porkert 120 (Porkert, Czechoslovakia) designed for milling maize, dried beans and spices have also found use as peanut butter mills in Zimbabwe.

A preliminary study conducted by the Development Technology Centre (DTC) of the University of Zimbabwe (UZ), identified technical problems related to the design and operation of the manually-operated Omega IV (DTC, unpublished reports). One such problem was that the mills were too heavy for women to operate and consequently the operational time and overall output were limited. The other major problems identified in the study were that the mills were prohibitively expensive and that the two-pass operation required to produce fine peanut butter was uneconomic.

In view of the importance of peanut butter processing, an ergonomic study was conducted in 2001. Ergonomics is the scientific study of the relationship between a person and his/her working environment (Gite, 1993; Smith *et al.*, 1994). Application of ergonomics can help in increasing the efficiency and thereby productivity of technical systems, in heightening the quality of life in work conditions and in promoting health and well-being of workers (Gite, 1993).

One of the major problems identified in the preliminary study, was high effort required to operate mills on the market, which was stressful to the operator resulting in increased downtime and low daily peanut butter output (DTC, unpublished reports). To address some of the problems highlighted in the study, new designs of peanut butter mills were developed and two types of machines were built. An evaluation of the performance of the old and new mills was conducted to determine their performance and specifically, to alleviate the problem of high effort requirements. A separate field experiment was conducted with the traditional stone-mill to generate baseline data for comparison purposes.

The specific objectives of the study were:

1. To verify findings of the preliminary field study to the effect that the mills in the field were too heavy for manual operation;
2. To validate claims by designers that the new mills are lighter and more appropriate for manual operation compared to the ones on the market;
3. To generate information which could be used to further improve on the productivity of the mills; and

4. To generate reliable data in specifying the performance of manually-operated peanut butter mills.

Materials and Methods

The ergonomic performance of two machines was assessed in the laboratory at DTC, UZ. The design of the first mill (modified Omega IV) was based on the Omega IV model which is currently available on the local market. The second machine, code-named DTC 1, was designed locally to replace the imported Porkert mill as a way of reducing the cost of the machine. The DTC 1 mill had a different main shaft support system from the original Porkert mill to make it more robust. Varying the number of groove openings in the feed control device regulated the flow rate of peanuts into the modified Omega IV and the DTC 1 mills (Table 1).

Preliminary measurements were conducted at three pre-determined mill settings to determine the feed rates. Whilst effort was made to achieve the same feed rate with either mill at each setting, small variations due to the mill design differences were observed. The mill settings and the pre-determined feed rates used are given in Table1.

Table 1: Mill setting and feed rates.

Mill Type		Feed rate (kg/h)*	
	One groove	Two grooves	No feed control
DTC 1	1.5	2.3	11.8
Omega IV	1.1	2.4	11.4**

*Achievable when cranking the mills at 50 rpm.

**Setting simulated the original design of the mill.

Twelve female subjects with experience in manual peanut butter processing were used in the experiment. They were randomly selected from Batanai Peanut Butter Processing Club in Mhondoro Communal Area of Mashonaland West Province. The subjects were in their early forties (42$\pm$3.2 years sd) and weighed an average ($\pm$ sd) of 76 $\pm$ 11.8kg. The subjects were randomly divided into three groups of four to constitute experimental replications. Each group performed the experiment for a week. All the subjects were initially familiarised with the operation of the peanut butter mills. Prior to the experiment, each subject was interviewed to ensure that she was medically free from cardiac or other related ailments. The subjects reported to the laboratory daily at 0900 hours during the experimental period and the objectives of the experiment were explained to them to ensure their full co-operation. The subjects operated the mills in turns.

