INFLUENCE OF CROP-MACHINE SYSTEM PARAMETERS ON PERFORMANCE OF SINGLE ROW CORN PICKING MECHANISM

एक पंक्ति में भुट्टे तोड़ने की क्रियाविधि के निष्पादन पर फसल–मशीन पद्धति के प्राचल की प्रभुता

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(Om Prakash Pareek)

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SYMBOLS AND ABBREVIATIONS

Particular		Description
%	:	Per cent
&	:	and
Anon	:	Anonymous
Anova	:	Analysis of variance
ASAE	:	American Society of Agricultural Engineers
CD	:	Critical difference
cm	:	Centimeter
CTAE	:	College of Technology and Engineering
DOL	:	Direct on line
DOR	:	Directorate of Research
Engg.	:	Engineering
FAO	:	Food and agriculture organizations
FIG	:	Figure
GOI	:	Government of India
h	:	Hour
ha	:	hectare
hp	:	Horse power
i.e.	:	That is
ISAE	:	Indian Society of Agricultural Engineers
ISLB	:	Indian standard long bean
ISMC		Indian standard medium channel
kg	:	Kilogram
Kg- m	:	Kilogram – meter
Kg/ha	:	Kilogram per hectare
km/h	:	Kilometer per hour
Kw	:	Kilowatt
LSD	:	Least Square difference
m/min	:	Meter per minute
MCB	:	Main circuit breaker
MJ	:	Mega joule
mm	:	Millimeter
MoA	:	Ministry of agriculture
MPUAT	:	Maharana Pratap University of Agriculture & Technology

MS	:	Mild steel
NB	:	Nominal bore
pp	:	Pages
RPM	:	Revolution per minute
SEm	:	Standard error
Stat	:	Statistics
Tab	:	Table
USA	:	United state of America
Vol	:	Volume
www	:	World wide web
ϕ	:	diameter

CHAPTER - I

INTRODUCTION

India is predominately an agricultural country. Agriculture continues to remain a significant sector of the Indian economy. Agriculture contributes 26 per cent of GDP provides 60 per cent of the employment and continued to be primary source of living for 70 per cent of the population in India. India has a total geographical area of 328 mha, out of which 142.4 mha is net cultivable area, around 40 per cent is irrigated and rest is rain fed (Bector *et al.* 2008). The population of India is increasing at the rate of 1.8 per cent annually and will be about 1.3 billion by the end of 2030. This will require 260 to 264 mt of food grains to feed the population.

The farm mechanization contributes to raising farm productivity as farm labour combined with machine power can perform a greater amount of work per unit time. Thus, it can be a vital element and important determinant towards the development and design of a suitable food security system of the country performing the function of food production, productivity of the farming inputs, timely application of the farming inputs, managerial capabilities of the farmers and growth environment supported by educational infrastructure and government policy. In India, concept of mechanization is not very clear at all levels. Some links with only tractorization and therefore, its justification in Indian context is often debated. In spite of this there is an increasing trend in selective mechanization.

Maize (*Zea mays.L*) is one of the most important cereal crops in the world next to rice and wheat. Worldwide the area, production and productivity of maize are 137 mha., 610 mt and 4.43 tha^{-1} respectively. In India during 2003-04 maize was grown in an area of 7.42 mha with the production and productivity of 14.72 mt and 1983 $kgha^{-1}$ respectively. Major proportion (45%) of maize is consumed as food. The additional use of maize includes feed, forage and in processing industry (Singh *et al.* 2006).The area, production and productivity of maize for the world, India and Rajasthan are presented in Table 1.1.

Table1.1 Area, production and productivity of maize

Year	World*			India*			Rajasthan**		
	Area (mha)	Production (*mt*)	Productivity (kg ha^{-1})	Area (mha)	Production (*mt*)	Productivity (kg ha^{-1})	Area (mha)	Production (*m*.)	Productivity (kg ha^{-1})
2001	139.2	615.3	4419	6.58	13.16	1999	1.01	1.47	1370
2002	138.3	603.0	4358	6.64	11.15	1679	0.98	0.87	718
2003	143.9	644.8	4480	7.34	14.98	2041	1.11	2.07	1688
2004	147.4	728.0	4939	7.43	14.17	1907	1.04	1.26	1037
2005	147.7	715.8	4844	7.59	14.70	1938	1.0	1.10	1016
2006	146.7	699.2	4767	7.86	14.98	1906	1.03	1.11	1055
2007	157.8	784.6	4971	7.77	16.78	2160	1.05	1.95	1626

Source : * FAOSTAT/© FAO Statistics Division 2008, ** www.rajasthankrishi.gov.in

The maize crop is so important that some or other part of the plant is utilized either for food, fodder or industry. In India, the use pattern of maize is 65 per cent for human, 15 per cent for livestock and poultry, 18 per cent for industry and 2 per cent for seed purpose (Kamble *et al. 2004*). The important major products of wet milling are starch, gluten and a large number of starch derivatives. Corn oil is also extracted. Gluten is used as animal feed. Starch and its derivatives find extensive uses in various industries like textile and pharmaceuticals. Corn oil is getting popularity as a harmless cooking medium. Maize flour consumed for various domestic preparations is a typical product of dry milling. A part of dry milling products also finds use as corn flakes. Secondary processing of starch produce Dextrose Monohydrates, Dextrin, Sorbitol modified Starch and high Fructose corn syrup (Biswas *et al. 2004*).

Varghese (2006) studied the structure of cost of cultivation of major cereals in Rajasthan and reported that cost of cultivation for maize was Rs. 13359.46 ha^{-1} which comprised of 72.59% operational cost and 27.41% fixed cost. Contribution of human, bullock and machine labour was 38.29%, 13.78%and 1.98% respectively. Table 1.2 represent the economics of maize cultivation in Rajasthan. This reflected that maize cultivation was not profitable. For profitable cultivation of maize, the share of human and bullock labour in total cost of production is to be reduced which is only possible by adopting farm mechanization in maize cultivation. Kamble *et al.* (2004) also reported that one of the important constraints identified for low level of productivity is lack of mechanization for the cultivation of maize crop.

Table 1.2 Economics of maize cultivation in Rajasthan

Year	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)
1998-1999	10270	8225	(-) 2045
1999-2000	11638	9202	(-) 2436
2000-2001	13360	6025	(-) 7335
2001-2002	13301	8780	(-) 4521
2002-2003	13796	12212	(-) 1584

Mechanization in maize cultivation is proper for intercultural and threshing operation but there is no machine used for maize harvesting. The status of agricultural mechanization and energy utilization pattern for maize production in Rajasthan (Zone iv a)) is presented in Table 1.3 (Mehta, 1994)

Table 1.3 Mechanization pattern for Zone IV-a and energy utilization for maize cultivation

Operation	Mechanical (MJ/ha)	Animal (MJ/ha)	Electrical (MJ/ha)	Human (MJ/ha)	Total (MJ/ha)
Ploughing	9.08	114.65	0.00	84.95	**208.68**
Sowing	0.00	66.73	0.00	66.63	**133.36**
Manuring	0.00	5.32	0.00	22.85	**28.17**
Interculture	0.00	43.09	0.00	431.69	**474.78**
Irrigation	26.24	30.43	104.76	63.58	**225.01**
Harvesting	0.00	0.00	0.00	356.93	**356.93**
Threshing	72.27	38.72	0.00	342.14	**453.13**
Total	**107.59**	**298.94**	**104.76**	**1368.77**	**1880.06**

*Average out put of a man is considered 0.18 MJ/man hr.

The farm power available in India has increased from 0.25 kW/ha in the year 1951 to 1.35 kW/ ha in 2001(Srivastava, 2004). Power availability was 1.44 kW/ha in year 2004-2005. For enhancing the mechanization, farm power available will have to be increased to 2.00 kW/ha by 2020 (Singh, 2007). The higher contribution of power reflects the importance of improved agricultural machinery/implements and tractors in agriculture. The percentage of mechanical power has also increased from 2.1 in 1951 to 46.0 in 2001 (Table 1.4).

Table 1.4 Farm power availability in India

Year	Farm power ($kW\ ha^{-1}$)	Animate (%)	Mechanical (%)	Electrical (%)
1951	0.25	97.4	2.1	0.5
1961	0.31	94.9	3.7	1.4
1971	0.36	79.2	16.3	4.5
1981	0.63	48.2	32.3	19.5
1991	0.92	35.5	34.7	30.8
2001	1.35	18.0	46.0	36.0

Source : Srivastava, 2004.

Farm mechanization denotes the use of various types of agricultural machines and implements during the production, transportation and processing of agricultural products. It results in increased production of food-grains which might be due to timely sowing, harvesting and transportation of inputs to the field's thereby better prices for their products as they can easily access the nearest market outlets. It has become essential to ensure timely and proper farm operation that can only be achieved by using efficient and well adopted machinery and implements. Machines are available for land preparation, sowing, weeding and threshing of maize but harvesting of maize is still done by traditional method only. Therefore, there is a need of mechanizing the harvesting operation of maize.

When the crop is matured and cob moisture is about 25-40 per cent, plants are cut by sickle and laid on side. While harvesting the man walks along a row and with sickle shears the plant at a height of about 15-20 cm. He bends himself for harvesting of maize plant. Harvested plants are bundled and heaped together known as shucks. In shucks, drying of cob takes place by sun and natural air circulation. Later on when the cob moisture is brought down to 15-20 per cent and picking of individual cobs from the plant is done. These operations require about 250-400 man-hr/ha (Gupta *et al.* 1985).

Between harvesting and picking time, there is a gap of 6-8 weeks. Cobs are sun dried by spreading on the ground after dehusking. Long exposure of the plants to sun in shucks makes the plants completely dry. The value of the fodder is affected as nutrients are lost and for chaff making, it requires more energy. If plants are chopped immediately after manual picking of cobs, there is optimum moisture content for making silage and we get desirable quality fodder.

In crop production system, labour peaks develop due to high labour demands in operations which can not be or have not been mechanized so far. In the operations of picking of cobs and harvesting of maize plants, labour peaks have to be mechanized to have high return from enterprise. The farming system of the country consists of small and scattered holdings. The inheritance law is such that the land gets divided and average size of holding is getting reduced over the years. The average size of holdings in 1971 was 2.28 ha which got reduced to1.55 ha in 1991 and it is presently estimated as less than 1.3 ha (Srivastava, 2000). The commercially available corn harvesters / combines being used in western countries are not suitable in Indian conditions due to small farms and high cost of machines. Therefore there is need to have a small and suitable corn picking machine to overcome labour peaks and to reduce the cost of maize cultivation.

With above cited discussion, it is clear that due to lack of mechanization and increased share of human energy in production of maize, the cost of cultivation is increasing day by day and on the other hand no substantial increase has been noticed in the yield of maize. This has resulted in diminishing return in maize production. An alternative strategy of mechanizing small farm holdings is the introduction of smaller machines that would be more appropriate for the present farm sizes. Therefore, to make faster picking of cob and to overcome the shortage of labour during peak season, mechanical corn picking is recommended and there is need to develop suitable corn picking mechanism. Therefore, the present study was carried out to know the influence of crop machine system parameters on performance of single row corn picking mechanism with the following objectives.

1. To develop experimental laboratory setup to study the performance of corn picking mechanism.
2. To study the effect of crop-machine system parameters on the performance of corn picking mechanism.
3. To select suitable system and crop parameters for improving the performance of corn picking mechanism.

CHAPTER - II

REVIEW OF LITERATURE

The review relating to the operational and performance parameters of corn picker/harvester are presented in this chapter. The review of literature reveals that some preliminary work has been done in India related to the development of corn picking/harvesting operation. However, efforts have been done to collect the important and basic reviews available on different aspects of study.

2.1 Harvesting Methods

Gupta *et al.* (1985) reported that maize is one of the most important cereal crops of India. Harvesting and dehusking of maize is done manually and these operations require about 250-400 man-hrs per hectare and are quite labour intensive.

Pandey *et al.* (1997) mentioned that the traditional method of maize harvesting is to collect matured cobs manually. Grain combines equipped with corn head snapping units are being used in developed countries.

Singh *et al.* (1997) reported that there are two popular methods of harvesting of the grain from maize crop viz.; removal of cobs (ears) when the grain have dried and do not have more than 20 per cent moisture in them. At this stage almost all the plants remain very green and after removal of the ears. They may be used for fodder. The second method is harvesting the ear bearing plants and piling them for few days before separation of cobs.

Anon (2006) reported that maize crop grown for the grain should be harvested when it reaches physiological maturity containing 25-30 per cent moisture and preferably the ears should be removed before cutting the stalks.

2.2 Corn Picker

Several workers have reported harvesting of maize through corn picking machine. Corn picker is a machine equipped with snapping rolls to remove the ears from the standing stalks. Corn picker use a pair of snapping rolls that pull the stalk down through and snap the ear off as it hits the roll. Corn picker is being used extensively in western countries to replace the slow, hard, hand method of harvesting. It is time and labour saver. Only one man is required to operate the machine.

2.2.1 History of development

Smith (1955) reported that Quincy (1850) first invented the corn picker. He further mentioned about the second investigation of corn picker in 1874 by William Watson of Chicago. The snapping roller type corn picker was not patented until about ten years later. The first invented machine picked the ears by means of wooden rollers studded with iron pegs. The shredding machine of 1880's was stationary unit so that farmers did not have to pick ears in the field. After 1874, pusher type machines were produced with dividers to guide the corn into the snapping rolls, which at the front were low enough to pass under the ears. The ears were pinched off as the stalks were pulled down between the rollers of the advancing machine.

Seferovich (1961) recorded dates for some of the important developments in corn picking as follows -

S.No.	Year	Developments
1.	1880	First corn picker patent.
2.	1885	Corn husker shredder appeared.
3.	1892	Corn picker patented (Self binding)
4.	1909	Corn picker built commercially
5.	1928	Two rows PTO operated and one row mounted picker.
6.	1929	Two row mounted corn picker
7.	1946	Self propelled corn picker
8.	1954	Corn head attachment for commercially available combine
9.	1958	Shelling attachment for corn picker.

2.2.2 Corn combines

Mc Kay built the first of a series of self propelled stripper harvester. He in collaboration with Internal Harvester offer electronic monitoring of machine functions on the combines. The company introduced the system in 1969 on various models 815. These machines were a radical departure in combine development. The model 815 combine was having 39"(975 mm) cylinder equipped with soybean header with pick up reel and flexible floating cutter ban. The model 915 combine consisted of 48 inch (1200 mm) cylinder, five row corn head.

Pandey *et. al.*, (1997) reported that latest trend of cereal harvesting is by combines. Various designs of combine harvester having 2 to 6 m long cutter bar are commercially available. The function of the combine harvester is to cut, thresh, winnow and clean grain or seed. It consisted of header unit, threshing unit, separation unit, cleaning unit and grain collection unit.

2.3 Machine Parameters

2.3.1 Snapping unit

Bainer *et. al.,* (1955) reported that most snappers, pickers and picker sheller had spiral ribbed snapping rolls. These were usually made of cast iron and had spiral ribs or lugs on their surfaces. The roll length ranged from 1020 to 1270 mm and diameters from 75 to 100 mm. Peripheral speeds were usually about 180 m min^{-1}.

Richey *et. al.,* (1961) reported that snapping rolls straddle the row and pull the stalks down and through, pinching off the ears. Two types were in common usages. The spiral lugged roll and positive fluted roll. Many combination of roll material were in use, the most popular being metal against metal, metal against rubber and wood against rubber.

Johnson and Lamp (1966) reported that the spiral lugged roll was commonly made of cast iron of about $3^{1/2}$ inches (88 mm) in diameter and had a tapered point to facilitate stalk entrance. The peripheral speed of roll was about 600 ft. per minute (180 m/min) and performed best at ground travel speeds of below 3mph (4.8 kmph). The positive fluted roll was made of cast iron or a built up steel section, generally 3 inches (75 mm) in diameter or less. The peripheral speed of this type of roll was about 1000-1100 ft. per minute (300-330 m/min). This roll type was commonly used in corn combines and had an advantage of permitting higher capacities and ground travel rates.

Mathur (1979) reported that roll length varied from 1000-1100 mm and had 70 mm diameter snapping rolls. These were made of M.S. pipe and the peripheral speed was 182.88 m. min^{-1}.

2.4 Operating Parameters

2.4.1 Forward travel speed

Burrough & Harbage (1953) studied the performance of a corn picker sheller during 1950-51 to evaluate the effect of harvesting date on the efficiency of the picker sheller and to determine the crop characteristics. The machine operated quite satisfactorily at ground speed of 2.5 and 3.5 mph (4.0 and 5.6 kmph) in corn harvesting at 24.5 per cent moisture content. Due to in sufficient sheller capacity, it was not possible to operate at higher ground speed.

Byg and Hall (1968) observed that forward rate of travel for combines decreased as the number of rows per machine increased. This might be due to lack of power, lack of separating capacities or it due to the physical disability of the operator to watch all rows units for proper functioning and for proper header height. The ground speed for various row combinations is shown in Table 2.1.

Table 2.1. Rows per machine and forward travel speed of corn combines

Rows per machine	Average ground speed
2	4.16 kmph
3	4.16 kmph
4	3.52 kmph
6	3.2kmph

Mathur (1979), Bardwa (1980) and Paik (1985) studied the performance of tractor semi mounted single row corn picker and reported that corn picker performance was found satisfactory at forward travel speed ranging from 1.9 kmph to 3.0 kmph.

Pandey *et. al.*, (1997) described the technical specification of the cereal crops harvesting equipment in India developed under FIM scheme on AICRP. They reported that self propelled vertical conveyor reaper performed satisfactorily at 2.1 kmph for rice, 3.18-3.39 kmph for soybean, 2.35-3.54 kmph for safflower and 3.00-3.90 kmph for sesamun. They further quoted forward travel speed of various farm machineries at their optimum performance. The self propelled rice harvester was operated at 2.7 kmph. Wheat harvested with CIAE tractor front mounted vertical conveying reaper winder gave the highest performance results when machine was operated at 2.18 kmph. Similarly PAU tractor front mounted vertical conveyor reaper winder was operated at 2.5-3.5 kmph to obtain best performance results. Groundnut digger shaker windrower and groundnut digger was operated at 2.5 kmph and 3.0kmph respectively. Tractor mounted 2 row potato digger was operated at 2.0-3.5 kmph for its optimum performance.

