DEVELOPMENT OF A POWER OPERATED BLACK PEPPER THRESHER

by
Suma Nair

THESIS
Submitted in partial fulfilment of the
requirement for the degree of

MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology
KERALA AGRICULTURAL UNIVERSITY

Department of Farm Power, Machinery, and Energy
Kelappaji College of Agricultural Engineering and Technology
Tavanur - 679 573
1998

DECLARATION

I hereby declare that this thesis entitled " Development of a Power Operated Black Pepper Thresher " is a bonafide record of work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

SUMA NAIR

Tavanur

Date: 12.11.98

CERTIFICATE

Certified that this thesis entitled " Development of a Power Operated Black Pepper Thresher " is a record of original work done independently by Smt. Suma Nair, under my guidance and supervision, and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Tavanur

Date: 12·11·98

Er. Jippu Jacob
(Chairman, Advisory Committee),
Associate Professor,
Dept. of FPM & E,
KCAET, Tavanur.

CERTIFICATE

We, the undersigned, members of the Advisory Committee of Smt. Suma Nair, a candidate for the degree of Master of Technology in Agricultural Engineering with major in Farm Power and Machinery, agree that the thesis entitled " Development of a Power Operated Black Pepper Thresher " may be submitted by Smt. Suma Nair, in partial fulfillment of the requirement for the degree.

Er. Jippu Jacob
(Chairman, Advisory Committee)
Associate Professor
Dept. of FPM & E
KCAET, Tavanur.

Er. C.P. Muhammad
Professor and Head
Dept. of FPM & E
KCAET, Tavanur
(Member)

Dr. M. Sivaswami
Associate Professor
Dept. of FPM & E
KCAET, Tavanur
(Member)

Er. Xavier. K. Jacob
Assistant Professor (Senior Scale)
Dept. of Agric. Engng.
College of Agriculture, Vellayani
(Member)

External Examiner

ACKNOWLEDGMENT

At the outset I wish to express my deep gratitude and heartfelt thanks to Er Jippu Jacob, Associate Professor and the Chairman of the Advisory Committee, Department of Farm Power, Machinery, and Energy, KCAET, Tavanur, for his invaluable, encouraging, and infinitely patient guidance, which has helped me to complete this work successfully.

I would like to express my sincere thanks to Dr. K. John Thomas, Dean, KCAET, Tavanur, for his interest and kind advice given to me at all stages of my study.

I am very grateful to Er. C.P. Muhammad, the Professor and Head, and the Member of Advisory Committee, Department of Farm Power, Machinery, and Energy, KCAET, Tavanur, for his constructive suggestions.

I would also like to thank Dr. M. Sivaswami, Associate Professor, Department of Farm Power, Machinery, and Energy and Er. Xavier K. Jacob, Assistant Professor (Senior Scale), Department of Agricultural Engineering, College of Agriculture, Vellayani; both Members of the Advisory Committee, for their help and co-operation at all stages of my thesis work.

Guidance rendered by Dr. K. I. Koshy, Professor and Head, Department of SAC, KCAET, Tavanur, is gratefully remembered.

Words do not suffice to express my gratitude to all the staff members of the KCAET workshop. I would also like to thank all my classmates and friends who have helped me immensely during the period of my study and my thesis work.

I cannot forget the constant encouragement and untiring support given to me by my parents, my husband, and my daughter at each and every stage of my work, without which the completion of this thesis would have been difficult.

Above all, I express my indebtedness to that Supreme power which gave me the strength to complete this work.

(Suma Nair)

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SYMBOLS AND ABBREVIATIONS USED

A	-	ampere(s)
ac	-	alternating current
AD	-	*Anno domini*
Agric.	-	Agricultural
ANOVA	-	Analysis of Variance
ASAE	-	American Society of Agricultural Engineers
BC	-	Before Christ
cm	-	centimetre(s)
Co.	-	Company
CRD	-	Completely Randomised Design
Dept.	-	Department
Engng.	-	Engineering
et al.	-	and others
etc.	-	et cetera
Fig.	-	Figure
FPM & E	-	Farm Power, Machinery, and Energy
g	-	gram(s)
GI	-	Galvanised Iron
h	-	hour(s)
ha	-	hectare(s)
hp	-	horsepower
ICAR	-	Indian Council of Agricultural Research
i.e	-	that is
IRRI	-	International Rice Research Institute
J.	-	Journal
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
kg	-	kilogram(s)

Ltd.	-	Limited
m	-	metre(s)
min.	-	minute(s)
mm	-	millimetre(s)
MS	-	Mild Steel
No.	-	Number(s)
p:	-	pages
PTO	-	Power Take Off
PV	-	Peripheral Velocity
Pvt.	-	Private
Res.	-	Research
RNAM	-	Regional Network for Agricultural Machinery
rpm	-	revolution(s) per minute
Rs	-	Rupees
s	-	second(s)
SAC	-	Supportive and Allied courses
T	-	Tonnes
Tech.	-	Technology
Trans.	-	Transactions
USA	-	United States of America
V	-	volt(s)
viz.	-	namely
W	-	watt(s)
/	-	per
%	-	per cent
°C	-	degree Celsius

INTRODUCTION

INTRODUCTION

Black pepper, obtained from the vine *Piper nigrum* Linn., is one of the world's oldest and most important spices. Known as the 'King of Spices', it has its roots in India, where it has been a highly esteemed spice since time immemorial. It was also one of the first oriental spices to be introduced into Europe and occupies an important market to date. A native of the Western Ghats, pepper is the most abundant and famous spice of Kerala.

Down the centuries, pepper has occupied an important place in trade. The Greeks had recognised black pepper as early as 300 B.C. It was the riches involved in spices trade that lured the Europeans to establish trade links with the East. By AD 40, pepper trade was firmly established from the Malabar coast of India to Arabia, Egypt, Alexandria, the Mediterranean, and Rome. Since then, it has been a significant contributor to the economy of the country in terms of the revenue earned from export. Of the Rs 250 to 350 crores earned annually as foreign exchange from the export of spices, 25-75 % comes from black pepper alone.

As per the statistics available, the total area under pepper in India in the year 1991 was 1,74,870 ha., with a production of 42,690 T. Kerala contributes about 96 % of the total pepper produced followed by Karnataka with 3.5 %. Tamil Nadu, Andhra Pradesh, Pondicherry, and West Bengal also produce pepper, though their contribution is hardly significant. Apart from India, the other major players in the world pepper trade are Indonesia, Malaysia, Brazil, Sri Lanka, Thailand, and other tropical countries; trading around 1,00,000 T of black pepper annually.

The chief importers of black pepper are USA followed by Germany, Britain, Italy, France, and the erstwhile Soviet bloc. Black pepper always fetches a good revenue due to its good demand. In the year 1992-93, India earned foreign exchange worth Rs 386.78 crores from the export of spices out of which the export of black pepper alone contributed Rs 70.07 crores, by trading 21,646.4 T of black pepper. It is thus clear that black pepper is a significant earner of foreign exchange and its increased production could give India still larger profits.

Piper nigrum L. is a perennial, glabrous woody climber 10 m or more in height, carrying many globose single seeded fruits on spikes 5-15 cm long. Each spike carries generally 20-60 berries. A wide variety of cultivars such as Balamcotta, Kalluvally, Kuthiravaly, Karimunda, Panniyur-1, Panniyur-2, etc., have been adopted for cultivation. Pepper requires a warm and humid climate, heavy and well distributed rainfall, and high temperature for optimum growth. Pepper berries become mature and ready for harvest in about 180-200 days, depending on the variety. Black pepper is produced by drying the mature berries in the sun for 4-7 days after their separation from the spikes by threshing.

Being an essential ingredient of numerous commercially available food stuffs and in culinary seasoning, black pepper is employed in a wide range of foods such as meats, soups, fish, pickles, etc.. It also acts as a preservative. It has a stimulating action on the digestive organs producing an increased flow of gastric juices and saliva. It is also termed as a cure for the various ailments such as dyspepsia, malaria, delirium, etc.

However, pepper production is handicapped in many ways in India. Though the quality of pepper produced in India is far superior to those from other countries, the country is unable to earn a corresponding revenue from export. This is primarily due to the high cost of production created by the shortage of labour and high wages, particularly during the harvesting and threshing periods. Besides, labour is the costliest single input in pepper production. The wages of agricultural labourers have increased tremendously over the years whereas there has not been a commensurate increase in the price of black pepper. Further, untimely threshing causes high losses as well as a reduction in the quality of black pepper produced. Threshing being a critical post-harvest operation in processing of pepper, adoption of improper threshing methods results in post-harvest losses reducing black pepper recovery. Another problem observed is the contamination of black pepper with foreign matters such as mud, stones, and insect and animal excreta, etc., which reduce its value in the international market.

The conventional method of pepper threshing is by treading the pepper spikes under human feet. The pepper spikes are heaped on ground after harvest, and after a day or two, are spread on floor or mats and trod upon. The berries get separated from the stalks by the shearing action. This method is, however, uneconomical, time consuming, and laborious. Besides, this often leads to contamination of pepper with mud, stones, cowdung, etc.

To overcome these problems, the use of mechanical threshers is advocated as these reduce the drudgery, lessen the problems due to labour shortage, increase the level of performance, and make the operation cleaner and economical. However, to date, no thresher is available in the market for threshing of green pepper. A mechanical thresher would help in hastening the production of black pepper from green pepper by speeding up the operation of threshing. Recognizing the need for a mechanical thresher for pepper, a study was undertaken at the Kelappaji College of Agricultural Engineering and Technology, Tavanur, to develop a suitable power operated black pepper thresher with the following objectives.

1. Selection of a suitable threshing unit for threshing black pepper.
2. Modification of this unit for improving its performance.
3. To evaluate the thresher for ascertaining its operational parameters for best performance.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

This chapter presents a brief review of the crop, its characteristics, processing of black pepper, the conventional and mechanical methods of threshing and the different types of threshers used for threshing.

2.1 Origin and agronomic aspects

Black pepper (*Piper nigrum* Linn.) is a member of the Piperaceae family and is one of the most popular spices (Pruthi, 1979). As stated by Gupta (1980) in the Handbook of Agriculture, it is one of the earliest known and most important spice crops of India.

According to Pruthi (1979), black pepper is a branching vine or climbing perennial shrub found mostly in the hot and moist parts of South India, notably Kerala, Karnataka, Tamil Nadu, and Pondicherry. There are nearly twenty four varieties of black pepper grown in India. Hybrid varieties such as Panniyur-1, Panniyur-2, etc., have also been developed. Under best cultivation, when height is restricted, the mature vine has a bushy columnar appearance and is about four meters high. Black pepper is propagated from the cuttings of runner shoots which originate from the base of the vines. The stem and branches bear alternate, shiny, dark-green leaves. Hanging spikes originate from the nodes and bear small, sessile and white flowers without perianth. The spikes are ready for harvest when they are fully mature and start yellowing. Mature spikes vary from 5-30 cm in length and support 30-150 flowers, which after fertilization, develop into small, sessile and indehiscent berries which are dark green when mature and turn yellow to red when ripe.

2.2 Harvesting and yields

The vines are permitted to bear flowering spikes only after two years. It takes about 6-8 months from flowering to harvesting. As reported by Krishnamurthy *(1969)*, there are usually two crops of *P. nigrum* in India - one during August-September and the other in March-April. Harvesting in Kerala is usually done from November to February. Harvesting is done by removing the whole spikes from the vines. The spikes are kept for a day and threshed to remove the berries from the spikes. Generally 100 kg of fresh berries yield about 26-39 kg of black pepper of commerce (Pruthi,1979).

2.3 Forms of pepper and by-products

Generally pepper is sold as black pepper, white pepper, and processed green pepper. Tender and semi-mature spikes are harvested in order to prepare processed green pepper, whereas the fully mature but unripe berries are used to prepare black pepper. The mature and ripe berries go into the making of white pepper. Canned and processed forms of green pepper are also available. The Central Food Technological Research Institute, Mysore, has evolved a technique for dehydration of green pepper which can be stored for a year or more and can be reconstituted by steeping in water (Pruthi, 1979). The mature, unripe berries are dried for 4-7 days in the sun, till the outer skin becomes dark brown to black and gets shrivelled to form black pepper. The pericarp of ripe berries are removed before drying in order to prepare white pepper.

Pepper rejections or unfertilised buds, the stems, and inflorescence stalks are the by-products of pepper available in the market. These fractions are obtained consequent to the threshing of black pepper.

2.4 Threshing

Trivedi and Arya (1965) defined threshing as the group of operations that are designed to detach the desired product from the mass of the harvested material and their separation from the mass. Threshing is the first post-harvest operation for separating the grain (RNAM, 1983). It is generally a laborious, labour intensive, and time consuming operation. Threshing is effected by employing various principles.

2.5 Principles of threshing mechanisms

Kepner *et al.* (1978) reported that threshing may be accomplished by;

a. impact of a fast moving member upon the material;
b. rubbing;
c. squeezing the pods;
d. a combination of two or more of these actions, and
e. some other methods of applying the required forces.

Many different threshing devices have been developed using the above principles either singly or in combination; but very few have achieved even limited field use. Observations on the traditional methods of black pepper threshing indicated that the principles cited at (a) and (b) are most effective in separating the berries from the stalk.

2.6 Methods of threshing

Threshing is generally carried out by the following methods.

a. Manual threshing
b. Animal threshing
c. Mechanical threshing

2.6.1 Manual threshing

Guenther (1952) observed that in order to remove the berries from the stalks the heaped up material was beaten with sticks, or people trod upon it barefooted; the latter procedure entailing minimum of waste.

Hoppem (1981) stated that primitive threshing was done by spreading the ripe crop on a threshing floor where it was beaten with sticks or flails, or trampled under feet by men or under hooves of animals.

Separation of the grains from the ears could also be achieved by striking the ears against bars or hard surfaces or by squeezing between two plain or grated surfaces. In either case the ears were deposited on a hard surface. The latter method was adopted for incorporation in the thresher developed in this study.

According to Sureshkumar (1996), Andrew Meikle, a Scotsman in 1785 was the first to replace the heavy and laborious work of threshing with hand raspbars by mechanical work with the use of four revolving bars attached to the circumference of a drum 25 cm in diameter. Part of the drum's circumference was enclosed by a sheet metal casing, now called concave. The threshing process took place in the space formed in between the two elements. The peripheral speed of the drum was in the range of 4-6 m/s. Grain was delivered manually between two notched feeding shafts conveying grain into the split place. The threshing machine described was driven by a hand crank.

Threshing of pepper entails the removal of the berries from the stalk. Conventionally, pepper is threshed manually by treading the harvested crop under human feet. The harvest is spread on the floor of the threshing yard and the labourer, usually with a gunny bag covering his feet to enhance threshing, tramples the crop. The shearing action separates the berries from the spikes. This process, however, is laborious and time-consuming.

2.6.2 Animal threshing

Sahay (1992) reported that threshing by bullocks was a very common method adopted in villages. The harvested crop was spread on a clean threshing space and the bullocks were tied in a line with the help of a strong pole fixed in the centre of the threshing space. Bullocks moved round and round on the harvest and trampled them continuously till the grains were completely separated from the straw. One man drove the bullocks from the back. Various methods of animal threshing adopted are tree branch threshing, punched sheet threshing, disk harrow threshing, threshing sleds, etc. Though these methods are effective in threshing grains, these cannot be adopted for threshing black pepper as the berries get crushed under the weight of the hooves of the animals.

2.7 Development of mechanical threshers

The following were some of the reasons given by Pradhan (1968) and Johnson (1969) for the increasing popularity of power driven threshers.

1. Unavailability of efficient labourers during harvesting season.
2. Quick and time saving.
3. Some improved varieties are more difficult to thresh by the traditional methods.
4. Minimise the grain loss irrespective of the threshable character of the variety.
5. Even small quantity of the crop can be threshed separately without deterioration in the quality.

These are relevant also in the case of black pepper threshing.

Irshad Ali (1983) pointed out the increasing popularity of small power threshers among Indian farmers. He reported on the availability of a variety of threshers with varying cylinder designs and sizes. According to him, the threshing drum was cylindrical in shape and was generally provided with pegs on the periphery. The drum was rotated at about 600-700 revolutions per minute. The crop was threshed by the impact and rubbing action between the drum and the concave.

Investigations by Lamp and Buchele (1960) resulted in the conclusion that wheat and other grains could be threshed by the application of centrifugal force. The threshing and separating processes can be integrated, eliminating the need for special straw separation, for the centrifugally threshed grains. Some degree of seed separation by weight is achieved in threshing mechanisms by varying the centrifugal force.

Hamdy *et al.* (1967) proposed a centrifugal thresher. They recognised its potential in reducing the impact level associated with threshing, and in achieving threshing, separation, and cleaning in one process.

Mathew (1987) designed a hand operated pepper thresher at the Agricultural Research Station, Mannuthy. The approximate capacity of the thresher was only 60 kg/h which is comparatively very small.

Marisamy *et al.* (1992) developed a raspbar thresher for pepper. The raspbar members were made of rubber. A sieve assembly with provisions for adjusting the inclination was provided. The power required for operation was provided from a 1-hp 3-phase ac-motor.

Ambujan and Ravikumar (1993) modified the hand operated model described by Mathew (1987) into a power operated one. A 0.5-hp electric motor was used to power the machine. The drum and concave were coated with rubber for friction.

Based on the above, a pepper thresher with a cylinder-concave arrangement was selected for further study in this project. The padding material was suitably changed to increase separation and to reduce the mechanical damage.

Guenther (1952) reported the use of machines on large estates for separation of berries from spikes of pepper.

2.8 Parameters affecting threshing

Kepner *et al.* (1978) found that threshing effectiveness was related to:

1. the peripheral speed of the cylinder,
2. the cylinder-concave clearance,
3. the number of times the material passed the concave,
4. the type of crop,
5. the condition of the crop in terms of moisture content, maturity, etc., and
6. the rate at which the material was fed into the machine.

Among these, the parameters 1, 2, 3 and 6 were selected for study in the project to determine their effect on threshing. Arnold *et al.* (1958) stated that increased feed rate tends to reduce seed damage although the effect is usually small.

Comparison of the front-to-rear clearance ratios of 3 to 1 and 1 to 1 was carried out by Arnold (1964). Very little difference in cylinder loss, visible damage, and germination of barley and wheat was noted, for any given mean clearance. Front-to-rear clearance convergence is generally desirable because the wider front opening tends to improve the threshing characteristics of a cylinder.

It was observed that the number of passes had a definite influence on the recovery of grain from spikes. The most important operating parameter with regard to threshing and seed damage was the speed of cylinder, the increase of which improved threshing but increased damage too.

The susceptibility to damage varied among the different crops. In general, seed damage increased as the seed moisture content was reduced (Kepner *et al.*, 1978).

Cylinder-concave clearance also had an effect on threshing and damage. However, it was rather small when compared with that of cylinder speed. Decreasing the clearance increased threshing as also the damage to the seeds.

In order to determine the effect of the parameters selected, various levels of these parameters were chosen as detailed in the next chapter.

MATERIALS AND METHODS

MATERIALS AND METHODS

In order to carry out the objectives, an experimental set-up consisting of the black pepper thresher and the necessary instrumentation was made, the details of which are presented in this chapter. The experimental procedures adopted in the performance evaluation and the analysis of data are also described.

3.1 Experimental Set-up

This set-up comprised the following major components.

1. Threshing drum
2. Concave
3. Template
4. Cover
5. Padding material
6. Sieve
7. Collection tray
8. Frame
9. Power source
10. Instrumentation

3.1.1 Threshing drum

A hollow threshing drum, 300 mm in diameter and 210 mm wide, was fabricated out of 18 gauge MS sheet (Fig.1 and 2). The sides of the drum were covered using 22 gauge GI sheet. A cylinder shaft, 20 mm in diameter, passed through the centre of the drum and rested in bearings fixed on the frame.

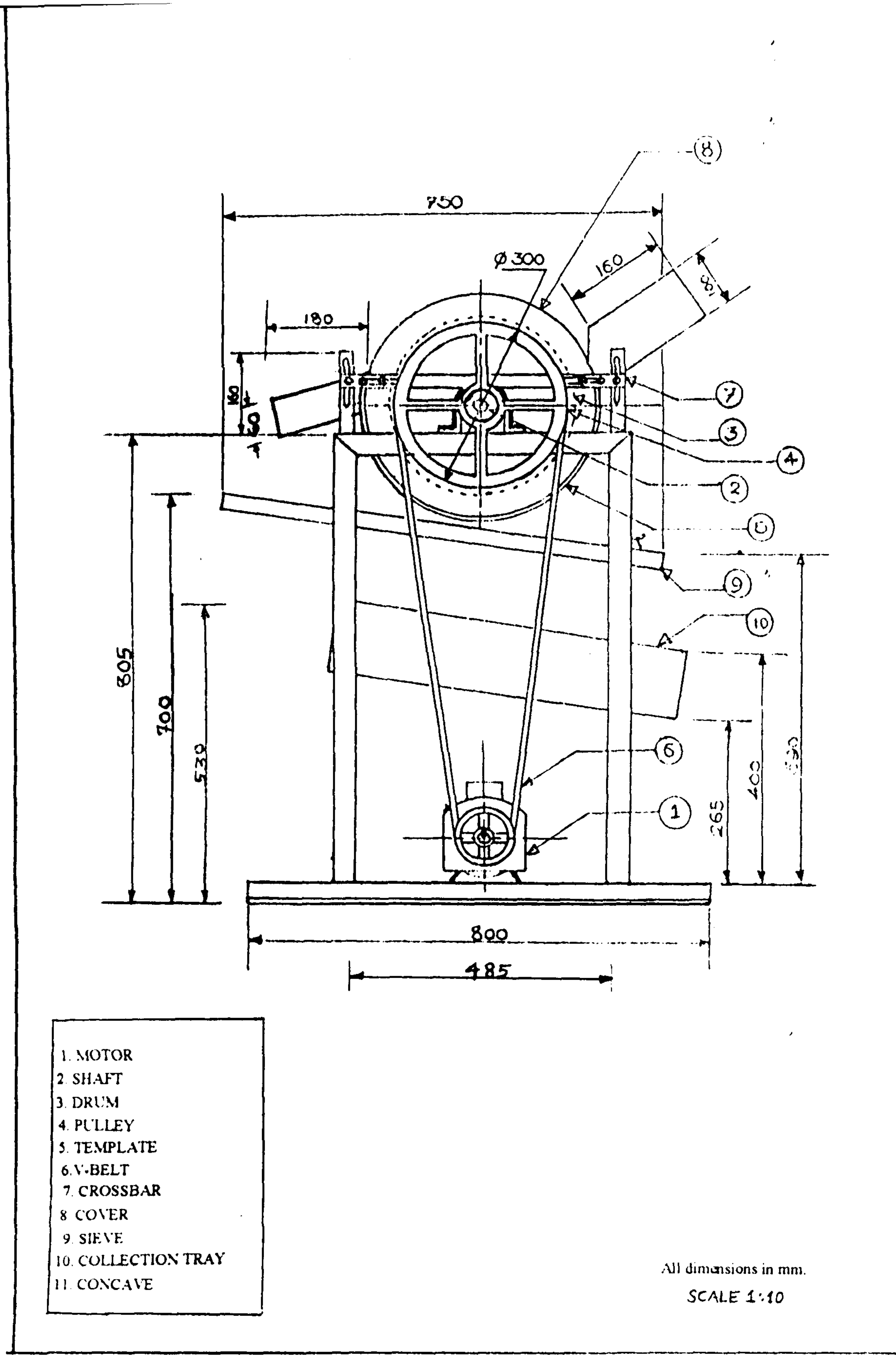
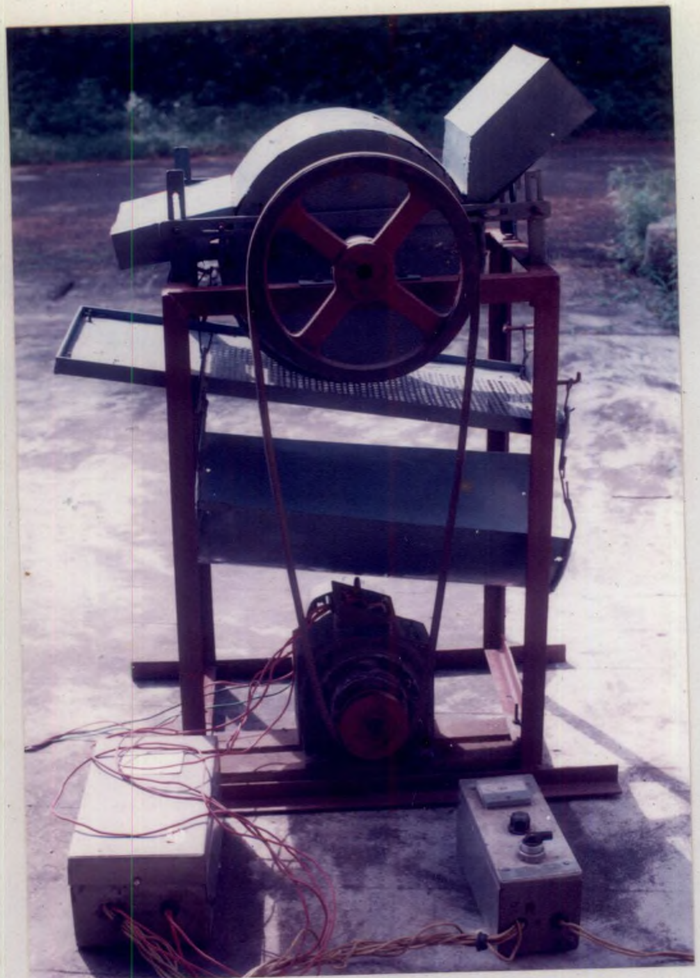