Two methods of assessing workload on a subject operating a manual peanut butter mill were used:

(a) Heart rate method

A BCI heart rate monitor (BCI International, United States of America) was used to measure heart rate (Gite, 1993). A subject was prepared for the test by fitting BCI electrodes on her left and right shoulders and lower left side of the stomach and connecting the electrodes to the BCI heart rate monitor. An initial rest period of three minutes in a sitting position was provided. During the rest period the heart rate was noted. At the lapse of the rest period the subject was asked to get into a standing posture and start cranking a peanut butter mill, which was already set at a particular feed rate. Operation was allowed to continue until one felt tired or up to 20 minutes. Once tired, the subject was allowed to rest in a sitting position until the heart rate went down to the initial rest level before resuming the operation. Heart rate readings were recorded from the monitor every 30 seconds during operation and rest times.

(b) Body discomfort chart

The body discomfort scale is a subjective method of determining work related stress based on how an individual feels. Body discomfort is measured qualitatively on a body chart with 17 parts (Figure 1) using a five-point psychophysical rating scale (0 = no discomfort, 1 = some discomfort, 2 = uncomfortable, 3 = very uncomfortable and 4 = extreme discomfort) by asking the individual to relate which part of the body feels strained and the extent of the stress (Corlett and Bishop, 1976 cited by Gite, 1991). Each subject was interviewed for body part discomfort, immediately after the heart rate measurements. The subject was asked to indicate on the body chart (Figure 1) the strained parts of the body and rate the extent of the strain. At the end of each week, each group was asked to give an overall assessment of the performance of the mills.

During the experiment the mean room conditions were relatively comfortable with temperature of 24 ± 1.9°C (sd) and relative humidity of 60 ± 12.4% (sd). After the laboratory measurements, the same experimental procedure was repeated under field conditions with the same subjects but using the traditional stone-mill instead of the peanut butter machines. An average feed rate of 4.2kg/hour was determined with the stone-mill.

Other parameters measured in the experiment were throughput, speed of rotation and peanut butter smoothness. Peanut butter smoothness was determined using a grind gage (Precision Gage and Tool Company, Dayton, USA) according to Weiss, 1983.

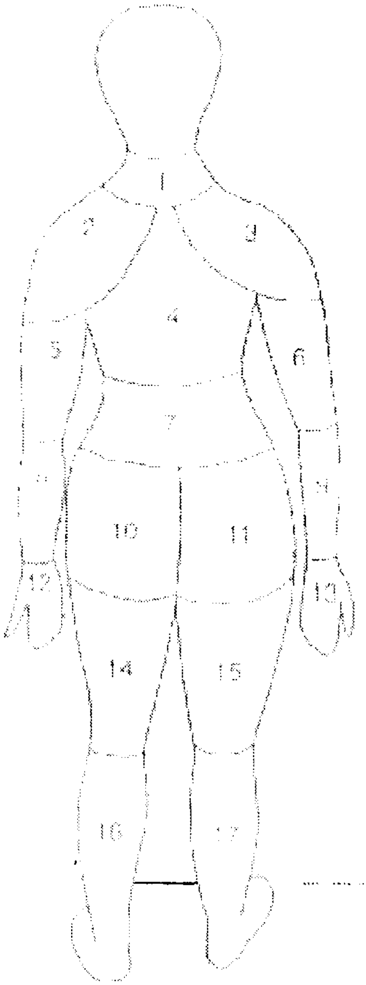

Figure 1: Body regions for assessing discomfort (Source: Smith *et al.*, 1994).

Results

An analysis of variance (ANOVA) of the operational heart rates showed highly significant differences between the treatments (p=0.0000). Significantly greater effort was required to operate the stone-mill followed by cranking Omega IV and DTC 1 mills without feed control (Table 2). The least effort was recorded when operating DTC 1 at one groove.

Table 2: Mean heart rate responses during the operation of the various types of mills.

Peanut butter mill setting	*Mean heart rate (beats/min)	Increase in heart rate (%)
Stone-mill	150a	89
Omega (no feed control)	138b	77
DTC 1 (no feed control)	130bc	68
Omega (two grooves)	123cd	63
DTC 1 (two grooves)	121cde	52
Omega (one groove)	115de	51
DTC 1 (one groove)	112e	49
$LSD_{0.05}$ value = 9.274		

*Means followed by the same letter are not significantly different.