2.4.2 Peripheral speed of snapping rolls

Srivastava *et. al.*, (1993) opined that proper peripheral speed of snapping rolls was important for adequate operation. Faster speed would results in shelling of cobs at the point of attachment to the stalk while slower speed might result in stalk slippage and trash build up on the rolls. They further asserted that it was important to operate the snapping rolls at the speed proportional to the forward speed of the machine. If the snapping rolls operate too slow the machine would run the corn stalks down before they were pulled through. Too high a velocity would cause them to bounce off the snapping bars and fall to the ground. They gave peripheral speed of the rolls as 180 m. min^{-1}.

Mathur (1979) and Bardwa (1980) and Paik (1985) used snapping rollers for picking cobs from the standing plants with peripheral speed of about 182.88 m/ min.

2.4.3 Angle of inclination

Hurlbut (1955) conducted experiments to determine the harvesting efficiency of mechanical corn pickers. An experimental ear corn harvesting attachment was designed so that the incoming corn stalks pass between two inclined gathering points. The snapping rolls were set at angle of about 30° to the row so as to cause the stalks to travel away from the row while at the same time they travel forward between the snapping rolls.

2.4.4 Moisture content

Pickard (1954) conducted laboratory studies of corn combining. A rasp bar cylinder and a channel bar concave were used in the studies from 1950 to 1954. He compared the various cylinder and concave bar arrangements as to shelling efficiency and kernel damage and to correlate these effects with other variables such as cylinder speed, concave clearance, and moisture content of corn and orientation of the ears. He reported critical moisture content between 30 and 25 per cent.

Prince (1961) investigated the ultimate strength and physical properties of forage stalks. The moisture content corresponding to minimum fiber strength in bending for different stalks varied between 35-60 per cent, while the ultimate strength in parallel compression was reported to be maximum at the moisture content 20-30 per cent.

Johnson *et.al.,* (1963) studied the corn harvesting performance at various dates for lodged crop. They reported that many factors need to be determined and integrated to determine the optimum time for harvesting corn as a grain. Peak harvesting efficiencies were observed for 20 to 30 per cent kernel moisture depending on the degree of the lodging. The peak harvest efficiency was up to 35 per cent for the lodged crop.

Miles (1963) reported average kernel moisture of 26 per cent at maturity. Yields were less at both higher & lower moisture and increased less at higher moisture. Ear corn harvested at 33 per cent kernel moisture yielded 42 per cent more dry matter when shelled after drying on the cob than direct high moisture shelling. The weight gain was independent of the drying rate.

Maire and Parsons (1996) referred ASAE Standards D241.3 for Kernel and cob moisture content of corn plant. They reported that cob and kernel moisture are equal at about 13 per cent, while at higher kernel moisture the cob is significantly wetter (Table 2.2).

Table 2.2. Kernel verses cob moisture contents for corn

Kernel moisture %	10	15	20	25	30	35	40
Cob moisture %	9	18	35	45	52	56	59

Maier and Parsons (1996) recommended that when kernel moisture is about 30 per cent, to improve the shelling efficiency, higher cylinder speeds and closer concave spacing will usually be required with both conventional and rotary machines.

Ahlawat *et al.* (1999) suggested to harvest maize crop when husk turned yellow and grains were hard with less than 30 per cent moisture.

2.5 Performance and Losses

Pickard and Bateman (1954) reported the corn losses in the combine test. The test was conducted for full height 10 feet (3 m) of corn and corn topped at 6 feet (1.8 m). They reported that results were insignificant (Table 2.3)

Table 2.3. Corn losses in combine Test

Corn Height	**Losses (Per cent of total yield)**					
	Ears	**Unshelled**	**Cutter bar**	**Over shaker shoe**	**Over deck**	**Total**
Full,3.0m	4.4	0.3	0.4	0.1	1.4	6.6
Topped at 1.8m	3.0	0.2	0.4	0.08	1.7	5.4

Hurlbut (1955) reported that economics of corn production is depended on the efficient harvest and for preserving the quality of the grain. To develop an ideal corn harvesting machine, work was conducted on an experimental ear corn harvesting attachment to a combine. The snapping rolls were set at angle of about 30° to the row so as to cause the stalk to travel away from the row while at the same time they travel forward between the snapping rolls. The data from the harvesting tests indicate that the threshing and separating units wasted only about 2 per cent of the total corn yield whereas the pre-harvest losses plus the snapper and gathering losses amounted to range form 13 to 30 per cent of the total yield.

Richey *et. al.*, (1961) reported that corn picker losses were normally much higher than as considered acceptable for combines. They conducted a number of experiments and reported their losses contests ranged from 5 to 20 per cent with an average of 10 per cent, excluding previously detached ears. Approximately half of these losses were from missed ears and half from shelled corn lost through the snapping rolls.

Johnson *et. al.*, (1963) reported that corn harvesting efficiency ranges from 75 to 99 per cent with mechanization. Factors such as degree of lodging, moisture content, field conditions and the crop variety all influence the losses. The most significant factor was the farmer and his ability to adjust and operate the machines.

Byg and Hall (1968) studied the corn losses and kernel damage in field shelling of corn. The fields sellers losses were due to imperfect shelling and constituted corn kernel tips left on the cob and corn chips that were discharged from the rear of the machine. The extent of these losses was related to corn moisture. These are presented in Table 2.4.

Table 2.4. Corn moisture and field shelling losses

Corn moisture content (%)	Field sheller losses (%)	
	Picker	Sheller
35	0.5	2.9
30	0.2	2.1
25	0.0	13.3
20	0.0	0.8

Waelti *et. al.*, (1969) determined the corn losses occurring before and during the harvesting season for five different varieties. They reported that for most varieties the losses increased rapidly as the grain moisture dropped below 25 per cent. 85 to 95 per cent of all losses were eardrop losses before or during the harvesting operation. Large differences in these losses existed among varieties. The results indicated that poor ear attachment (weak ear stank) was a major factor causing very high ear losses for same varieties at kernel moisture below 25 per cent.

Quaye and Schertz (1982) analyzed the samples of combined discharged collected during corn harvest to determine the constitution of the sieve and walker discharges. He observed that the distribution of constituents from the walker discharge; cobs, husks, stalks and other material were 68, 26, 4 and 2 per cent respectively. The distributions of the same constituents from the sieve discharges were 72, 6, 15 and 7 per cent respectively.

Maier and Parsons (1996) opined that to minimize ear loss the speed of snapping rolls and gathering chain must be reasonably well timed to combine ground speed. To prevent ear loss and excessive shelling at the header both the stripper plates and snapping rolls should be closer for smaller stalk and ear sizes.

2.6 Power Requirement

Richey *et. al.,* (1961) concluded that power requirement for snapping corn varied greatly with conditions. Early picking of green corn required much more power than picking after stalks have been killed by frost, when ears snap more easily. They further reported the PTO power requirement for corn picking vary greatly with amount of picker mechanism, types of bearing, amount and toughness of corn stalks. The average power requirement of 4.75 and 6.3 hp were reported for two row corn picker. For one row corn picker the power requirement is presented in Table 2.5.

Table 2.5 : Power requirement for one row corn picker

Particulars	Average snapping unit power (hp)
No load	1.5 hp
Dry conditions	
1.9 mph (3.04 kmph)	4.3 hp
3.0 mph (4.8 kmph)	5.0 hp
Damp condition	
1.9 mph (3.04 kmph)	6.2 hp
3.0 mph (4.8 kmph)	6.6 hp
Snap unit clogged	13.8 hp

CHAPTER - III

MATERIALS AND METHODS

The details of the experimental laboratory set up procedure and criteria used for treatment evaluation during the course of investigation are described in this chapter.

The chapter has been divided into the following main sections –

1. Experimental laboratory set up
2. Design of picking unit
3. Selection of parameters
4. Criteria for performance evaluation
5. Experimental procedure
6. Statistical analysis of the test results

3.1 Experimental Laboratory Set Up

The experimental laboratory set up consisted of a test track, a mounting trolley, a pipe frame assembly, a corn picking mechanism, two separate power transmission systems, one for forward and backward motion of the mounting trolley and other for the snapping unit. The corn picking mechanism consisted of snapping rolls, a gathering a gear box and a discharge pan. The power transmission was controlled by two control panels. In this set-up, the actual picking operation was simulated and experiments conducted to evaluate the performance of the developed corn picking mechanism.

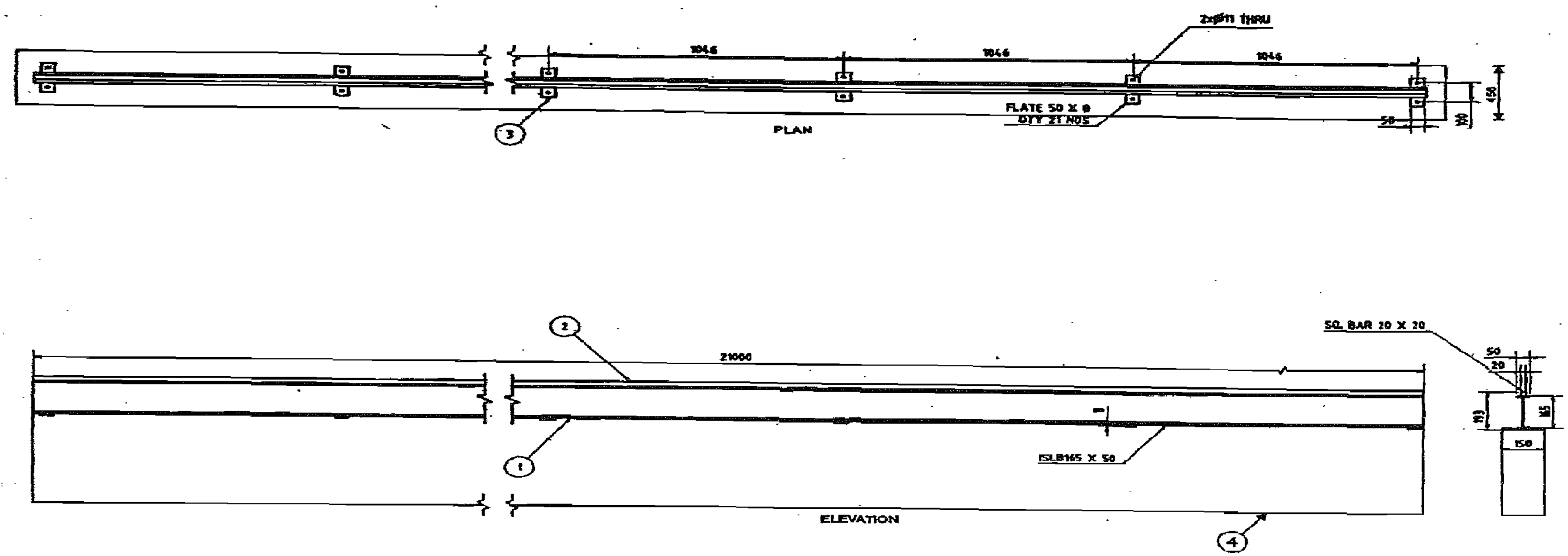
3.1.1 Test Track

Foundation wall of the test track was constructed by 450 mm thick stone masonry having dimensions of 21.0 × 2.75 × 0.9 m. as shown in Fig. 3.1. Two parallel I - shaped ISLB section of 165 × 50 mm were fixed on the masonry wall at 2.30 m apart. This was developed to impart uniform motion to the mounting trolley (Section 3.1.2). I shaped sections were welded to 50 × 8 mm MS flat of 150 mm length. These were held tightly by 300 mm long 12 mm ø bolt grouted in the masonry wall at a distance of about a meter. Steel square bar of 20 × 20 mm was welded on the centre of the ISLB to provide track for the mounting trolley as shown in Fig. 3.2.

Fig. 3.1 A view of test track for evaluation of corn picking mechanism

3.1.2 Mounting trolley

Mounting trolley was fabricated to provide platform for installation of pipe frame assembly and corn picking mechanism. The frame of the mounting trolley was rectangular in shape. This was mounted on four cast iron wheels of diameter 200mm resting on the test track. Pedestal bearings were used to mount the trolley frame on 50 mm diameter axle. The trolley was fabricated by ISMC 100 × 50 mm. The size of mounting trolley was 2.47 × 1.50 m. Two channels 'a b' were welded perpendicular to the out side channel of the trolley frame at 250mm distance from the centre line of the trolley frame. Similarly two channels 'c d' were welded perpendicular to the channels 'a b' at 300mm from the centre line of the trolley frame (Fig. 3.3).



1 ISLB 165 x 50 mm
2 20 x 20 mm steel square bar
3 MS flat 50 x 8 grouted with 300 mm long 12 mm dia bolt
4 Masonry wall 450 mm thickness

ALL DIMENSIONS IN mm

Fig. 3.2 Details of the test track

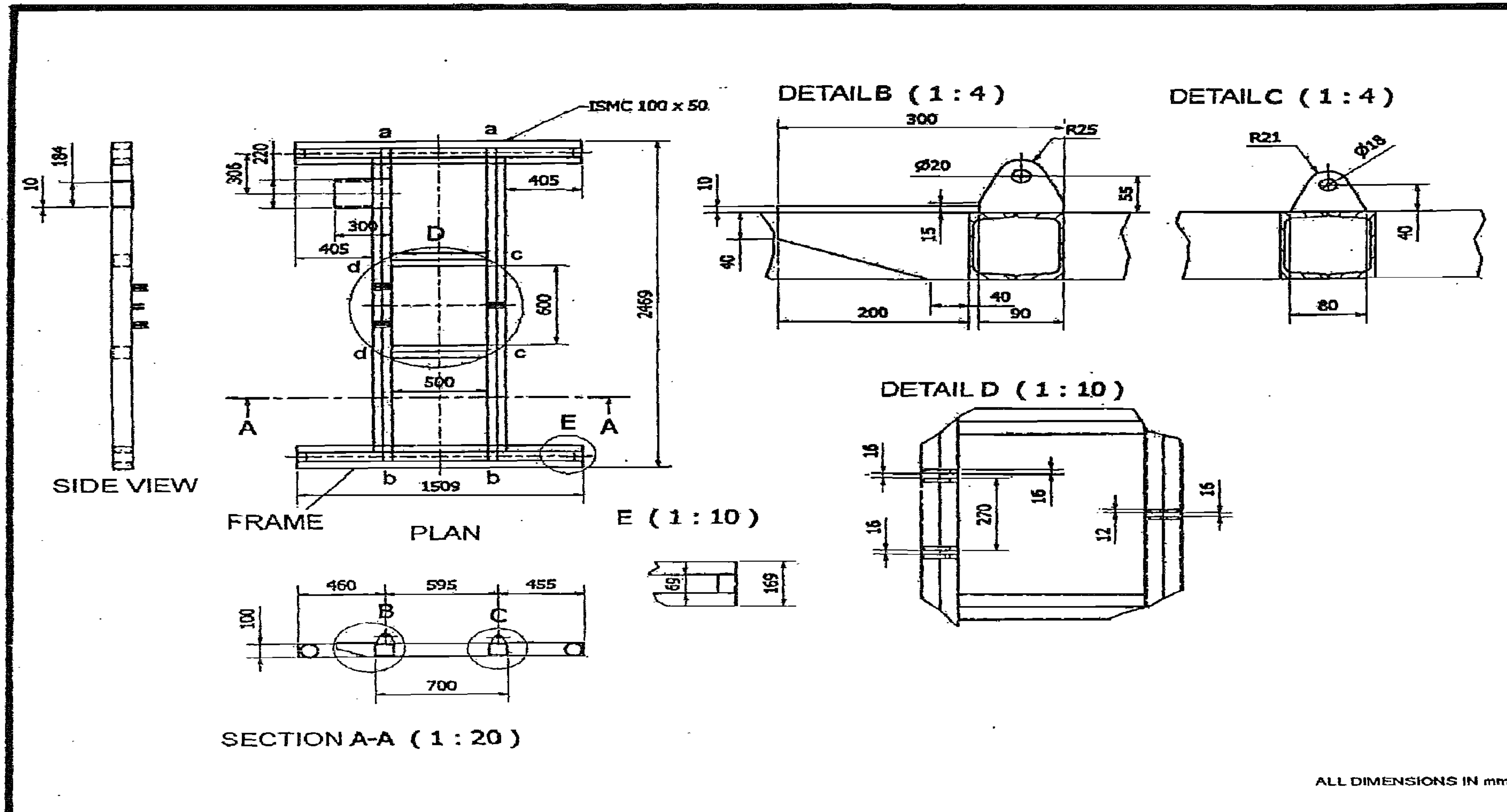


Fig. 3.3 Sectional view of a mounting trolley

3.1.2.1 Power transmission system

Power required for forward travel of the mounting trolley was transmitted through belt pulley system. A variable speed drive was used to control the RPM of the electric motor. By increasing or decreasing the RPM of the electric motor, the forward travel speed of mounting trolley was controlled. Power required for forward travel of the trolley was calculated by the formula given below (Anon, 1995) -

$$P_T = \frac{W \times v}{\eta \times 75} \quad .....(3.1)$$

where, P_T = power requirement for trolley motion, hp

W = resistance to motion, kgf

= BQ w

B = factor to account for flange friction

= 1.25 to 1.4 for wheels (runs on sliding bearing)

Q = weight of load in tonnes (limiting load)

= 1 ton

w = coefficient of resistance to motion, kgf ton^{-1}

η = transmission efficiency, 0.93

v = traveling speed of trolley, m/s

$$w = \frac{(d\mu + 0.1)}{D} \times 1000 \quad ..... (3.2)$$

d = wheel axle diameter, cm

μ = coefficient of friction of bearing, 0.10

D = diameter of trolley wheel, cm

$$w = \frac{[5 \times 0.1 + 0.1]}{20} \times 1000$$

= 30 kgf/t

Therefore, W = 1.25 (1) × 30

= 37.5 kgf

Putting this value in Equation 3.1

$$P_T = \frac{37.5 \times 1.25}{0.93 \times 75}$$

= 0.67 hp

Considering $\sqrt{3}$ times power required for initial starting, power required is 1.16 hp. Considering the factor of safety 2, the electric motor of 3 hp was selected for operation of the system.