Fig. 1. Front view of the thresher

Plate I Front view of the thresher

Plate II Side view of the thresher



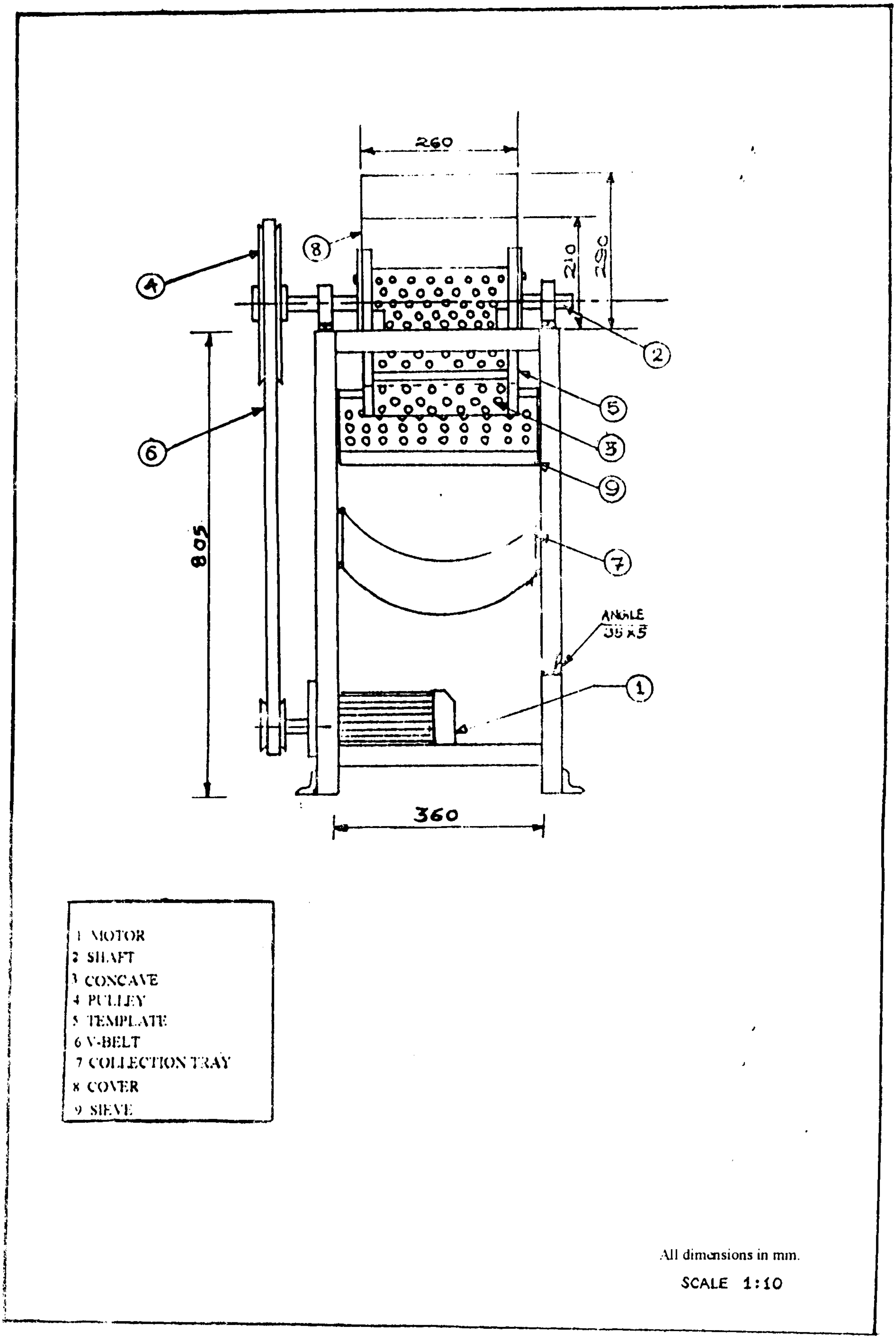
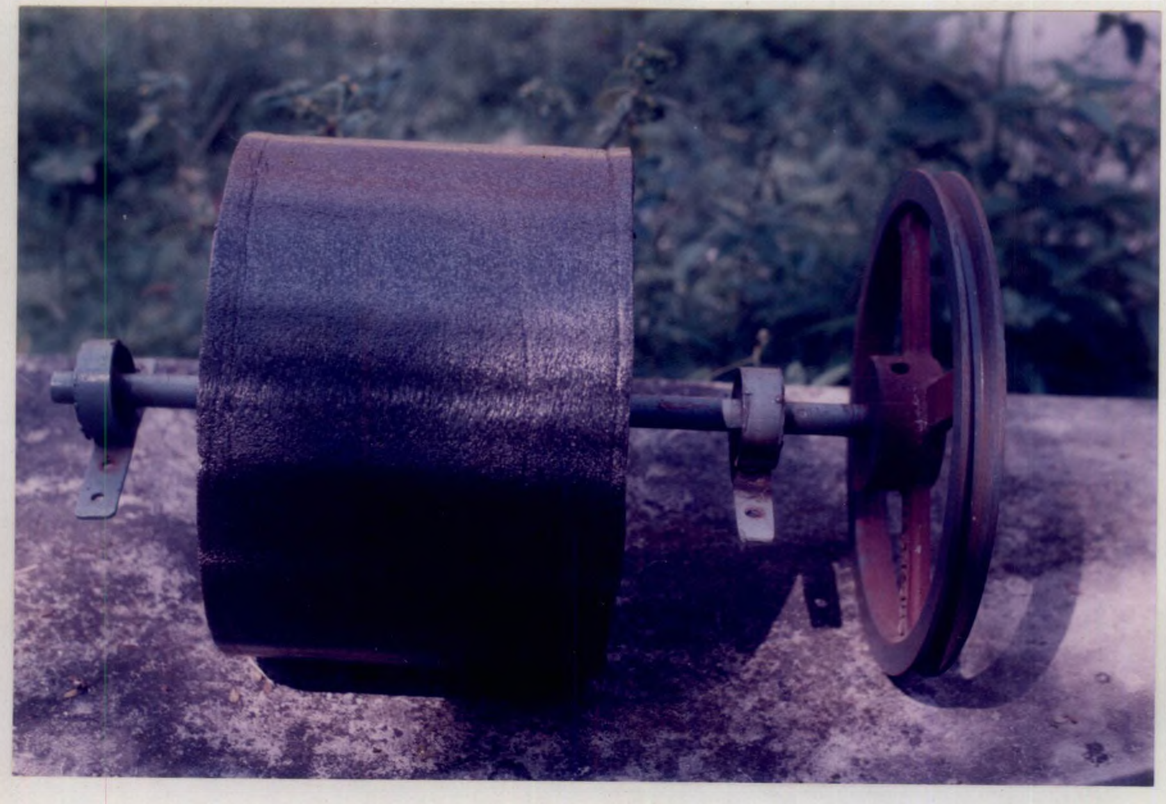
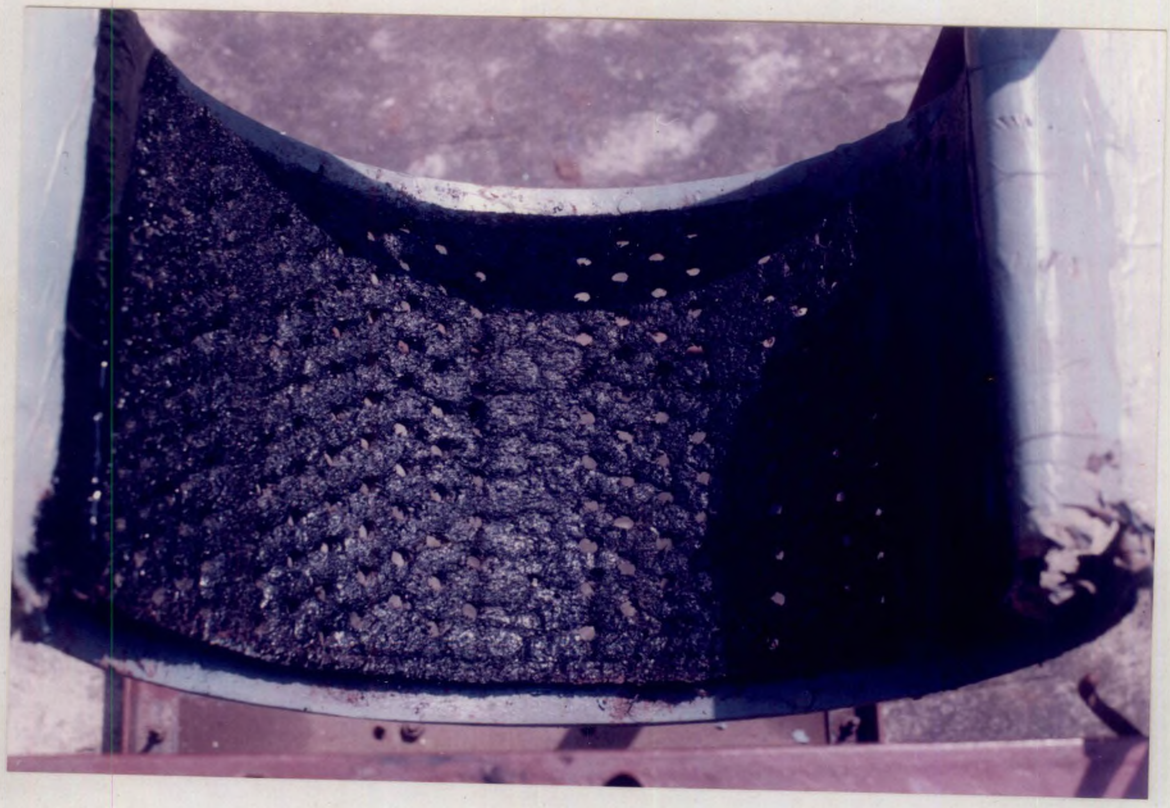


Fig.2. Side view of the thresher

Plate III Threshing drum with thermofoam padding

Plate IV Concave-template unit with thermofoam coating





3.1.2 Concave

A concave of arc length 680 mm, width 260 mm and made of 18 gauge GI sheet enveloped the lower half of the drum . Circular holes, 10 mm in diameter, were provided on the concave such that adjacent holes were located at a centre to centre distance of 2 cm. The ends of concave were bent outward to act as chutes at the feed and discharge ends. The concave was reinforced with a template riveted to it.

3.1.3 Template

A semi-circular template, 700 mm in length, was fabricated by bending two MS flats of 25 x 6 mm and connecting them together by four equally spaced bars, 210 mm in length, as shown in the Fig.3. These spacer bars were made of 12 x 5 mm MS flat bar. Two bars were provided at either ends to complete the template.

The concave-template unit was fixed to the main frame using four bolts and nuts. These bolts passed through the slots provided on the crossbars of the main frame and this arrangement facilitated the adjustment of the contact length. In order to vary the contact length, the concave-template unit was shifted in the horizontal direction perpendicular to the longitudinal axis of the cylinder shaft.

3.1.4 Cover

The drum-concave unit was provided with a cover except for the bottom of the concave. The cover comprised a fixed part and two inspection covers. The inspection covers were provided on either side of the lower part of the drum-concave unit. The fixed portion or the top cover was for the remaining portion. Extensions on the top cover at the

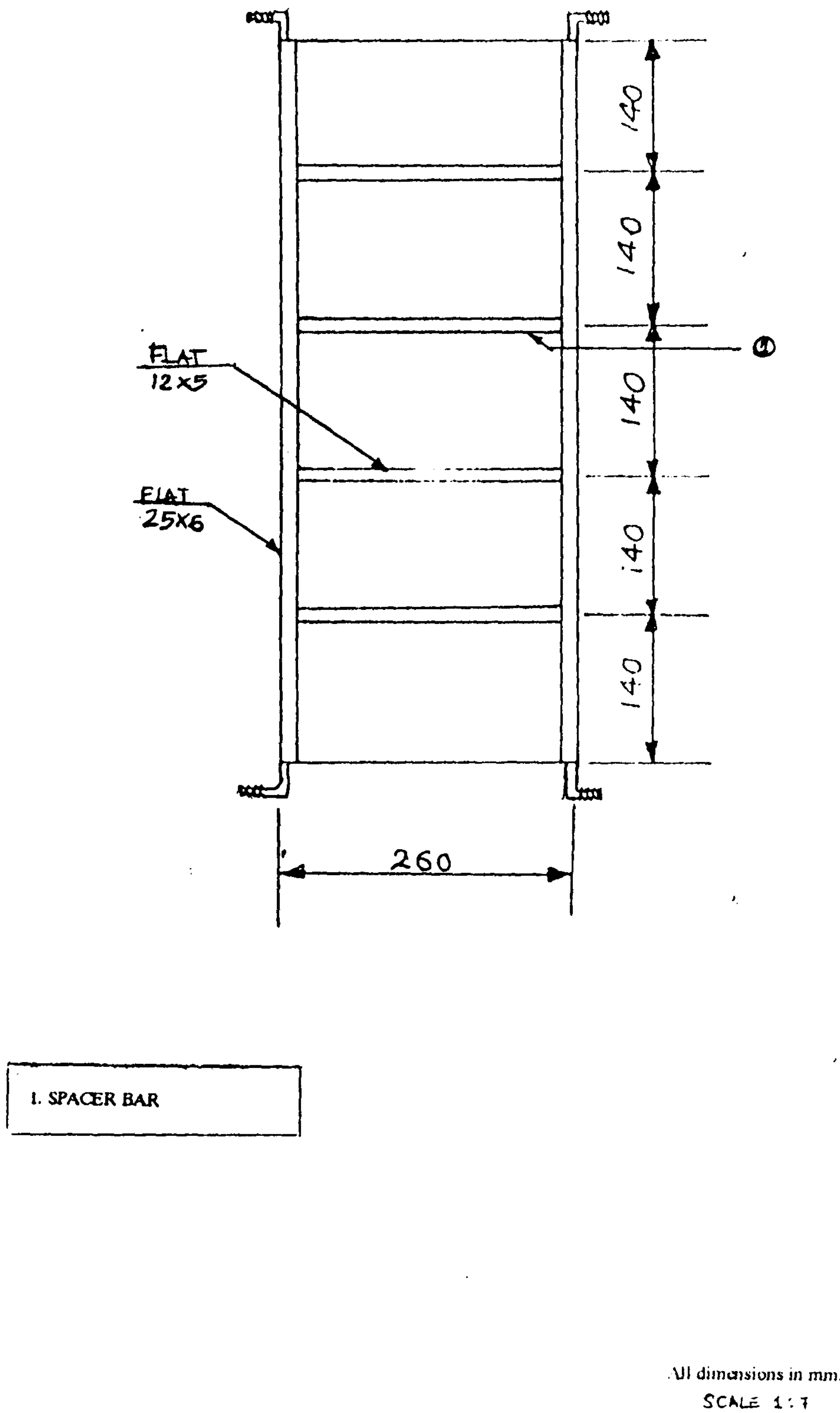


Fig. 3. Template

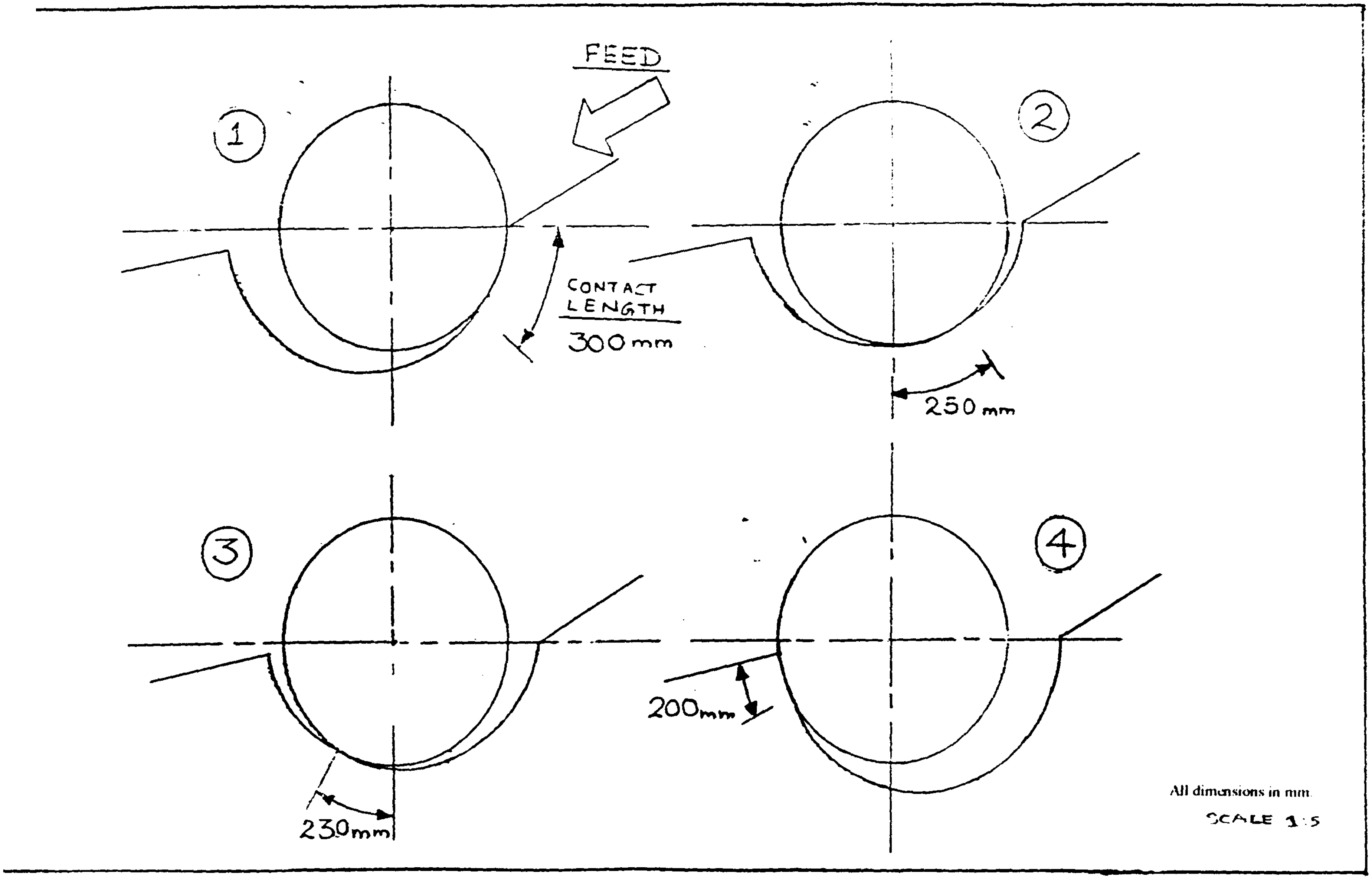


Fig. 4. Representation of the different contact lengths

feed and the discharge ends covered the two chutes. Provisions were made for the lateral adjustments of the cover to match with the shifting of the concave-template unit.

3.1.5 Padding Material

One of the major problems encountered in mechanical threshing of pepper was the damage to the berries due to the compressive and shear forces experienced by them in the clearance between the drum and the concave. Abrasive action, of the hard coating materials on the drum and the concave, further increased damage. In order to overcome this problem and to avoid damage, both the drum and the concave were padded with thermofoam sheet of 15 mm thickness. Holes of the same size and corresponding to the holes in the concave were punched on this sheet to facilitate the removal of detached berries from the threshing zone.

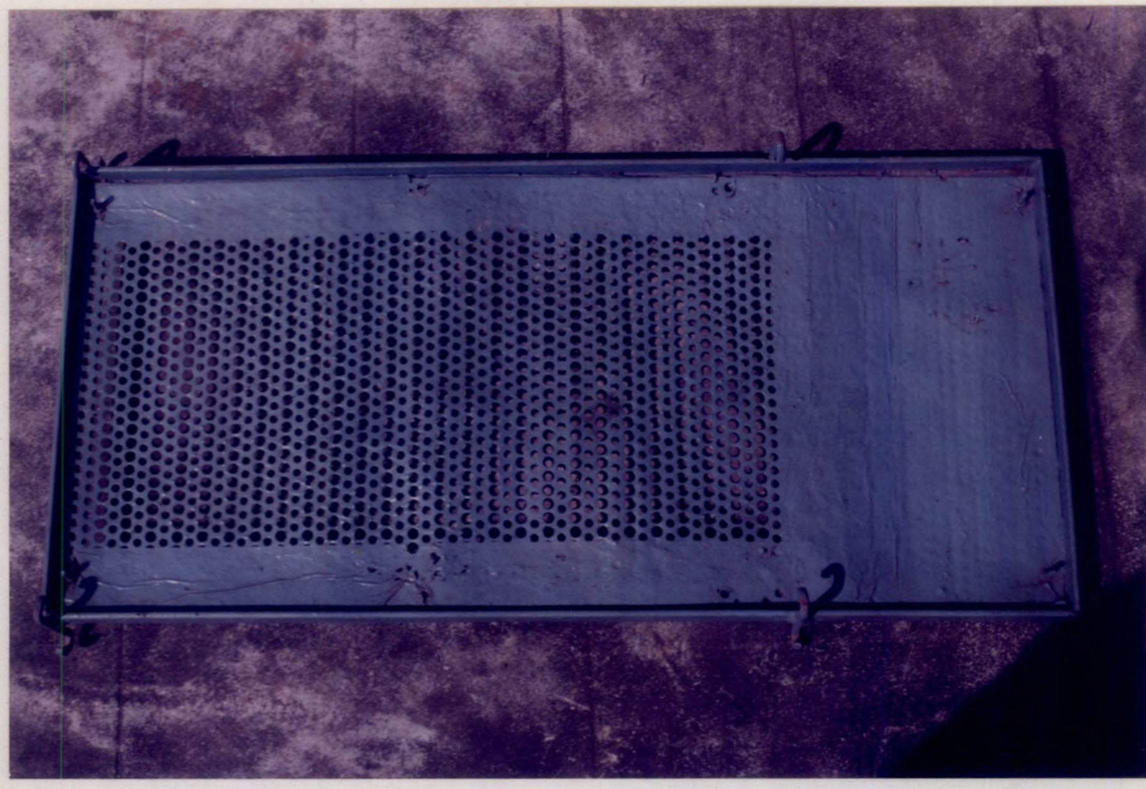
3.1.6 Sieve

A perforated screen of 8 mm hole diameter was screwed to a 750 x 350 mm frame made of 25 x 25 x 5 mm MS angle. The sieve was suspended from the main frame. This suspended arrangement enabled manual oscillation of the sieve to separate the berries and the larger chaff.

3.1.7 Collection tray

A trough of length 565 mm, width 370 mm and depth 182 mm respectively, made of 22 gauge GI sheet, was used for collecting the detached berries. It was suspended from hooks welded to the sieve.

Plate V Sieve



3.1.8 Frame

The main frame was fabricated out of 35 x 35 x 5 mm MS angle with overall dimensions 485 x 360 x 805 mm. The MS angles at the bottom were extended to a length of 800 mm to provide stability. Two wooden planks, 540 x 55 x 28 mm, were fixed at the bottom and the motor was mounted on it. Supports of 25 x 25 x 3 mm MS angles, 130 mm in length, were screwed to the main frame and slots, 75 mm in length, were cut to enable vertical movement of the crossbar to which the concave-template unit was bolted. The drum-concave clearance could be adjusted by this arrangement.

3.1.9 Power source and transmission

A 3-phase, 0.5-hp, variable speed motor was used as the prime mover. The speed could be varied in the range 300-1400 revolutions per minute with the help of a thyristor control unit. A belt and pulley system transmitted the power to the cylinder shaft. A 100-mm pulley was fitted to the motor shaft and was connected to a 300-mm pulley on the cylinder shaft by a V- belt, giving a speed reduction ratio of 3:1.

3.1.10 Instrumentation

A 5-ampere ammeter and a 440-volts voltmeter were connected to the motor circuit in order to note the current and the voltage readings necessary for the determination of the power required.

3.2 Experimental Methods

In order to evaluate the performance of the thresher developed, pepper spikes were collected and then the thresher was tested at various operating conditions. The experimental design selected and the procedure adopted in carrying out these experiments and the methods for determination of the various performance parameters are described below.

3.2.1 Experimental Design

With the objective of determining the effects of the various machine parameters on the performance of the machine, a 3-factor factorial experiment in Completely Randomised Design (CRD) was adopted. Accordingly, the various factors selected and their levels were:

I	Independent Variables	Level
(i)	Peripheral Velocity (m/min.)	230.9, 263.9, 296.9, 329.9
(ii)	Contact length (cm)	20.0, 23.0, 25.0, 30.0
(iii)	Feed rate (kg/h)	50, 40, 30, 24

II Dependent Variables

(i) Threshing efficiency (%)

(ii) Percentage of damage (%)

(iii) Capacity (kg/h)

(iv) Power requirement (W)

The number of experiments for the different factor-level combinations were 64. Each experiment was replicated three times. Thus, the total number of experiments were 4 x 4 x 4 x 3=192.

Preliminary studies showed that thermofoam provided adequate friction for stripping the berries without damaging them. Thus, thermofoam was chosen as the coating or padding material.

Preliminary trials showed that the thresher gave acceptable performance as regards threshing at peripheral velocities of 263.9 m/min. and 296.9 m/min. Two other peripheral velocities, 230.9 m/min. and 329.9 m/min. were also selected for the study.

From preliminary trials, it was seen that feed rates of 30 kg/h and 40 kg/h gave reasonable results as regards threshing efficiency. Two other feed rates of 24 kg/h and 50 kg/h were also selected. Four levels of the contact length with decreasing length and increasing feed end clearance were also selected.

3.2.2 Experimental Procedure

A fixed quantity of pepper spikes were weighed on an electronic precision balance, the details of which are provided in Appendix-A. These were fed to the thresher at the selected feed rates. The time required for threshing was noted. The materials from all the outlets were collected, and the threshed berries, the damaged berries, the unthreshed spikes, the partially threshed spikes, and the partially threshed spikes with damaged berries were separated and weighed. The unthreshed berries, the partially threshed berries, and the partially threshed spikes with damaged berries were again fed for threshing, at the end of which the quantity of these fractions were again recorded.

3.2.3 Performance Evaluation

The threshing efficiency, the percentage of damage, and the capacity were separately determined for each pass of each sample and from these the overall values were determined. The mean of each treatment was computed based on the formulae given below:

3.2.3.1 Threshing efficiency

Threshing efficiency is the weight of berries detached expressed as a percentage of the total weight of whole spikes fed. It is expressed as

$$\eta_t = \frac{B_t \times 100}{s}$$

where,

η_t = threshing efficiency, %;

B_t = total weight of detached berries, kg; and

s = total weight of spikes fed, kg.

3.2.3.2 Percentage of damage

Percentage of damage is defined as the total weight of the berries damaged and the partially threshed spikes with damaged berries expressed as a percentage of the weight of spikes. It is expressed as

$$d_p = \frac{(B_d + T_{pd}) \times 100}{s}$$

where,

d_p = percentage of damage, %;

B_d = weight of damaged berries, kg; and

T_{pd} = partially threshed spikes with damaged berries, kg.

3.2.3.3 Capacity

Capacity of the machine is defined as the output by weight of the threshed material including the partially threshed spikes in an hour.

It is expressed as

$$C_t = \frac{[(B_t + T_p)]}{t} \times 3600$$

where,

C_t = capacity, kg/h;

T_p = total weight of partially threshed material, kg; and

t = feed time, seconds.

3.2.3.4 Power requirement

It was determined from the readings of the voltmeter and ammeter connected to the motor circuit.

The power was calculated as:

$$P = \sqrt{3}\ VI \cos\phi$$

where,

P = power requirement, W;

V = voltmeter reading, V;

I = ammeter reading, A; and

$\cos\phi$ = power factor = 0.8.

3.2.4 Economic Analysis

The operating cost of the machine was calculated considering both the fixed and the variable costs (Appendix-B). The total fixed cost was the sum of the depreciation and the interest on investment. The depreciation was calculated using the straight line method. The variable costs included electricity charges, labour, and repair and maintenance. The cost of manual threshing is presented in Appendix-C.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Results of the experiments and that of the performance evaluation of the thresher developed are presented and discussed in this chapter.

The machine was operated at the following levels of the three independent variables.

	Variable	Level
1.	Feed rate (kg/h)	50, 40, 30, 24
2.	Contact length (cm)	30, 25, 23, 20
3.	Peripheral velocity (m/min.)	230.9, 263.9, 296.9, 329.9

Values of the threshing efficiency, percentage of damaged berries, and capacity were noted for the 64 different combinations of variables (Appendix-D).

The values of efficiency of the overall threshing and the threshing in individual passes, the percentage of damaged berries, and the capacity were determined. Appendix-E shows a comparison of these values under different sets of conditions. In Appendix-E.1, E.2, E.3 & E.4, the variations of the threshing efficiency at the four contact lengths for both passes and for the overall values are presented. It was observed that generally efficiency of the first pass was greater than that of the second pass. This was because the spikes were full and intact when initially fed into the small clearance between the drum and the concave. This led to the application of larger compressive and shear forces upon the spikes causing the separation of more number of berries from the spikes. On the other hand, in the second pass, it was the reduced bulk of the spikes that was presented to the clearance between the drum and the concave. As a result, only smaller compressive and shear forces acted upon the spikes. Obviously, only fewer number of berries than that of the first pass were separated from the spikes leading to lower threshing efficiency. Simultaneously, the overall threshing efficiency was also higher than that of the first pass as some more berries were separated from the spikes during the second pass.

A comparison of the percentage of damaged berries at different contact lengths at different feed rates is shown in Appendix-E.5, E.6, E.7 & E.8. Percentage of damaged berries was found to be generally larger at higher cylinder speeds. This was because the impact force exerted was greater at higher speeds. The damage caused in the second pass was seen to be higher than that in the first pass. This was because of the cumulative effect of repeated application of impact, compressive and shear forces. The occurrence of ripe berries in a lot increased the percentage of the damaged berries. This was due to the weakening of the tissues of the berries on ripening leading to a reduction in turgidity.

Appendix-E.9, E.10, E.11 & E.12 present the variation in the capacity. The capacity in the first pass was obviously higher because of the greater interference between the threshing drum and the full and intact spikes of larger bulk.

4.1 Effect of feed rate

A three-factor factorial experiment in CRD was conducted on the results for the threshing efficiency, the percentage of damaged berries, and the capacity. The ANOVA indicates that the feed rate had significant influence on all the three dependent variables, that is, threshing efficiency, percentage of damaged berries, and capacity (Tables 1 through 3). The ANOVA results of CRD on the values of percentage of damaged berries showed that feed rate had the maximum influence on this dependent variable. Feed rate is also a parameter having significant influence on the capacity.

The effect of feed rate on the threshing efficiency, the percentage of damage, and the capacity is shown in Figs. 5 through 7. The values of threshing efficiency were found to vary from 82.87 to 93.52% under different machine set-ups.

Table 1. Analysis of variance table of the 3-factor CRD on threshing efficiency.

K value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Prob
2	Factor A	3	120.413	40.138	16.1122	0.0000
4	Factor B	3	161.313	53.771	21.5849	0.0000
6	AB	9	55.028	6.114	2.4544	0.0130
8	Factor C	3	454.998	151.666	60.8824	0.0000
10	AC	9	169.148	18.794	7.5444	0.0000
12	BC	9	258.375	28.708	11.5242	0.0000
14	ABC	27	237.420	8.793	3.5299	0.0000
15	Error	128	318.865	2.491		
	Total	191	1775.560			

Factor A : Feed rate, kg/h
Factor B : Contact length, cm
Factor C : Peripheral velocity, m/min

Table 2. Analysis of variance table of the 3-factor CRD on percentage of damaged berries.

K value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Prob
2	Factor A	3	0.191	0.064	3.7241	0.0131
4	Factor B	3	0.108	0.036	2.1051	0.1028
6	AB	9	0.200	0.022	1.3011	0.2425
8	Factor C	3	0.174	0.052	3.3824	0.0203
10	AC	9	0.106	0.012	0.6913	
12	BC	9	0.232	0.026	1.5080	0.1518
14	ABC	27	0.328	0.012	0.7108	
15	Error	128	2.191	0.017		
	Total	191	3.531			

Factor A : Feed rate, kg/h
Factor B : Contact length, cm
Factor C : Peripheral velocity, m/min

Table 3. Analysis of variance table of the 3-factor CRD on capacity.