The pooled heart rate data for the 12 subjects are shown in Figure 2. There was a rise in heart rate as the subject started operating the mill, a steady heart rate as the work continued and decline in heart rate at the end of the operation. At the uncontrolled feed rates, the subjects took two breaks of 3.5 to 6.5 minutes during the test period depicted as troughs (Figure 2).

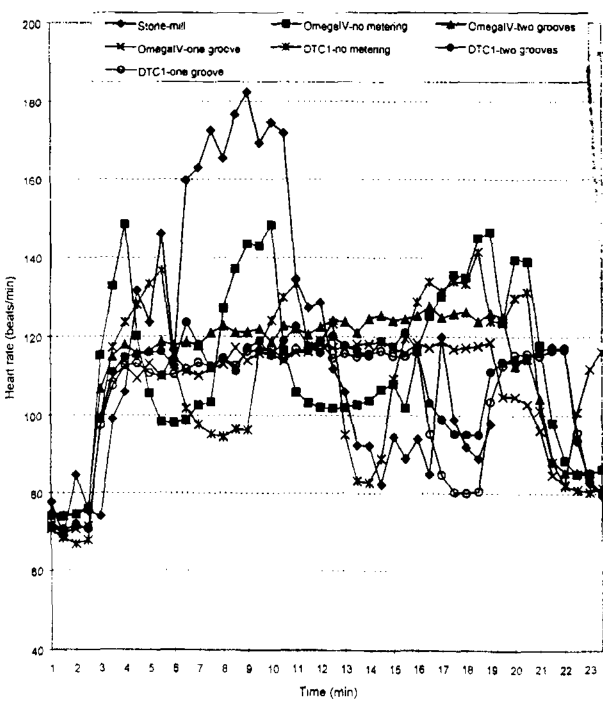

Figure 2: Mean heart rate (beats/min) obtained during operation of different mills at different settings.

Milling at the other feed rates was relatively comfortable. The subjects could crank the machines continuously for more than 17 minutes and only needed a few minutes rest to recover. The subjects only took one rest period of 2.5 to 3 minutes during the test period.

The speed of rotating the mills varied from 40 to 50 revolutions per minute. At higher feed rates, the subjects tended to reduce the cranking speed as the load became heavier. There was a significant reduction (p=0.0039) in speed as the feed rate was increased. Significantly low speeds of rotation were recorded when cranking Omega IV and DTC 1 mills without feed control (Table 3).

There were highly significant differences (p=0.0000) in throughput among mill settings. Further comparison showed that DTC 1 with no feed control had significantly higher throughput than the rest of the mill settings whereas DTC 1 and Omega IV, both with one groove setting, had the least (Table 4).

Table 3: Mean speed of rotation at different mill settings.

Peanut butter mill setting	*Mean speed of rotation (rev/min)
DTC 1 (two grooves)	49.67a
DTC 1 (one groove)	49.00a
Omega (one groove)	47.43a
Omega (two grooves)	46.00ab
DTC 1 (no feed control)	42.00bc
Omega (no feed control)	41.00c
$LSD_{0.05}$ value = 4.198	

*Means followed by the same letter are not significantly different

Table 4: Mean throughput (kg/h) of the various types of mills at different settings.

Peanut butter mill setting	*Mean throughput (kg/h)
DTC 1 (no feed control)	8.20a
Omega (no feed control)	5.26b
Stone-mill	4.40b
DTC 1 (two grooves)	3.12c
Omega (two grooves)	2.20cd
DTC 1 (one groove)	1.34d
Omega (one groove)	1.08d
$LSD_{0.05}$ value = 1.204	

*Means followed by the same letter are not significantly different

In instances where the feed control device was set to feed nuts at rates between 1.5 and 2.5kg/hour (one and two groove settings, respectively), all subjects managed to operate the mills continuously without feeling the need for resting. The peanut butter produced from both machines at the one groove setting was much smoother than that from the two groove and no feed control settings (Figure 3). At any given setting, there were no significant differences in peanut butter particle size between Omega IV and DTC 1.