Power to the wheel drive shaft was transmitted through a belt pulley system as shown in Fig. 3.4. Same size pulleys were used to transmit power of the electric motor to the wheel drive shaft. The speed of electric motor was regulated by the variable speed drive installed on the panel board.

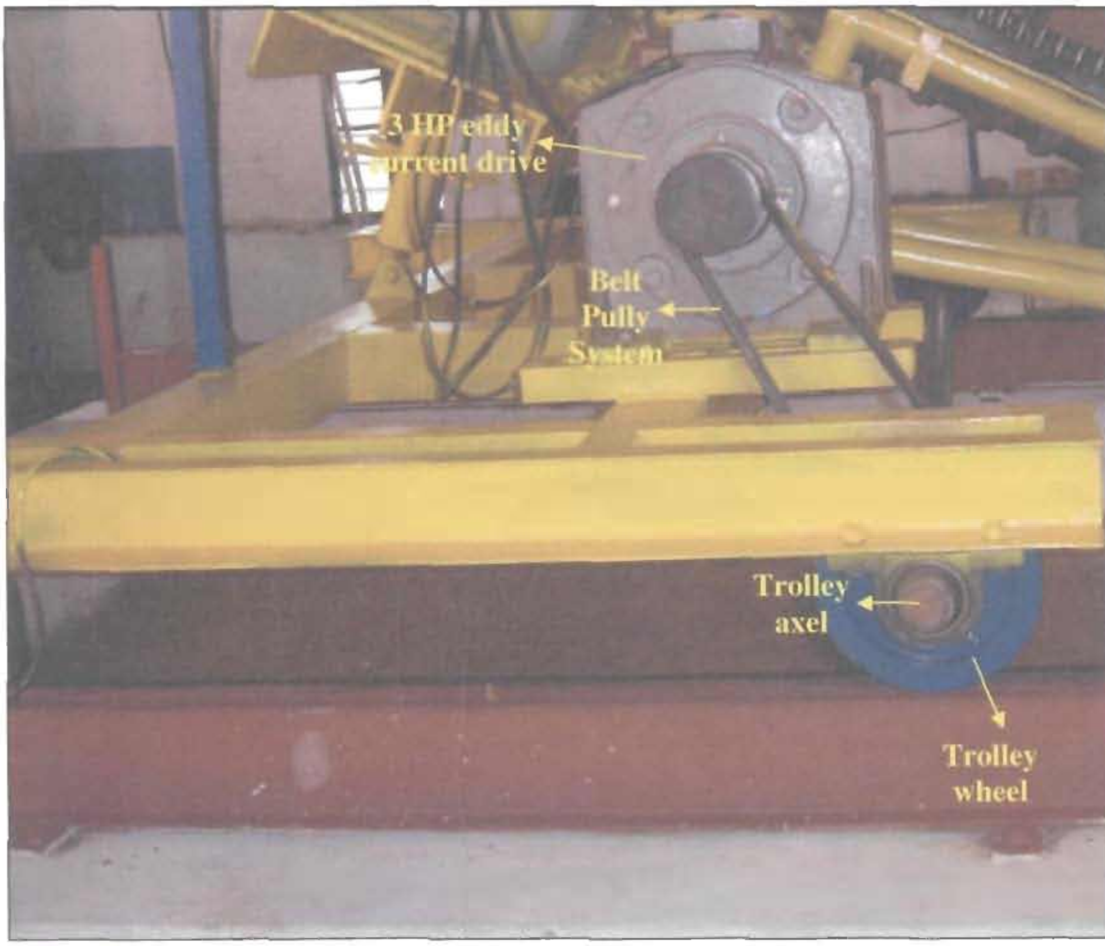


Fig. 3.4 Power transmission system for mounting trolley

3.1.2.2 Control panel board

The control panel was used for eddy current drive, to provide forward and backward motion to the mounting trolley. This consisted of three phase main switch, DOL starter, variable speed drive, two push button, two 16A contactor and one energy meter (Fig. 3.5).

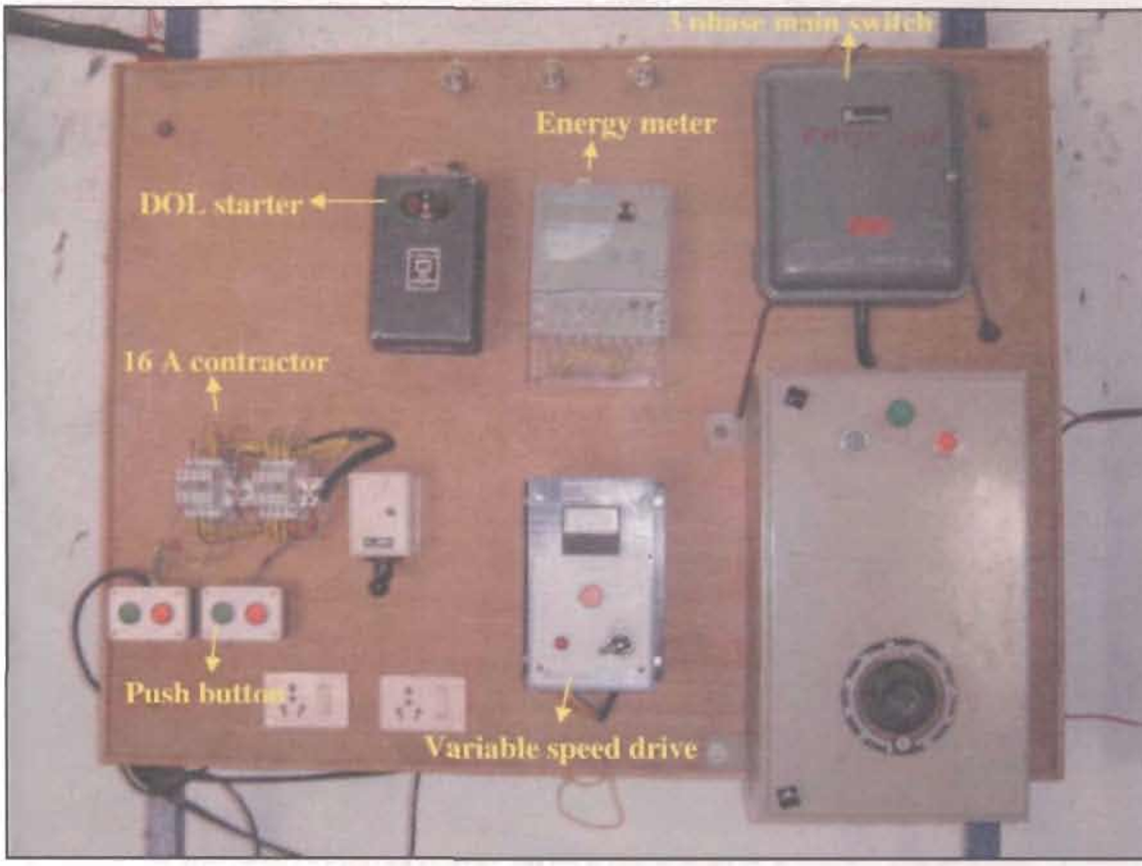


Fig. 3.5 A view of Panel Board

3.1.3 Safety features

Initially the electric motor was tested at lower speed to observe the time required for obtaining uniform speed and time taken to stop the electric motor. It was observed that at higher speed it was not safe to operate the tool mounting trolley as it reached the other end of the test track. To avoid this problem, two lever type limit switches were installed at start and stop locations to regulate the distance travelled by the mounting trolley. These automatically disconnect the power supply, but due to inertia force the trolley travelled 2 to 3 m ahead prior to stoppage. Further a "S" type brake system was incorporated which worked on the solenoid principle.

3.1.3.1 Limit switch

Two lever type limit switch with remote control contactor were used. These switches were operated by means of a lever which was connected to the trolley frame extending from the operating head. Movement of lever in clock wise or anti clock wise from the normal position operates the contactor and limits the distance travel by the tool mounting trolley (Fig. 3.6).

3.1.3.2 Braking system

'S' type brake which worked on the solenoid principle was used to stop the trolley. The size of brake was 100 mm .When solenoid was energized, an armature which was linked with the shoe lever pulls the shoe lever apart to release the brake. When supply cut off the mechanism, it returned to its original position under spring action. As a result brakes were applied (Fig. 3.7).

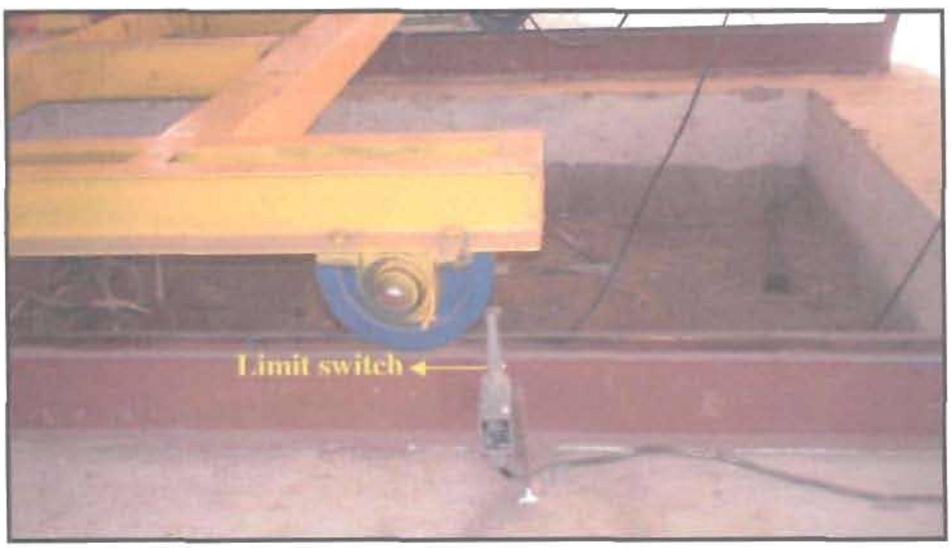


Fig. 3.6 Lever type limit switch

Fig 3.7 Brake system used in mounting trolley

3.2 Development of Corn Picking Mechanism

The initial function of the corn picking mechanism is to pick the ear of corn without shelling the kernel or erring stalk material. The snapping rolls are designed to straddle the standing row of corn to remove the ears with a pair of contra-rotating rolls that pull the stalk downward while pinching off the ears. The spiral ribbed or spiral lugged rolls are commonly used in corn picker. These rolls have spiral ribs on them and the space between them should be kept as narrow as possible without causing clogging and stalk breakage. They have tapered point to facilitate stalk entrance. The rolls are usually adjusted to snap off most of the ears just behind the gathering chains thus leaving the upper roll space for stubborn stalks and trash.

The gathering units are fitted with gathering chains equipped with finger links that also assist in moving the stalks into and through the snapping rolls. The gathering chains moves the stalks into the snapping rolls after they have been come through or have been picked up by gathering points. Gathering chains prevent loose ears from sliding forward and falling to the ground as a loss. For maximum effectiveness, the lineal chain speed should be somewhat faster than ground speed. It is essential that the chain speed match the speed at which snapping rolls feed the stalks (Johnson and Lamp, 1966). Gathering chains equipped with finger links are 200 mm to 250 mm. apart and are commonly used.

3.2.1 Design consideration

1. Design should make use of available standard parts and materials.
2. Design should be simple without sacrificing workability and efficiency.
3. Design should be low cost without sacrificing performance, durability and safety.
4. Capable of picking maximum cobs with minimum damage.
5. Reasonable power and energy requirement.

3.2.2 Selection of factors affecting corn picking efficiency

The function of the picking unit is to remove the ears from the stalk with as little damage or loss of the ears as possible. The gathering chain moves stalk into the snapping roll after they have come through the guiding points. The capacity of any picking equipment depends on a number of factors. Among these are: ground condition, toughness and moisture content of the stalk, moisture content of ears, density of corn cob and available power. Smith (1955) has suggested factors like mechanical, plant and miscellaneous factors that influence the performance or efficiency of corn pickers.

Among plant characteristics; variety or hybrid suitable for machine harvesting, stiff stalk that stand up and do not break over and lodge, condition of the stalk, height of ears and stalks, toughness of the ear shanks, size of ears-large ears reduce shelling losses, hard-shelling characteristics reduce shelling losses, thick, tight husk on ear desirable for snapping but not for husking are main factors.

The mechanical factors like type of snapping roll surface, adjustment of snapping rolls-distance apart, timing of snapping rolls, rate of travel, adjustment to pick-up stalks which are down affect the corn picking efficiency.

The field losses are less if harvesting is done early, carefulness of operator, weather conditions, cleanliness of fields, i.e. free from all weeds and grass, length of rows, row spacing suitable for machine are the miscellaneous factors affecting the corn picking efficiency..

3.2.3 Selection of snapping rolls

The snapping rolls are provided to detach the ear from the standing corn stalk. The snapping rolls are long and have a taper on the lower end to ease the entry of the stalk between the rolls. The rolls are made into two basic shapes. Either they have a raised spiral on the surface or they are fluted. In either case, they must be properly timed so that the protrusions on one roll fit between protrusions on the mating roll. The rolls turn towards each other in order to grasp the stalk and pull them down between the roll and snap the ears from the stalks.

The spacing between the snapping roll is critical. If the rolls are set too apart, the rolls will not grasp the stalk firmly enough to snap the ears from stalk and the ears will be held against the rolls for too long a time. This spacing causes shelling of the lower part of the ears, loss of nubbins and possible plugging of the snapping rolls. If the rolls are set too close, the stalks may be crushed and the upper part of the stalk will remain attached to the ear. This undesirable result usually occurs if the stalks are extremely brittle or dry.

Peripheral speed is important for adequate operation. Faster speed would result in shelling of the cobs at the point of attachment to the stalk while slower speed may result in stalks slippage and trash build upon the rolls. It is important to operate the snapping rolls at the speed proportional to the forward speed of the machine. If the snapping rolls operate too slowly, the machine would run them down before they are pulled through.

Too high a velocity would cause them to bounce off the snapping roll surface and fall to the ground.

Based on the review of literature described earlier under section 2.4.1 snapping rolls having length of 1100 mm and diameter of 75 mm spiral ribbed rolls with 15 mm MS round bar and 100mm pitch were fabricated.

3.2.3.1 Fabrication of snapping rolls

A pair of snapping rolls were fabricated from 75 mm diameter 530 mm long MS pipe (Section 3.2.3) and three pieces of 80 mm MS round of length 175 mm, 460 mm and 685 mm. On one side of the MS pipe, MS round of 175 mm length was welded and machined to equip it in the snapping roll bearing housing. To the other end of MS pipe, MS round of length 460 was welded and tapered to 45 mm and 35 mm as shown in Fig. 3.8 and Fig. 3.9. Further it was fixed in another hollow MS round to a length of 460 mm. The total length of outside MS round was 685 mm. The 50 mm length of front end was machined to 26 mm to equip snapping rolls in brash bush for installation on pipe frame assembly (Section 3.2.5). The total length of the snapping roll was 1260 mm and effective length was 1100 mm. knurling of 2 mm x 2 mm was made on the surface of the pipe for roughness. 15 mm MS round bar was used for spiral on the snapping rolls. The pitch of the spiral was 100 mm.

3.2.4 Selection of gathering units

The gathering unit must be able to guide the corn stalks into the snapping rolls and also capable of lifting lodged stalks with a minimum number of ears lost during the process. It consisted of a gathering chain, gathering chain cover and gathering points.

3.2.4.1 Gathering chain

Gathering chain having finger links 200 mm apart, lift low ears and stalks and feed all stalks back into the snapping roll to prevent loose ears from sliding forward to be lost. Chain sprocket was used to guide the picked cobs to be collected in the discharge pan. A chain adjuster was fabricated for tightening of the chain having 38.10 mm pitch (Fig. 3.10). It consisted of chain wheel, ball bearing, chain wheel pin drive side and spring retaining ring.