K value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Prob
2	Factor A	3	15250.493	5083.498	8383.9563	0.0000
4	Factor B	3	14.284	4.761	7.8526	0.0001
6	AB	9	31.713	3.524	5.8113	0.0000
8	Factor C	3	57.448	19.149	31.5821	0.0000
10	AC	9	34.545	3.838	6.3304	0.0000
12	BC	9	35.006	3.890	6.4149	0.0000
14	ABC	27	39.308	1.456	2.4011	0.0006
15	Error	128	77.611	0.606		
	Total	191	15540.408			

Factor A : Feed rate, kg/h
Factor B : Contact length, cm
Factor C : Peripheral velocity, m/min

The relationship between threshing efficiency and feed rate was in the form of a second-degree polynomial, which could be written, in the general form

$y = ax^2 + bx + c$

where

y = threshing efficiency, %;

x = feed rate, kg/h;

a and b = regression coefficients; and

c = regression constant.

The coefficients of the equations are presented in Appendix-F.

It was seen that, in general, the threshing efficiency showed an increasing trend on increasing feed rates, for different contact lengths (Fig. 5). As the feed rate was increased, more bulk of material was introduced into the drum and the concave. This led to greater interference between the material and the drum, resulting in more berries getting separated due to the shear force acting on the bulk. At the lower feed rates, the spikes were more widely spread out on the concave and this prevented the inter-spike collision. For increased separation of berries, inter-spike collision is necessary.

It was observed from Fig. 5 that at the peripheral velocities of 230.0 and 263.9 m/min., the maximum threshing efficiency was reached at the feed rate of about 40 kg/h. Further increase in the feed rate to 50 kg/h caused a reduction in threshing efficiency. The increased feed rates tended to partially choke the throat resulting in slow movement of the material mass. This also reduced the rate of relative motion between the spikes and the machine components resulting in decreased separation of the berries. But, at increased peripheral velocities of 296.9 and 329.9 m/min., the drum speed was adequate enough to accelerate the movement of the material bulk leading to higher relative velocities and inter-particle material collision. This was responsible for increasing the threshing efficiency.

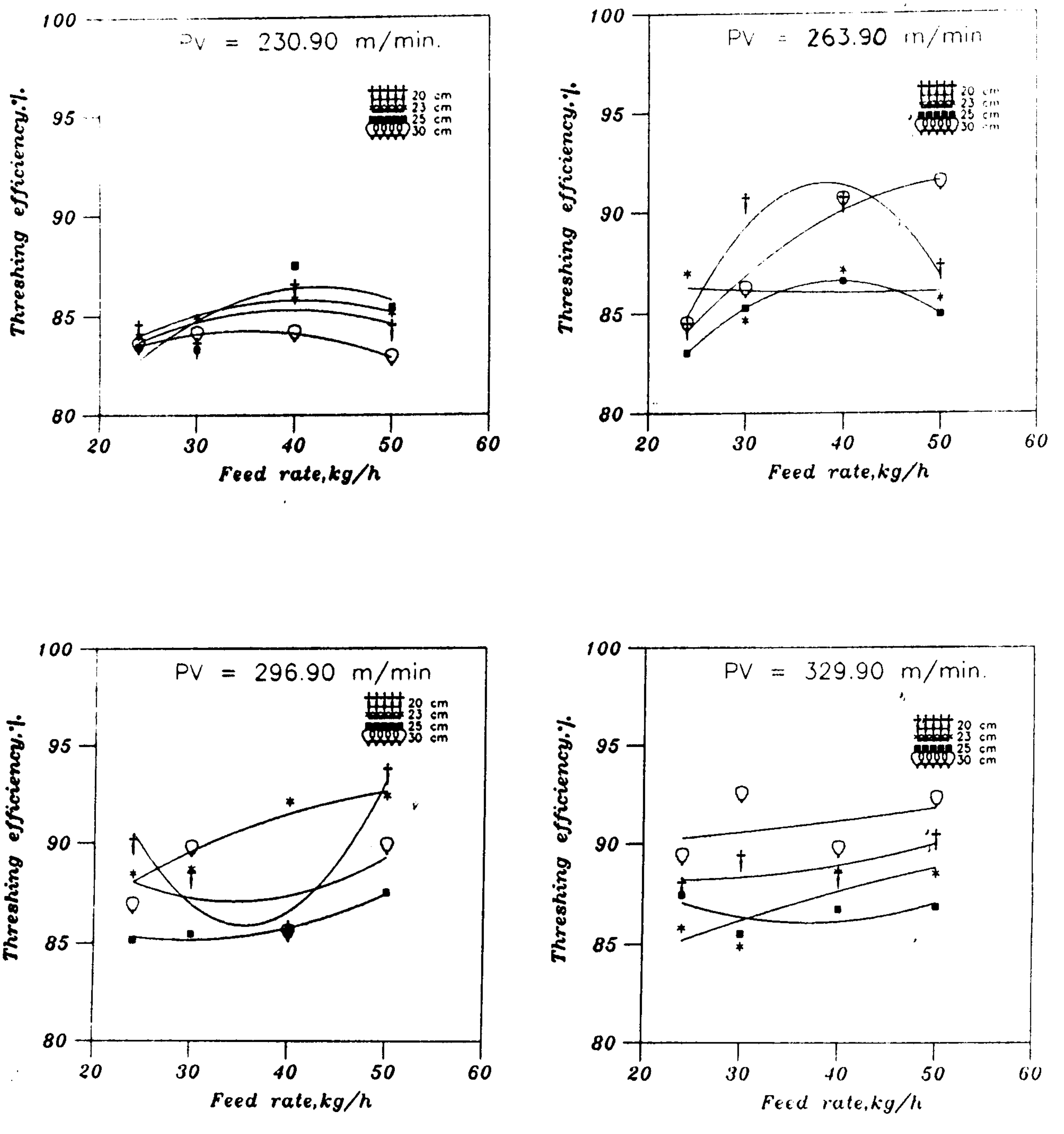


Fig. 5. Comparison of threshing efficiency with feed rate at different peripheral velocities and contact lengths

The effect of feed rate on the percentage of damaged berries at different contact lengths and different peripheral velocities are shown (Fig. 6). The relationship between the two parameters was a second-degree polynomial function, which was of the form

$$y = ax^2 + bx + c$$

where

y = percentage of damaged berries, %;

x = feed rate, kg/h;

a and b = regression coefficients; and

c = regression constant.

The coefficients of the equations are presented in Appendix-F.

The type of damage observed in majority of the cases was abrading of the pericarp. This showed that the damage was mainly due to sliding of the berries that remained attached to the spikes, either individually, or collectively. At lower peripheral velocities, as the threshing efficiency was lower, the spike was forced to move by sliding and this might have resulted in the pericarp getting abraded from the pepper. But, as the feed rate was increased, the threshing efficiency increased, indicating detachment of more number of berries from the spikes. The reduction in the overall diameter of the spike caused to apply compressive and shear forces of only lower magnitudes, thereby, inflicting lesser damage. However, at feed rates above 40 kg/h, the general trend was to cause an increase in damage. Above this, the threshing efficiency decreased due to choking. As a result, the material moved on the concave at a slow rate. This tended to move the material by sliding, thus inflicting abrasions on the berries. The higher percentage of damage was observed mostly in the cases where the fed material consisted of more number of ripe berries.

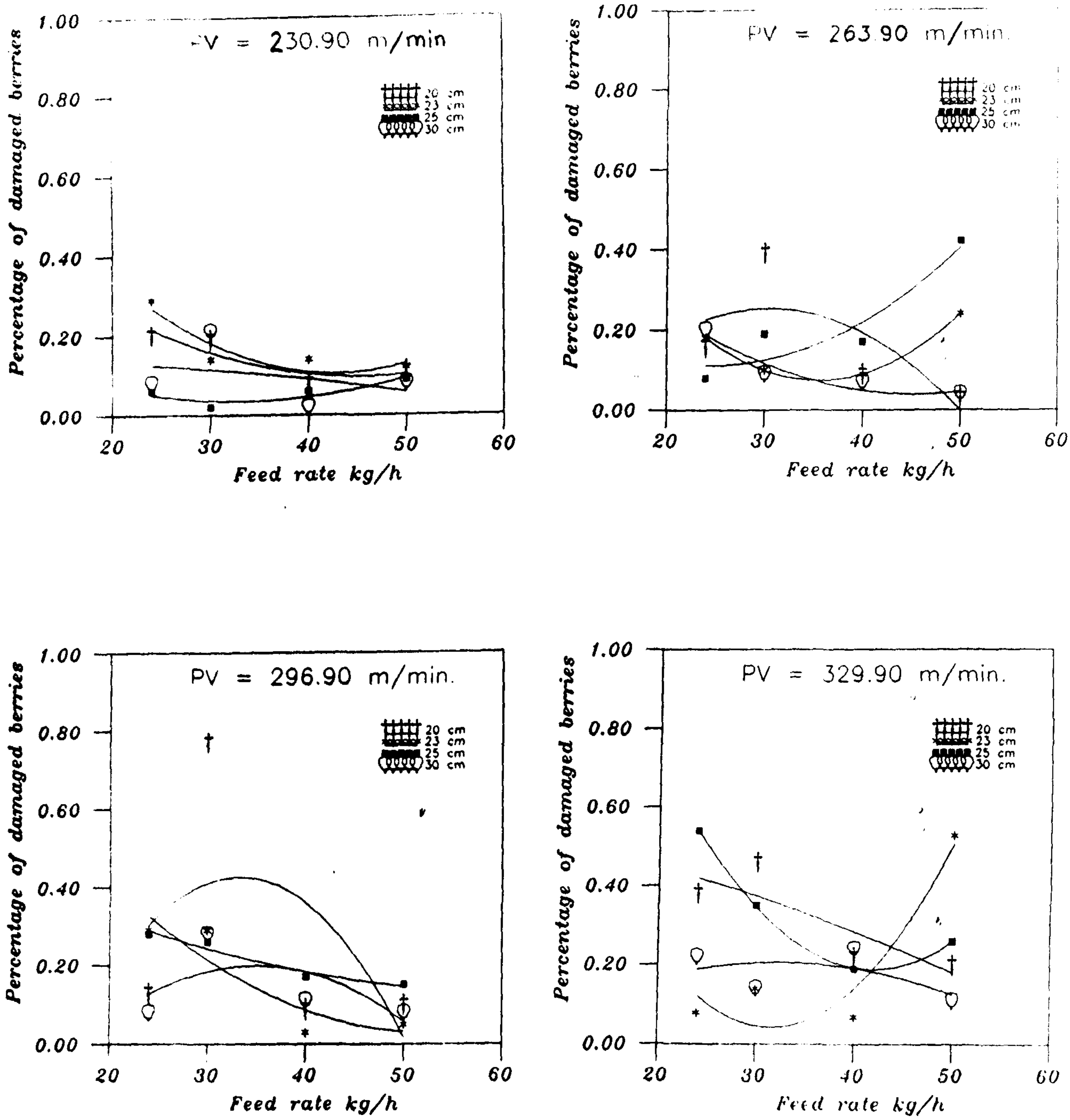


Fig. 6. Comparison of percentage of damaged berries with feed rate at different peripheral velocities and contact lengths

The relationship between feed rate and capacity are shown in Fig. 7. Capacity and feed rate could be related using a polynomial function of the second order, which could be written as

$$y = ax^2 + bx + c$$

where

y = capacity, kg/h; and

x = feed rate, kg/h;

a and b = regression coefficients; and

c = regression constant.

The coefficients of the equations are presented in Appendix-F.

This indicated that the capacity increased with every increment in the feed rate and this variation was in an almost linear manner. This was true for almost all the experiments conducted at different peripheral velocities and contact lengths. For the same feed rate, the capacities did not vary significantly when the contact lengths were changed especially at the peripheral velocities of 263.9, 296.9, and 329.9 m/min. The slight reduction in capacity observed in the case of peripheral velocity of 230.9 m/min. was due to the lower magnitudes of the impact forces and shear forces exerted by the rotating mass of the drum. Further, it showed that the changes in the contact length did not produce appreciable changes in respect of the capacities for the same feed rates. This was true in all the cases. This indicated that among the four lengths of contact selected in the study, the minimum, i.e., 20 cm could be selected in the design of the pepper thresher.

4.2 Effect of peripheral velocity

The results of ANOVA of the factorial experiment are presented in Tables 1, 2, and 3. It showed that peripheral velocity had a significant influence on threshing efficiency, the percentage of damage and the capacity. Threshing efficiency was most influenced by peripheral velocity. Peripheral velocity, in combination with the other two independent variables, also influenced the dependent variables significantly.

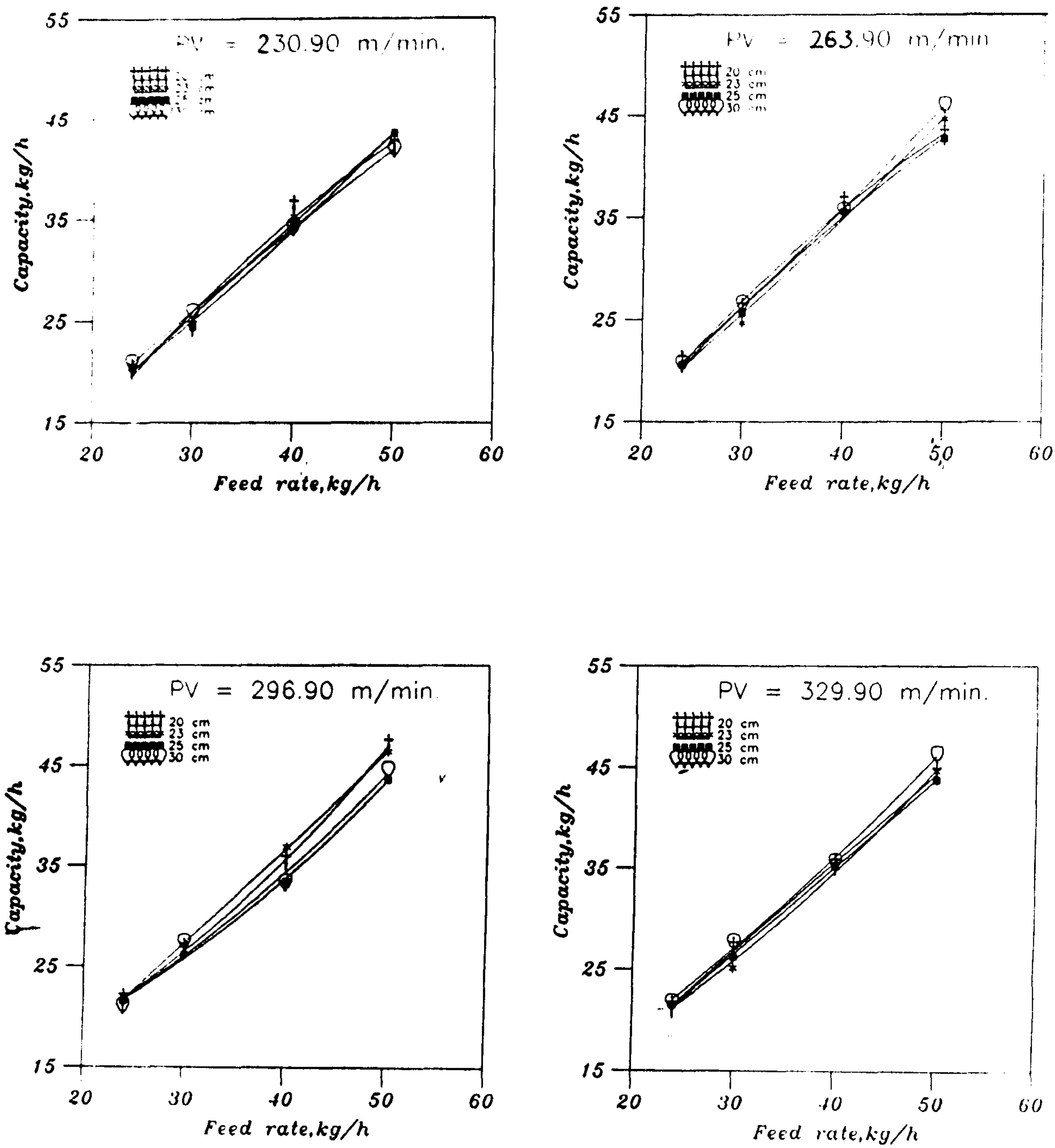


Fig. 7. Comparison of capacity with feed rate at different peripheral velocities and contact lengths

Figures 8 through 10 showed the variation of threshing efficiency, the percentage of damage, and the capacity with respect to peripheral velocity of the drum at the different contact lengths for different feed rates.

A second degree polynomial of the form $y = ax^2 + bx + c$,

where

y = threshing efficiency, %;

x = peripheral velocity, m/min;

a and b = regression coefficients; and

c = regression constant,

showed the relation between the threshing efficiency and peripheral velocity. The coefficients of the equations are presented in Appendix-F.

Threshing efficiency was found to increase generally upto a peripheral velocity of 296.9 m/min. beyond which it showed a decreasing trend at the different feed rates. At lower peripheral velocities the impact and the shear forces causing the separation were of smaller magnitude. Correspondingly, the threshing efficiency was also lower. As the peripheral velocity was increased, there was a corresponding rise in the magnitude of impact and shear forces, leading to easier separation of the berries from the spikes. However, at a peripheral velocity of about 300 m/min., the threshing efficiency reached its peak. When the peripheral velocity was further increased to about 329.9 m/min., the threshing efficiency showed a decrease. This was because, after the initial separation, the spikes moved faster through the clearance allowing shorter time of residence for the spikes in the concave. This led to the reduction in threshing efficiency. Therefore, increasing the peripheral velocity beyond about 300 m/min. was not conducive for attaining higher threshing efficiency. It was also observed that higher threshing efficiencies were attained at higher feed rates of 50 and 40 kg/h. At higher feed rates, the material moving through the space between the concave and the drum was more densely packed facilitating inter-spike collisions and contacts. In addition, there was more of interference by the drum on the material paving the way for detachment of more number of berries per unit time.

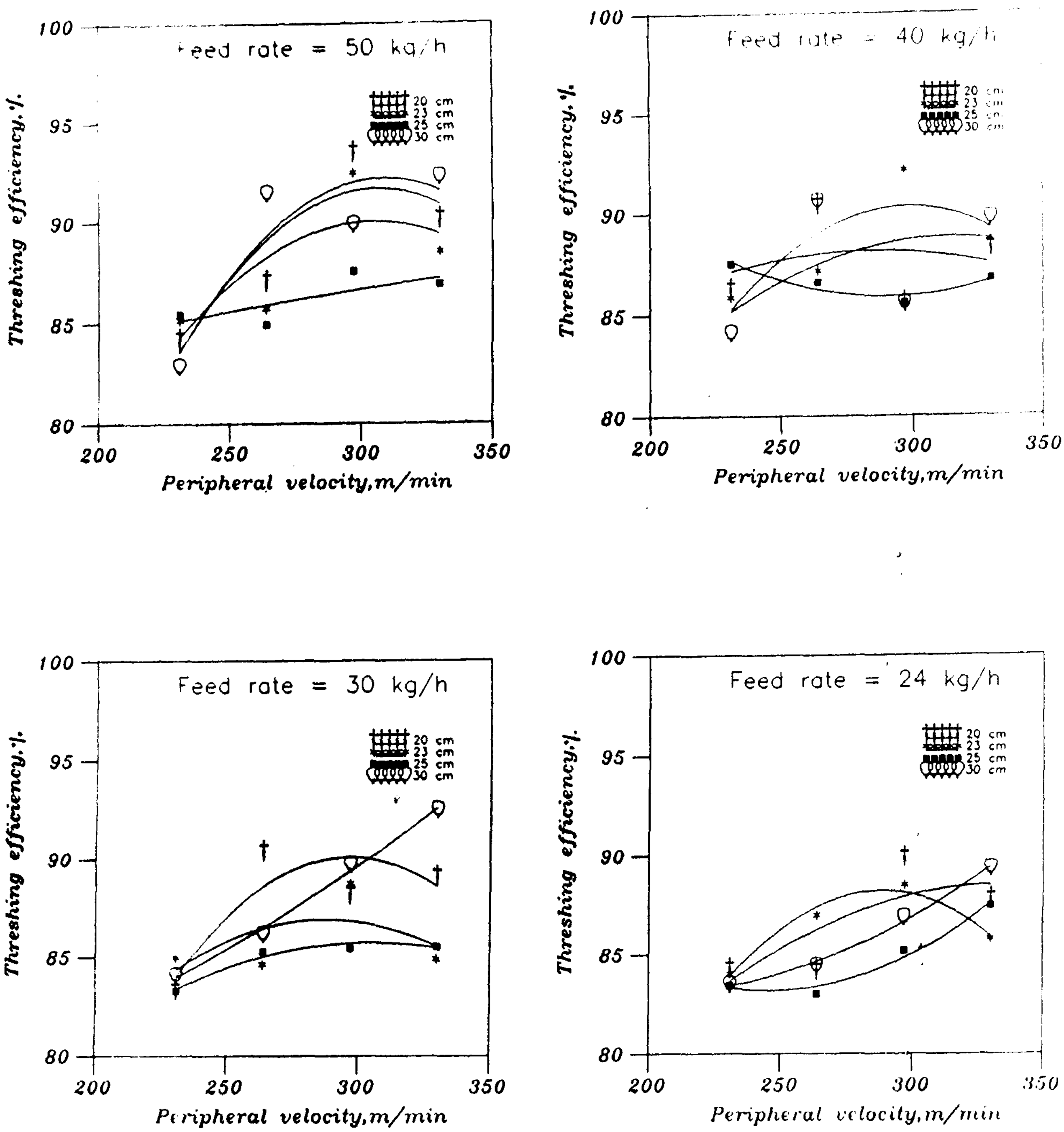


Fig. 8. Comparison of threshing efficiency with peripheral velocity at different feed rates and contact lengths

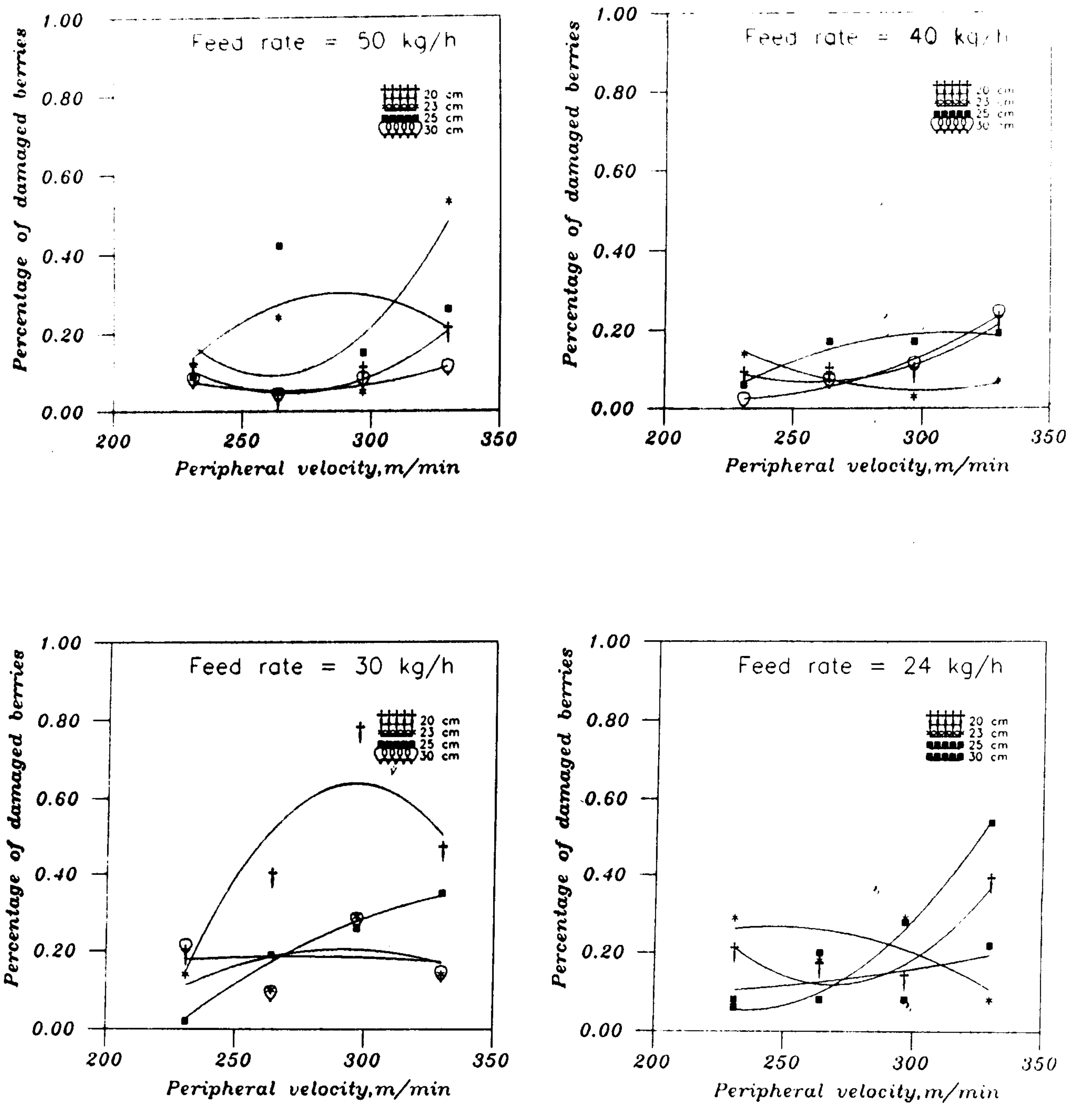


Fig. 9. Comparison of percentage of damaged berries with peripheral velocity at different feed rates and contact lengths

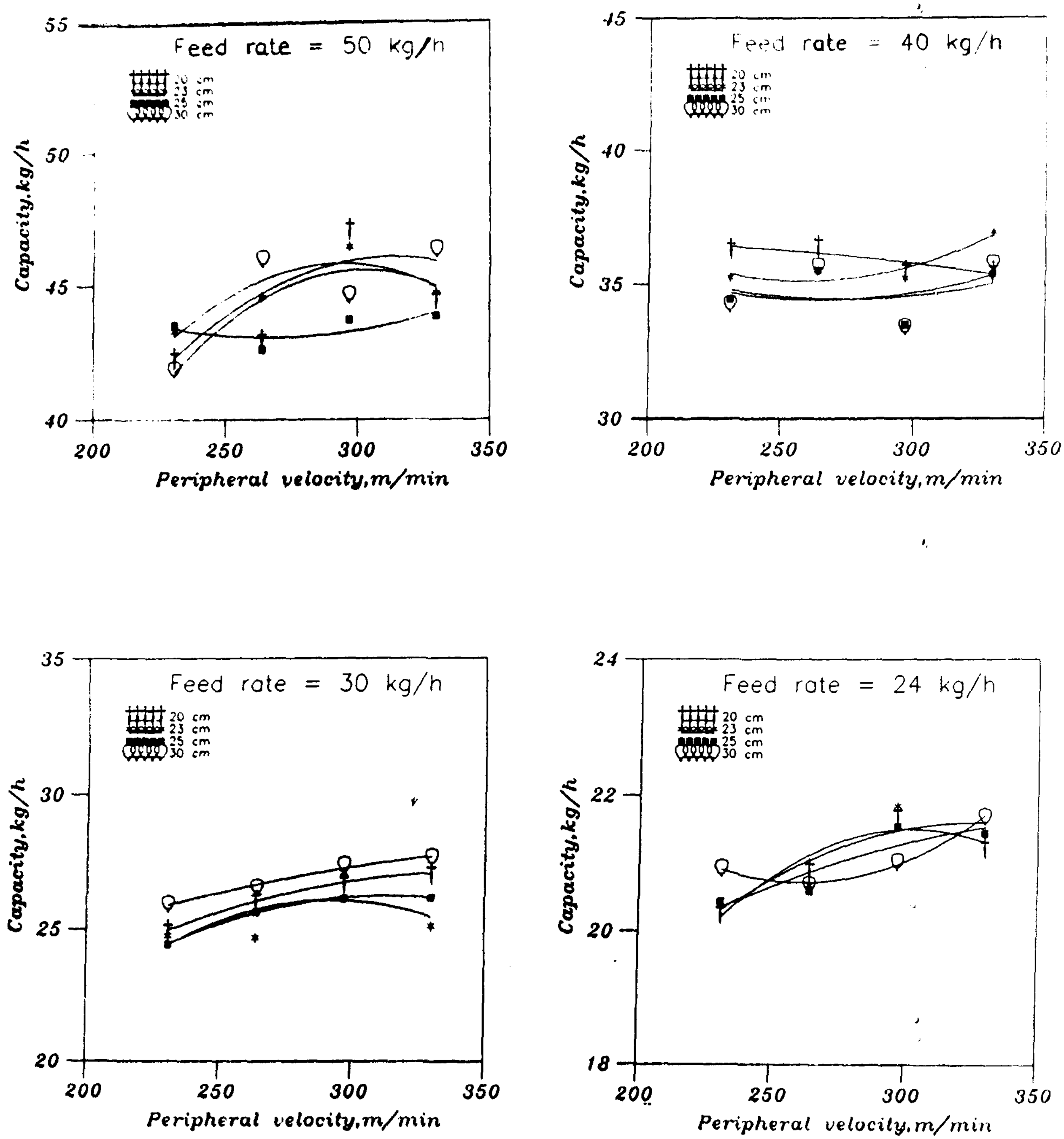


Fig. 10. Comparison of capacity with peripheral velocity at different feed rates and contact lengths

In general, the damage caused to the berries was negligible as the maximum value of mechanical damage was 0.77%. The higher percentage of damaged berries was observed mostly at higher peripheral velocities though in some cases it occurred at lower peripheral velocities. Higher peripheral velocities led to larger impact forces causing more damage. The feed rate, however, showed a mixed trend as the peripheral velocity was varied. In some cases, the damage was more when the feed rate was less whereas in the remaining cases the damage was less at higher feed rates. This may be due to the presence of ripe berries in the feed.