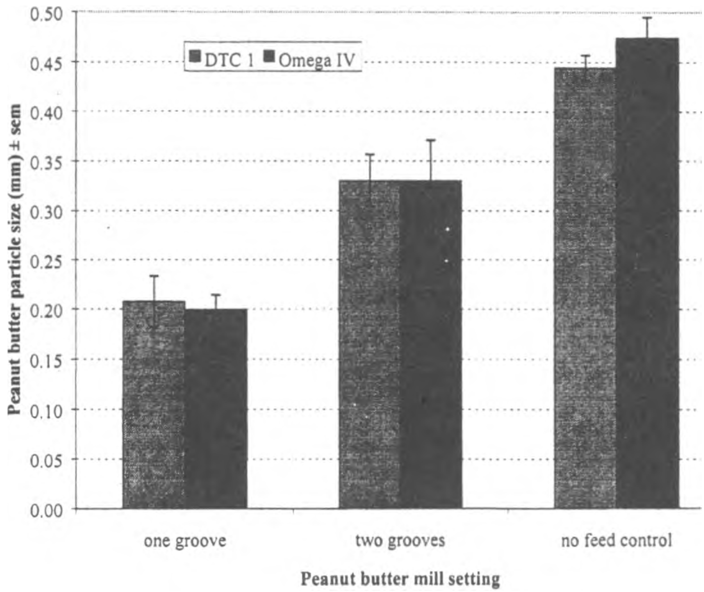

Figure 3: Peanut butter particle size obtained from two mills at different settings (n=3).

During the experiment, varying levels of discomfort were experienced in the lower back, neck, chest, lower arm, upper arm and shoulder. In all cases, without exception, the subjects felt the need to rest frequently while operating the stone-mill and the Omega IV and DTC 1 mills without feed control. The highest frequency of complaints by the subjects was associated with the stone-mill and the complaints fell into the medium to high category; whereas DTC 1 had the least overall complaints, irrespective of machine setting (Figure 4). The most stressed regions when operating the stone-mill were the lower back, shoulders, neck and the upper arm whereas with the two machines, it was the lower back, chest and upper arm. The discomfort in the chest, lower arm, upper arm and shoulder was primarily due to stroking and cranking the mills. The operators had to kneel down with the back bent when operating the stone-mill and stand in a stoop posture when cranking the machines. The stress levels experienced at one and two groove settings were all in the low discomfort category.

The subjects made the following comments on the Omega IV and DTC 1 settings and respective performance.

(a) The mills should be mounted on a stand, which allows for adjustment of machine height to suit operator height.
(b) The mills should have a facility that allows for a firm mounting.
(c) The handle should not have features that are likely to interfere with the turning operation.
(d) Both machines are suitable for hand-milling if fitted with a feed control device to regulate the amount of groundnuts milled at any given time.

The question of which setting was most desirable was posed to the subjects. Responses from all the twelve subjects favoured a low feed rate setting in which smoother peanut butter was produced in one pass and the levels of stress are in the comfortable range.