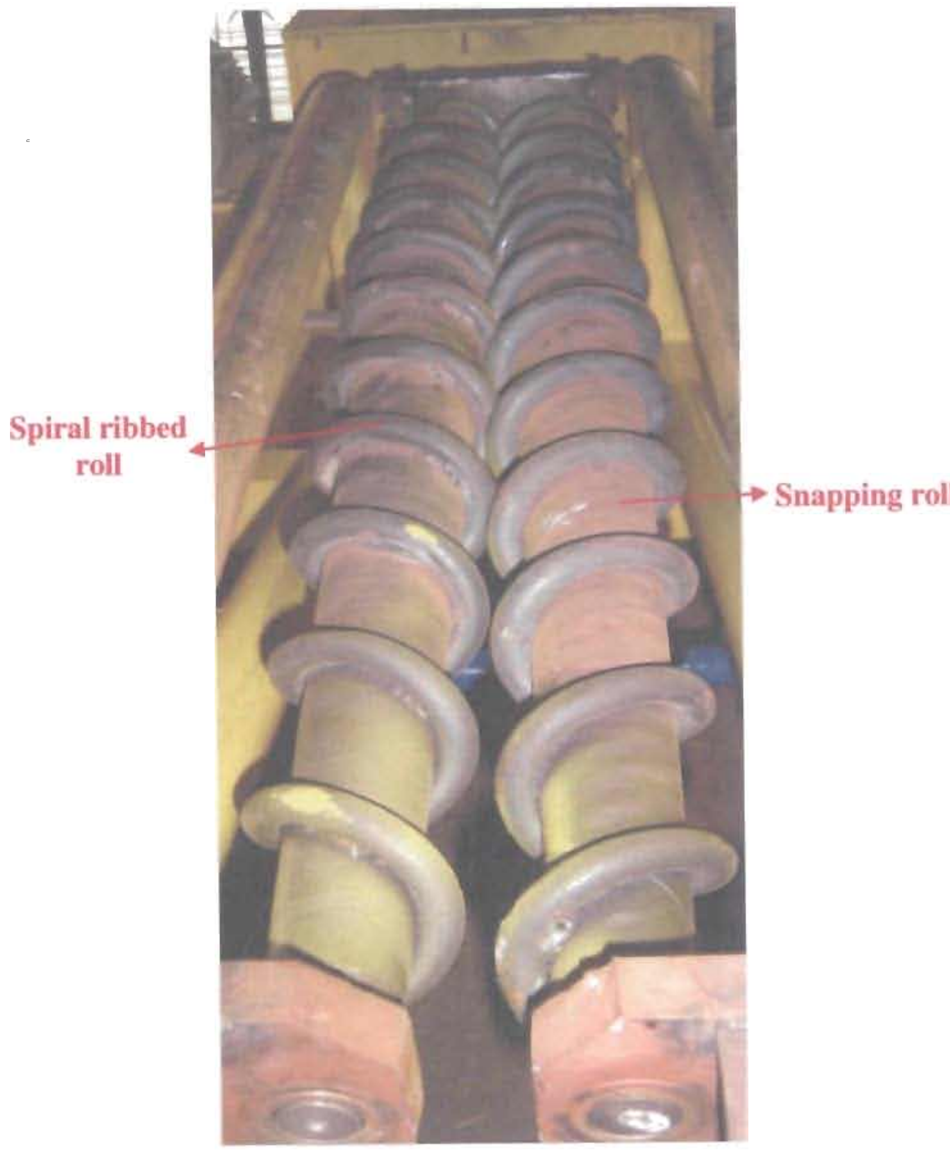


Fig. 3.8 A view of fabricated snapping rolls

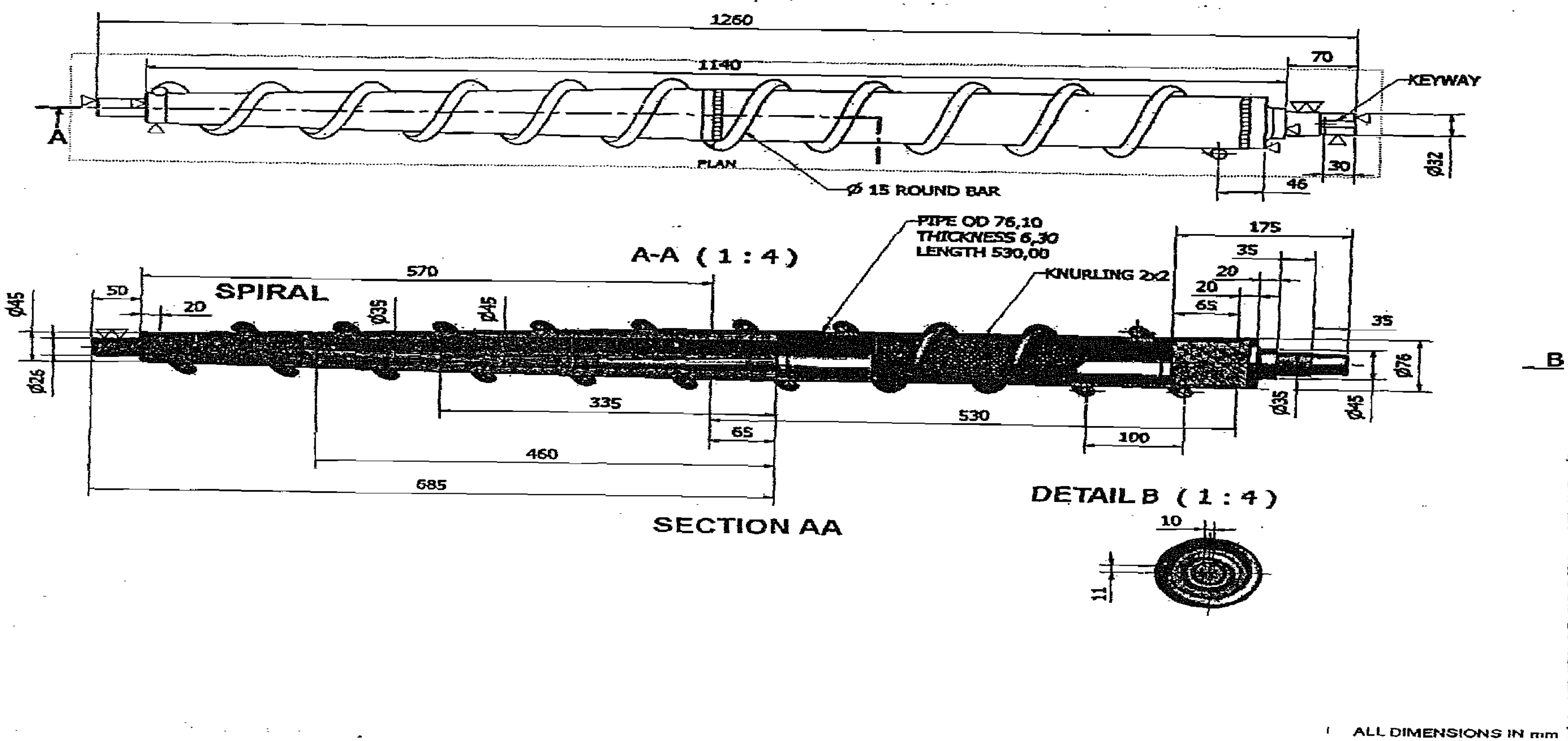


Fig. 3.9 Schematic diagram of a snapping roll used in corn picking mechamism

3.2.4.2Gathering chain covers

The safety covers of the gathering chain were made from 3 mm MS plate with total length of 2240 mm. In the front it was tapered to 45^0 from the centre to guide the corn stalk. The safety covers were fitted on the pipe frame assembly with nuts and bolts. The end points of safety cover were gathering points. Gathering points help to pick and guide the stalks to snapping rolls chain and gathering chain.

3.2.5 Pipe frame assembly

Snapping rolls were held in position by a pipe frame assembly to avoid losses when stalk pass through the rolls. It consisted of a pipe frame, a snapping roll cover plate, chain guards and base plate for mounting of gear box.

3.2.5.1 Pipe frame

The basic structure of pipe frame was fabricated by 50 mm CI pipe for mounting different components of the corn picking mechanism (Section 3.2.8) such as snapping rolls, gathering chain, sprockets etc. Two pairs of CI pipes, having length of 1270 mm and 1143 mm and 808 mm and 285 mm were repetitive cut and welded to give shape to pipe frame so that the developed corn picking mechanism could be installed within it as shown in Fig.3.11 and Fig.3.12.

Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Chain wheel pin drive side	
2	1	chain wheel 38.1n8	
3	1	DIN 625 T1 - 6205 - 2S x 52 x 15	Deep Groove Ball Bearing
4	1	DIN 471 - 25 x 1.2	Spring Retaining Ring
5	1	DIN 472 - 52 x 2	Spring Retaining Ring

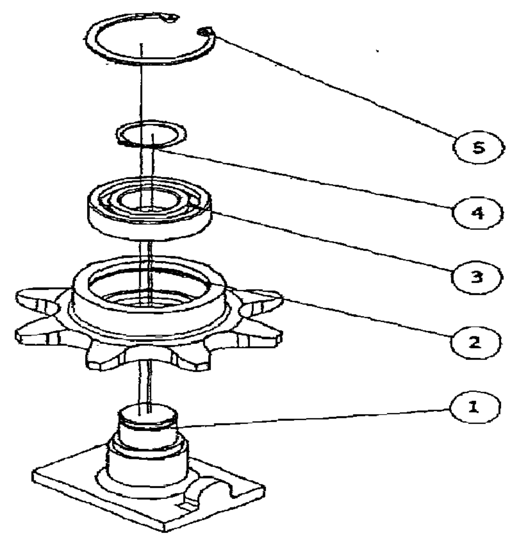


Fig. 3.10 Chain Adjuster used for gathering chain

3.2.5.2 Snapping roll cover plate

A snapping roll cover plate was fabricated from 8 mm thick MS plate of size 1910x400 mm to cover the both snapping rolls so that under size cob may not pass through these rolls. Smooth rotations of the rolls were also ensured.

3.2.5.3 Chain guards

Chain guards were fabricated to ensure smooth movement of the gathering chain and to protect its side movement. For this purpose pair of MS flat of size 1340x50x8 mm were welded on both sides of snapping roll cover plate.

3.2.5.4 Base plate

Base plate was used to install the gear box. It was fabricated from 850 X 450 X 10 mm MS plate. Pipe frame was welded to this base plate. This frame was fixed to the mounting trolley with the help of hinge system to adjust the angle of inclination of the snapping rolls through jack screw (Section 3.2.6).