The relation between percentage of damaged berries and peripheral velocity is given by the equation $y = ax^2 + bx + c$

where,

y = percentage of damaged berries, %;

x = peripheral velocity, m/min;

a and b = regression coefficients; and

c = regression constant.

The coefficients of the equations are presented in Appendix-F.

The capacity varied with respect to the peripheral velocity generally in the same manner in almost all cases. At lower peripheral velocities, the capacity was lower. Conversely, at higher peripheral velocities, the capacity was higher except in a few cases. The variation in capacities observed for the minimum and maximum peripheral velocity were not large. This made it clear that it was not necessary to increase the peripheral velocities considerably. The range selected for the peripheral velocity was enough to give maximum capacity.

The coefficients of the equations giving the relation between these two quantities are presented in Appendix-F. The general form of the equations is:

$y = ax^2 + bx + c$

where,

y = capacity, kg/h;

x = peripheral velocity, m/min;

a & b = regression coefficients; and

c = regression constant.

4.3 Effect of contact length

Contact lengths of 20, 23, 25, and 30 cm were selected and their interactions with the peripheral velocities of 230.9, 263.9, 296.9, and 329.9 m/min. and feed rates of 50, 40, 30, and 24 kg/h were noted.

The relationship between the contact length and the threshing efficiency, the percentage of damage, and the capacity could be expressed as:

$y = ax^2 + bx + c$

where,

y = threshing efficiency, %; or

percentage of damaged berries, %; or

capacity, kg/h;

x = contact length, cm;

a & b = regression coefficients; and

c = regression constant.

The coefficients of the equations are presented in Appendix-F.

The results of ANOVA of the three-factor factorial experiment conducted are shown in Tables 1, 2, and 3. It was seen that contact length exerted significant influence on the threshing efficiency, the percentage of damaged berries, and the capacity singly and in combination with the other independent variables.

The effect of the contact lengths on the threshing efficiency at the four levels of peripheral velocities and feed rates is shown in Figs.11 through 13.

The effect of length of contact on the threshing efficiency at the smallest peripheral velocity of 230.9 m/min. was, in general, opposite to that of the peripheral velocities of 263.9 , 296.9, and 329.9 m/min. It was observed that separation of some berries occurred in the clearance at the feed end which preceded the threshing area due to the inter-spike collision effected by the rotating drum. This effect was, however, controlled by the magnitude of the peripheral velocity and the bulk of the spikes in the clearance space. It was also seen that the separation of berries largely occurred in the constricted threshing space between the drum and the concave. At the lowest peripheral velocity of 230.9 m/min. and the contact length of 20 cm the percentage of threshing efficiency remained lower. In this set-up, the feed end clearance was larger and the radius of influence of the slowly rotating drum remained closer to the drum. Therefore, the quantity of berries separated was lower. Besides, a small contact length caused separation of only a small quantity of berries. As the contact length was increased, it contributed to an increase in the threshing efficiency. The separation of berries was also more at the feed end clearance due to increase in radius of influence of the drum. But, further increase in the contact length to 30 cm reduced the threshing efficiency mainly because of the least contribution from the feed end clearance. Though there was an increase in the quantum of threshing due to increase in contact length the contribution from the feed end clearance had decreased resulting in a reduction in the overall threshing efficiency than the earlier contact lengths of 23, and 25 cm.

But, at the peripheral velocities of 263.9, 296.9, and 329.9 m/min., the variation of threshing efficiency with respect to the contact length showed an opposing trend. At the contact length of 20 cm the threshing efficiency was more mainly at the feed end clearance. The higher peripheral velocities were responsible for increasing the radius of influence. Further increase in the contact length to 23 cm and 25 cm however caused a reduction in the threshing efficiency largely due to the reduction in the feed

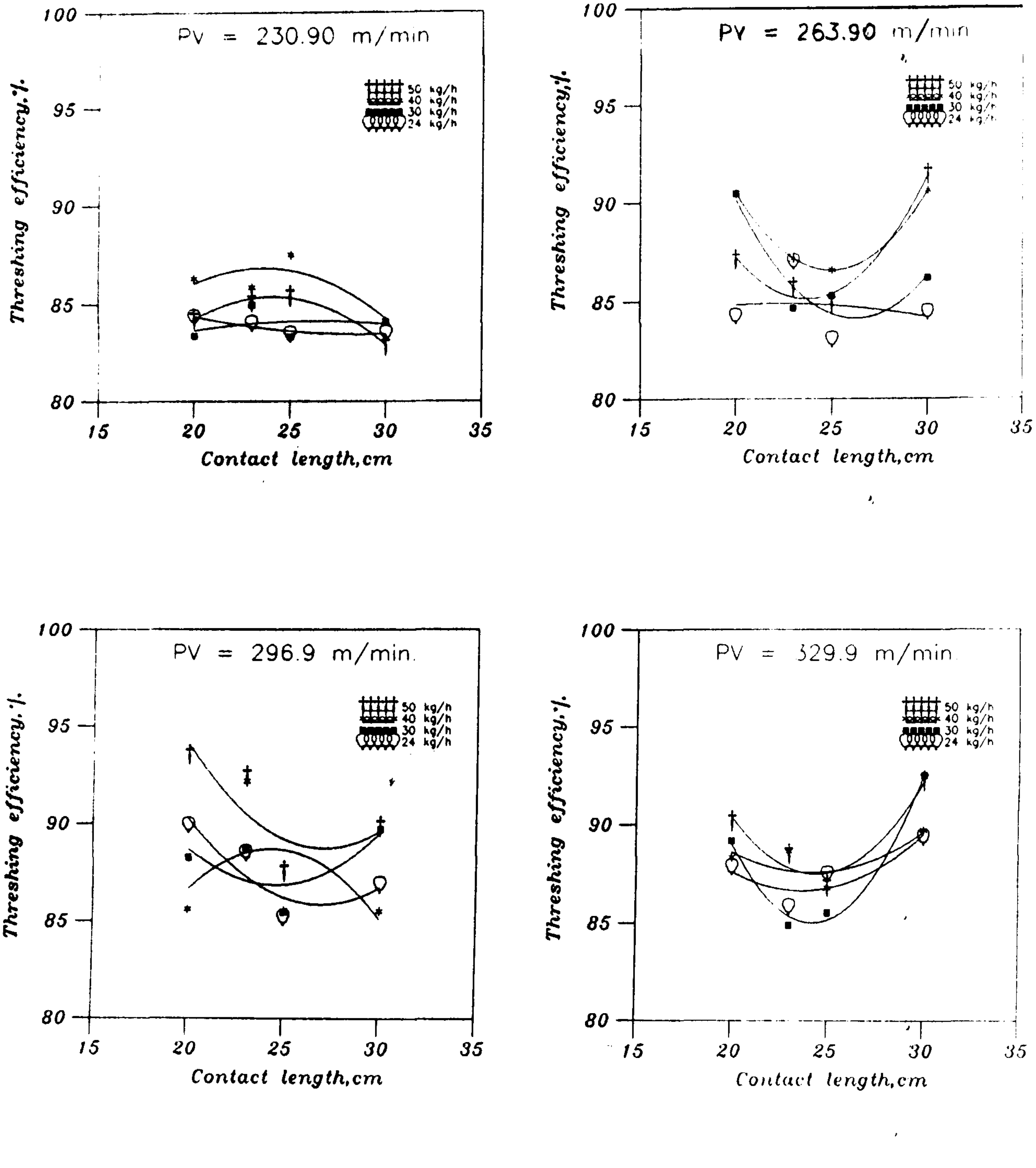


Fig. 11. Comparison of threshing efficiency with contact lengths at different feed rates and peripheral velocities

end clearance and the lesser bulk of the feedstock in that area. The increase in threshing due to the increase in contact length was not adequate enough to compensate for the reduction in threshing in the feed end clearance. However, threshing efficiency showed an increase at the contact length of 30 cm. Though there was a reduction in threshing in the feed end clearance, the increasing contact length coupled with the increase in peripheral velocities forced more separation of berries in the threshing area and substantially raised the threshing efficiency.

Therefore, when a peripheral velocity as small as 230.9 m/min. is used the contact length conducive for achieving the maximum threshing efficiency lies between 23, and 25 cm. At the same time, for peripheral velocities above 230.9 m/min. higher threshing efficiencies are attainable at contact lengths of 20 cm and below or at contact lengths of 30 cm and above.

The effect of different levels of contact lengths on the percentage of damaged berries at the four peripheral velocities are also presented (Fig. 12). The percentage of damaged berries was generally only in the range 0.05 to 0.55 %. This low extent of damage is very encouraging. The variation in the percentage of damaged berries with respect to the changes in the peripheral velocities and changes in the contact lengths at the peripheral velocities of 230.9, 263.9, 296.9, and 329.9 m/min. showed a random behaviour. Similarly, for the different levels of feed rates also the extent of damage was not significant. It showed a random behaviour. This was largely because of the presence of ripe berries and immature berries in varying proportions in the feedstock, the control of which was not possible. Further, the varietal homogeneity could not be achieved due to the heterogeneity in the plantations from where the feedstock was collected.

In general, it was observed that the capacity did not vary considerably with respect to the increase in the contact lengths at different peripheral velocities and feed rates. As expected, higher feed rates produced higher capacities. The relationship between contact length and capacity for the feed rate of 50 kg/h at the different

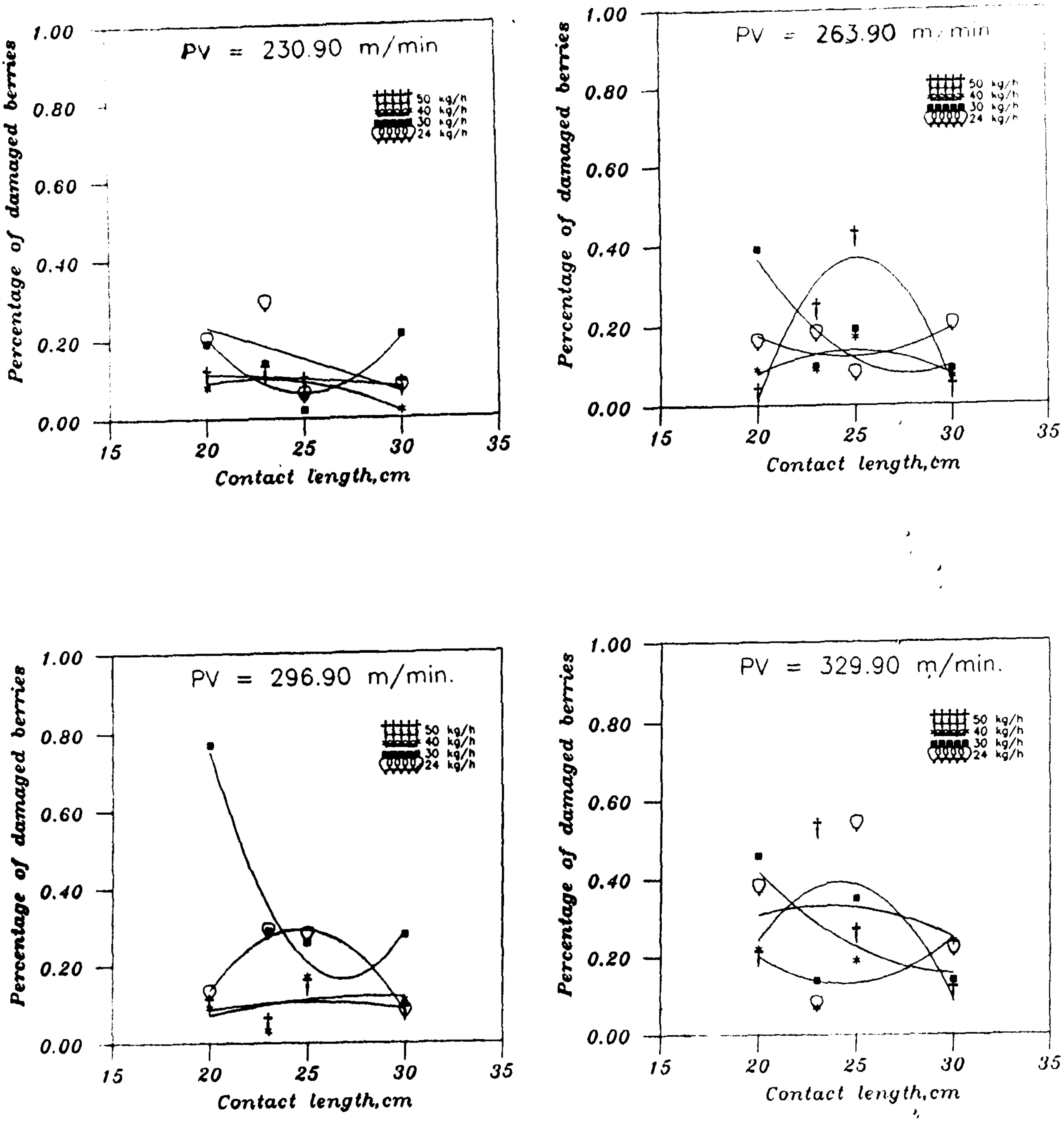


Fig. 12. Comparison of percentage of damaged berries with contact lengths at different feed rates and peripheral velocities

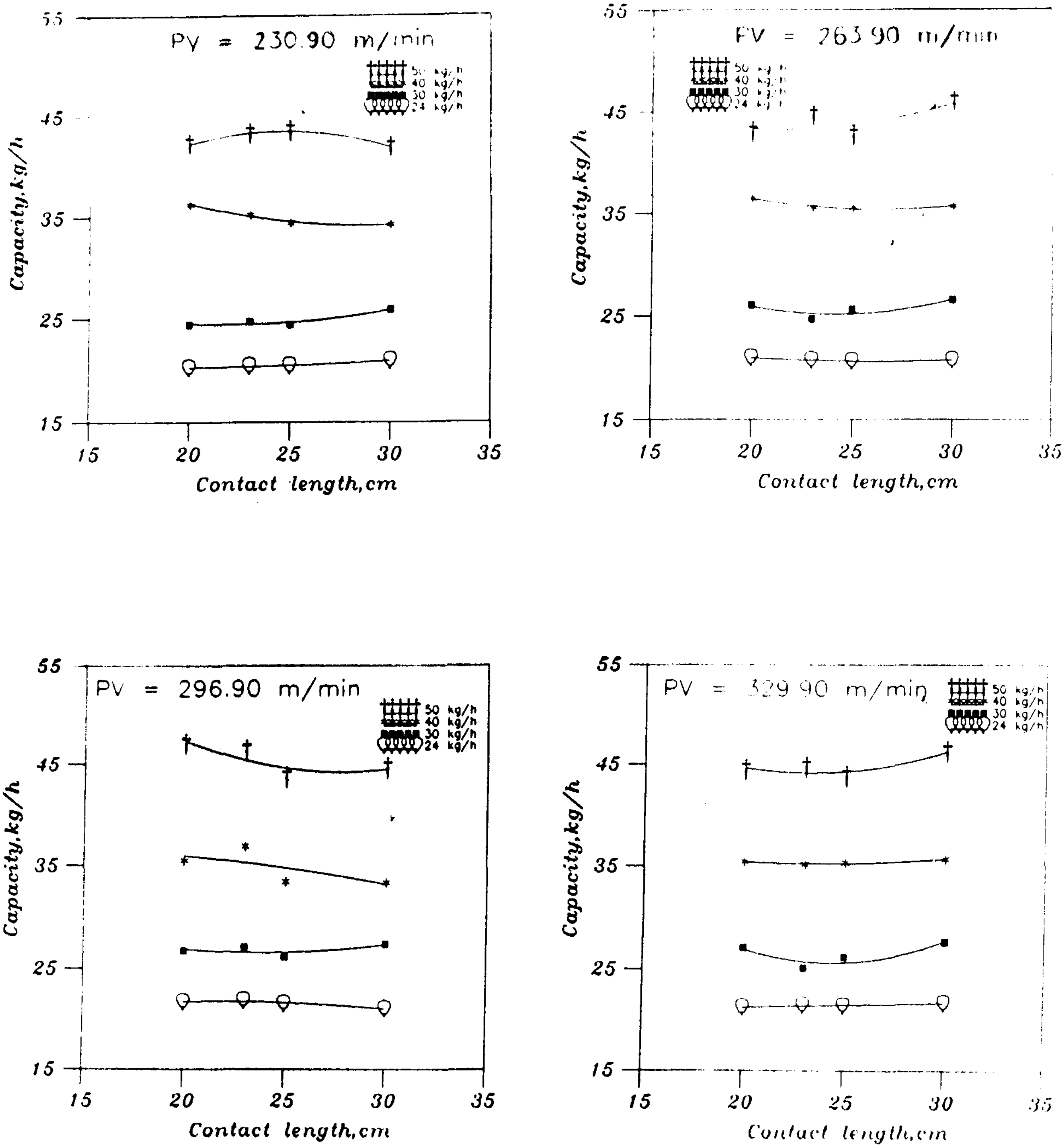


Fig. 13. Comparison of capacity with contact lengths at different feed rates and peripheral velocities

peripheral velocities showed varying trends. This was true for the feed rates of 40, and 24 kg/h This may be due to the fact that the levels selected for the contact lengths and the peripheral velocities were not enough to produce substantial and similar changes in the capacity.

The feed rate of 30 kg/h, however, showed a constant pattern of increase in the capacity towards a contact length of 30 cm after an initial reduction between 20 cm and 25 cm. This might be due to the fact that the feed rate of 30 kg/h was matching with the peripheral velocities and the contact lengths at their different levels.

4.4 Power Requirement

The power required to operate the thresher at no load and load conditions were noted and the data are presented in Appendix-G.

The power required to operate the thresher under no load varied from 0.32 hp to 0.35 hp whereas under load conditions it varied from 0.36 hp to 0.48 hp. The power requirement corresponding to the maximum efficiency of 93.52% was 0.46 hp.

An empirical relationship between the power requirement and the various machine parameters was developed by multiple regression analysis using the computer software Lotus 123. The observations and the results are presented in Appendix G.

The multiple linear regression equation was:

$$Y = 0.1841 + 0.00072\,F - 0.001\,L + 0.00081\,PV$$

where,

Y = power requirement, hp;

F = feed rate, kg/h;

L = contact length, cm; and

PV = peripheral velocity, m/min.

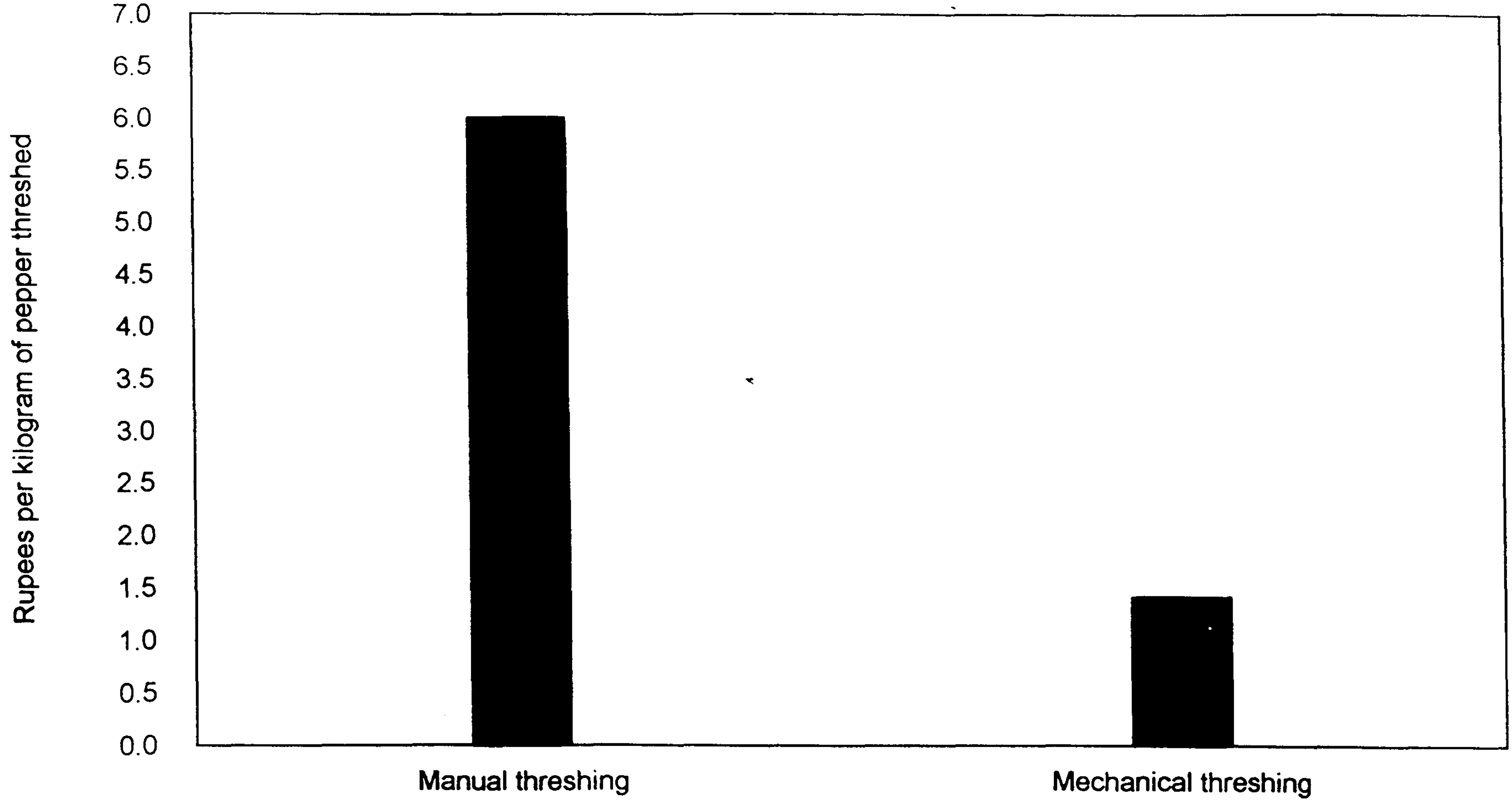


Fig. 14. Comparison of cost of manual threshing and mechanical threshing.

4.5 Cost of operation

The cost of operation of the this thresher was calculated and are presented in Appendix B

The cost of threshing one kilogram of pepper was only Rs 1.42. A comparison of the cost of manual threshing and that of threshing by the this thresher was also made (Fig.14). It was clear that the cost of operation for the this thresher was less.

This thresher could, therefore, be used in the threshing of pepper, making the operation more easy and efficient, alleviating the problems of labour shortage during the peak periods, and increasing the revenue earned by the farmer.

SUMMARY

SUMMARY

Black pepper is an important spice of India, earning the country Rs 70.07 crores as foreign exchange, during the year 1992-93. India produced 42,690 T of black pepper from an area of 1,74,870 ha in 1991. About 96 % of the total pepper produced by India comes from Kerala. It has a wide variety of uses in various forms.

Pepper production is however facing a crunch. Though India produces better quality pepper, the cost of production is high, thereby denying the farmer a commensurate revenue. The high cost of labour, shortage of labour during the peak periods, etc., seriously affect pepper production. Therefore, there is an urgent need for mechanising various operations involved in pepper cultivation and processing. One of the post-harvest operations to be mechanised immediately is threshing. Timely and proper threshing with machines ensures better quality of the end product.

A few models of pepper threshers were reported to have been developed in the country. The threshers developed by Mathew (1987), Marisamy (1992), and Ambujan and Ravikumar (1993) consisted of a rotating drum and concave. The padding material used in these was industrial rubber and this was found to be harmful. Further, detailed studies were seen not conducted on these threshers with regard to the operating parameters. So, this study was undertaken with the objective of developing an improved power operated pepper thresher and determining the operating parameters.

The thresher was fabricated at the KCAET workshop. It consisted of basically (i) a threshing drum and a concave lined with thermofoam (ii) a template to support and help in adjusting the concave clearance (iii) a sieve, and (iv) a collection tray.

The threshing drum made out of 18 gauge MS sheet was 210 mm wide and 300 mm in diameter. The drum shaft, 20 mm in diameter, was supported in bearings on the frame. The concave fabricated out of 18 gauge GI sheet covered the lower half of the drum. Both the drum and concave surfaces were covered with 15 mm thermofoam, as padding. Holes, 10 mm in diameter, were punched at a spacing of 2 cm centre to centre on the concave to allow removal of separated berries from the threshing zone.

A semicircular template, 700 mm long, made of 25 x 6 mm MS flat bar was riveted to the concave. Two MS flat pieces 25 x 6 mm in size, were bent and connected together by four equally spaced MS flat bars of 12 x 5 mm size and 210 mm length, to form a semicircular trough. Two bars at either ends completed the template. This adjustable concave template unit was fixed to the main frame and passing through slots in the crossbars provided on the main frame. This facilitated adjustment of the contact length.

A perforated screen of 8 mm holes was fixed on a 750 x 350 mm frame made of 25 x 25 x 5 mm MS angle to make the sieve. It was suspended from the main frame to enable manual oscillation. It helped to separate the berries from the larger chaff. A collection tray made of 22 gauge GI sheet, 565 mm long, was used to collect the separated berries.

The main frame was made of 35 x 35 x 5 mm MS angle bar with overall dimensions of 485 x 360 x 805 mm. The MS angle bars at the bottom were extended to a length of 800 mm to provide stability. Two wooden planks 540 x 55 x 28 mm were fixed at the bottom to mount the motor. Supports of 25 x 25 x 3 mm MS angle bars, 130 mm long, were screwed to the main frame, and slots, 75 mm long, were cut to allow vertical movement of the crossbar.

A 3-phase, 0.5-hp, variable speed motor was used as the prime mover, to run the thresher drum at the different speeds required in the study. A belt and pulley system transmitted the power to the cylinder shaft.

A 5-ampere ammeter and a 440-volts voltmeter were connected to the motor circuit in order to note the current and voltage readings required for determination of power requirement.

Pepper spikes were collected from the instructional farm of the College and from other local farms. A three-factor factorial experiment in CRD was adopted. The various factors and their levels were:-

I.	Independent Variables	
(i)	Peripheral Velocity (m/min.)	230.9, 263.9, 296.9, and 329.9
(ii)	Contact length (cm)	30, 25, 23, and 20
(iii)	Feed Rate (kg/h)	50, 40, 30, and 24

II. Dependent Variables

(i) Threshing Efficiency (%)

(ii) Percentage of damaged berries (%)

(iii) Capacity (kg/h)

(iv) Power requirement (W)

The number of experiments for the different factor-level combinations were 64. Each experiment was replicated thrice making the total number of experiments to be 4 x 4 x 4 x 3 = 192.

The spikes were fed into the thresher and the time required for threshing was noted. The materials from all outlets were collected and separated into different fractions such as the threshed berries, damaged berries, unthreshed spikes, partially threshed spikes, and partially threshed spikes with damaged berries, and their weights were recorded. The unthreshed and partly threshed spikes were again fed for threshing and the weight of their fractions were recorded separately. The threshing efficiency, percentage of damaged berries, and capacity were calculated. Power consumption was also calculated.

Generally, the threshing efficiency of the first pass was greater than the efficiency of the second pass. Percentage of damaged berries was found to be larger at higher cylinder speeds. Capacity was higher in the first pass because of the greater interference between the drum and the intact spikes.

Effect of feed rate:

The results of analyses of data indicated that feed rate exerted significant influence on the threshing efficiency, percentage of damaged berries, and capacity. In general, threshing efficiency showed an increasing trend on increasing feed rates, for the different contact lengths. It was observed that, for the smaller peripheral velocities of 230.9 and 263.9 m/min., the maximum threshing efficiency was obtained at a feed rate of about 40 kg/h. At the higher peripheral velocities of 296.9 and 329.9 m/min., the threshing efficiency was found to be higher only for the higher feed rates of 50 kg/h. The higher peripheral velocity accelerated the movement of the larger material bulk, thus improving threshing. The damage was found to be higher for the higher feed rate and at lower peripheral velocities. Due to choking of the material, the material tended to move largely by sliding which inflicted more abrasions on the berries. The presence of ripe berries in a lot increased damage. Generally, capacity increased with feed rate. For the same feed rates, the capacities did not vary much as the contact lengths were changed. Hence, among the four contact lengths tested, 20 cm could be selected for the design of the thresher.