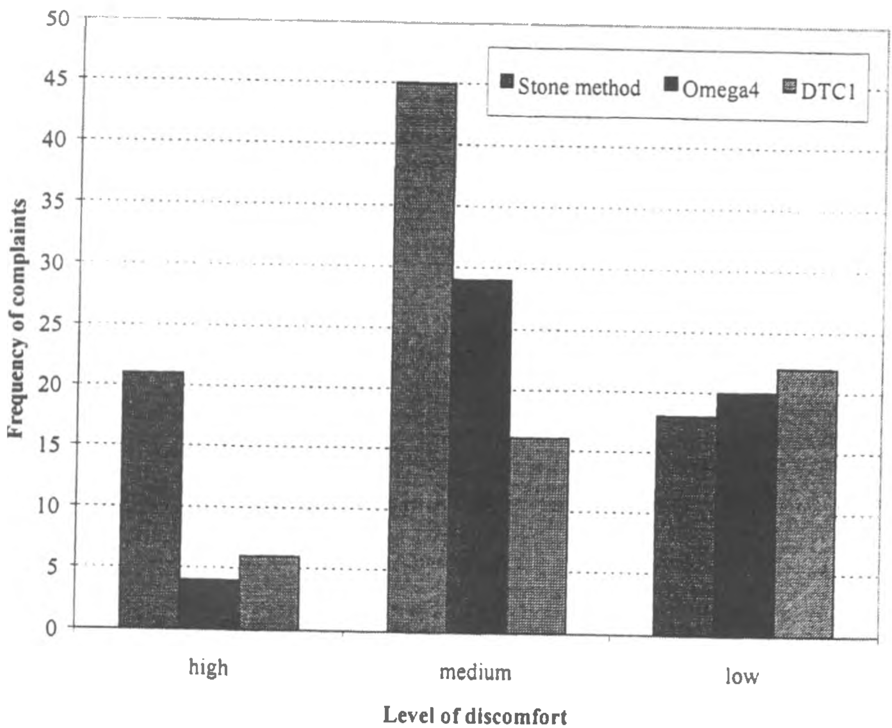

Figure 4: Overall discomfort levels experienced by the subjects using different milling methods (low = 0-1; medium = 2; high = 3-4).

Discussion

The study demonstrated that the use of stone-mills and mechanical mills where feed rate is not regulated results in the highest heart rates compared to mills incorporating a feed rate control device. According to the Food and Agriculture Organization (FAO) standards (Smith *et al.*, 1994), heart rates exceeding 125 beats per minute are classified as high (Table 4); hence the machines without a mechanism to control feed rate are not suitable for manual operation.

The operator heart rate indicates the magnitude of cardiac stress due to physical workload and increases linearly with energy expended, provided the work is dynamic and is performed with a steady rhythm (Gite, 1993). The heart rate method was used to measure the physical work-load instead of the respiration rate method. The need for the operator to be connected to a measuring and sampling device can be obstructive and although the respirometer is mounted on the person's back, it restricts the operator and furthermore, it is an additional workload, particularly where much bending or stooping is required (Matthews and Knight, 1971).

Table 4: Heart rate (beats/min) as an indication of workload.

Heart rate (beats /min)	60-70	75 -100	100-125	125-150	150-175	Over 175
Assessment of workload	Very low	Low	Moderate	High	Very high	Extremely high

Source: Smith *et al.*, 1994.

During operation, cases where the "steady state" was not attained were noted (see Figure 2), the implication being that the workload was too heavy for the subject to sustain. There is evidence that operating the stone-mill and cranking the Omega IV and DTC 1 mills with no feed rate control are heavy work as indicated by the failure to reach a "steady state". The heart rate results also show that Omega IV and DTC 1 are moderately heavy at the one groove and two groove settings.

The high work load obtained when the mills are not fitted with feed rate control devices, is also reflected by a great reduction in the rotational speed and increased down time. Comparison of the two mills at any given feed rate, indicated no significant differences in terms of operator effort requirement. However, currently DTC 1 is less expensive, costing Z$50 000 compared to Omega IV which costs Z$400 000 (US$1 = Z$1500) at time of experiment. The results also confirm that the energy expenditure increases with an increase in feed rate. It was not possible to control the feed rate of the stone mill and this resulted in the use of one feed rate hence the very high effort requirements. The heaviness of the stone mill is also shown by the frequent rest periods during operation; especially after the first 10 minutes (refer to Figure 2). Although the body discomfort method was not used to assess the discomfort experienced by the subjects when operating the stone-mill, postural discomfort was evident thereby necessitating frequent rests; hence no "steady state" heart beat was achieved when using this milling method.

According to scaling of physical work proposed by Christensen (1953) as cited by Matthew and Knight (1971), there is a linear relationship between heart rate and energy expenditure, which can be expressed in the form:

$y = 0.1x - 5$; where y is the energy expenditure and x is heart rate.