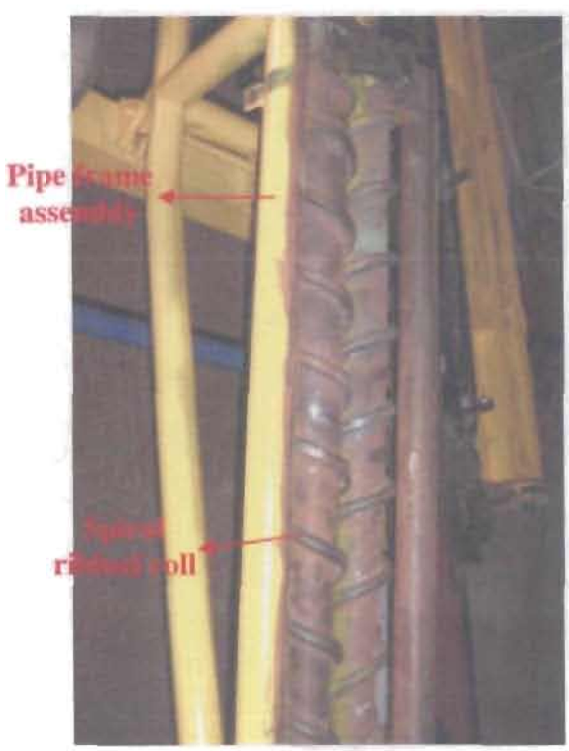


Fig. 3.11 A view of pipe frame fabricated for snapping roll assembly

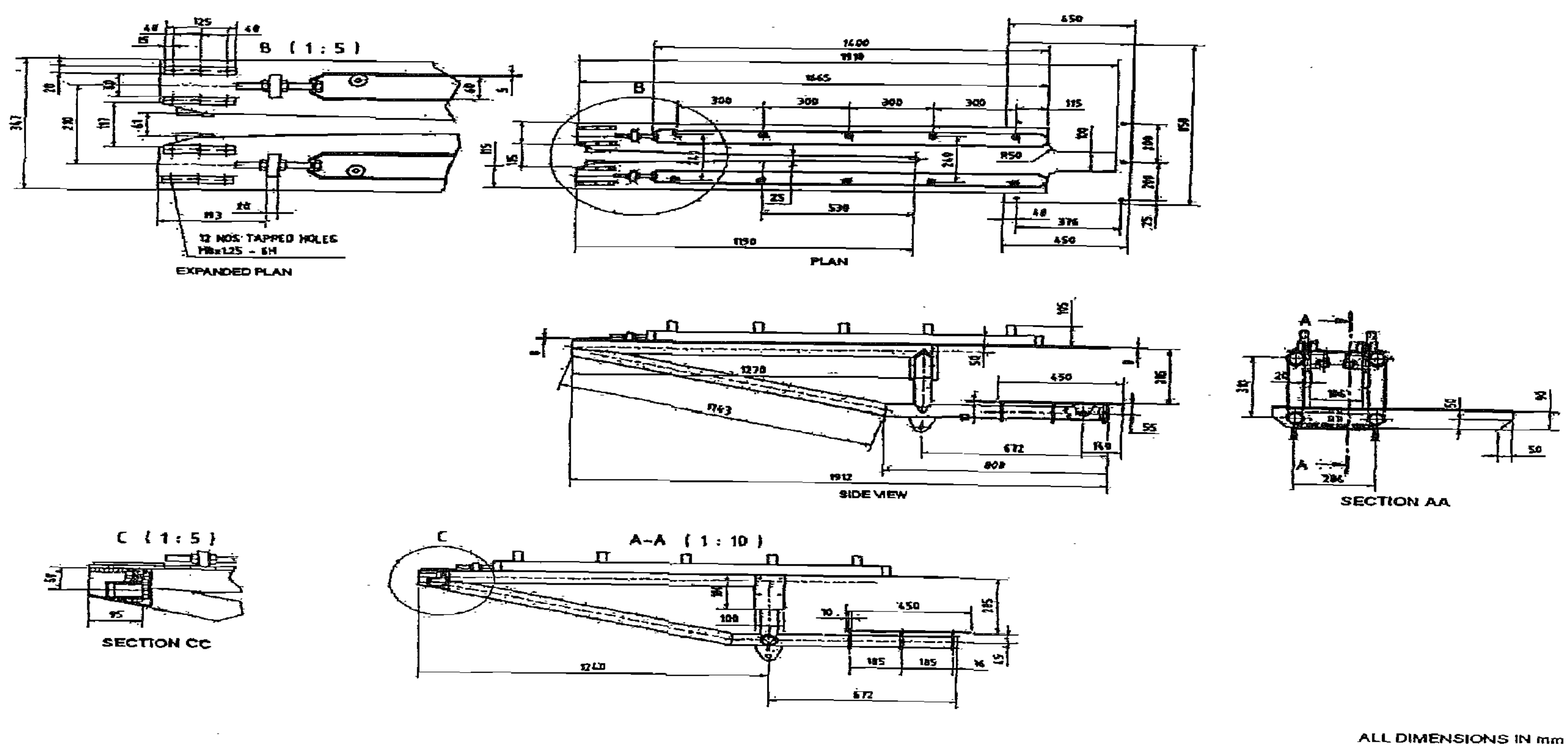


Fig. 3.12 Schematic diagram of pipe frame with snapping roll cover

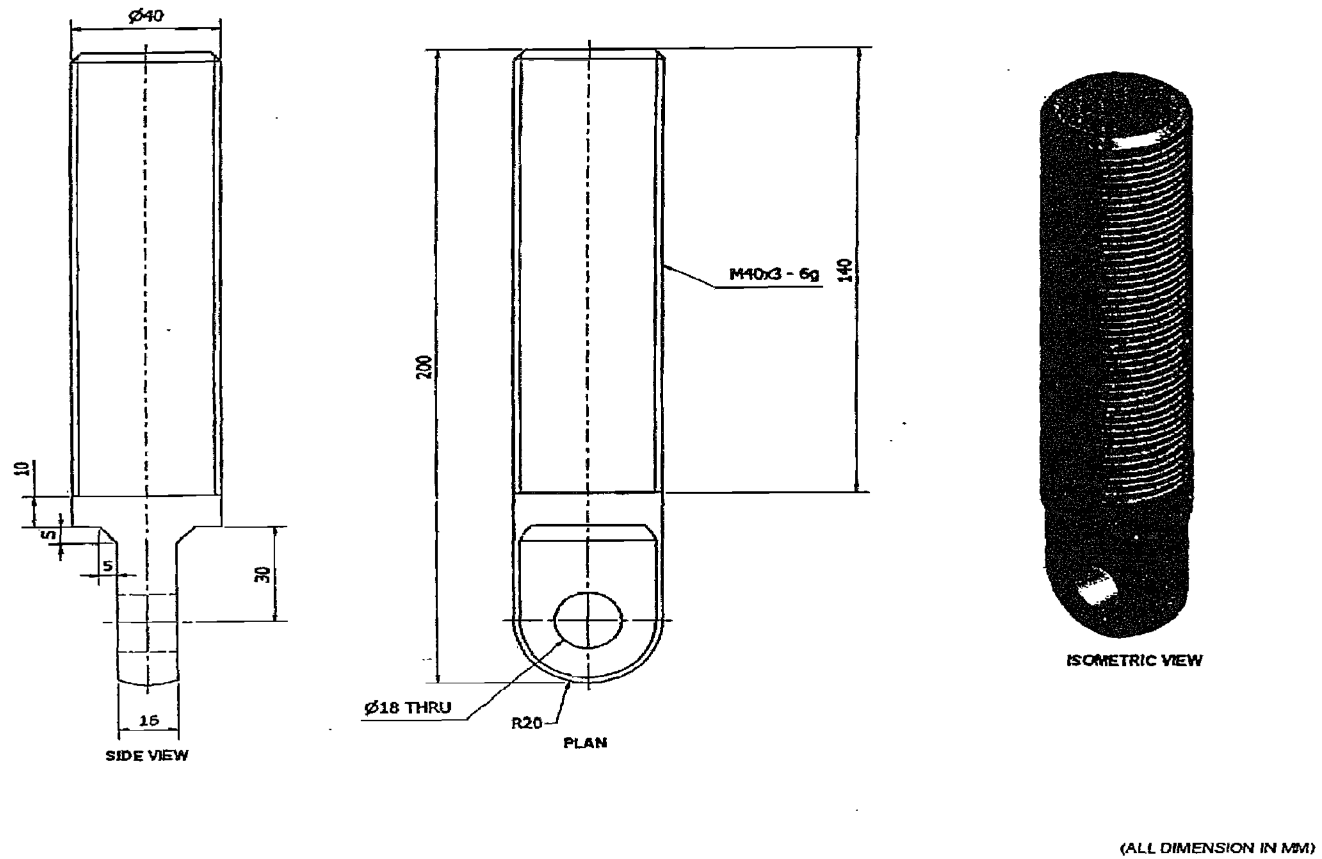


Fig. 3.13 Jack Screw

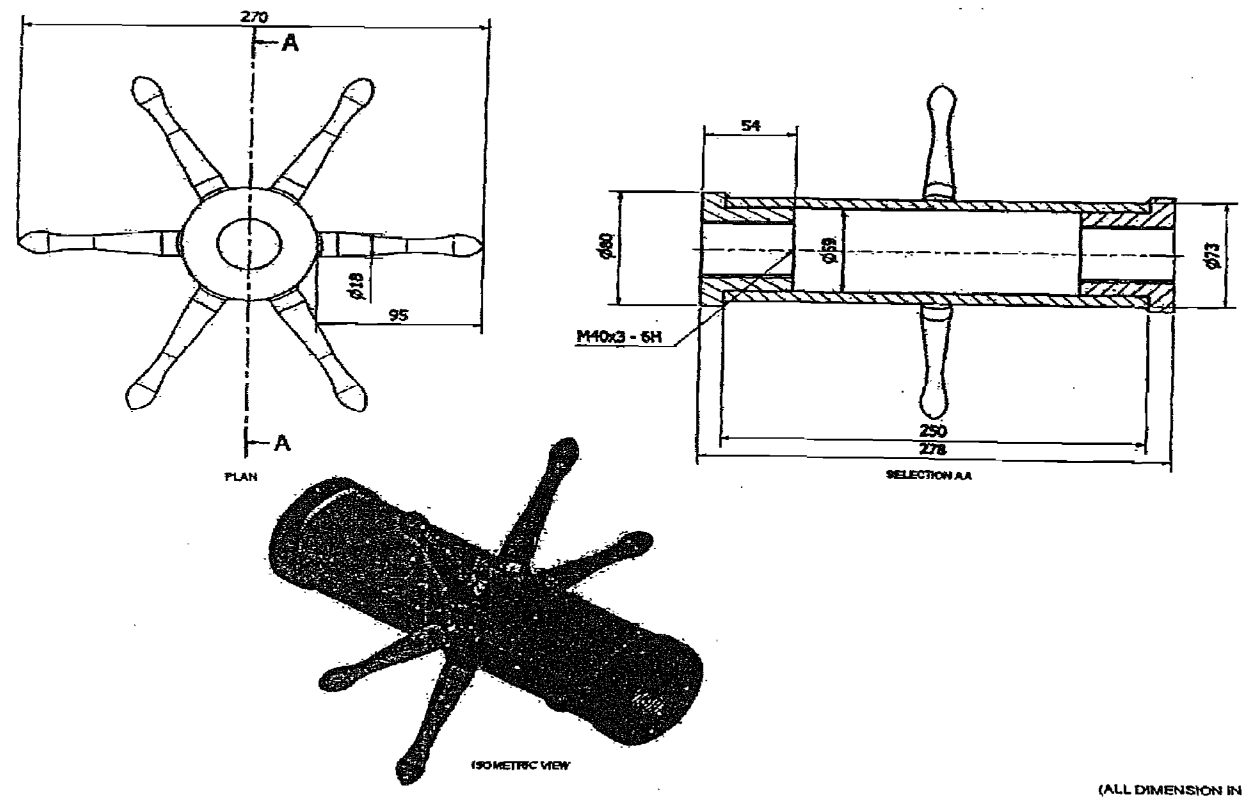


Fig. 3.14 Screw Housing

3.2.6 Jack Screw

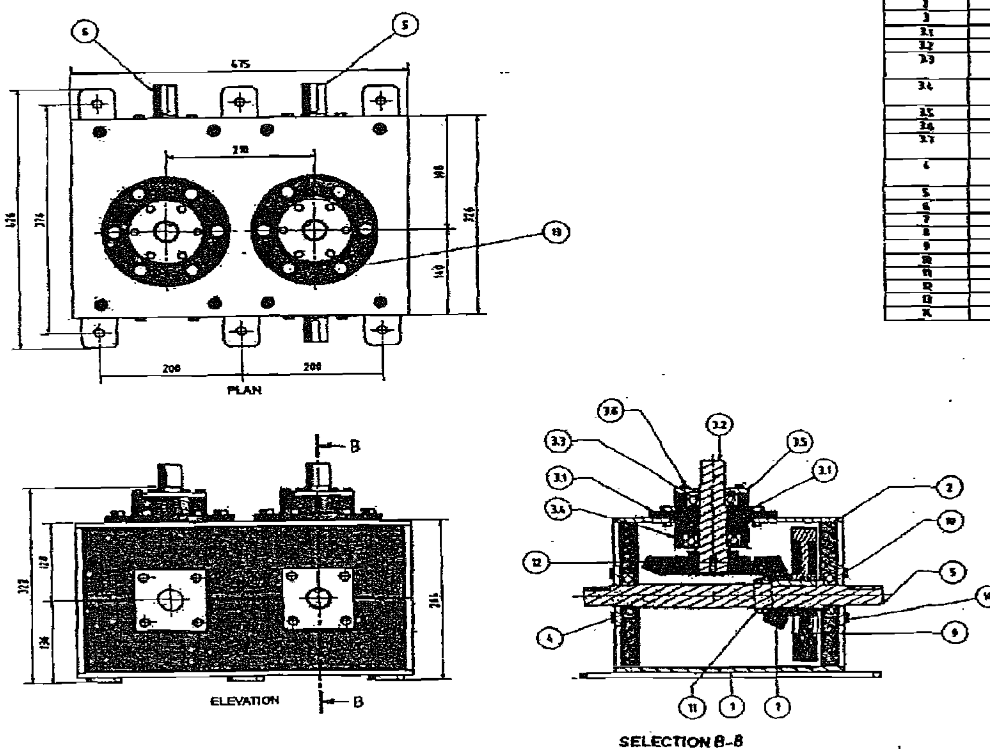
Jack screw was used to change the angle of inclination of the snapping rolls. This consisted of a screw and screw housing. The screw was fabricated from 200 mm length 40 mm diameter MS round (Fig. 3.13 and Fig. 3.14). The screw housing was fabricated from 278 mm length and 80 mm diameter MS round. M 40X3 – 6H metric threads were cut inside of the screw housing and M 40X3 – 6g metric threads were cut on the surface of the screw. The jack screw was fixed to the trolley frame and base plate of the gear box.

3.2.7 Power transmission system

The power requirement for snapping corn varied greatly with damp and dry conditions. In damp condition the power required for single raw rained from 6.2 to 6.6 hp (Richey et.al., 1961). Keeping this in view a gear box was designed for transmitting 7.5 hp powers so that the complete corn picking mechanism could be used to develop a prototype. Presently during experiments the gear box transmitted power to snapping rolls and to the gathering chain through universal shaft and chain sprocket mechanism respectively. The size of gear box was 475 × 326 × 264 mm. It was fabricated by 8mm MS plate. The length of spur gear shafts were 369 mm and 320 mm whereas the length of each bevel gear shafts was 182 mm. Suitable factor of safety was assumed at various stages of fabrication to take care of the unavoidable load during its operation. The schematic diagram of the gear box is presented in Fig. 3.15.

Spur and Bevel gears were designed as per the procedure followed by Bhandari (1994) and Khurmi and Gupta (2005). Various dimensions of shaft for Spur and Bevel gear and other dimension used are presented in Table 3.1. Details of the calculation for the design of gear box is given in Appendix –A.

A Control panel was fabricated to control the power input to the snapping rolls. This panel board consisted of three phase MCB, energy meter, and a variable frequency drive (Fig.3.16). Three phase 4 hp electric motor was used to transmit power to the gear box. The speed was regulated by variable frequency drive. The energy meter was installed to measure the power required for picking mechanism (Snapping rolls and Gathering chain) during the experiment.



Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	GEARBOX BOTTOM	
2	1	GEARBOX TOP	
3	2	BEVEL GEAR BEARING HOUSING	
3.1	1	BEVEL GEAR BEARING HOUSING	
3.2	1	BEVEL SHAFT	
3.3	1	DIN 625 T1 - 6207 - 35 x 72 x 17	Deep Groove Ball Bearing
3.4	1	DIN 625 T1 - 6208 - 40 x 80 x 18	Deep Groove Ball Bearing
3.5	1	COVER PLATE	
3.6	6	IS 1363-2 - M6 x 25	Hex-Head Bolt
3.7	1	IS 2048 - 1983 - Parallel Key A 12 x 8 x 32	Parallel Key
4	4	DIN 625 T1 - 6207 - 35 x 72 x 17	Deep Groove Ball Bearing
5	1	GEAR SHAFT	
6	1	GEAR SHAFT1	
7	2	Bevel Pinion 20-Teeth 5-Module	
8	2	[illegible]	Parallel Key
9	2	Gear 42-Teeth 5-Module	
10	4	COVER PLATE1	
11	4	CHECK NUT M42	
12	2	Bevel Gear 40-Teeth 5-Module	
13	12	ISO 4017 - M12 x 25	Hex-Head Bolt
14	16	ISO 4017 - M8 x 20	Hex-Head Bolt

(ALL DIMENSION IN MM)

Fig. 3.15 Schematic diagram of a gear box to transmit power to snapping rolls and gathering chain

Table 3.1 : Various dimensions of gears used in the design of Gear Box

Particulars	Spur gear	Bevel gear
Diameter of shaft	35 mm for both shafts	35 mm for both shafts
Shaft length	369, 320 mm	182 mm
Distance between shafts	210mm	200 mm
Number of teeth	42 on both gears	40 on both gears
Module	5 mm	5 mm
Addendum	5 mm	5 mm
Deddendum	6.25 mm	6.0 mm
Working depth	10 mm	10 mm
Total depth	11.25 mm	-
Tooth thickness	7.85 mm	7.85 mm
Clearance	1.25 mm	1.0 mm
Fillet radius	2.0 mm	-

3.2.8 Discharge pan

A discharge pan of size 300 x 250 x 225 mm was fabricated to collect the cobs picked by the mechanism. The collection pan was fixed to the corn picking mechanism by an inclined plate of size 488 X 300 mm at 35 degree inclination with the top plate to facilitate easy collection of the cobs. The discharge pan was fixed with gear box in such a manner that it did not interfere the power transmission system of corn picking mechanism (Fig. 3.17).

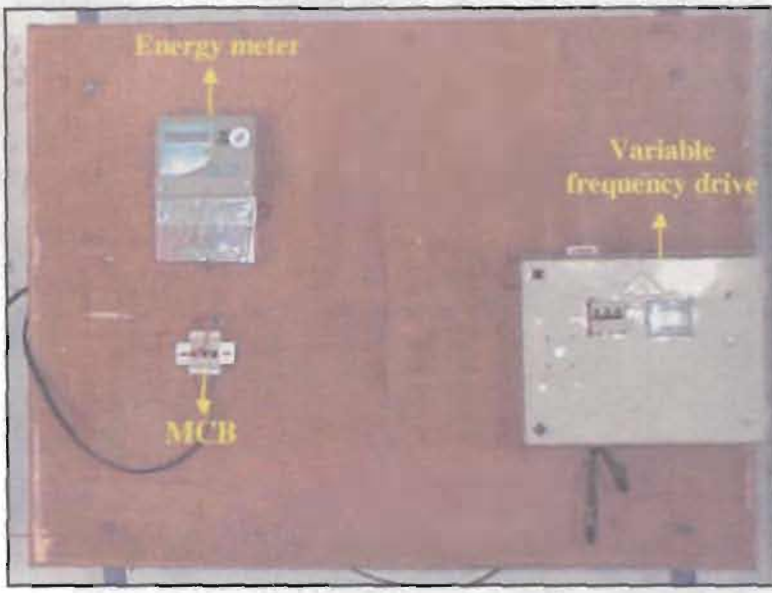


Fig. 3.16 A view of panel board

Fig. 3.17 Discharge pan to collect the picked cobs

3.2.9 Assembly of the developed corn picking mechanism

The developed corn picking mechanism (Section 3.2.1 to 3.2.7) was then assembled as per the assembly drawing shown in Fig. 3.18. A complete laboratory set up of the corn picking mechanism is shown in Fig. 3.19. Schematic diagram of the experimental set up is shown in Fig. 3.20. A view of the developed corn picking mechanism is presented in Fig. 3.21.