Effect of peripheral velocity:

The results of the ANOVA of the factorial experiment showed that peripheral velocity had a significant influence on the threshing efficiency, percentage of damaged berries, and capacity. Threshing efficiency was influenced mostly by peripheral velocity. The combined effect of all the three variables also had a significant influence.

The threshing efficiency was found to increase up to a peripheral velocity of 296.9 m/min. beyond which it showed a decreasing trend. At lower peripheral velocities, the resulting smaller impact forces and shear forces caused lesser separation. As the peripheral velocity was increased the magnitude of these forces also increased; effecting more separation. The threshing efficiency reached its peak at approximately 300 m/min., beyond which it decreased. The spikes, after initial separation, moved faster through the clearance, thereby reducing threshing. Thus, a peripheral velocity of 300 m/min. could be selected for the operation of the thresher. The percentage of damaged berries was only in the range of 0.05 to 0.55 %., which by all means was encouraging. The occurrence of such insignificant levels of damage was due to the effect of the padding material used. The capacity generally increased with increase in peripheral velocities. The maximum variation in the capacity was 26.07 kg/h and the minimum variation in capacity was 22.91 kg/h. This showed that the range of peripheral velocities selected was enough to give maximum capacity.

Effect of contact length:

The results of the ANOVA of the factorial experiments conducted, showed that the contact length had significant influence on all the three dependent variables, namely, threshing efficiency, percentage of damaged berries, and capacity. The contact length, in combination with the other three independent variables, also showed a significant influence.

The relationship between contact length and threshing efficiency showed opposing trends when considering the peripheral velocity of 230.9 m/min. and the remaining, viz., 263.9, 296.9, and 329.9 m/min. At the lower peripheral velocity of 230.9 m/min., the figures indicated lower threshing efficiency at the contact lengths of 20 and 30 cm and higher threshing efficiency values at 23 and 25 cm. For the contact length of 20 cm, the larger feed-end clearance reduced the radius of influence of the rotating drum, thereby, decreasing the threshing. In the case of contact length of 30 cm, though the threshing due to passage of material through the constricted cylinder-concave clearance was more, there was a drastic reduction in the contribution from the feed end clearance and this reduced threshing efficiency. So, for a lower peripheral velocity of 230.9 m/min., threshing was best done at the contact lengths of 23 and 25 cm. When the peripheral velocities increased, the trend reversed. As the radius of influence increased due to increase in the peripheral velocities, threshing in the feed end clearance also increased. This increased the threshing efficiency at the contact length of 20 cm. The contact lengths of 23 and 25 cm showed a reduction in the threshing efficiency largely because of the reduction in the feed end clearance and the lesser bulk of the feed stock in that area. At the contact length of 30 cm, the reduction in feed end clearance was compensated by the increased contact length, which together with increased peripheral velocities , forced more separation and raised threshing efficiency substantially. For the higher peripheral velocities, maximum threshing efficiency was obtained at contact lengths of 20 and 30 cm. There was, however, a random pattern for the change in the percentage of damaged berries with the contact length. Small values of the damage indicated that the damage inflicted was negligible. The presence of ripe and immature berries in the feed stock increased the value of the percentage of damaged berries. The non-homogeneity of the feed material could be another reason for the random pattern of damage. Homogeneity was difficult to achieve because of the heterogeneity in the varieties cultivated. Capacity did not vary considerably with respect to the increase in contact length at the different peripheral velocities, and the feed rates selected in the study. Higher feed rates produced higher capacity. The condition of maximum threshing efficiency of 93.52% was obtained for a feed rate of 50 kg/h and a contact length of 20 cm.

The multiple regression equation developed for the prediction of the power requirement is:

$$Y = 0.1841 + 0.00072\,F - 0.001\,L + 0.00081\,PV$$

where,

Y = power requirement, hp;

F = feed rate, kg/h;

L = contact length, cm; and

PV = peripheral velocity, m/min.

The cost of threshing pepper using the this was only Rs 1.42 per kilogram. Against this, the cost of manual threshing was Rs 6.01 per kilogram. This showed that this thresher considerably increased the revenue earnings.

This thresher was suitable to thresh pepper faster and in a cleaner manner. It reduced the drudgery involved in the threshing operation and could be a solution to the labour shortage faced during the peak period. The cleaner end product would fetch better prices in the market, thereby improving the earnings of the farmer. Since the threshing operation is considerably faster, the farmer could also add to his revenue by hiring out his machine. Hence, it is clear that the mechanisation of the threshing of pepper with this thresher would significantly improve the revenue earned.

A few aspects could be considered by future researchers for further improvement of the machine. A larger capacity would be required to handle the crop produced from larger plantations. For this, the sizes of the drum and concave would have to be increased. A padding material with better food grade properties can be used to make the threshed product absolutely safe for human consumption.

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Appendix - A

Details of the precision balance used for measurement of weights

1	Manufacturer	-	CONTECH Instrument Company 32 & 33/2, Bhandup Industrial Estate Pannalal Compound, L.B.S Marg, Bhandup (West), Mumbai - 400 078.
2.	Type	-	CONTECH- Precision Balance- CB Series
3.	Description	-	Electronic Balance high accuracy Class II
4.	Model	-	CB 300, Class II
5.	Sr. No.	-	952434
6.	Capacity	-	300 g (Maximum) 200 mg (Minimum)
7.	Sensitivity	-	0.01 g
8.	Power	-	230 V AC, 50 Hz
9.	Temperature range	-	15° C - 40° C

Appendix - B

Cost of operation

Total Cost = Fixed Cost + Variable Cost

Approximate cost of the thresher:

Item	Quantity		Cost (Rs)
Prime Mover (0.5 hp, 3 phase, variable speed motor)	1 No.	=	8000.00
MS angles and flats	15 kg	=	1500.00
Nuts and Bolts	1 kg	=	50.00
V-belt	1 No.	=	150.00
Pulleys (2 nos.)	2 No.	=	200.00
GI sheet 18 gauge	4 ' x 4'	=	550.00
Thermofoam (Padding material)	1 m^2	=	100.00
Miscellaneous items		=	200.00
Labour charges		=	250.00
Total	**= P**	=	**11000.00**

Assumptions:

Extent of plantation	=	10 ha
Yield @ 300 kg/ha.	=	3000 kg = 3 T
Rated capacity of the thresher	=	48 kg/h
∴ No. of working hours	=	62.5 h
Expected number of working hours (H)	=	63 h

Life of the thresher (L)	=	10 years
Salvage value @ 10% of the total cost of the thresher (S)	=	Rs 1100.00
Rate of interest	=	15% per annum
Number of labourers	=	1

I. Fixed Cost:

1. Depreciation per hour

$$= \frac{(P-S)}{(L \times H)}$$

$$= (11000 - 1100) / (10 \times 63)$$

= Rs 15.71

2. Interest per hour

$$= \frac{(P+S) \times 15}{2 \times 100 \times H}$$

$$= (11000 + 1100)/2 \times 15/100 \times 1/63$$

= Rs 14.41

∴ Total Fixed Cost = Rs 15.71 + Rs 14.41

= Rs 30.12

II. Variable Cost:

1. Repair and maintenance charges (@ 10% of the total cost) per hour

$$= \frac{P \times 10}{H \times 100}$$

$$= 11000/63 \times 10/100$$

= Rs 17.46

2. Labour charges

Number of labourers	=	1
Working hours per day	=	6
Labour charges per day	=	Rs 120.00
Labour charges per hour	=	Rs 20.00

3. Energy consumption per hour = 0.34 W

Electricity charges per unit = Rs. 1.00

Electricity charges per hour	=	0.34 x 1
	=	Rs 0.34
∴ Total Variable Cost	=	Rs 37.80

Total cost of threshing per hour = Total Fixed Cost + Total Variable Cost

= 30.12 + 37.80

= Rs 67.92

∴ Cost of threshing per kilogram = Rs 1.42

Appendix - C

Cost of manual pepper threshing

Number of labourers	=	1
Working hours per day	=	6
Labour charges per day	=	Rs 120.00
∴ Labour charges per hour	=	Rs 20.00
Amount of pepper threshed per day	=	20 kg
∴ Amount of pepper threshed/hour	=	3.33 kg/h
Cost of threshing per kilogram	=	Rs 6.01

Appendix - D

Table D-1. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 50 kg/h
Contact Length: 20 cm

Feed Input for Pass I : 200 g
Feed Time for Pass I : 14 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	Overall	Pass I	Pass II	Overall	Pass I	Pass II	Overall
230.9	34.91	2.6	143.11	21.76	0.2	0.0	17.17	3.06	0.0	0.0	71.56	62.33	82.43	0.1	0.0	0.1	40.07	34.37	39.2
	37.34	2.7	149.63	24.32	0.1	0.19	29.26	11.87	0.0	0.0	74.82	65.13	86.98	0.05	0.51	0.14	44.72	48.25	45.28
	36.28	2.6	144.74	21.97	0.13	0.0	27.15	5.63	0.0	0.0	72.37	60.56	83.36	0.06	0.0	0.06	42.97	38.22	42.24
263.9	34.27	2.5	154.17	20.87	0.1	0.0	20.8	3.21	0.0	0.0	77.08	60.9	87.52	0.05	0.0	0.05	43.74	34.68	42.4
	37.07	2.7	156.11	21.1	0.0	0.0	20.8	3.21	0.0	0.0	78.06	56.92	88.61	0.0	0.0	0.0	46.07	36.09	44.49
	34.88	2.5	151.27	19.1	0.1	0.0	21.2	5.4	0.0	0.0	75.64	54.76	85.19	0.05	0.0	0.05	43.12	35.28	41.96
296.9	11.87	0.9	173.12	10.77	0.25	0.0	9.7	0.0	0.0	0.0	86.56	90.73	91.94	0.13	0.0	0.13	45.7	43.08	45.55
	20.16	1.5	176.25	13.29	0.35	0.0	19.14	3.92	0.0	0.0	88.14	65.92	94.78	0.17	0.0	0.17	48.85	41.3	48.14
	20.15	1.5	171.27	16.41	0.0	0.0	20.15	0.0	0.0	0.0	85.64	81.44	93.84	0.0	0.0	0.0	47.85	39.38	47.06
329.9	20.3	1.5	169.93	15.8	0.39	0.0	16.12	0.73	0.0	0.0	84.96	77.83	92.86	0.19	0.0	0.19	46.51	39.67	45.87
	31.75	2.3	154.51	20.82	0.58	0.0	18.8	1.68	0.0	0.0	77.25	65.57	87.66	0.29	0.0	0.29	43.33	35.22	42.21
	24.61	1.8	165.52	14.55	0.2	0.02	21.71	2.23	0.0	0.0	82.76	59.12	90.04	0.1	0.08	0.11	46.81	33.56	45.34

Table D-2. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 50 kg/h
Contact Length: 23 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 14 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	II pass	II pass	I pass	II pass	I pass	II pass	I pass	II pass	I pass	II pass	I pass	II pass	Overall	I pass	II pass	Overall	I pass	II pass	Overall
230.9	10.75	0.7	166.26	3.06	0.0	0.0	10.75	2.71	0.0	0.0	83.13	28.47	84.66	0.00	0.00	0.00	44.25	29.67	43.58
	5.75	0.4	170.32	1.24	0.0	0.1	5.16	1.43	0.59	0.0	85.16	21.57	85.78	0.00	1.74	0.05	44.02	24.03	43.48
	12.04	0.9	163.45	6.53	0.0	0.0	9.88	1.97	0.0	0.0	81.72	54.24	84.99	0.00	0.00	0.00	43.33	34.00	42.78
263.9	29.49	2.1	148.09	20.11	0.39	0.0	24.66	5.78	0.0	0.0	74.04	68.19	84.10	0.19	0.00	0.19	43.19	44.38	43.34
	31.44	2.3	151.3	19.34	0.0	0.0	29.19	6.36	0.0	0.0	75.65	61.51	85.32	0.00	0.00	0.00	45.12	40.23	44.45
	28.83	2.1	157.13	18.48	0.2	0.2	28.22	6.17	0.61	0.0	78.57	64.10	87.81	0.10	0.69	0.20	46.49	42.26	45.95
296.9	7.63	0.6	174.46	3.06	0.09	0.1	5.75	1.93	1.88	0.0	88.68	46.45	91.66	0.00	0.00	0.00	46.48	32.04	45.63
	6.87	0.5	176.75	2.19	0.2	0.0	6.87	1.06	0.0	0.0	90.79	29.79	92.36	0.00	0.00	0.00	47.55	29.11	46.58
	8.11	0.6	171.4	3.27	0.0	0.0	8.11	0.0	0.0	0.91	91.48	37.70	93.32	0.15	0.00	0.15	48.18	24.58	47.09
329.9	12.83	0.9	177.35	5.96	0.0	0.0	8.57	2.05	0.0	0.0	87.23	40.10	88.76	0.05	1.31	0.09	45.52	29.94	44.90
	10.54	0.8	181.58	3.14	0.0	0.0	8.61	3.33	0.0	0.0	88.38	31.88	89.47	0.10	0.00	0.10	45.90	23.40	45.15
	9.76	0.7	182.96	3.68	0.3	0.0	9.76	1.1	0.0	0.0	85.70	40.32	87.33	0.00	0.00	0.00	44.88	25.08	44.09

Table D-3. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 50 kg/h
Contact Length: 25 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 14 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	Pass I	Pass II	Pass I	Pass II	Overall	PassI	Pass II	Overall	Pass I	Pass II	Overall
	26.39	1.9	149.03	18.03	0.26	0.11	24.19	4.81	0.0	0.0	74.51	68.32	83.53	0.13	0.42	0.19	43.31	43.28	43.30
230.9	40.12	2.9	137.74	33.11	0.13	0.0	30.24	3.03	0.0	0.0	68.87	82.53	85.43	0.06	0.00	0.06	42.00	44.86	42.48
	29.48	2.1	152.14	22.6	0.0	0.0	27.3	3.17	0.0	0.0	76.07	76.66	87.37	0.00	0.00	0.0	44.86	44.18	44.77
	46.32	3.3	138.96	26.42	0.41	0.55	29.83	12.35	1.33	0.0	69.48	57.04	82.69	0.20	1.19	0.48	42.53	42.29	42.49
263.9	32.1	2.3	146.67	24.41	0.0	0.0	21.38	1.99	0.0	0.0	73.33	76.04	85.54	0.00	0.0	0.0	42.01	41.32	41.92
	40.2	2.9	142.52	30.67	0.2	0.0	32.54	2.98	0.0	0.0	71.26	76.29	86.60	0.10	0.0	0.1	43.76	41.77	43.43
	41.27	3.0	146.24	29.49	0.91	0.0	29.11	4.2	0.0	0.0	73.12	71.46	87.87	0.46	0.0	0.46	43.84	40.43	43.25
296.9	38.09	2.7	149.82	26.15	0.0	0.0	27.46	5.85	0.0	0.0	74.91	68.65	87.99	0.00	0.0	0.0	44.32	42.67	44.06
	32.36	2.3	152.63	20.91	0.0	0.0	25.98	3.76	0.0	0.0	76.32	64.62	86.77	0.00	0.0	0.0	44.65	38.61	43.82
	21.48	1.6	160.07	10.76	0.45	0.33	19.07	5.8	0.0	0.0	80.04	50.09	85.42	0.22	1.54	0.39	44.79	37.26	44.03
329.9	23.18	1.7	165.97	10.86	0.26	0.0	18.94	3.94	0.0	0.0	82.99	46.85	88.42	0.13	0.0	0.13	46.23	31.34	44.66
	37.71	2.7	149.16	24.43	0.24	0.3	25.65	4.18	0.0	0.0	74.58	64.78	86.79	0.12	0.8	0.27	43.70	38.15	42.83

Table D-4. Threshing efficiency, extent of damage of berries, and capacity obtained at different peripheral velocities.

Feed Rate: 50 kg/h
Contact length: 30 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 14 s

Peripheral Velocity (m/min)	Feed Input (gm)	Feed Time (sec.)	Berries Threshed (gm)		Damaged Berries (gm)		Partially Threshed Spikes (gm)		Partially Threshed Spikes with Damaged Berries (gm)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	Overall	Pass I	Pass II	Overall	Pass I	Pass II	Overall
230.9	12.21	0.9	153.43	6.39	0.4	0.0	12.21	1.7	0.0	0.0	76.71	52.33	79.91	0.2	0.0	0.2	41.41	32.36	40.88
	16.16	1.2	158.02	15.24	0.04	0.0	13.53	0.13	0.0	0.0	79.01	94.31	86.63	0.02	0.0	0.02	42.89	46.11	43.14
	12.96	0.9	156.15	7.91	0.02	0.0	11.64	0.97	0.0	0.0	78.07	61.03	82.03	0.01	0.0	0.01	41.95	35.52	41.57
263.9	15.54	1.1	171.5	12.38	0.13	0.0	15.54	1.94	0.0	0.0	85.75	79.67	91.94	0.06	0.0	0.06	46.76	46.87	46.77
	17.49	1.3	169.65	12.87	0.0	0.0	13.79	1.07	0.0	0.0	84.82	73.58	91.26	0.0	0.0	0.0	45.86	38.6	45.26
	15.71	1.1	169.1	13.1	0.11	0.0	15.71	0.0	0.0	0.0	84.55	83.39	91.1	0.05	0.0	0.05	46.2	42.87	45.97
296.9	11.62	0.8	171.12	7.54	0.4	0.0	9.19	2.3	0.0	0.0	85.56	64.89	89.33	0.2	0.0	0.2	45.08	44.28	45.04
	17.15	1.2	168.93	13.66	0.0	0.0	9.93	0.54	0.0	0.0	84.46	79.65	91.29	0.0	0.0	0.0	44.71	42.6	44.55
	11.65	0.8	169.24	8.68	0.05	0.0	8.13	1.01	0.0	0.0	84.62	74.51	88.96	0.03	0.0	0.03	44.34	43.6	44.30
329.9	14.28	1.0	178.16	11.81	0.13	0.0	11.51	0.0	0.0	0.0	89.08	82.7	94.99	0.06	0.0	0.06	47.42	42.52	47.1
	10.32	0.7	173.85	4.96	0.3	0.0	9.2	2.14	0.0	0.0	86.93	48.06	89.41	0.15	0.0	0.15	45.76	36.51	45.33
	12.1	0.9	177.63	7.09	0.19	0.0	12.1	1.2	0.0	0.0	88.82	58.6	92.36	0.09	0.0	0.09	47.43	33.16	46.59

Table D-5. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities

Feed Rate: 40 kg/h
Contact Length: 20 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 18 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing efficiency (%)			Damaged berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	Overall	PassI	Pass II	Overall	PassI	Pass II	Overall
230.9	42.60	3.8	147.31	28.75	0.22	0.06	41.50	6.03	0.00	0.00	73.65	67.49	88.03	0.11	0.14	0.14	37.76	32.95	36.92
	36.77	3.3	148.25	20.98	0.18	0.00	36.77	9.13	0.00	0.00	74.13	57.06	84.61	0.09	0.00	0.09	37.00	32.85	36.36
	30.93	2.8	152.11	20.44	0.00	0.00	28.63	4.32	0.00	0.00	76.06	66.08	86.28	0.00	0.00	0.00	36.15	31.83	35.57
263.9	18.35	1.7	171.45	9.12	0.32	0.00	14.20	3.40	0.00	0.00	85.72	49.70	90.28	0.16	0.00	0.16	37.13	26.51	36.21
	14.68	1.3	174.28	6.22	0.00	0.00	14.68	2.10	0.00	0.00	87.14	42.37	90.25	0.00	0.00	0.00	37.79	23.04	36.80
	13.58	1.2	175.65	6.00	0.24	0.00	10.72	0.97	0.00	0.00	87.82	44.18	90.82	0.12	0.00	0.12	37.27	20.91	36.25
296.9	25.07	2.3	159.74	12.02	0.26	0.02	21.97	6.55	0.00	0.00	79.87	47.95	85.88	0.13	0.08	0.14	36.34	29.07	35.52
	22.91	2.1	161.23	10.68	0.00	0.01	20.11	4.32	0.00	0.00	80.61	46.62	85.96	0.00	0.04	0.00	36.27	25.71	35.17
	20.28	1.8	160.99	8.96	0.22	0.00	20.28	6.77	0.00	0.00	80.50	44.18	84.98	0.11	0.00	0.11	36.25	31.46	35.82
329.9	26.96	2.4	166.03	12.37	0.44	0.19	17.73	4.53	0.00	0.00	83.01	45.88	89.20	0.22	0.70	0.31	36.75	25.35	35.41
	33.42	3.0	150.00	19.27	0.40	0.00	25.31	6.37	0.00	0.00	75.00	57.66	84.64	0.20	0.00	0.20	35.06	30.77	34.45
	20.63	1.9	169.99	12.19	0.28	0.00	16.11	3.15	0.00	0.00	85.00	59.09	91.09	0.14	0.00	0.14	37.22	29.07	36.44

Table D-6. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 40 kg/h
Contact Length: 23 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 18 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	PassI	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	Overall	PassI	Pass II	Overall	PassI	Pass II	Overall
230.9	52.05	4.7	140.16	31.13	0.20	0.40	41.85	11.12	0.00	0.00	70.08	59.81	85.65	0.10	0.77	0.30	36.40	32.36	35.57
	48.47	4.4	142.27	30.02	0.10	0.00	40.13	6.87	0.00	0.00	71.14	61.94	86.15	0.05	0.00	0.05	36.48	30.18	35.24
	46.35	4.2	140.45	31.10	0.12	0.00	38.93	5.06	0.00	0.00	70.22	67.10	85.78	0.06	0.00	0.06	35.88	30.99	34.95
263.9	32.59	2.9	149.24	21.17	0.34	0.01	24.00	8.80	0.00	0.00	74.62	64.96	85.21	0.17	0.03	0.17	34.65	37.20	35.00
	32.79	3.0	154.91	22.04	0.15	0.00	28.17	4.59	0.00	0.00	77.46	67.22	88.48	0.08	0.00	0.08	36.62	31.96	35.95
	29.91	2.7	155.18	20.41	0.01	0.00	24.32	4.60	0.00	0.00	77.59	68.24	87.79	0.00	0.00	0.00	35.90	33.35	35.57
296.9	27.15	2.4	160.08	20.52	0.14	0.17	17.72	1.32	0.00	0.00	80.04	75.58	90.30	0.07	0.63	0.16	35.56	32.76	35.23
	19.67	1.8	163.15	9.83	0.10	0.00	12.93	4.38	0.00	0.00	81.57	49.97	86.49	0.05	0.00	0.05	35.22	28.42	34.60
	23.88	2.2	164.11	14.01	0.00	0.00	17.99	4.64	0.00	0.00	82.06	58.67	89.06	0.00	0.00	0.00	36.42	30.52	35.785
329.9	11.27	1.0	177.11	6.02	0.06	0.00	7.73	1.30	0.00	0.00	88.56	53.42	91.57	0.03	0.00	0.03	36.97	26.35	36.41
	14.64	1.3	177.63	7.10	0.10	0.00	13.39	2.40	0.00	0.00	88.82	48.50	92.37	0.05	0.00	0.05	38.20	26.31	37.40
	12.02	1.1	179.13	5.97	0.00	0.00	10.56	0.00	0.00	0.00	89.57	49.67	92.55	0.00	0.00	0.00	37.94	19.54	36.88

Table D-7. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 40 kg/h
Contact Length: 25 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 18 sec.

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	PassI	Pass II	Pass I	Pass II	Overall	PassI	Pass II	Overall	PassI	Pass II	Overall
230.9	34.94	3.2	154.47	23.78	0.11	0.13	20.53	3.52	0.00	0.00	77.24	68.06	89.13	0.05	0.37	0.12	35.00	30.71	34.35
	28.63	2.6	159.93	16.70	0.00	0.00	18.13	4.31	0.00	0.00	79.96	58.33	88.31	0.00	0.00	0.00	35.61	29.09	34.79
	28.28	2.6	156.44	14.25	0.12	0.00	19.38	5.17	0.00	0.00	78.22	50.39	85.35	0.06	0.00	0.06	35.16	26.89	34.12
263.9	36.46	3.3	154.26	18.76	0.45	0.29	29.61	6.52	0.00	0.00	77.13	51.45	86.51	0.22	0.80	0.37	36.77	27.58	35.35
	38.39	3.5	149.30	22.17	0.30	0.00	32.23	6.94	0.00	0.00	74.65	57.75	85.74	0.15	0.00	0.15	36.31	29.94	35.27
	40.99	3.7	149.82	25.21	0.00	0.00	33.78	7.56	0.00	0.00	74.91	61.50	87.51	0.00	0.00	0.00	36.72	31.88	35.90
296.9	36.39	3.3	147.74	16.57	0.00	0.00	24.71	7.91	0.00	0.00	73.87	45.53	82.15	0.00	0.00	0.00	34.49	26.71	33.28
	39.08	3.5	145.58	21.87	0.29	0.24	28.11	6.56	0.00	0.00	72.79	55.96	83.72	0.14	0.61	0.26	34.74	29.24	33.84
	39.92	3.6	144.31	19.17	0.20	0.00	28.77	7.10	0.00	0.00	72.15	48.02	81.74	0.10	0.00	0.10	34.62	26.27	33.22
329.9	38.23	3.4	148.57	21.29	0.45	0.10	29.69	8.54	0.00	0.00	74.29	55.69	84.93	0.22	0.26	0.28	35.65	31.58	35.01
	41.55	3.7	149.98	27.38	0.30	0.15	32.28	3.56	0.00	0.00	74.99	65.90	88.68	0.15	0.36	0.23	36.45	30.10	35.37
	40.08	3.6	150.20	23.06	0.10	0.00	35.07	5.78	0.00	0.00	75.10	57.53	86.63	0.05	0.00	0.05	37.05	28.84	35.68

Table D-8. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 40 kg/h
Contact Length: 30 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 18 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (s)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	Pass I	Pass II	Overall	PassI	Pass II	Overall	Pass I	Pass II	Overall
	28.48	2.6	151.31	15.56	0.00	0.00	19.32	4.99	0.00	0.00	75.65	54.63	83.43	0.00	0.00	0.00	34.13	28.45	33.41
230.9	25.08	2.3	157.20	10.72	0.09	0.00	20.41	6.28	0.00	0.00	78.60	42.74	83.96	0.05	0.00	0.05	35.52	26.61	34.51
	39.81	3.6	147.24	22.70	0.00	0.00	32.90	5.95	0.00	0.00	73.62	57.02	84.97	0.00	0.00	0.00	36.03	28.65	34.80
	22.40	2.0	164.06	16.22	0.19	0.00	16.64	1.95	0.00	0.00	82.03	72.41	90.14	0.09	0.00	0.09	36.14	32.71	35.80
263.9	20.60	1.9	164.70	16.74	0.00	0.23	12.53	0.48	0.00	0.00	82.35	81.26	90.72	0.00	1.12	0.12	35.45	32.63	35.18
	21.32	1.9	167.10	14.72	0.00	0.00	15.67	1.20	0.00	0.00	83.55	69.04	90.91	0.00	0.00	0.00	36.55	30.16	35.94
	27.77	2.5	144.93	16.91	0.25	0.29	17.83	3.39	0.00	0.00	72.46	60.89	86.23	0.13	1.04	0.27	32.55	29.23	32.15
296.9	29.82	2.7	149.93	18.66	0.10	0.00	23.17	5.84	0.00	0.00	74.96	62.58	84.29	0.05	0.00	0.05	34.62	32.67	34.37
	26.63	2.4	150.60	14.15	0.00	0.00	19.38	6.28	0.00	0.00	75.30	53.14	85.38	0.00	0.00	0.00	34.00	30.64	33.60
	24.25	2.2	167.57	14.25	0.31	0.00	20.61	1.00	0.00	0.00	83.79	58.76	90.91	0.16	0.00	0.16	37.64	24.95	36.25
329.9	14.43	1.3	163.44	10.93	0.00	0.70	9.73	0.37	0.00	0.00	81.72	75.74	87.18	0.00	4.85	0.35	34.63	31.29	34.41
	23.52	2.1	169.14	12.95	0.00	0.40	18.57	3.26	0.00	0.00	84.57	55.06	91.04	0.00	1.70	0.20	37.54	27.79	36.52

Table D-9. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 30 kg/h
Contact Length: 20 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 24 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (s)	Berries Threshed, (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	Overall	Pass I	Pass II	Overall	PassI	Pass II	Overall
230.9	18.66	2.2	161.18	7.6	0.25	0.0	11.12	3.26	0.0	0.0	80.59	40.73	84.39	0.13	0.00	0.13	25.84	17.77	25.17
	14.81	1.8	157.24	6.89	0.25	0.0	12.13	1.37	0.0	0.0	78.62	46.52	82.07	0.13	0.00	0.13	25.41	16.52	24.79
	32.77	3.7	150.92	16.37	0.0	0.01	18.32	7.32	0.63	0.0	75.46	49.95	83.64	0.00	0.03	0.00	25.48	23.05	25.16
263.9	35.69	4.3	157.64	27.71	0.65	0.25	17.85	5.13	0.0	0.0	78.82	77.08	92.579	0.32	0.70	0.45	26.32	27.33	26.48
	31.34	3.8	150.69	26.5	1.05	0.36	20.58	1.11	0.0	0.0	75.35	84.56	88.60	0.52	1.15	0.70	25.69	26.16	25.75
	32.39	3.9	156.17	24.15	0.03	0.0	18.93	2.08	0.0	0.0	78.08	74.56	90.16	0.01	0.00	0.01	26.26	24.21	25.98
296.9	11.5	1.4	167.98	7.4	0.42	0.01	8.93	0.58	0.57	0.0	83.99	64.35	87.69	0.21	0.09	0.21	26.62	20.52	26.29
	22.41	2.7	160.36	14.75	0.53	0.19	19.22	2.68	0.84	0.32	80.18	65.82	87.56	0.26	0.85	0.36	27.06	23.67	26.72
	15.4	1.8	169.32	9.65	0.33	0.2	12.53	1.97	1.19	0.0	84.66	62.66	89.49	0.17	1.30	0.27	27.46	23.24	27.16
329.9	27.24	3.3	160.55	19.22	0.63	0.17	21.74	2.39	0.0	0.0	80.28	70.48	89.88	0.31	0.62	0.40	27.34	23.55	26.89
	21.66	2.5	166.66	10.42	0.71	0.0	17.86	6.77	0.0	0.0	83.33	48.11	88.54	0.35	0.00	0.35	27.68	24.75	27.40
	21.08	2.5	165.41	12.75	0.24	0.08	16.97	3.34	0.92	0.0	82.71	60.48	89.08	0.12	0.38	0.16	27.49	23.17	27.09

Table D-10. Threshing efficiency, extent of damage of berries and capacity at different peripheral velocities.