Applying the same equation to each milling method investigated in the current study and using the corresponding heart rates, energy expenditure associated with each method was estimated (Table 5). Table 5 provides evidence that it is strenuous to operate all the three mills at the maximum feed rate (where feed-rate is uncontrolled) and the operation is lightest at the one groove setting.

Table 5: Energy expenditure (kJ/min) at different mill settings.

Mill type	One groove	Two groove	No feed control
Omega IV	27.2	30.5	36.8
DTC 1	25.9	29.7	33.4
Stone mill	—	—	41.8

- = not applicable

The Standards Association of Zimbabwe (SAZ) (1971) classifies peanut butter with particle diameter above 1.5mm in diameter (10-30% m/m) as crunchy; while peanut butter of smooth texture should have even particles with no perceptible grains. According to these standards, all the peanut butter produced in the current experiment could be graded smooth as all particles were less than 0.5mm in diameter. However, the subjects considered the peanut butter produced without feed rate control to be coarse. At the two-groove setting for both machines, there were some coarse particles even though the smooth fraction was much higher because the subjects were still not satisfied with the smoothness. The views of the subjects are in concurrence with the USA standards in which the maximum size of finely milled peanut butter particles should be about 0.08mm and that of more coarse ground regular butter may have 0.18 to 0.28mm (Weiss, 1983). The discrepancy on peanut butter quality, in terms of particle size, in Zimbabwean standards vis-à-vis peanut butter miller perceptions and international standards needs to be addressed.

Based on the perception of the subjects, the transition point from smooth to course peanut butter would therefore be at feed rates that fall between 1.5 and 2.5kg/hour for both mills. Though good quality peanut butter was produced in one pass at low feed rates of 1.5kg/hour, the throughput was quite low. The throughput of mills without feed rate control are effectively not as high as they appear to be, considering that the peanut butter produced at these settings was perceived as course by the subjects, necessitating one or two more runs to achieve the acceptable quality. The throughput will be much lower in the second and third run because the coarse peanut butter is more difficult to transport with an auger in the machine compared to the unmilled nuts. This could explain why women prefer the low feed rate setting to the high feed rate setting.

Though the body discomfort method is subjective, the stress levels experienced at one and two groove settings were all in the low discomfort category. This further supports findings using the heart rate method which showed that the one and two groove settings are light and sustainable.

The question of which setting was most desirable was posed to the subjects. Considerations were made of the facts that high feed rates resulted in high throughput, high operator stress levels and produced coarse peanut butter that needed re-running to smoothen it. Lower feed rates, on the other hand, exerted less stress on the operator and produced low quantities of fine peanut butter in one pass. Responses from all the twelve subjects showed that they preferred a low feed rate setting in which smooth peanut butter is produced in one pass and the levels of stress are in the comfortable range.

Conclusion

The study confirmed that peanut butter mills currently on the market are not suitable for manual operation. The mills result in heart rates that exceed the general FAO guidelines on safe and healthy operation of manual machines. The use of feed control devices allows for a significant reduction in the effort required to operate the mills, resulting in reduced downtime and making the machines appropriate for manual operation. Inclusion of a variable feed control device allows for a good match between the effort required to operate the mill and operator capacity. Based on the findings from this study, feed rates of 1.5 and 1.1kg/hour are ideal for the Omega IV and DTC 1 mills respectively as smooth peanut butter is produced in a single run. These rates are achievable at the one groove setting for both machines. There is also need to revise the standards of classifying peanut butter smoothness as the current national standards do not reflect the perceptions of the peanut butter millers.

Peanut butter mills already on the market need to be modified to install feed control devices in order to comply with FAO recommendations regarding safe operating stress levels. For those mill owners who cannot afford to upgrade their machines, it is advisable that they feed the nuts in small quantities by hand. New mills should incorporate feed control devices. There is need to incorporate features on the mill stands that allow for firm mounting and adjustment for mill elevation. The overall design should promote safety of the operator. The criterion for deciding on optimum feed rate should be minimum body discomfort to the operator, reasonable throughput and good peanut butter in a single run.

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