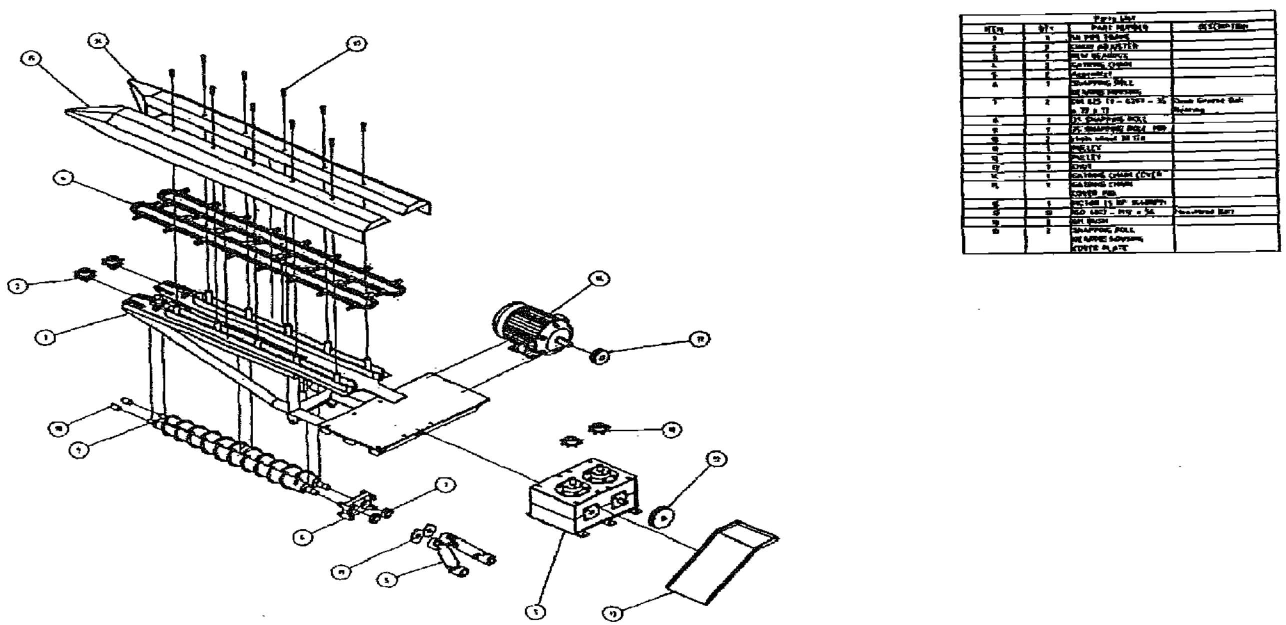


Fig. 3.18 Assembly drawing of corn picking mechanism

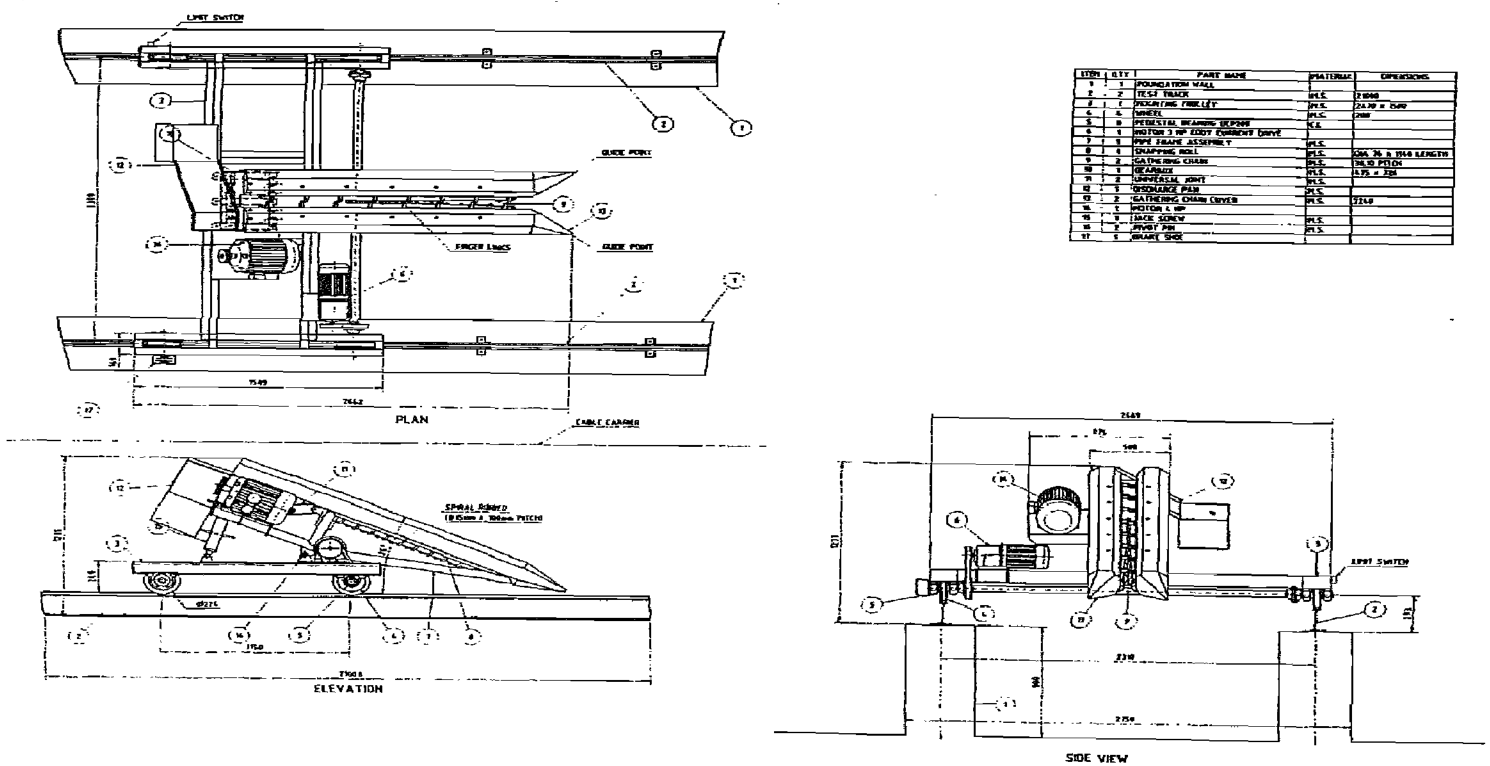


Fig. 3.19 A complete laboratory set up for corn picking mechanism

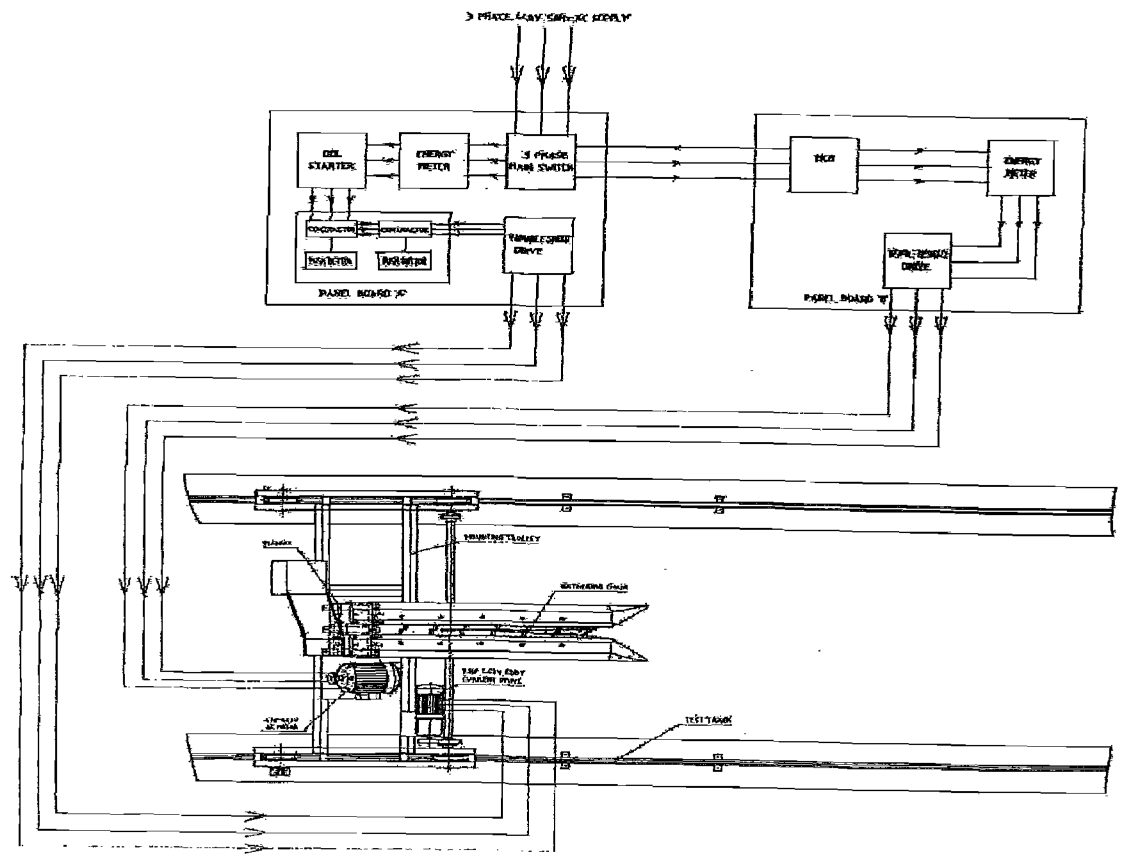


Fig. 3.20 Schematic diagram of the experimental set up of a corn picking mechanism

Fig. 3.21 A view of developed corn picking mechanism

1 Test track **2 Mounting trolley** **3 Pipe frame assembly**
4 Gathering chain **5 Eddy current drive for mounting trolley** **6 Electric motor for picking mechanism**
7 Cable carrier **8 Trolley axel** **9 Control panel**
10 Snapping roll cover plate

3.2.10 Plant holder

A Plant holder was fabricated to hold the stalks of the corn plant. This was positioned on the test track. This was fabricated from "C" channel of size 75 × 40 × 7.3 mm. Holes were drilled at 250 mm distance, taking into consideration the plant to plant spacing for the maize crop. The maize plants of desired density and interval were clamped in the plant holder. Plants were held rigidly by fixing them in the clamp fabricated by MS flat and tightened by nuts and bolts.

3.3 Selection of the Operating Parameters of the Corn Picking Mechanism

The operating parameters consisted of crop parameter and machine parameters. The crop parameter included kernel moisture content whereas machine parameters included angle of inclination and peripheral speed of snapping rolls and forward travel speed.

3.3.1 Kernel moisture content

Number of research studies made for the harvesting of maize and cob picking suggests that both kernel and cob moisture plays an important role in selecting the time of harvesting or cob picking. The moisture content corresponding to minimum fibre strength in bending for different stalks varied between 35 to 60 per cent, while the ultimate strength in parallel compression was reported to be maximum at moisture content ranging from 20 to 30 per cent (Prince 1961). According to Johnson *et al.* (1963) many factors need to be considered for determining the optimum time of harvesting corn as a grain. Peak harvesting efficiencies were observed ranging for 20 to 30 per cent kernel moisture depending on the degree of the lodging. Corn would not reach full maturity until average kernel moisture of 26 per cent was reached (Miles,1963). Ear corn harvested at 33 per cent kernel moisture yielded 42 per cent more dry matter when shelled after drying the cob than direct high moisture shelling. Similarly, Anon (2006) reported that maize crop grown for the grain should be harvested when it reaches physiological maturity containing 25-30 per cent moisture and preferably the ears should be removed before cutting the stalks. Accordingly, kernel moisture content between 25 to 40 per cent were considered for the study.

Standard method was adopted to determine the kernel moisture content. The moisture content of the kernel was measured on the day when experiment was to be conducted. Average moisture content was worked out for a set of experiments. Correspondingly the average moisture content of 38.50, 32.70 and 25.90 per cent were selected.

3.3.2 Angle of inclination of snapping rolls

Hurlbut (1955) suggested the angle of inclination of snapping rolls in corn picker as 30^0 to the row so as to cause stalk to travel away from the row while at the same time they travelled forward between the snapping rolls. Accordingly, 25°,30° and 35° inclination was selected to observe its effect on the performance of the developed corn picking mechanism. Jack screw was used to change the angle of inclination of the snapping rolls (Fig.3.22) and measurement of inclination angle by Abney level (Fig. 3.23).

Fig. 3.22 Change of angle of inclination of snapping rolls with Jack screw

Fig. 3.23 Measurement of angle inclination with the help of Abney level

3.3.3 Forward travel speed of the corn picking mechanism

The forward travel speed of self propelled and tractor mounted cereal crop harvesters under Indian conditions generally varies from 2.0 to 3.5 kmph (Pandey *et al.* 1997). Further, Mathur (1979), Bardawa (1980) and Paik (1985) also tested the performance of single row corn picker with forward travel speed ranging from 1.9 to 3.0 kmph. Accordingly forward travel speed from 2.0 to 3.5 kmph was selected. The required forward travel speed was obtained by varying the rpm of 3.0 hp eddy current drive electric motor mounted on the mounting trolley and calibrated in terms of rpm of the mounting trolley wheels. The corresponding rpm for 2.0 kmph, 2.5 kmph, 3.0 kmph and 3.5 kmph were 53, 66, 80 and 93 rpm respectively.

3.3.4 Peripheral speed of the snapping rolls

Burrough and Harbage (1953), Johnson and Lamp (1966) and Byg and Hall (1968) suggested that corn harvesting machine operated satisfactorily at 3.5 to 5.5 kmph forward travel speed with peripheral speed of the snapping roll as 180 m/min. The developed corn picking mechanism was operated at snapping rolls speed of 180 m/min with four selected levels of forward travel speed (Section 3.3.3). The performance of the developed corn picking mechanism at these speeds was found very unsatisfactory. The cob crushing, shelling, stalk chewing and pulling out of the plants from the plant holder were observed.

It was felt that for proper operation of the corn picker, synchronization of the forward travel speed and peripheral speed of the snapping rolls was required as particular harvesting machine is bound to be operated under various extreme varying conditions. Kanafojski and Karmowaski (1973) mentioned the dependence between the peripheral speed of the reel bar and operational speed of the machine and suggested this value to be from 1.25 to 2.5 for cereal harvesting machines. Proper matching of forward travel speed, peripheral speed of snapping rolls and gathering chain speed reduces gathering problem. Excessive chain speed could break, plug the rear end of snapping rolls, increase chain wear and overload the machine (Section 3.2). Different gear ratios were tried to vary linear speed of the gathering chain, slightly higher than the forward speed of the mounting trolley. It was found that the gear ratio of 1.05 resulted in satisfactory performance during trials (Section 3.2). The gear box designed is presented in Section 3.2.

Considering the forward travel speed of operation on higher side as 5.5 kmph with 180 m/min, peripheral speed of the snapping rolls, the ratio of the peripheral speed to the forward travel speed comes out to be 1.9. Taking this ratio into consideration, the peripheral speed corresponding to the selected forward travel speed of 2.0, 2.5, 3.0 and 3.5 kmph (Section 3.3.3) works out to be 63.33, 79.15, 95 and 110 m/min. It was decided to select the peripheral speeds of the snapping rolls as 70, 80, 90 and 100 m/min. These peripheral speeds were calibrated in terms of rpm of the snapping rolls. Variable frequency drive was used to maintain the rpm of the snapping rolls during experimentation.

3.4 Physical Characteristics of Crop

Pratap Makka-5 variety of maize species was grown in area of about 0.2 ha on the instructional farm. The observation on physical characteristics of corn plants and cobs were collected. Some particulars of the crop used during the experiments are given in Table 3.2.

Table 3.2 Some particulars of the crop harvested

S.No.	Particulars	Observation	Mean
1.	Plant height	1690-2100 (mm)	1970 (mm)
2.	Stem diameter at 300 mm above ground level	16.2 - 21.6 (mm)	19.2 (mm)
3.	Number of cobs on the plants	1-2	1.44
4.	Cob height above the ground	715-1220 (mm)	1025.64 (mm)
5.	Length of cob	225-360 (mm)	278.42 (mm)
6.	Diameter of cob	27-58 (mm)	47.14 (mm)

3.5 Snapping Roll Clearance

Wide clearance can cause shelling from the cobs and may also cause small ears to drop. Narrow clearance is recommended for damp and tough stalks (Srivatava *et al.* 1993). The clearance between the snapping rolls was decided on the basis of maximum diameter of the stalk and minimum diameter of the cob and was kept as 25 mm at the rear end and 55 mm at the front end.

3.6 Performance Evaluation of Corn Picking Mechanism

The experiments on performance evaluation of corn picking mechanism were conducted on the test track in the laboratory. The various variables and levels used in the experiments are presented in Table 3.3.

Table 3.3 Research plan for performance evaluation of the corn picking mechanism

A. Independent variable	No. of levels	Level value	Statistical design
1. Corn picking mechanism			Factorial CRD with three replication
(a) Forward travel speed, kmph	4	2.0, 2.5, 3.0, 3.5	
(b) Peripheral speed of the snapping rolls, m/min	4	70, 80, 90, 100	
(c) Angle of inclination of the snapping rolls, degree	3	25°, 30°, 35°	
2. Crop variable			
(a) Kernel moisture content, %	3	25.90, 32.70, 38.50	
B. Dependent variable			
1. Corn picking efficiency, %			
2. Per cent cob damage, %			
3. Power requirement of picking mechanism, kW			

3.6.1 Experimental procedure

The experiments were conducted and following steps were followed in performance evaluation of developed corn picking mechanism.

1. Fresh and healthy corn plants of PM-5 variety were manually harvested from C.T.A.E instructional farm and transported to the laboratory. Depending on the length of the plant holder fifteen plants were taken in a set of experiment and each plant was held tightly in the clamp with help of nuts and bolts. Plants were kept straight in plant holder at a distance of 25cm.
2. Number of cobs on each plant was counted. Total number of cobs on fifteen plants was then calculated.
3. Standard procedure was followed to measure the moisture content of the kernel of each plant and average moisture content was worked out.
4. Angle of inclination of the snapping roll was kept as 25° and forward travel speed of corn picking mechanism was maintained at 2.0 kmph (Section 3.3.3) and peripheral speed of snapping rolls as 70 m/min (Section 3.3.4). At this position

the corn picking mechanism was below the lowest location of cob on the individual plant. This ensured the entry of the plant in the gathering unit.

5. Control panel switch was put on the start position and power was transmitted to mounting trolley through belt pulley mechanism and snapping rolls through the gear box. The power required by the snapping rolls was observed in the energy meter installed on the panel board.
6. Total numbers of cobs picked were counted from discharge pan and numbers of cobs damaged were also counted.
7. Steps 2 to 6 were repeated for peripheral speed of the snapping rolls as 80, 90 and 100 m/min.
8. Forward travel speed of the corn picking mechanism was maintained as 2.5, 3.0 and 3.5 kmph and steps from 4 to 7 were repeated.
9. Angle of inclination of the snapping rolls was kept as 30° and 35°.At this position the corn picking mechanism was below the lowest location of cob on the individual plant. This ensured the entry of the plant in the gathering unit. . The angle of inclination of the snapping rolls was changed by jack screw and steps 4 to 8 were repeated
10. The experiment were conducted for average moisture content of kernel as 32.7 and 25.9 per cent and steps 4 to 9 were followed..

Various experiments were conducted using factorial CRD design as per research plan indicated in Table 3.3. Observations of total number of cobs on fifteen plants, number of cobs collected in the discharge pan and number of cobs damaged were recorded and dependent parameters corn picking efficiency and per cent cob damage were calculated. Power requirement of picking mechanism was recorded from energy meter installed on the control panel board. Standard procedure was followed to measure the moisture content of the kernel of each plant and average moisture content was worked out.

It was ensured that the plants and cobs were free from any kind of damage and disease. At all levels of angle of inclination of the snapping rolls position the corn picking mechanism was below the lowest location of cob on the individual plant. This ensures the entry of all cobs on the individual plant in the gathering unit. The results of these experiments are presented in Section 4.2 through Section 4.5 in the chapter IV.

3.6.2 Criteria for performance evaluation

The basic function of the corn picking mechanism is to pick the maximum cobs with minimum cob damage at reasonable power requirement. The corn picking efficiency and per cent cob damage were the criteria considered for performance evaluation and determined as follows:

$$\text{Corn picking efficiency} = \frac{Total\ No.of\ cobs\ picked}{Total\ No.of\ cobs} \times 100 \quad \ldots\ldots\ (3.3)$$

$$\text{Per cent damage of cob} = \frac{No.of\ cobs\ damaged}{Total\ No.of\ cobs} \times 100 \quad \ldots\ldots\ldots\ (3.4)$$

The criteria for damaged cob was taken as change in cob configuration due to compression and dehusking and/or shelling during picking and conveying through the snapping rolls while they enter the gathering unit. However, it is does not affect the yield. The test procedure is presented in Fig. 3.24 and Fig. 3.25.

3.7 Statistical Analysis of the Test Results

The technique of analysis of variance is an indispensable tool in the scientific and industrial research for the analysis of the experimental data and is particularly helpful when several independent source of variation are present in the data. Factorial CRD statistical design was adopted for univariate analysis of variance for test of significance. A step wise multiple regression analysis was performed to find out significant and non-significant terms and only significant terms were included in the regression model. The results of statistical analysis are presented in Section 4.2 through Section 4.5.

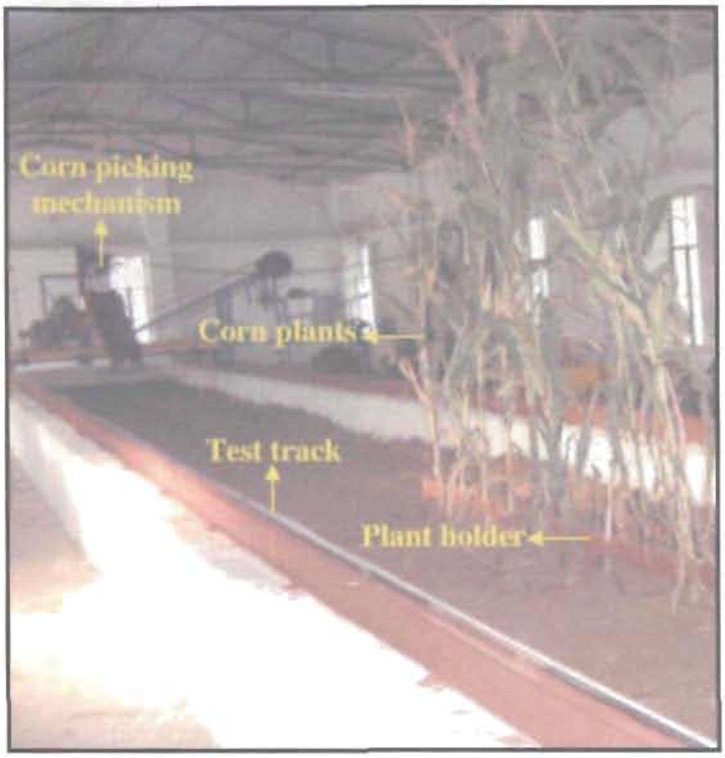


Fig. 3.24 Experimental laboratory setup during testing of corn picking mechanism

Fig 3.25 Corn plants in the plant holder

CHAPTER IV

RESULTS AND DISCUSSION

The results of the experiments conducted in the laboratory are presented and discussed in this chapter.