Feed Rate: 30 kg/h
Contact Length: 23 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 24 s

Peripheral Velocity (m/min.)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes With Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	PassI	Pass II	Overall	Pass I	Pass II	Overall	PassI	Pass II	Overall
230.9	39.64	4.8	151.43	17.6	0.51	0.11	21.4	9.41	0.0	0.0	75.71	44.40	84.51	0.25	0.28	0.31	25.92	20.26	24.98
	29.54	3.5	154.79	15.41	0.17	0.0	13.21	4.83	0.0	0.0	77.39	52.17	85.10	0.09	0.00	0.09	25.20	20.82	24.64
	40.09	4.8	149.13	21.43	0.01	0.0	20.68	6.56	0.0	0.0	74.57	53.45	85.28	0.00	0.00	0.00	25.47	20.99	24.73
263.9	29.75	3.6	157.54	12.99	0.23	0.0	17.41	6.47	0.0	0.0	78.77	43.66	85.26	0.12	0.00	0.12	26.24	19.46	25.36
	26.12	3.1	157.22	10.46	0.0	0.0	10.83	4.33	0.0	0.0	78.61	40.05	83.84	0.00	0.00	0.00	25.21	17.18	24.29
	24.09	2.9	162.09	7.5	0.35	0.0	9.5	3.61	0.0	0.0	81.04	31.13	84.79	0.17	0.00	0.17	25.74	13.79	24.45
296.9	24.71	3.0	169.26	11.22	0.58	0.46	20.92	5.17	0.0	0.0	84.63	45.41	90.24	0.29	1.86	0.52	28.53	19.67	27.54
	20.26	2.4	166.25	2.95	0.36	0.0	15.52	5.2	0.0	0.0	83.13	14.56	84.60	0.18	0.00	0.18	27.27	12.22	25.90
	18.82	2.3	169.52	8.1	0.33	0.0	16.57	4.07	0.0	0.0	84.76	43.04	88.81	0.17	0.00	0.17	27.91	19.05	27.14
329.9	23.64	2.8	158.81	11.91	0.45	0.0	12.79	5.4	0.0	0.0	79.40	50.38	85.36	0.22	0.00	0.22	25.74	22.26	25.38
	22.74	2.7	160.41	9.87	0.0	0.0	10.97	4.09	0.0	0.0	80.21	43.40	85.14	0.00	0.00	0.00	25.71	18.61	24.99
	28.37	3.4	153.64	14.68	0.38	0.0	17.86	3.68	0.0	0.0	76.82	51.74	84.16	0.19	0.00	0.19	25.72	19.44	24.95

Table D-11. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 30 kg/h
Contact Length: 25 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 24 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (s)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	Overall	PassI	Pass II	Overall	PassI	Pass II	Overall
230.9	36.01	4.3	154.15	15.67	0.0	0.0	20.45	6.63	0.0	0.0	77.07	43.52	84.91	0.00	0.00	0.00	26.19	18.67	25.05
	33.54	4.0	150.62	16.81	0.03	0.0	21.41	5.79	0.0	0.0	75.31	50.12	83.71	0.01	0.00	0.01	25.80	20.34	25.02
	28.4	3.4	152.53	9.98	0.09	0.0	10.93	3.56	0.0	0.0	76.26	35.14	81.25	0.05	0.00	0.05	24.52	14.34	23.26
263.9	22.54	2.7	163.48	9.23	0.28	0.51	15.53	2.42	0.0	0.0	81.74	40.99	86.35	0.14	2.26	0.39	26.85	15.53	25.71
	37.24	4.5	150.05	21.39	0.15	0.0	26.58	7.45	0.0	0.0	75.03	57.44	85.72	0.08	0.00	0.08	26.49	23.07	25.95
	18.35	2.2	161.13	6.35	0.19	0.0	12.95	3.5	0.0	0.0	80.57	34.60	83.74	0.09	0.00	0.09	26.11	16.12	25.27
296.9	29.43	3.5	153.99	14.45	0.69	0.0	20.92	7.33	0.0	0.0	77.00	49.10	84.22	0.34	0.00	0.34	26.24	22.40	25.75
	33.26	4.0	151.4	20.47	0.0	0.15	26.76	4.51	0.0	0.0	75.70	61.55	85.93	0.00	0.45	0.08	26.72	22.48	26.12
	30.38	3.6	154.63	17.8	0.03	0.13	25.53	4.97	0.54	0.0	77.32	58.59	86.22	0.01	0.43	0.08	27.10	22.77	26.54
329.9	23.36	2.8	160.66	14.07	0.18	0.09	17.86	1.75	0.0	0.0	80.33	60.23	87.37	0.09	0.39	0.14	26.78	20.34	26.11
	18.18	2.2	163.3	7.03	0.16	0.02	17.41	3.66	0.77	0.0	81.65	38.67	85.17	0.08	0.11	0.09	27.22	17.49	26.41
	21.69	2.6	156.31	11.81	0.43	0.4	21.69	2.41	0.0	0.0	78.15	54.45	84.06	0.22	1.84	0.42	26.70	19.69	26.01

Table D-12. Threshing efficiency, extent of damage of berries and capacity at different peripheral velocities.

Feed Rate: 30 kg/h
Contact Length: 30 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 24 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (s)	Berries Threshed, (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	II pass	II pass	I pass	II pass	I pass	II pass	I pass	II pass	I pass	II pass	I pass	II pass	Overall	I pass	II pass	Overall	I pass	II pass	Overall
230.9	13.43	1.6	157.09	7.06	0.71	0.0	14.99	1.12	0.29	0.0	78.54	52.57	82.07	0.35	0.00	0.35	25.86	18.40	25.39
	22.14	2.7	156.11	13.74	0.23	0.0	20.96	2.65	0.0	0.0	78.06	62.06	84.93	0.12	0.00	0.12	26.54	21.85	26.08
	25.39	3.1	157.3	13.1	0.0	0.0	21.62	6.03	0.0	0.0	78.65	51.60	85.20	0.00	0.00	0.00	26.84	22.22	26.31
263.9	28.54	3.4	160.7	15.28	0.46	0.0	22.86	4.3	0.0	0.0	80.35	53.54	87.99	0.23	0.00	0.23	27.53	20.73	26.69
	25.78	3.1	150.68	10.4	0.05	0.0	22.08	6.25	0.0	0.0	77.34	40.34	82.54	0.03	0.00	0.03	26.51	19.34	25.69
	26.89	3.2	159.32	16.75	0.0	0.0	25.64	4.6	0.0	0.0	79.66	62.29	88.04	0.00	0.00	0.00	27.74	24.02	27.31
296.9	9.08	1.1	173.67	4.08	0.44	0.01	8.51	1.77	0.52	0.0	86.83	44.93	88.88	0.22	0.11	0.22	27.40	19.15	27.04
	12.36	1.5	176.56	5.12	0.41	0.0	12.36	1.86	0.0	0.0	88.28	41.42	90.84	0.20	0.00	0.20	28.34	16.75	27.66
	15.21	1.8	170.93	7.91	0.28	0.0	15.21	2.4	0.0	0.0	85.46	52.01	89.42	0.14	0.00	0.14	27.92	20.62	27.41
329.9	9.35	1.1	179.35	5.01	0.56	0.0	9.35	1.2	0.0	0.0	89.68	53.58	92.18	0.28	0.00	0.28	28.31	20.32	27.96
	6.41	0.8	183.6	2.82	0.3	0.0	6.41	0.0	0.0	0.0	91.80	43.99	93.21	0.15	0.00	0.15	28.50	12.69	27.99
	5.56	0.7	183.14	1.03	0.0	0.0	1.33	0.0	0.0	0.0	91.57	18.53	92.08	0.00	0.00	0.00	27.67	5.30	27.04

Table D-13. Threshing efficiency, extent of damage of berries and capacity at different peripheral velocities.

Feed Rate: 24 kg/h
Contact Length: 20 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 30 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	Pass I	Pass II	Overall	PassI	Pass II	Overall	PassI	Pass II	Overall
230.9	42.23	6.3	146.48	24.17	0.53	0.46	24.38	3.45	0.0	0.0	73.24	57.23	85.32	0.26	1.09	0.50	20.50	15.78	19.68
	41.8	6.3	142.83	20.49	0.0	0.0	33.24	10.44	0.0	0.0	71.42	49.02	81.66	0.00	0.00	0.00	21.13	17.67	20.53
	40.25	6.0	147.53	21.43	0.21	0.0	27.89	6.07	0.0	0.0	73.76	53.24	84.48	0.10	0.00	0.10	21.05	16.50	20.29
263.9	35.69	5.4	152.85	17.69	0.44	0.09	25.4	9.06	0.0	0.0	76.43	49.57	85.27	0.22	0.25	0.26	21.39	17.83	20.85
	35.08	5.3	150.62	15.81	0.4	0.0	24.32	11.18	0.0	0.0	75.31	45.07	83.21	0.20	0.00	0.20	20.99	18.33	20.59
	35.34	5.3	154.20	14.28	0.0	0.0	29.04	11.45	0.0	0.0	77.10	40.41	84.24	0.00	0.00	0.00	21.99	17.48	21.31
296.9	28.82	2.8	172.17	9.2	0.27	0.14	11.94	1.62	0.0	0.0	86.08	48.88	90.68	0.14	0.74	0.21	22.09	13.91	21.39
	12.83	1.9	174.36	5.19	0.19	0.0	12.83	2.36	0.0	0.0	87.18	40.45	89.78	0.09	0.00	0.09	22.46	14.31	21.98
	10.92	1.6	175.08	3.54	0.13	0.0	10.92	1.44	0.0	0.0	87.54	32.42	89.31	0.06	0.00	0.06	22.32	11.20	21.76
329.9	17.88	2.7	167.56	8.49	1.02	3.16	15.87	2.41	0.0	0.0	83.78	47.48	88.03	0.51	0.89	0.59	22.01	14.53	21.39
	30.77	4.6	155.31	16.55	0.38	0.29	20.39	5.34	0.0	0.0	77.65	53.79	85.93	0.19	0.94	0.33	21.08	17.13	20.56
	26.42	4.0	163.17	15.80	0.40	0.0	23.58	2.93	0.0	0.0	81.58	59.80	89.49	0.20	0.00	0.20	22.41	16.86	21.76

Table D-14. Threshing efficiency, extent of damage of berries and capacity at different peripheral velocities.

Feed Rate: 24 kg/h
Contact Length: 23 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 30 s

Peripheral velocity (m/min)	Feed input (g)	Feed time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes With Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	Pass I	Pass II	PassI	Pass II	Overall	PassI	Pass II	Overall	PassI	Pass II	Overall
230.9	47.45	7.1	140.54	23.72	0.79	0.28	32.56	12.65	0.0	0.0	70.27	49.99	82.13	0.40	0.59	0.54	20.77	18.44	20.33
	49.47	7.4	139.45	31.72	0.38	0.0	33.85	6.44	0.0	0.0	69.72	64.12	85.58	0.19	0.00	0.19	20.80	18.56	20.35
	53.42	8.0	135.54	33.15	0.29	0.0	40.29	8.63	0.0	0.0	67.77	62.06	84.35	0.14	0.00	0.14	21.10	18.80	20.62
263.9	34.23	5.1	153.27	20.83	0.45	0.29	14.34	6.30	0.0	0.0	76.64	60.85	87.05	0.22	0.85	0.37	20.11	19.15	19.97
	31.81	4.8	156.06	16.83	0.32	0.0	19.67	8.11	0.0	0.0	78.03	52.91	86.44	0.16	0.00	0.16	21.09	18.70	20.76
	33.22	5.0	156.91	18.17	0.0	0.0	25.02	7.36	0.0	0.0	78.46	54.70	87.54	0.00	0.00	0.00	21.83	18.38	21.34
296.9	23.55	3.5	160.37	18.6	0.44	0.17	17.2	0.0	0.0	0.0	80.18	78.98	89.49	0.22	0.72	0.31	21.31	19.13	21.08
	29.17	3.5	160.03	13.44	0.39	0.0	29.17	8.66	0.0	0.0	80.01	46.07	86.74	0.19	0.00	0.19	22.70	18.08	22.11
	32.23	4.8	158.22	20.24	0.0	0.15	31.65	5.50	0.58	0.0	79.11	62.80	89.23	0.00	0.47	0.08	22.85	19.30	22.36
329.9	31.49	4.7	155.56	17.19	0.13	0.0	27.88	7.07	0.0	0.0	77.78	54.59	86.38	0.06	0.00	0.06	22.01	18.58	21.55
	31.13	4.7	154.43	15.27	0.0	0.0	26.75	8.19	0.0	0.0	77.21	49.05	84.85	0.00	0.00	0.00	21.74	17.97	21.23
	31.32	4.7	155.00	17.47	0.20	0.0	31.32	5.06	0.0	0.0	77.50	55.78	86.24	0.10	0.00	0.10	22.36	17.26	21.67

Table D-15. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

Feed Rate: 24 kg/h
Contact Length: 25 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 30 s

Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	Pass I	Pass II	Overall	PassI	Pass II	Overall	I pass	II pass	Overall
230.9	46.65	7.0	142.21	27.74	0.34	0.0	35.1	8.01	0.0	0.0	71.11	59.46	84.98	0.17	0.00	0.17	21.28	18.39	20.73
	42.73	6.4	145.1	20.44	0.0	0.0	30.63	10.99	0.0	0.0	72.55	47.84	82.77	0.00	0.00	0.00	21.09	17.68	20.49
	43.68	6.6	145.01	20.19	0.0	0.0	29.36	9.81	0.0	0.0	72.50	46.22	82.60	0.00	0.00	0.00	20.92	16.36	20.10
263.9	38.63	5.8	149.16	18.54	0.23	0.0	28.52	11.17	0.0	0.0	74.58	47.99	83.85	0.12	0.00	0.12	21.32	18.44	20.85
	34.43	5.2	151.2	14.33	0.0	0.0	23.2	7.54	0.0	0.0	75.60	41.62	82.76	0.00	0.00	0.00	20.93	15.14	20.07
	35.07	5.3	149.93	14.94	0.22	0.0	20.68	11.23	0.0	0.0	74.96	42.60	82.43	0.11	0.00	0.11	20.47	17.78	20.07
296.9	30.26	4.5	156.74	12.77	0.0	0.0	22.85	9.93	0.0	0.0	78.37	42.20	84.76	0.00	0.00	0.00	21.55	18.16	21.11
	27.03	4.1	158.97	12.65	0.33	0.0	27.03	6.39	0.0	0.0	79.49	46.80	85.81	0.17	0.00	0.17	22.32	16.72	21.65
	29.93	4.5	159.03	10.93	0.29	0.10	28.92	9.76	0.96	0.0	79.51	36.52	84.98	0.14	0.33	0.19	22.67	16.55	21.87
329.9	20.44	3.1	165.22	7.78	0.32	0.10	19.28	4.52	1.16	0.0	82.61	38.06	86.50	0.16	0.49	0.21	22.28	14.28	21.53
	17.42	2.6	168.91	8.06	0.0	0.09	17.09	0.66	0.33	0.0	84.46	46.27	88.49	0.00	0.52	0.05	22.36	12.07	21.54
	10.79	1.6	170.67	4.08	0.44	0.0	10.79	0.32	0.0	0.0	85.33	37.81	87.38	0.22	0.00	0.22	21.78	9.90	21.17

Table D-16. Threshing efficiency, extent of damage of berries, and capacity at different peripheral velocities.

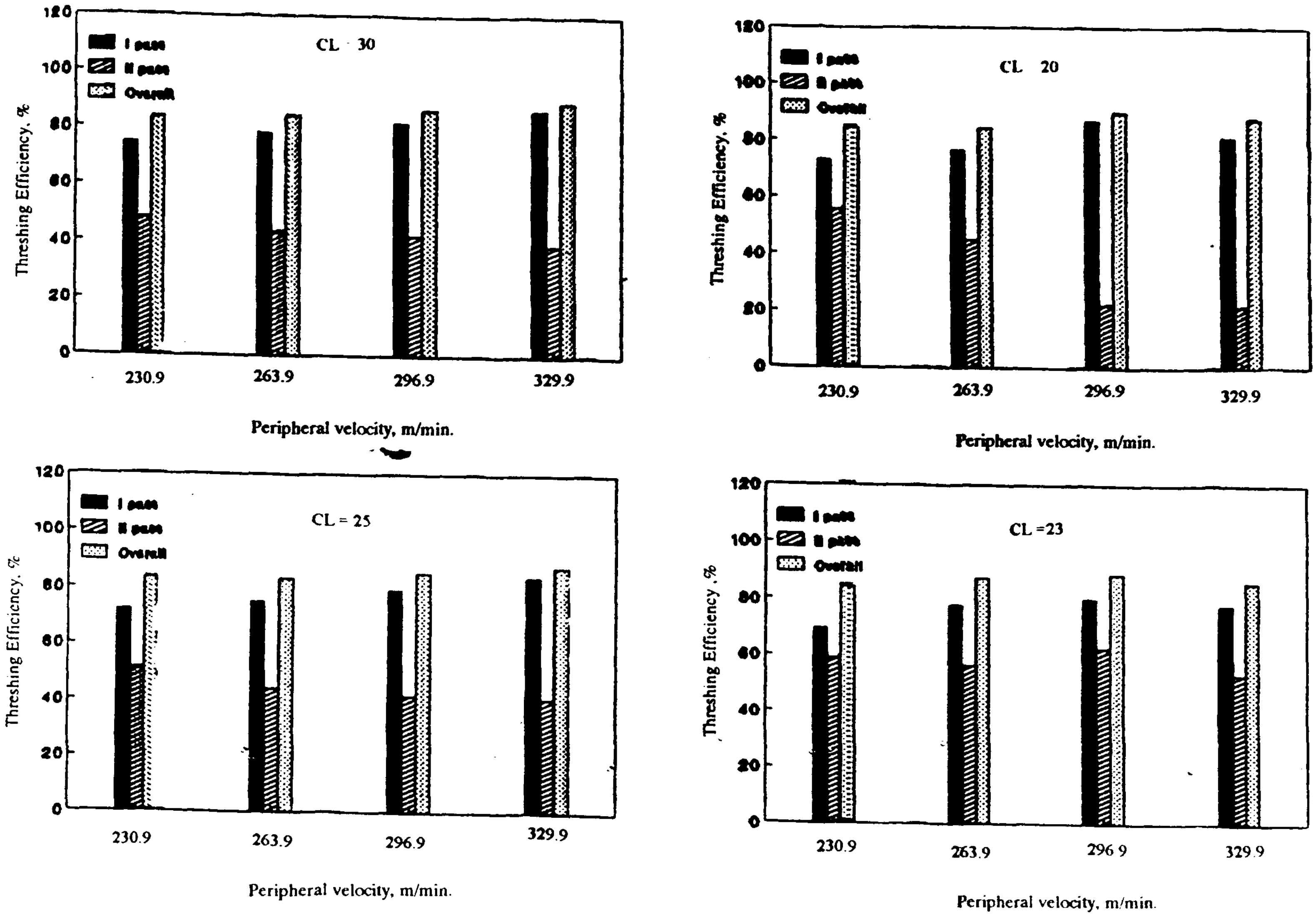
Feed Rate: 24 kg/h
Contact Length: 30 cm

Feed Input for Pass I: 200 g
Feed Time for Pass I: 30 s

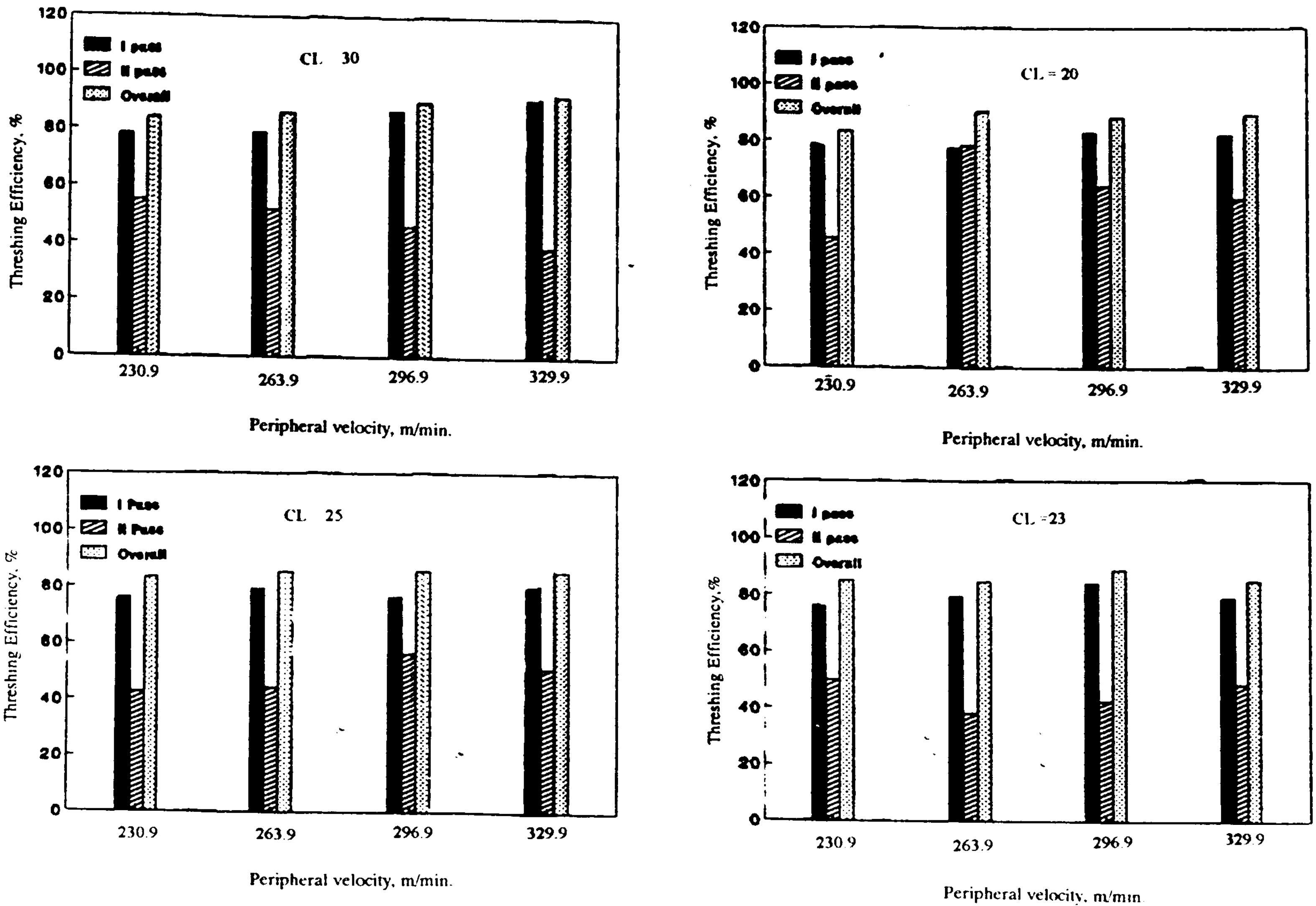
Peripheral Velocity (m/min)	Feed Input (g)	Feed Time (sec.)	Berries Threshed (g)		Damaged Berries (g)		Partially Threshed Spikes (g)		Partially Threshed Spikes with Damaged Berries (g)		Threshing Efficiency (%)			Damaged Berries (%)			Capacity (kg/h)		
	Pass II	Pass II	Pass I	Pass II	PassI	Pass II	PassI	Pass II	PassI	Pass II	Pass I	Pass II	Overall	PassI	Pass II	Overall	Pass I	Pass II	Overall
230.9	40.05	6.0	147.09	19.11	0.0	0.0	22.98	8.36	0.0	0.0	73.54	47.72	83.10	0.00	0.00	0.00	20.41	16.48	19.75
	36.01	5.4	150.77	16.96	0.18	0.0	23.52	5.97	0.0	0.0	75.39	47.10	83.87	0.09	0.00	0.09	20.91	15.29	20.06
	36.21	5.4	149.13	17.87	0.27	0.0	21.66	6.08	0.0	0.0	74.57	49.35	83.50	0.14	0.00	0.14	20.49	15.97	19.80
263.9	29.1	4.4	154.36	9.77	0.42	0.0	18.73	9.5	0.0	0.0	77.18	33.57	82.07	0.21	0.00	0.21	20.77	15.77	20.13
	25.13	3.8	157.93	11.65	0.4	0.0	16.53	5.73	0.0	0.0	78.96	46.36	84.79	0.20	0.00	0.20	20.94	16.47	20.43
	31.22	4.7	157.0	15.85	0.0	0.1	26.69	7.44	0.29	0.0	78.50	50.77	86.43	0.00	0.32	0.05	22.08	17.84	21.50
296.9	17.9	2.7	165.48	6.68	0.23	0.13	15.76	4.31	0.0	0.0	82.74	37.32	86.08	0.12	0.73	0.18	21.75	14.65	21.16
	27.2	4.1	160.79	12.13	0.11	0.0	18.17	6.23	0.0	0.0	80.39	44.60	86.46	0.05	0.00	0.05	21.48	16.12	20.83
	24.2	3.6	165.11	11.01	0.0	0.0	15.43	5.49	0.0	0.0	82.56	45.50	88.06	0.00	0.00	0.00	21.66	16.50	21.11
329.9	15.83	2.4	173.4	4.55	0.56	0.2	12.2	4.44	0.0	0.0	86.70	28.74	88.97	0.28	1.26	0.38	22.27	13.48	21.62
	11.03	1.7	176.38	5.33	0.36	0.0	9.96	0.0	0.0	0.0	88.19	48.32	90.86	0.18	0.00	0.18	22.36	11.29	21.77
	15.31	2.3	170.27	6.23	0.19	0.0	15.31	2.63	0.0	0.0	85.14	40.69	88.25	0.09	0.00	0.09	22.27	13.87	21.67

Appendix-E

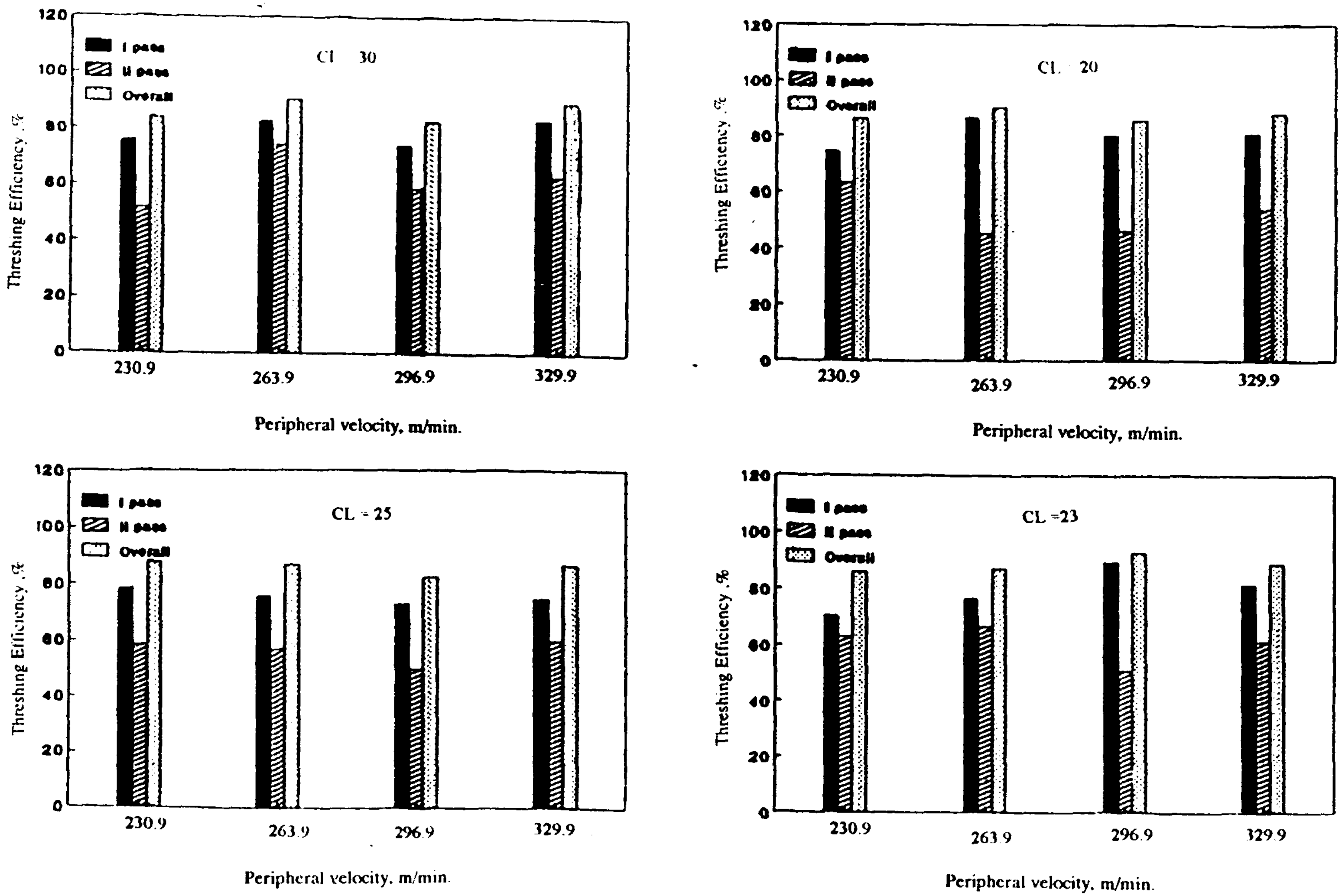
E.1 Comparison of the values of the threshing efficiency with the drum speed at the four contact lengths at the feed rate of 24 kg/h.



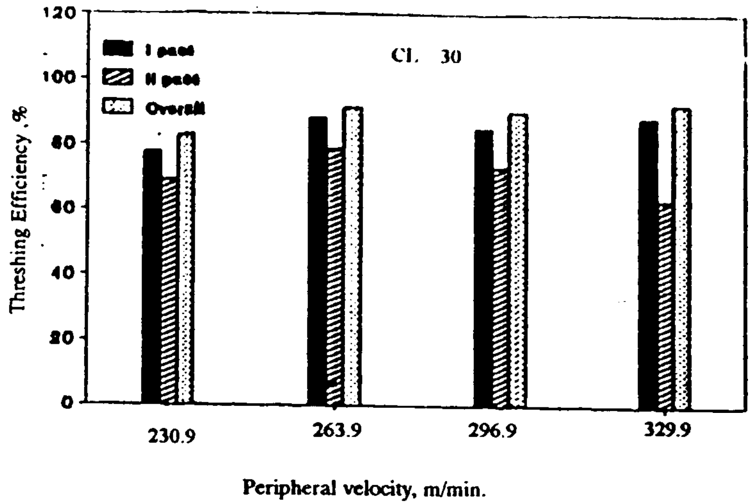
E.2 Comparison of the values of the threshing efficiency with the drum speed at the four contact lengths at the feed rate of 30kg/h.

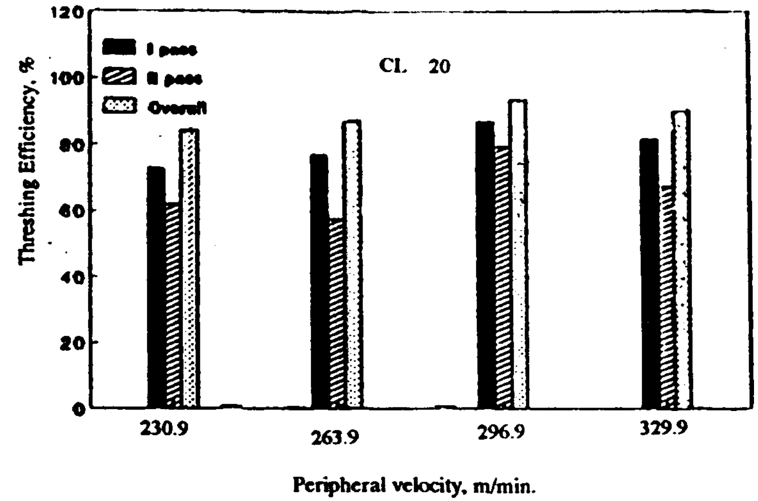


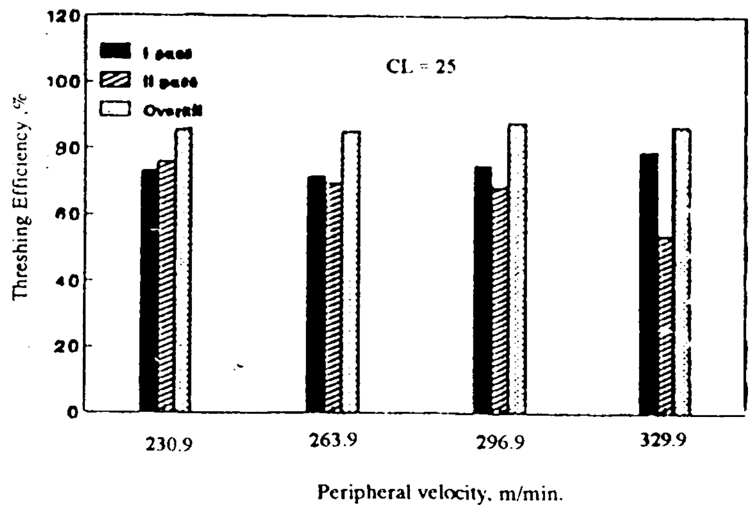
E.3 Comparison of the values of the threshing efficiency with the drum speed at the four contact lengths at the feed rate of 40kg/h.

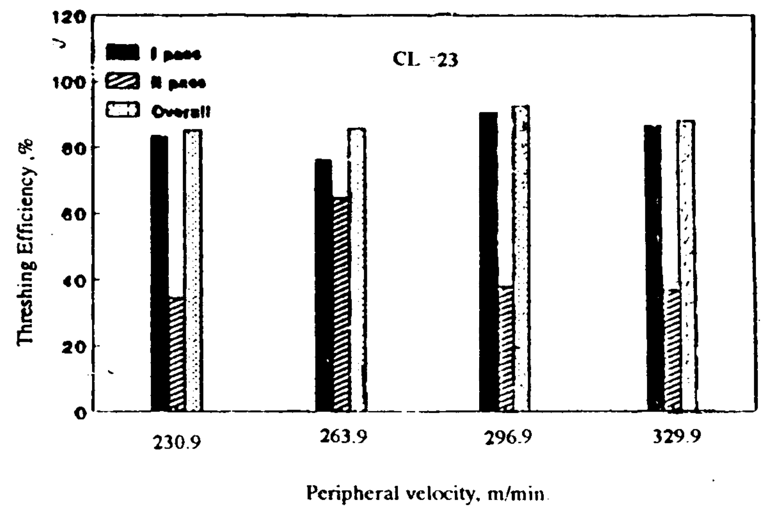


E.4 Comparison of the values of the threshing efficiency with the drum speed at the four contact lengths at the feed rate of 50kg/h.

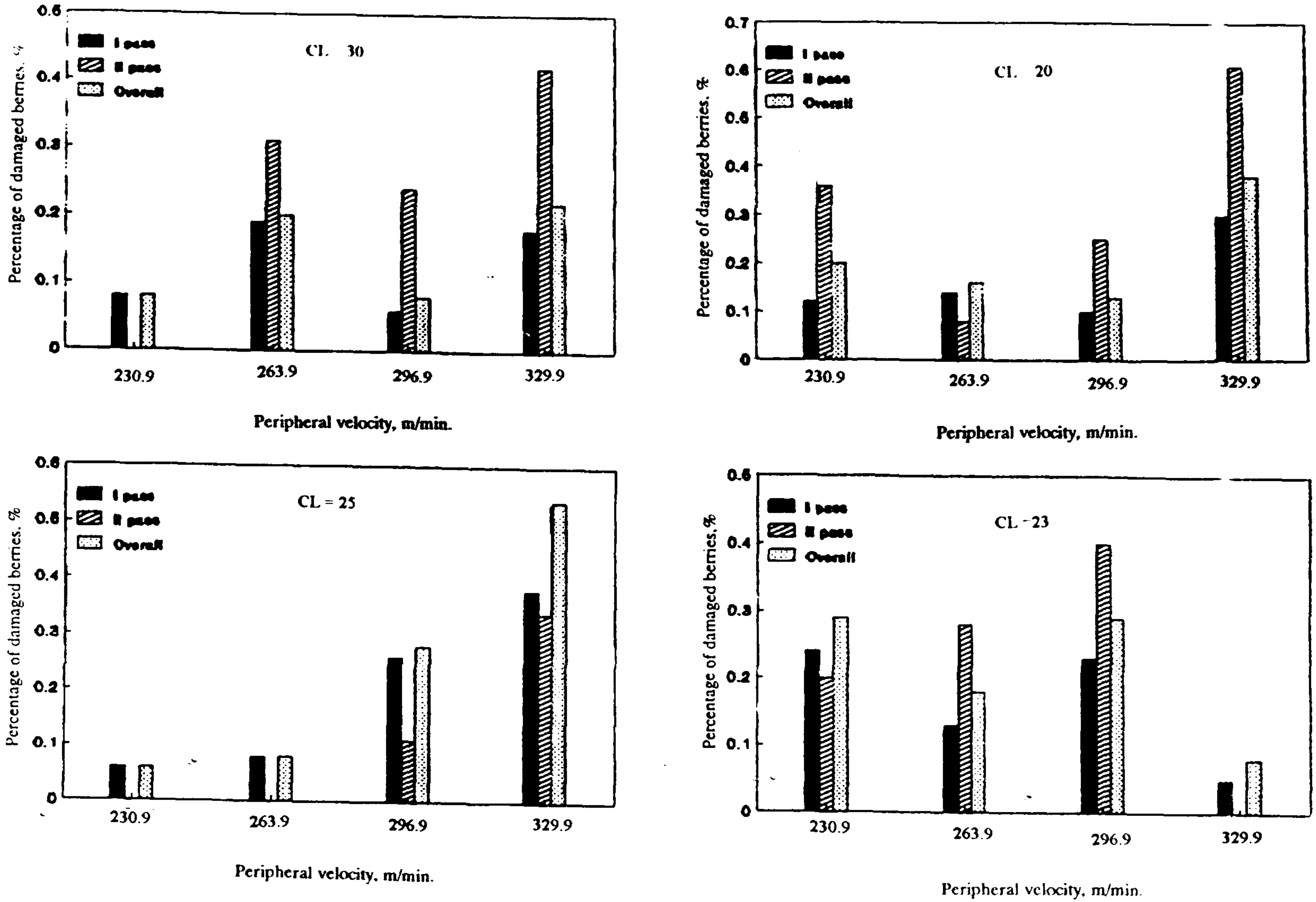




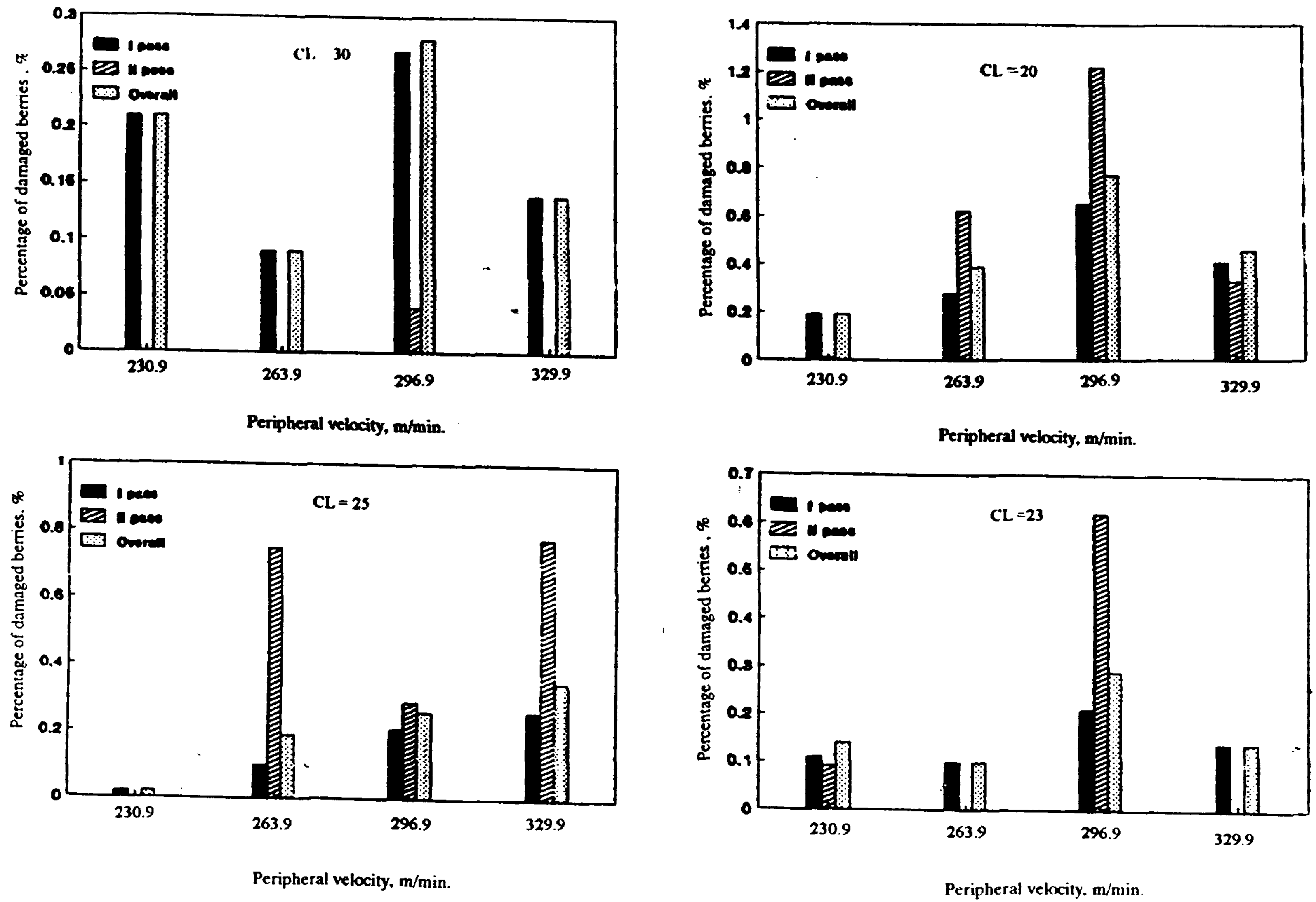




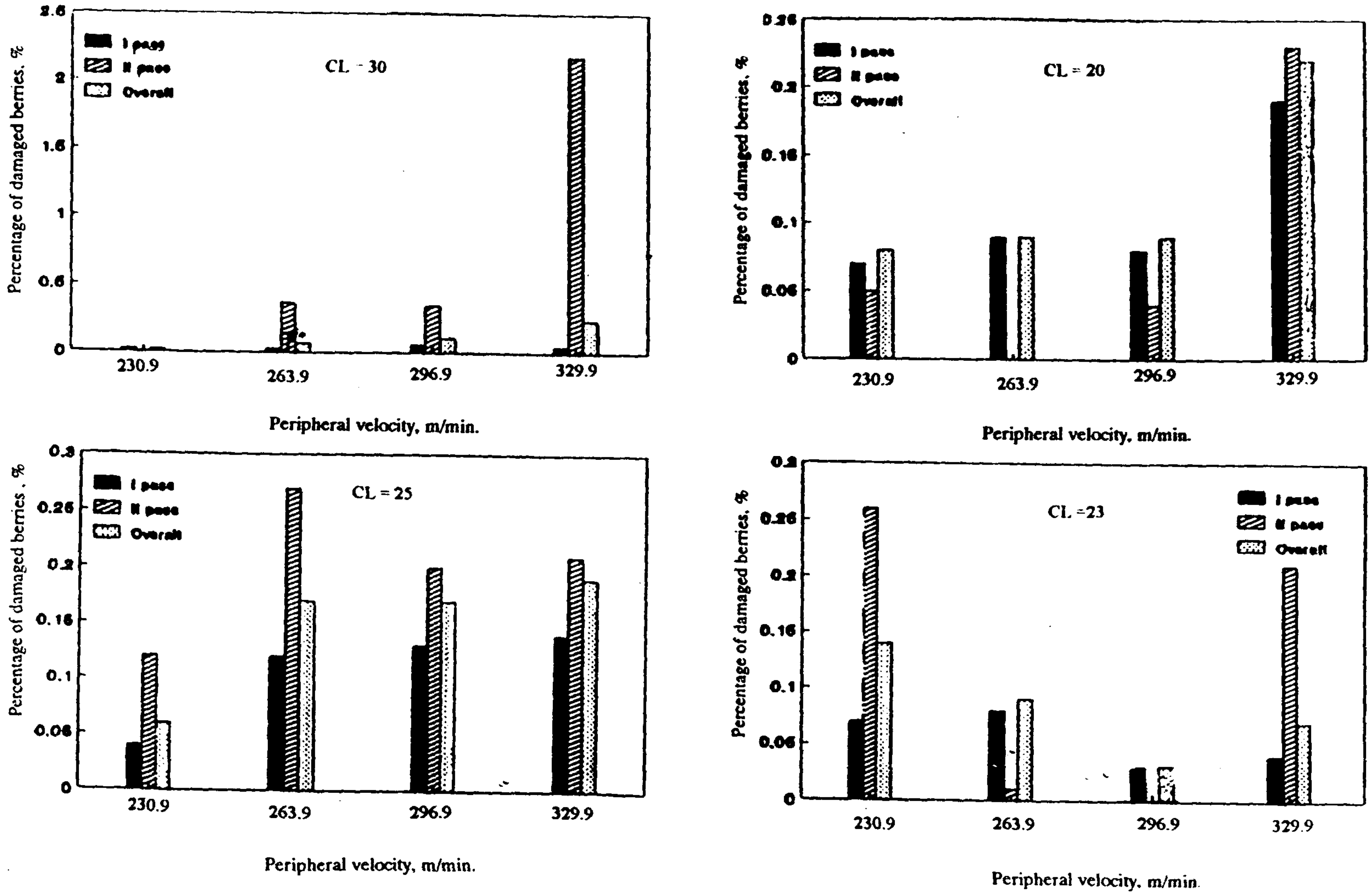
E.5 Comparison of the values of the percentage of damaged berries with the drum speed at the four contact lengths at the feed rate of 24kg/h.



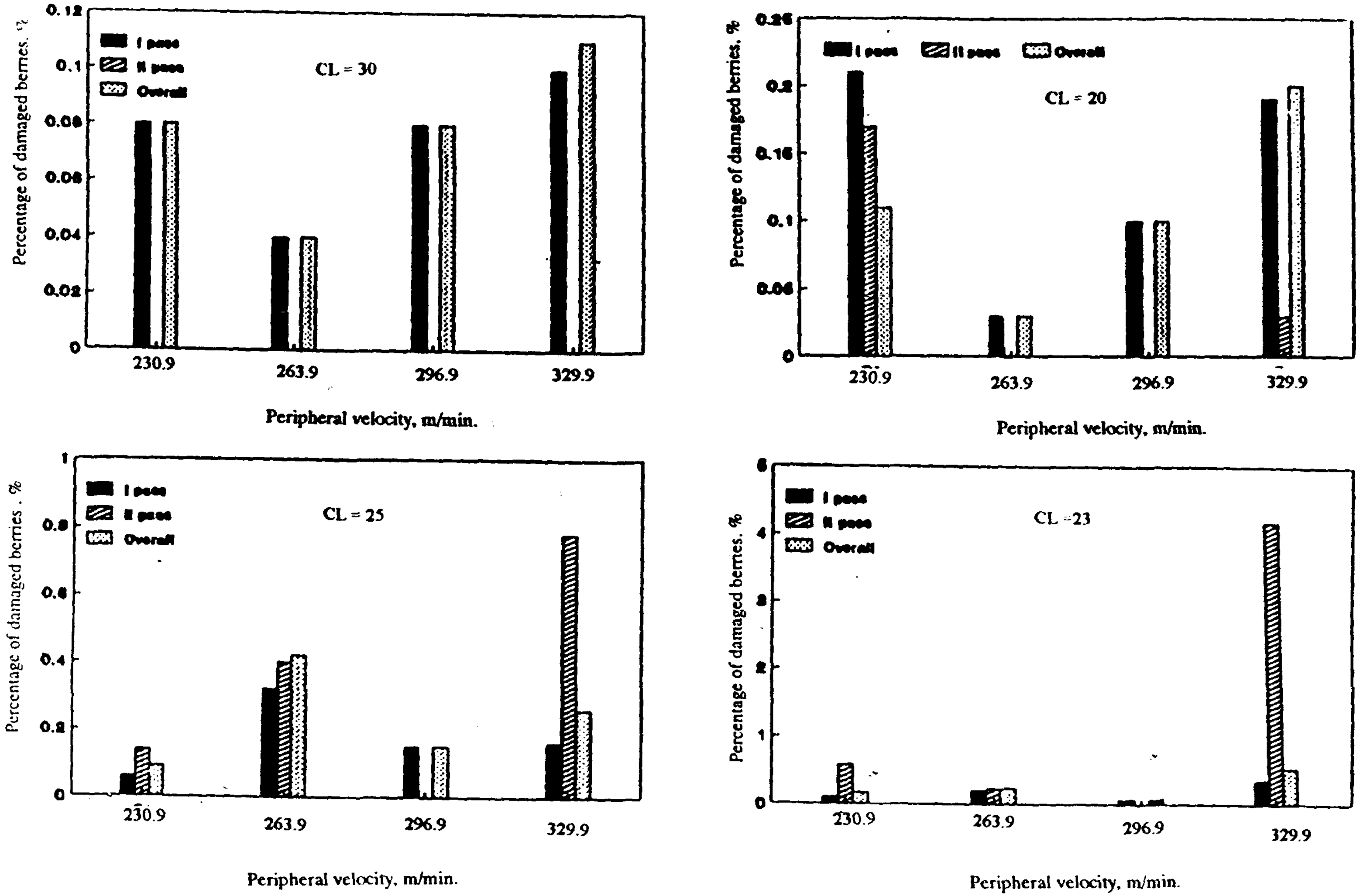
E.6 Comparison of the values of the percentage of damaged berries with the drum speed at the four contact lengths at the feed rate of 30kg/h.



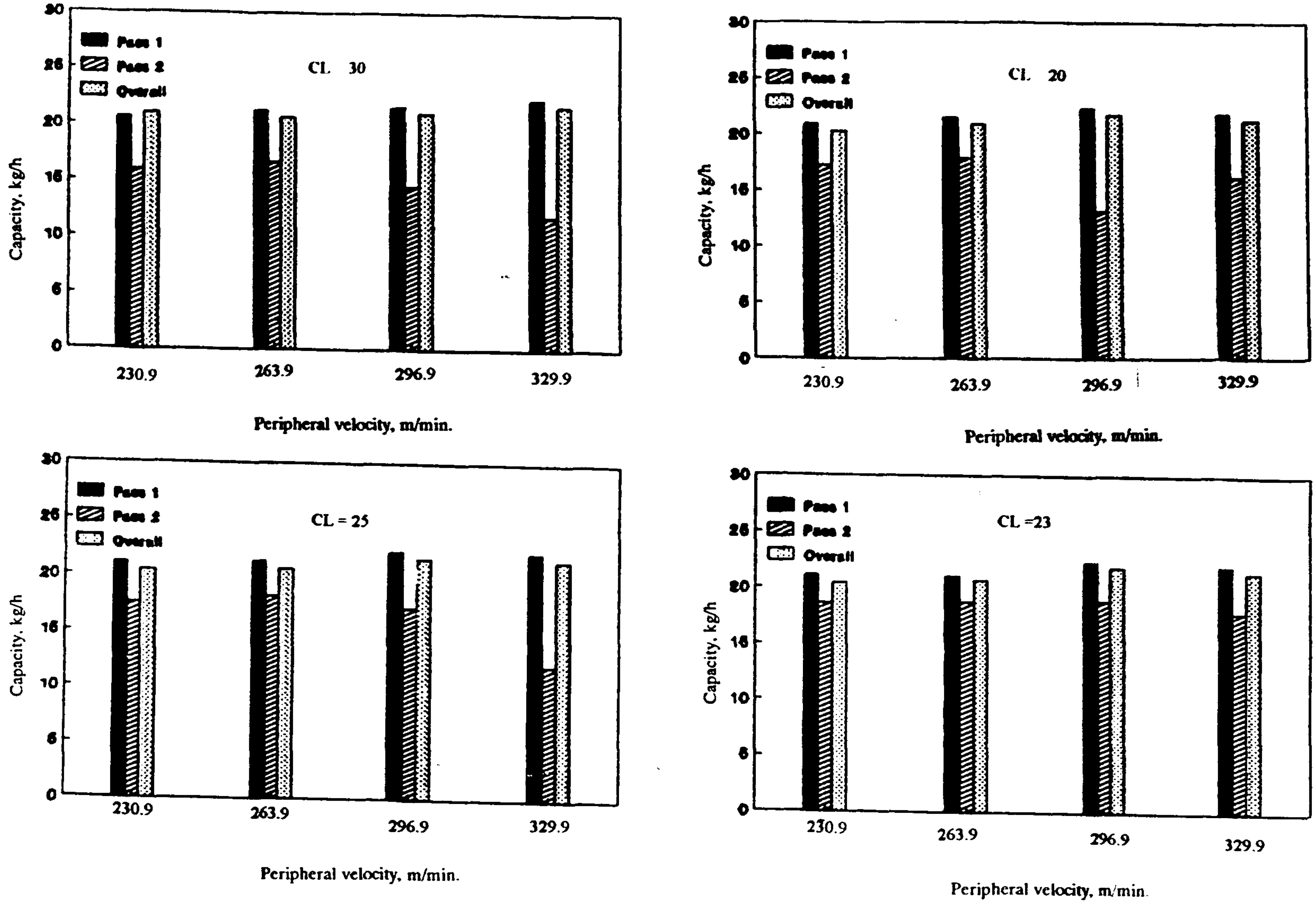
E.7 Comparison of the values of the percentage of damaged berries with the drum speed at the four contact lengths at the feed rate of 40kg/h.