During the present investigation, a corn picking mechanism was designed, developed and tested in the laboratory for picking of cobs from the standing plant. The laboratory set up consisted of a test track, mounting trolley, panel board and safety features. The developed corn picking mechanism was evaluated for its performance. Different experiments were conducted to assess the performance of crop-machine system parameters on corn picking efficiency, per cent cob damage and power requirement of picking mechanism. Factorial CRD experimental design was used. Data was analyzed using statistical SPSS package. Results of main effects and only significant interactions are presented and illustrated graphically for better understanding of the trends recorded.

The effect of system parameters, which included forward travel speed, peripheral speed of snapping rolls, angle of inclination of snapping rolls and kernel moisture content on corn picking efficiency and per cent cob damage was evaluated. Effect of these parameters on power requirement of picking mechanism was studied. These results are presented in Sections 4.2 through Section 4.4. The results of the experiments carried out are presented and discussed under the following headings:

1 Effect of system parameters on corn picking efficiency

2 Effect of system parameters on per cent cob damage

3 Effect of system parameters on power requirement of picking mechanism

4.1 Performance Evaluation of Corn Picking Mechanism

The performance of corn picking mechanism is judged by the degree of corn picking efficiency, cob damage and its power requirement. The performance of the corn picking mechanism is affected by crop and machine parameters. The critical crop factors affecting the performance are physical and physico-mechanical properties of corn stalks, moisture content in kernel of the cob whereas machine parameters include forward travel speed of the mechanism, peripheral speed and angle of inclination of the snapping rolls.

4.2 Effect of Various System Parameters on Corn Picking Efficiency

The results of effect of forward travel speed, peripheral speed of the snapping rolls, angle of inclination of snapping rolls and moisture content of the kernel on corn picking efficiency were statistically analyzed. The analysis of variance is presented in Table 4.1.The Table 4.1 shows that the effect of the independent parameters, viz., forward travel speed (FS), peripheral speed of the snapping rolls (PS), angle of inclination of snapping rolls (AI) and kernel moisture content (MC) was significant on picking efficiency of the corn. The combined effect of forward travel speed (FS) with peripheral speed of snapping rolls (PS) and peripheral speed of snapping rolls (PS) with kernel moisture content (MC) was also found significant on corn picking efficiency at 95 per cent confidence level.

4.2.1 Effect of forward travel speed on corn picking efficiency

Effect of forward travel speed on corn picking efficiency at different peripheral speed, angle of inclination of snapping rolls and moisture content of kernel are presented in Fig.4.1 through Fig 4.3. Fig 4.1 shows that picking efficiency increased with increase in forward travel speed from 2.0 to 3.0 kmph at peripheral speeds of 80, 90 and 100 m/min for all angle of inclination (kernel moisture content at 25.9 per cent). At peripheral speed of 70 m/min the corn picking efficiency increased up to forward travel speed of 2.5 kmph. At this peripheral speed, increasing forward travel speed decreased corn picking efficiency. At 32.7 per cent kernel moisture content and 25° angle of inclination corn picking efficiency increased with increase in forward travel speed from 2.0 to 3.0 kmph with peripheral speed of 80, 90, and 100 m/min. Whereas, at peripheral speed of 70 m/min, the corn picking efficiency increased only up to 2.5 kmph and there after it decreased (Fig. 4.2.a). Similar trends were also observed at 30° and 35° angle of inclination. Similar results were also obtained for 38.5 per cent moisture content (Fig. 4.3).

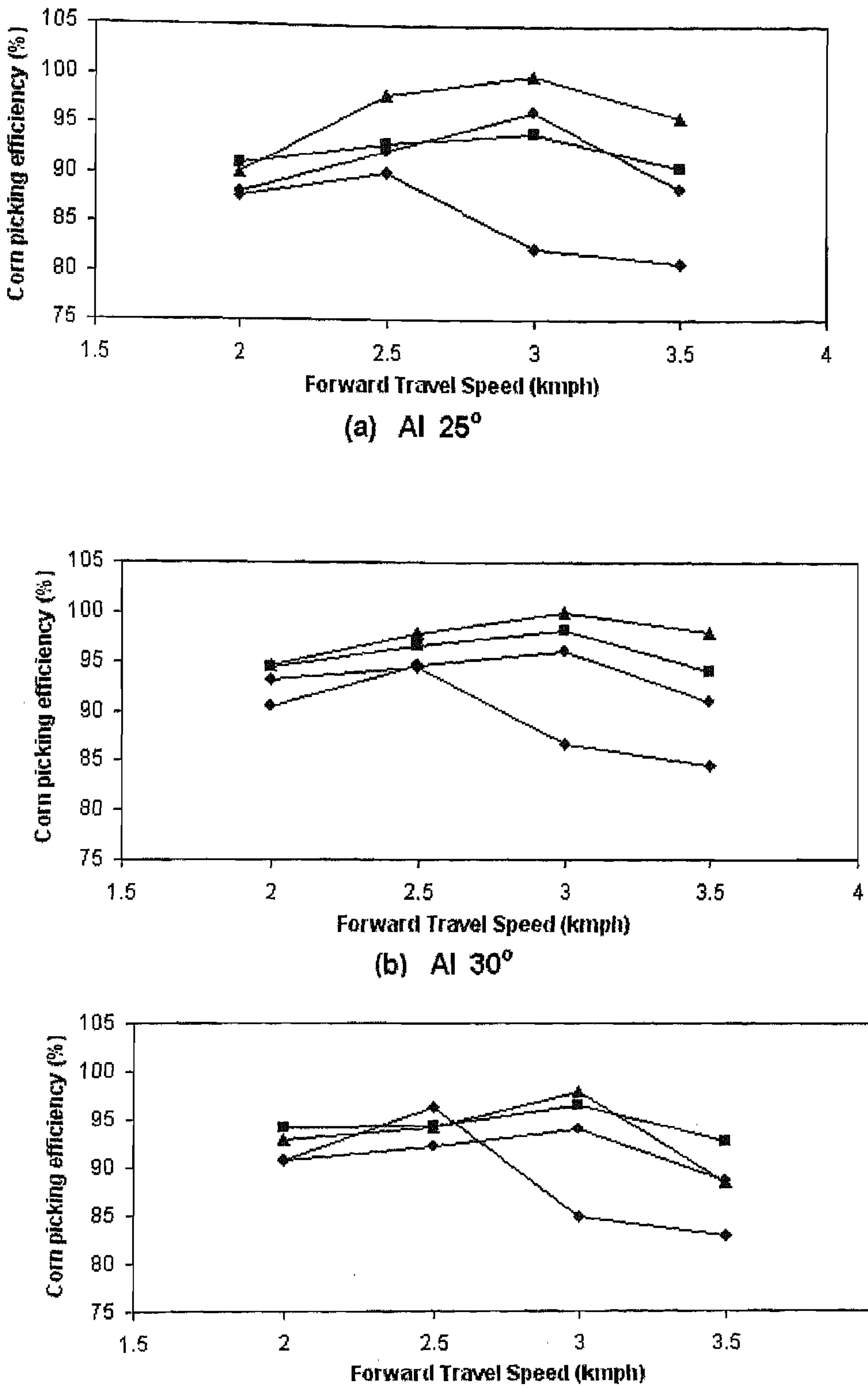
Table 4.1 **ANOVA table for the effect of forward travel speed, peripheral speed of the snapping rolls, angle of inclination of snapping rolls and kernel moisture content and their interactions on corn picking efficiency**

Source of variance	Degree of freedom	Sum of Squares	Mean Sum of Squares	Computed F
FS	3	579.724	193.241	17.902*
PS	3	5326.468	1775.489	164.481*
AI	2	943.785	471.893	43.716*
MC	2	2834.932	1417.466	131.314*
FS X PS	9	2785.293	309.477	28.670*
FS X AI	6	51.924	8.654	0.802
FS X MC	6	23.887	3.981	0.369
PS X AI	6	26.532	4.422	0.410
PS X MC	6	156.271	26.045	2.413*
AI X MC	4	16.392	4.098	0.380
FS X PS XAI	18	104.712	5.817	0.539
FS X PS X MC	18	54.105	3.006	0.278
FS X AI X MC	12	67.744	5.645	0.523
PS X AI X MC	12	65.592	5.466	0.506
FS X PS X AI X MC	36	202.111	5.614	0.520
Error	288	3108.816	10.794	
Total	431			

* Significant at 5 per cent level

It is evident from Figs 4.1 through Fig 4.3 that at peripheral speed of 90 m/min, the maximum corn picking efficiency was recorded with forward travel speed of 3.0 kmph irrespective of moisture content of kernels. At peripheral speed of 70 m/min, minimum corn picking efficiency was recorded at forward travel speed of 3.5 kmph

The mean value table for corn picking efficiency at different forward travel speed is presented in Table 4.2. The table revealed that the effect of forward travel speed was



(a) AI 25°

(b) AI 30°

(c) AI 35°

Fig 4.1 Effect of forward travel speed on corn picking efficiency at different peripheral speed and angle of inclination of snapping rolls at 25.9 per cent kernel moisture content

♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

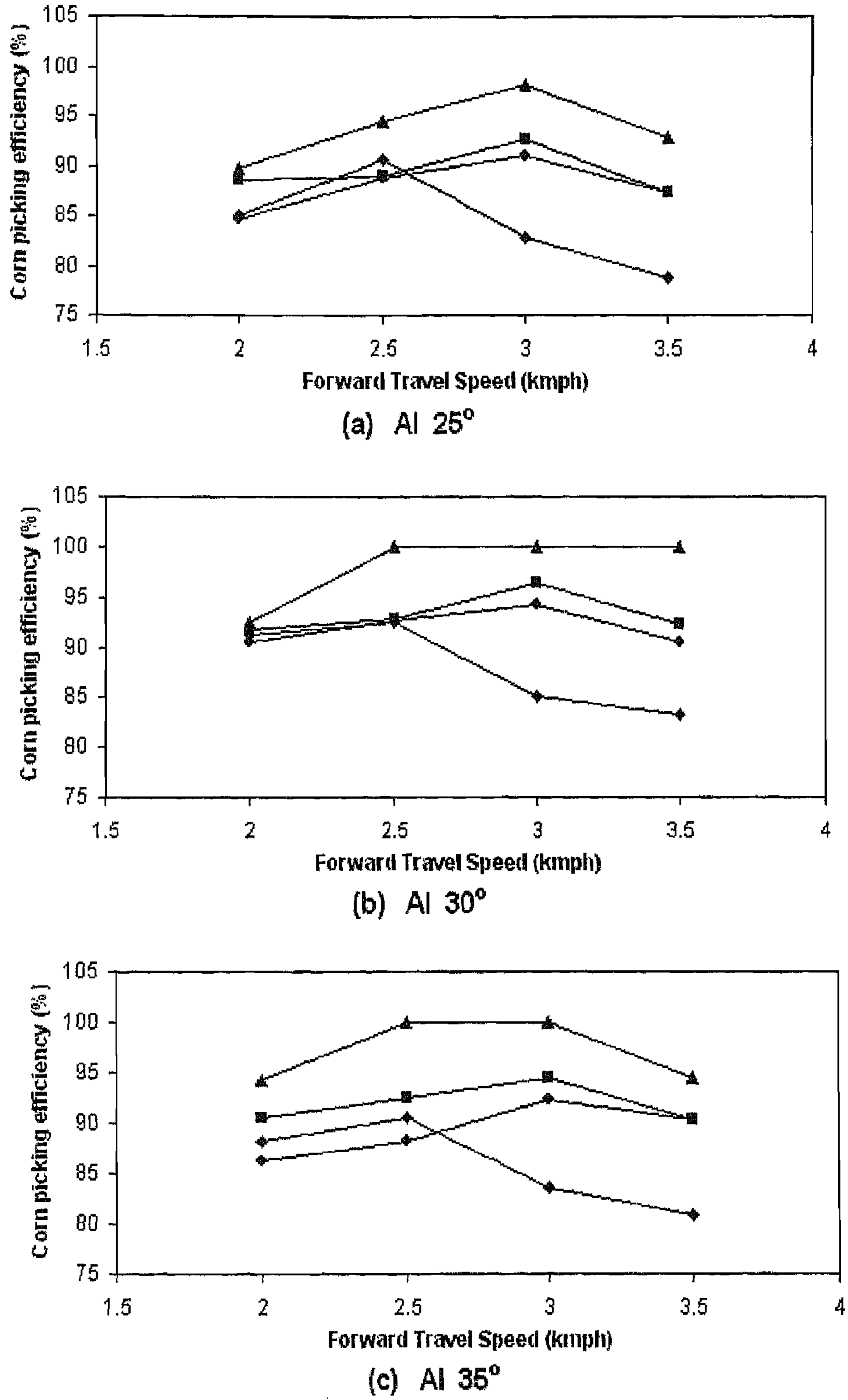


Fig 4.2 **Effect of forward travel speed on corn picking efficiency at different peripheral speed and angle of inclination of snapping rolls at 32.7 per cent kernel moisture content**

♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

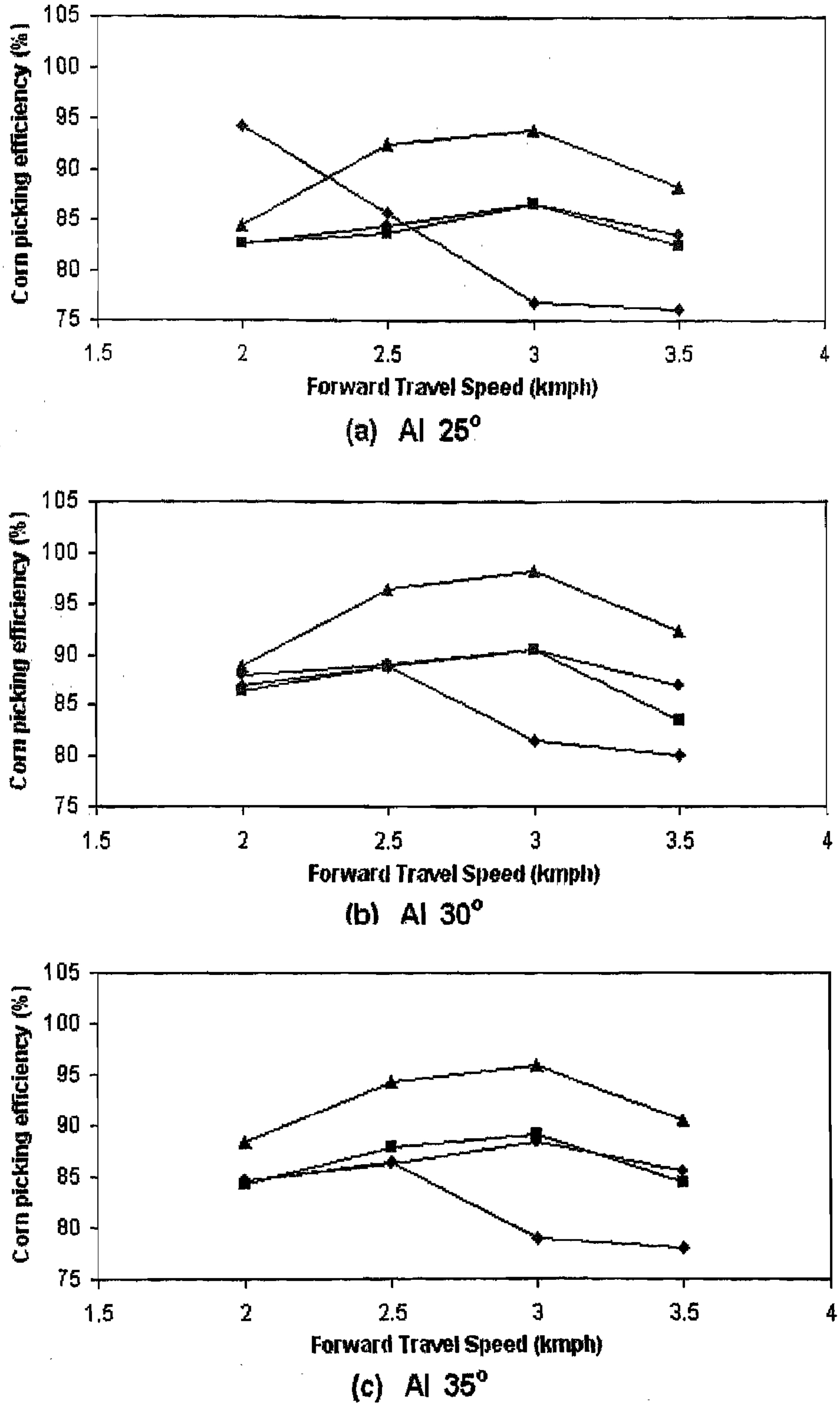


Fig 4.3 Effect of forward travel speed on corn picking efficiency at different peripheral speed and angle of inclination of snapping rolls at 38.5 per cent kernel moisture content

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

significant on corn picking efficiency. It was seen from Table 4.2 that the maximum corn picking efficiency was obtained at forward travel speed of 2.5 kmph which was significantly superior over forward travel speed of 2.0 and 3.5 kmph. Forward travel speed of 2.5 and 3.0 kmph were at par in respect of corn picking efficiency. Corn picking efficiency decreased with increase in forward travel speed beyond 2.5 kmph. This may due to the fact that with increase in forward travel speed the machine could not pick sufficient number of cobs from corn plant and missed few cobs. At lower forward travel speed stalk slippage and trash build up on snapping rolls took place, whereas at higher forward travel speed some shelling and dehusking of the cobs at the point of attachment to the stalk was observed. Therefore to obtain a higher corn picking efficiency, mechanism may be operated between 2.5 -3.0 kmph forward travel speed. Burrough and Harbage (1953) also reported similar effect for forward travel speed on efficiency of corn picker sheller.