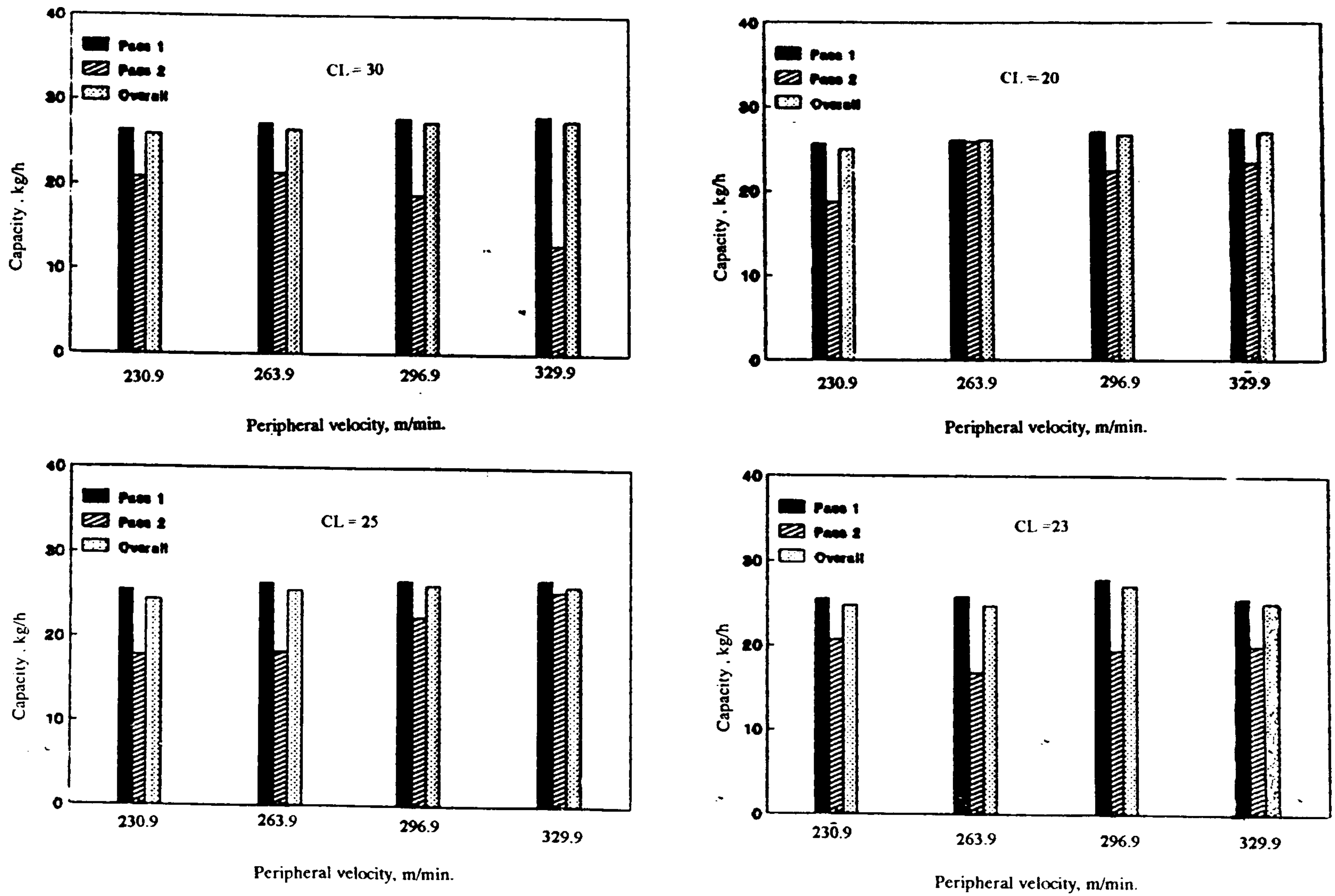
E.8 Comparison of the values of the percentage of damaged berries with the drum speed at the four contact lengths at the feed rate of 50kg/h.



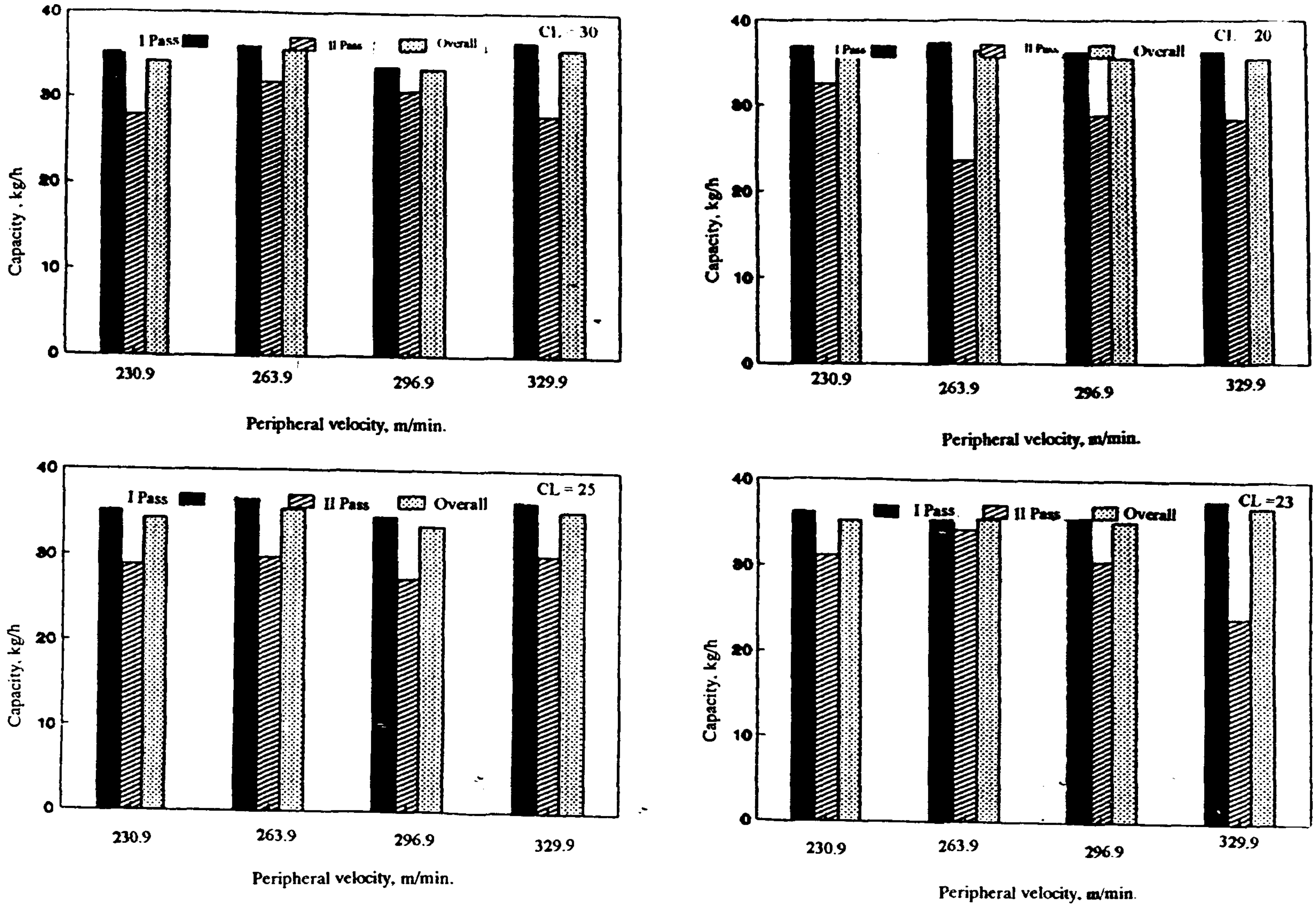
E.9 Comparison of the values of the capacity with the drum speed at the four contact lengths at the feed rate of 24kg/h.



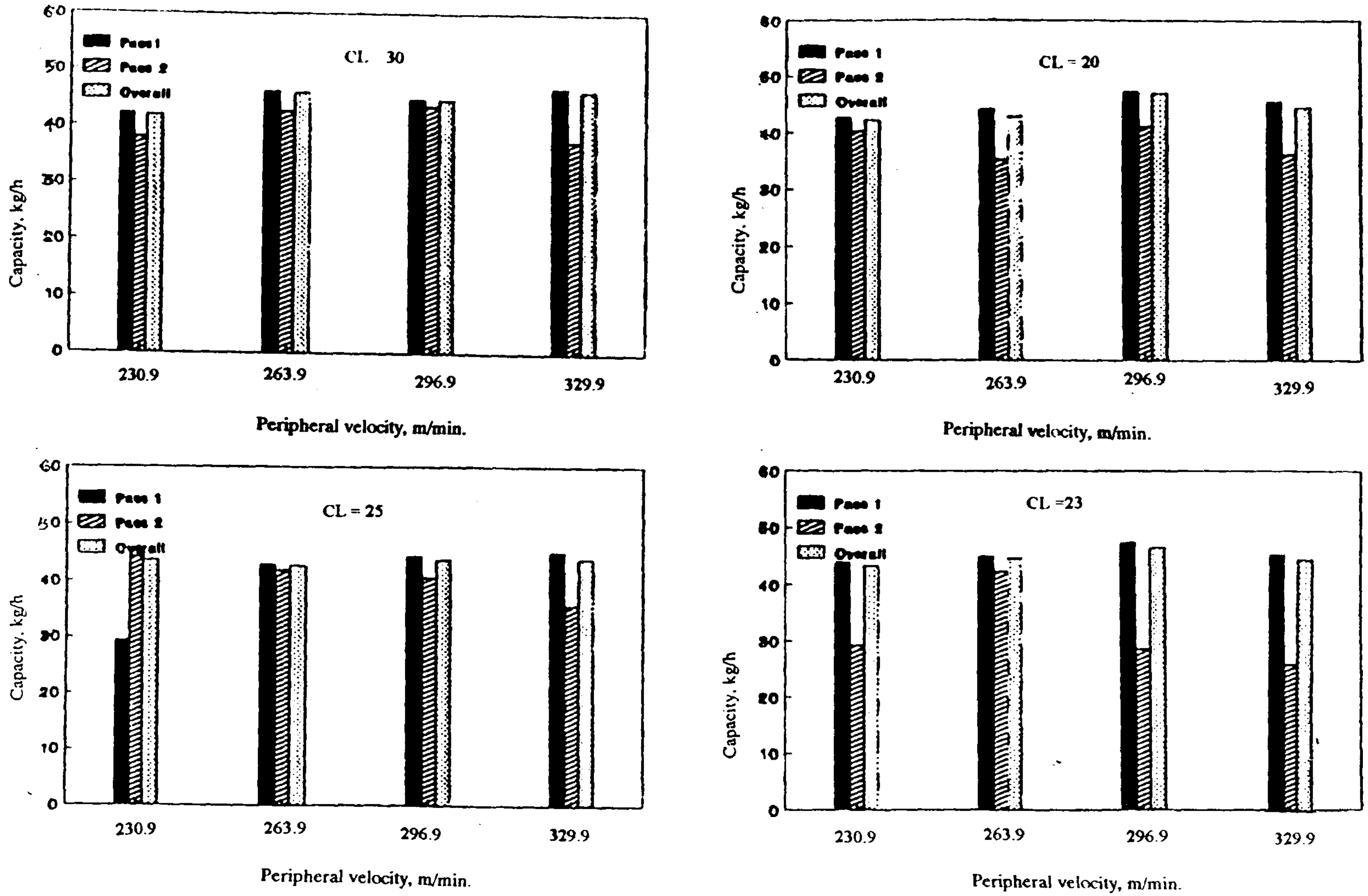
E.10 Comparison of the values of the capacity with the drum speed at the four contact lengths at the feed rate of 30kg/h.



E.11 Comparison of the values of the capacity with the drum speed at the four contact lengths at the feed rate of 40kg/h.



E.12 Comparison of the values of the capacity with the drum speed at the four contact lengths at the feed rate of 50kg/h.



Appendix F

Table F-1. Coefficients of the equation showing the relationship between threshing efficiency and contact length.

Peripheral Velocity (m/min.)	Feed Rate (kg/h)	a	b	c
230.9	50	-0.071	3.40	44.60
	40	-0.063	2.96	52.03
	30	-0.013	0.66	75.42
	24	0.013	-0.72	93.74
263.9	50	0.157	-7.43	173.12
	40	0.158	-7.88	184.96
	30	0.155	-8.15	190.97
	24	-0.012	0.53	78.99
296.9	50	0.107	-5.77	166.91
	40	-0.11	5.36	23.52
	30	0.09	-4.43	141.29
	24	0.092	-4.95	152.50
329.9	50	0.151	-7.36	177.27
	40	0.06	-2.92	122.77
	30	0.226	-10.93	217.42
	24	0.07	-3.35	126.3

Table F-2. Coefficients of the equation showing the relationship between threshing efficiency and feed rate.

Peripheral Velocity (m/min.)	Contact Length (cm)	a	b	c
230.9	20	-0.007	0.54	74.71
	23	-0.007	0.55	74.77
	25	-0.011	0.94	66.52
	30	-0.006	0.44	76.56
263.9	20	-0.033	2.53	43.21
	23	0.001	-0.068	87.46
	25	-0.015	1.18	63.30
	30	-0.009	0.92	66.88
296.9	20	0.035	-2.49	130.20
	23	-0.004	0.46	79.22
	25	0.006	-0.32	89.94
	30	0.009	-0.62	97.73
329.9	20	0.002	-0.11	89.47
	23	-0.001	0.24	80.22
	25	0.006	-0.43	94.10
	30	0.0004	0.03	89.38

Table F-3. Coefficients of the equation showing the relationship between threshing efficiency and peripheral velocity.

Feed Rate (kg/h)	Contact Length (cm)	a	b	c
50	20	-0.001	0.87	-41.44
	23	-0.001	0.63	-6.51
	25	-3.65×10^{-5}	0.04	77.49
	30	-0.001	0.88	-42.98
40	20	-0.0003	0.19	60.93
	23	-0.001	0.66	-8.71
	25	0.0005	-0.28	127.23
	30	-0.0005	0.33	37.02
30	20	-0.001	0.84	34.60
	23	-0.0008	0.46	20.45
	25	-0.0004	0.27	45.33
	30	0.0001	0.002	75.4
24	20	-0.0005	0.31	36.83
	23	-0.001	0.75	-19.96
	25	0.0006	-0.31	120.83
	30	0.0004	-0.14	96.53

Table F-4. Coefficients of the equation showing the relationship between percentage of damaged berries and peripheral velocity.

Feed Rate (kg/h)	Contact Length (cm)	a	b	c
50	20	4.14×10^{-5}	-0.022	3.02
	23	8.27×10^{-5}	-0.04	5.74
	25	-5.1×10^{-5}	0.03	-3.88
	30	1.61×10^{-5}	-0.009	1.21
40	20	2.76×10^{-5}	-0.01	1.89
	23	2.07×10^{-5}	-0.01	1.91
	25	-2.1×10^{-5}	0.01	-1.78
	30	1.84×10^{-5}	-0.008	0.94
30	20	-0.0001	0.07	-9.61
	23	-2.5×10^{-5}	0.015	-1.95
	25	-1.8×10^{-5}	0.014	-2.12
	30	-4.6×10^{-6}	0.002	-0.16
24	20	6.66×10^{-5}	-0.04	4.13
	23	-2.3×10^{-5}	0.011	-1.12
	25	5.52×10^{-5}	-0.03	3.11
	30	4.58×10^{-6}	-0.002	0.24

Table F-5. Coefficients of the equation showing the relationship between percentage of damaged berries and feed rate.

Peripheral Velocity (m/min.)	Contact Length (cm)	a	b	c
230.9	20	0.0003	-0.024	0.63
	23	0.0005	-0.04	0.96
	25	0.0002	-0.013	0.25
	30	-4.4 x 10-5	0.0007	0.14
263.9	20	-0.0007	0.04	-0.37
	23	0.0008	-0.06	1.07
	25	0.0005	-0.02	0.39
	30	0.0003	-0.03	0.69
296.9	20	-0.002	0.97	-1.18
	23	0.0004	0.04	1.04
	25	0.0001	-0.01	0.55
	30	-0.0006	0.04	-0.55
329.9	20	-7.2 x 10-5	-0.004	0.56
	23	0.001	-0.09	1.43
	25	0.001	-0.09	2.11
	30	-0.0003	0.02	-0.064

Table F-6. Coefficients of the equation showing the relationship between percentage of damaged berries and contact length.

Peripheral Velocity (m/min.)	Feed Rate (kg/h)	a	b	c
230.9	50	-0.0002	0.006	0.069
	40	-0.002	0.071	-0.704
	30	0.006	-0.279	3.56
	24	-6.6 x 10-5	-0.013	0.52
263.9	50	-0.013	0.67	-8.12
	40	-0.002	0.12	-1.37
	30	0.005	-0.26	3.7
	24	0.003	-0.12	1.60
296.9	50	-0.0008	0.04	-0.4
	40	-0.0007	0.04	-0.44
	30	0.013	-0.67	9.16
	24	-0.008	0.37	-4.24
329.9	50	-0.009	0.42	-4.71
	40	0.004	-0.18	2.31
	30	0.003	-0.15	2.44
	24	-0.002	0.09	-0.73

Table F-7. Coefficients of the equation showing the relationship between capacity and contact length.

Peripheral Velocity (m/min.)	Feed Rate (kg/h)	a	b	c
230.9	50	-0.06	2.79	9.11
	40	0.03	-1.65	57.78
	30	0.02	-0.94	34.76
	24	0.005	-0.18	21.87
263.9	50	0.04	-1.55	59.84
	40	0.03	-1.32	52.74
	30	0.04	-2.08	50.36
	24	0.008	-0.42	26.19
296.9	50	0.05	-2.99	85.54
	40	-0.009	0.18	36.05
	30	0.02	-0.98	38.22
	24	-0.01	0.45	16.91
329.9	50	0.05	-2.13	68.81
	40	0.01	-0.53	41.56
	30	0.07	-3.28	65.58
	24	-0.001	0.10	19.74

Table F-8. Coefficients of the equation showing the relationship between capacity and peripheral velocity.

Feed Rate (kg/h)	Contact Length (cm)	a	b	c
50	20	-0.0008	0.46	-23.48
	23	-0.0007	0.41	-14.24
	25	0.0002	-0.13	60.14
	30	-0.0006	0.35	-8.48
40	20	-4.8 x 10-5	0.02	35.12
	23	0.003	-0.17	57.33
	25	0.0002	-0.10	48.43
	30	0.0002	-0.12	49.90
30	20	-0.0002	0.12	6.89
	23	-0.0004	0.26	-11.57
	25	-0.0003	0.17	0.16
	30	-7.8 x 10-5	0.06	15.75
24	20	-0.0003	0.16	-1.98
	23	-0.0001	0.09	6.28
	25	-6.2 x 10-5	0.05	12.87
	30	0.0002	-0.11	34.84

Table F-9. Coefficients of the equation showing the relationship between capacity and feed rate.

Peripheral Velocity (m/min.)	Contact Length (cm)	a	b	c
230.9	20	-0.009	1.54	-12.37
	23	-0.001	0.98	-2.94
	25	0.004	0.6	3.42
	30	-0.002	0.98	-1.24
263.9	20	-0.009	1.52	-10.85
	23	0.003	0.72	1.34
	25	-0.006	1.31	-7.56
	30	0.003	0.77	0.89
296.9	20	0.01	0.22	10.81
	23	0.001	0.85	0.61
	25	0.009	0.18	12.37
	30	0.008	0.31	9.91
329.9	20	-0.0007	0.94	-0.69
	23	0.007	0.52	7.28
	25	0.0005	0.84	1.003
	30	0.004	0.61	4.86

Appendix-G

Calculation of power requirement.

Feed Rate kg/h	Contact length,cm	eripheral Veloci m/min.	I amperes	V volts	Power hp
50	30	230.9	0.75	345	0.48
50	30	230.9	0.75	345	0.48
50	30	230.9	0.7	346	0.45
50	30	263.9	0.9	345	0.58
50	30	263.9	0.9	345	0.58
50	30	263.9	0.95	345	0.61
50	30	296.9	1.1	345	0.70
50	30	296.9	1	345	0.64
50	30	296.9	1	345	0.64
50	30	329.9	1.2	345	0.77
50	30	329.9	1.15	345	0.74
50	30	329.9	1.2	345	0.77
50	20	230.9	0.8	345	0.51
50	20	230.9	0.75	346	0.48
50	20	230.9	0.8	345	0.51
50	20	263.9	0.85	345	0.54
50	20	263.9	0.85	346	0.55
50	20	263.9	0.85	345	0.54
50	20	296.9	1.15	345	0.74
50	20	296.9	1.15	345	0.74
50	20	296.9	1.15	345	0.74
50	20	329.9	1.35	345	0.87
50	20	329.9	1.3	345	0.83
50	20	329.9	1.3	345	0.83
50	25	230.9	0.7	346	0.45
50	25	230.9	0.75	346	0.48
50	25	230.9	0.7	346	0.45
50	25	263.9	0.9	345	0.58
50	25	263.9	0.9	345	0.58
50	25	263.9	0.9	346	0.58
50	25	296.9	1	345	0.64
50	25	296.9	1	345	0.64
50	25	296.9	1	345	0.64
50	25	329.9	1.15	345	0.74
50	25	329.9	1.1	345	0.70
50	25	329.9	1.15	345	0.74
50	23	230.9	0.7	345	0.45
50	23	230.9	0.75	345	0.48
50	23	230.9	0.7	345	0.45
50	23	263.9	0.85	345	0.54
50	23	263.9	0.8	345	0.51
50	23	263.9	0.85	345	0.54
50	23	296.9	1	346	0.64
50	23	296.9	1	345	0.64
50	23	296.9	1	345	0.64
50	23	329.9	1.3	345	0.83
50	23	329.9	1.3	345	0.83
50	23	329.9	1.3	345	0.83
40	30	230.9	0.65	345	0.42

40	30	230.9	0.65	346	0.42
40	30	230.9	0.65	345	0.42
40	30	263.9	0.8	345	0.51
40	30	263.9	0.8	345	0.51
40	30	263.9	0.8	345	0.51
40	30	296.9	0.95	345	0.61
40	30	296.9	0.95	345	0.61
40	30	296.9	0.95	346	0.61
40	30	329.9	1.05	345	0.67
40	30	329.9	1.05	345	0.67
40	30	329.9	1.05	345	0.67
40	20	230.9	0.7	345	0.45
40	20	230.9	0.7	346	0.45
40	20	230.9	0.7	345	0.45
40	20	263.9	0.85	345	0.54
40	20	263.9	0.8	345	0.51
40	20	263.9	0.85	345	0.54
40	20	296.9	1	346	0.64
40	20	296.9	1	345	0.64
40	20	296.9	1	346	0.64
40	20	329.9	1.05	345	0.67
40	20	329.9	1.05	346	0.67
40	20	329.9	1.05	345	0.67
40	25	230.9	0.7	345	0.45
40	25	230.9	0.7	345	0.45
40	25	230.9	0.7	345	0.45
40	25	263.9	0.75	345	0.48
40	25	263.9	0.75	345	0.48
40	25	263.9	0.75	345	0.48
40	25	296.9	0.85	345	0.54
40	25	296.9	0.85	345	0.54
40	25	296.9	0.85	345	0.54
40	25	329.9	0.95	345	0.61
40	25	329.9	0.95	345	0.61
40	25	329.9	0.95	345	0.61
40	23	230.9	0.65	345	0.42
40	23	230.9	0.65	346	0.42
40	23	230.9	0.65	345	0.42
40	23	263.9	0.8	345	0.51
40	23	263.9	0.8	345	0.51
40	23	263.9	0.8	345	0.51
40	23	296.9	0.95	345	0.61
40	23	296.9	0.95	345	0.61
40	23	296.9	0.95	346	0.61
40	23	329.9	1.1	346	0.71
40	23	329.9	1.1	345	0.70
40	23	329.9	1.1	345	0.70
30	30	230.9	0.55	345	0.35
30	30	230.9	0.55	345	0.35
30	30	230.9	0.55	345	0.35
30	30	263.9	0.6	345	0.38

30	30	263.9	0.6	346	0.39
30	30	263.9	0.6	345	0.38
30	30	296.9	0.8	346	0.51
30	30	296.9	0.8	345	0.51
30	30	296.9	0.8	345	0.51
30	30	329.9	1	345	0.64
30	30	329.9	1	345	0.64
30	30	329.9	0.95	345	0.61
30	20	230.9	0.55	345	0.35
30	20	230.9	0.55	345	0.35
30	20	230.9	0.55	345	0.35
30	20	263.9	0.65	345	0.42
30	20	263.9	0.6	345	0.38
30	20	263.9	0.65	345	0.42
30	20	296.9	0.75	345	0.48
30	20	296.9	0.75	346	0.48
30	20	296.9	0.75	345	0.48
30	20	329.9	0.95	346	0.61
30	20	329.9	0.95	345	0.61
30	20	329.9	0.95	345	0.61
30	25	230.9	0.5	345	0.32
30	25	230.9	0.5	346	0.32
30	25	230.9	0.5	345	0.32
30	25	263.9	0.6	345	0.38
30	25	263.9	0.6	345	0.38
30	25	263.9	0.6	345	0.38
30	25	296.9	0.65	346	0.42
30	25	296.9	0.65	346	0.42
30	25	296.9	0.65	345	0.42
30	25	329.9	0.85	345	0.54
30	25	329.9	0.85	345	0.54
30	25	329.9	0.85	345	0.54
30	23	230.9	0.7	345	0.45
30	23	230.9	0.7	345	0.45
30	23	230.9	0.7	345	0.45
30	23	263.9	0.85	345	0.54
30	23	263.9	0.85	346	0.55
30	23	263.9	0.85	345	0.54
30	23	296.9	0.95	345	0.61
30	23	296.9	0.95	345	0.61
30	23	296.9	0.95	345	0.61
30	23	329.9	1.05	345	0.67
30	23	329.9	1	345	0.64
30	23	329.9	1.05	345	0.67
24	30	230.9	0.5	346	0.32
24	30	230.9	0.5	345	0.32
24	30	230.9	0.5	345	0.32
24	30	263.9	0.65	345	0.42
24	30	263.9	0.6	345	0.38
24	30	263.9	0.65	345	0.42
24	30	296.9	0.75	345	0.48

24	30	296.9	0.75	345	0.48
24	30	296.9	0.75	345	0.48
24	30	329.9	0.95	345	0.61
24	30	329.9	0.9	345	0.58
24	30	329.9	0.95	346	0.61
24	20	230.9	0.65	345	0.42
24	20	230.9	0.65	345	0.42
24	20	230.9	0.65	345	0.42
24	20	263.9	0.7	345	0.45
24	20	263.9	0.7	346	0.45
24	20	263.9	0.7	345	0.45
24	20	296.9	0.9	345	0.58
24	20	296.9	0.9	345	0.58
24	20	296.9	0.9	345	0.58
24	20	329.9	0.95	346	0.61
24	20	329.9	0.95	346	0.61
24	20	329.9	0.95	345	0.61
24	25	230.9	0.55	346	0.35
24	25	230.9	0.55	345	0.35
24	25	230.9	0.55	346	0.35
24	25	263.9	0.6	345	0.38
24	25	263.9	0.6	345	0.38
24	25	263.9	0.6	345	0.38
24	25	296.9	0.75	345	0.48
24	25	296.9	0.75	345	0.48
24	25	296.9	0.75	345	0.48
24	25	329.9	0.85	346	0.55
24	25	329.9	0.85	346	0.55
24	25	329.9	0.85	345	0.54
24	23	230.9	0.7	346	0.45
24	23	230.9	0.7	345	0.45
24	23	230.9	0.7	345	0.45
24	23	263.9	0.8	345	0.51
24	23	263.9	0.8	345	0.51
24	23	263.9	0.8	345	0.51
24	23	296.9	0.9	345	0.58
24	23	296.9	0.9	345	0.58
24	23	296.9	0.9	345	0.58
24	23	329.9	0.95	345	0.61
24	23	329.9	0.95	346	0.61
24	23	329.9	0.95	346	0.61

Power required at no load conditions

Peripheral velocity, m/min.	Voltmeter readings, V	Ammeter readings, I	Power, hp
230.9	345	0.5	0.32
263.9	345	0.51	0.33
296.9	345	0.52	0.33
329.9	345	0.55	0.35

DEVELOPMENT OF A POWER OPERATED BLACK PEPPER THRESHER

by
Suma Nair

ABSTRACT OF THE THESIS
Submitted in partial fulfillment of the
requirement for the degree of

MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology
KERALA AGRICULTURAL UNIVERSITY

Department of Farm Power, Machinery, and Energy
Kelappaji College of Agricultural Engineering and Technology
Tavanur - 679 573
1998

ABSTRACT

A power operated black pepper thresher comprising mainly of a threshing drum and a concave; both lined with thermofoam, was developed. It was driven by a 0.5-hp, 3-phase, variable speed motor.

Pepper spikes were fed into the thresher and the threshed material from all the outlets were collected and separated into berries, damaged berries, unthreshed spikes, partially threshed spikes, and partially threshed spikes with unthreshed berries. The weights of all the fractions were recorded. The values of the threshing efficiency, the percentage of damaged berries, and the capacity were calculated. A three-factor factorial experiment was conducted taking the feed rate, the peripheral velocity, and the contact length as the independent variables, and the threshing efficiency, the percentage of damaged berries, and the capacity as the dependent variables.

From the analyses of data, it was seen that all the independent variables exerted significant influence on the threshing efficiency, the percentage of damaged berries, and the capacity. In general, threshing efficiency showed an increasing trend at increased feed rates for all the different contact lengths. It was most influenced by the peripheral velocity. Threshing efficiency was found to peak around 300 m/min. beyond which it showed a decrease. The percentage of damage was observed to be higher at higher feed rates and lower peripheral velocities. The values of percentage of damage was only between 0.05-0.55 %, which indicated that the thermofoam assisted in reducing damage to the berries. The capacity showed an increase with the feed rate. However, it did not vary much as the contact lengths were changed. The capacity generally increased with increase in peripheral velocity. A multiple regression equation was developed for the prediction of the power requirement. The maximum power requirement of 0.46 hp was at a feed rate of 50 kg/h and a peripheral velocity of 296.9 m/min.

The cost of threshing using this thresher was only Rs 1.42 per kilogram, showing that the thresher was very economical. It was highly cost effective compared to the cost of manual threshing which is Rs 6.01 per kilogram.