Table 4.2 Mean values of corn picking efficiency at different forward travel speed

Forward travel speed (kmph)	2.0	2.5	3.0	3.5
Mean corn picking efficiency (%)	88.81	91.97	91.50	87.66

SEm± 0.32 LSD $_{0.05}$ 0.88

4.2.2 Effect of peripheral speed of snapping rolls on corn picking efficiency

The results of effect of peripheral speed on corn picking efficiency are presented in Fig.4.4 through Fig. 4.6. Figure 4.4(a) shows that at kernel moisture content of 25.9 per cent and 25° angle of inclination, corn picking efficiency increased when peripheral speed increased from 70 to 90 m/min for forward travel speed of 2.5, 3.0 and 3.5 kmph and after 90 m/min it decreased, whereas, at forward travel speed of 2.0 kmph, the corn picking efficiency increased only up to peripheral speed of 80 m/min and then decreased. At 30° angle of inclination of snapping rolls, corn picking efficiency increased up to peripheral speed of 90 m/min at all four levels of forward travel speed and there after it decreased with increase in peripheral speed (Fig. 4.4.b). At 35° angle of inclination, increasing peripheral speed from 70 to 90 m/min increased corn picking efficiency for forward travel speed of 2.5 and 3.0 kmph. Whereas, at forward travel speeds of 2.0 and 3.5 kmph corn picking efficiency increased up to peripheral speed of 80 m/min, The maximum corn picking efficiency was recorded at peripheral speed of 90 m/min with forward travel speed of 3.0 kmph at 25.9 per cent moisture content and all three levels of angle of inclination of snapping rolls.

Figure 4.5 shows that at 32.7 per cent kernel moisture content and 25° angle of inclination, highest corn picking efficiency was recorded at 90 m/min with forward travel speed of 3.0 kmph. Whereas, at 30° and 35° angle of inclination, maximum corn picking efficiency was recorded at peripheral speed of 90 m/min at forward travel speed of 2.5 and 3.0 kmph, after peripheral speed of 90 m/min, the picking efficiency decreased at all the three angles of inclination of snapping rolls.

It is evident from the Fig.4.6 that at 38.5 per cent kernel moisture content and at all three angle of inclination of snapping rolls the corn picking efficiency increased with increasing levels of peripheral speed from 70 to 90 m/min for all forward travel speed and after that it decreased. The maximum picking efficiency was recorded at peripheral speed of 90 m/min for forward travel speed of 3.0 kmph.

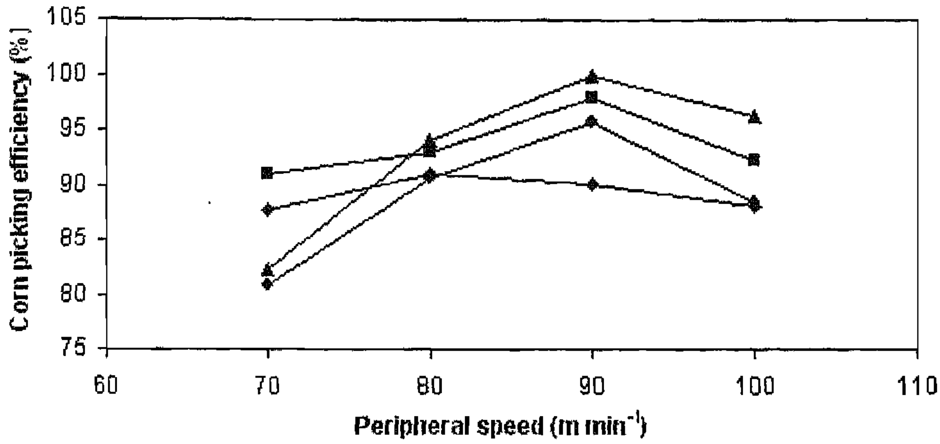
The mean value table for corn picking efficiency at different peripheral speed of the snapping rolls is presented in Table 4.3. This table revealed that the effect of peripheral speed was significant on corn picking efficiency. It was seen from Table 4.3 that peripheral speed 90 m/min recorded the highest picking efficiency of corn. Increasing the peripheral speed from 90 m/min to 100 m/min decreased the picking efficiency by 5.62 per cent and 9.73 per cent when peripheral speed decreased to 70 m/min. Peripheral speed of snapping rolls is important for adequate operation of the machine. Further synchronization of this speed with forward travel speed is required for optimum corn picking efficiency.

At lower peripheral speed of the snapping rolls, the mechanism might run the maize stalk down before they are pulled through the snapping rolls. Breaking of the stalks occurred when the peripheral speed is on higher side. Therefore, it is desirable to operate the corn picking mechanism at a peripheral speed of 90 m/min.

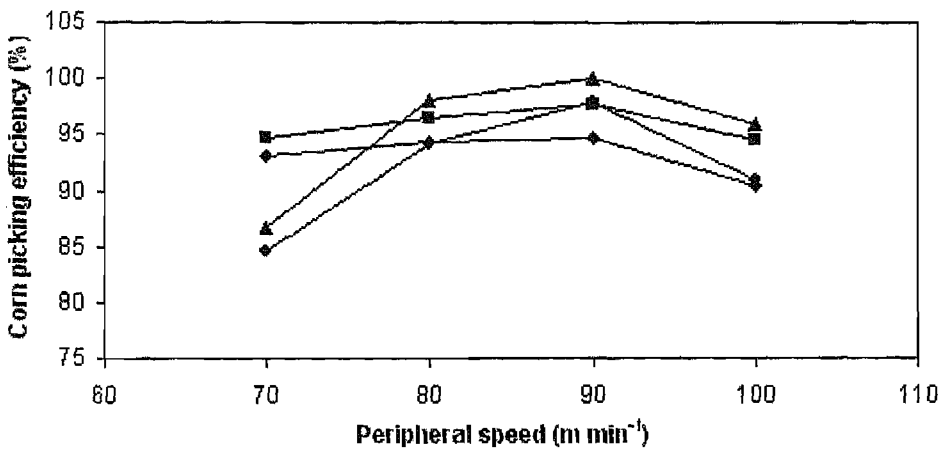
Table 4.3 Mean values of corn picking efficiency at different peripheral speed of snapping rolls

Peripheral speed of snapping rolls (m/min)	70	80	90	100
Mean corn picking efficiency (%)	85.44	90.51	94.65	89.33

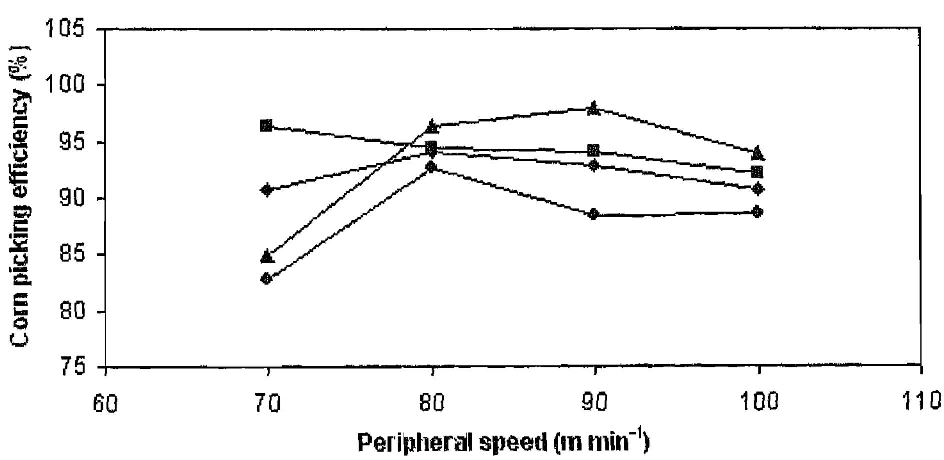
SEm± 0.32 LSD $_{0.05}$ 0.88



(a) AI 25°



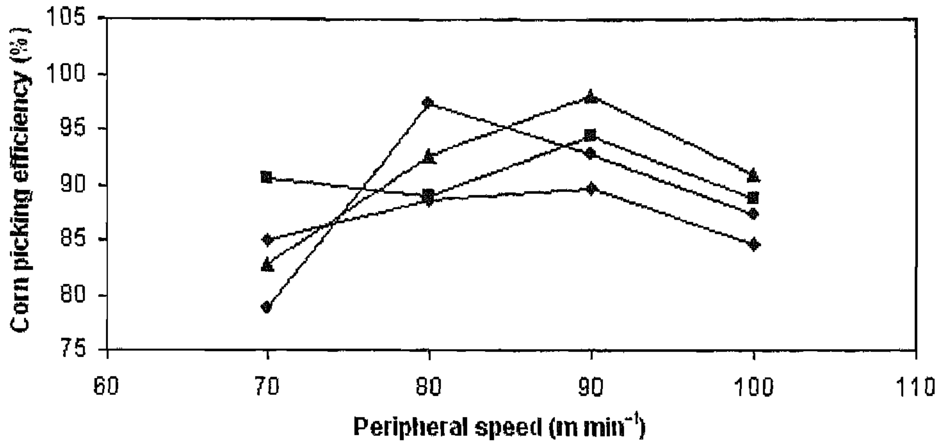
(b) AI 30°



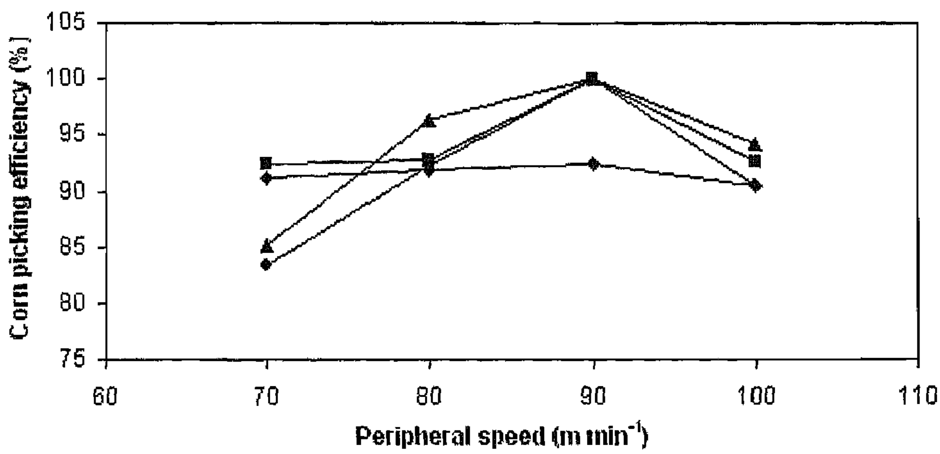
(c) AI 35°

Fig 4.4 **Effect of peripheral speed of snapping rolls on corn picking efficiency at different forward travel speed and angle of inclination of snapping rolls at 25.9 per cent kernel moisture content**

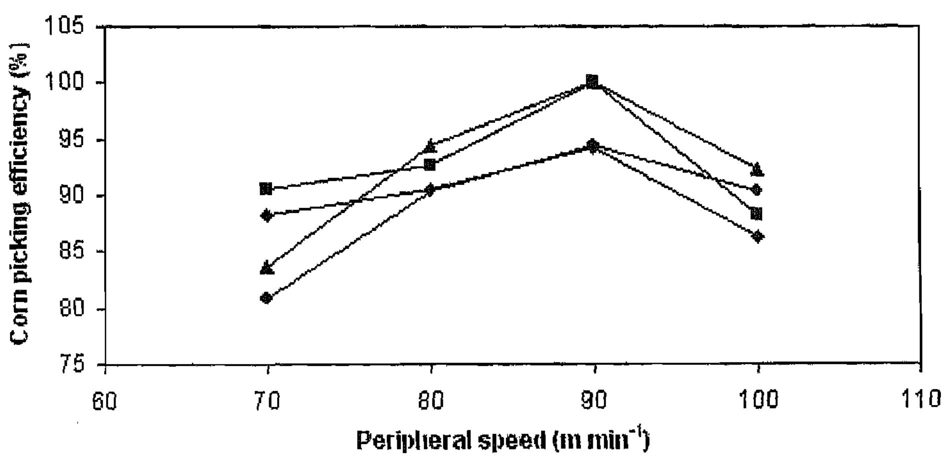
♦,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph



(a) AI 25°



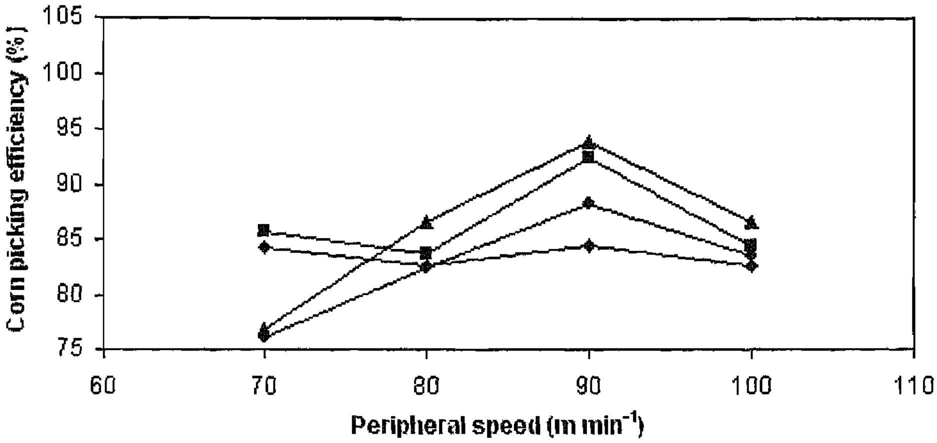
(b) AI 30°



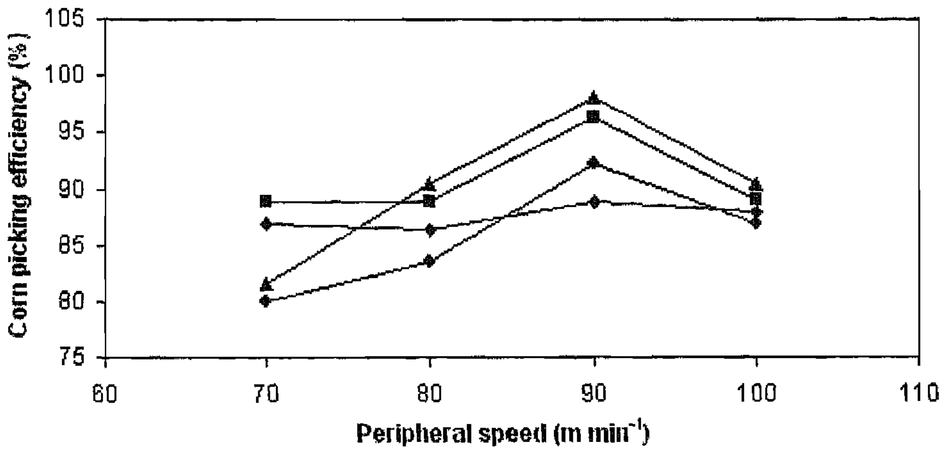
(c) AI 35°

Fig 4.5 Effect of peripheral speed of snapping rolls on corn picking efficiency at different forward travel speed and angle of inclination of snapping rolls at 32.7 per cent kernel moisture content

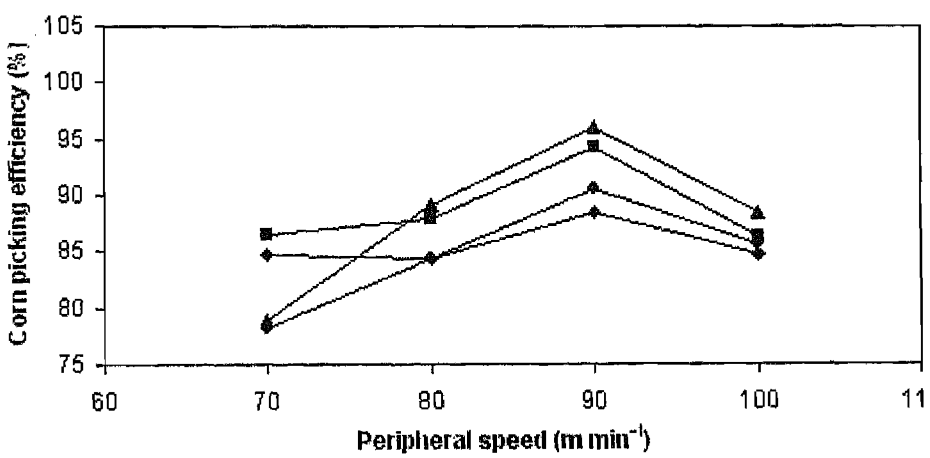
♦,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph



(a) Al 25°



(b) Al 30°



(c) Al 35°

ng efficiency at different forward travel speed and angle of inclination of snapping rolls at 38.5 per cent kernel moisture content

♦,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph

Srivastava *et. al.*, (1993) also mentioned that peripheral speed of snapping rolls is an important parameter for achieving maximum picking efficiency of cobs. Kanafojski and Karmowaski (1976) also suggested dependence of peripheral speed of reel and operational speed of machine for cereal harvesting. Maier and Parsons (1996) opined that the speed of snapping rolls and gathering chain must be reasonably well timed to combine ground speed.

4.2.3 Effect of angle of inclination of snapping rolls on corn picking efficiency

The results obtained during the study are presented in Fig.4.7 through Fig. 4.10. Results were analyzed statistically and Analysis of variance (Table 4.1) shows that the effect of angle of inclination was significant on corn picking efficiency. Mean value of corn picking efficiency at different angle of inclination is presented in Table 4.4. It was seen from the Table 4.4 that 30° angle of inclination of snapping rolls resulted in the highest corn picking efficiency. Increasing and decreasing the angle of inclination of the snapping rolls from 30° to 35° and 30° to 25° resulted in lower picking efficiency of cobs by 2.05 and 3.85 per cent, respectively. This might be due to change in exposed length of snapping the cobs.

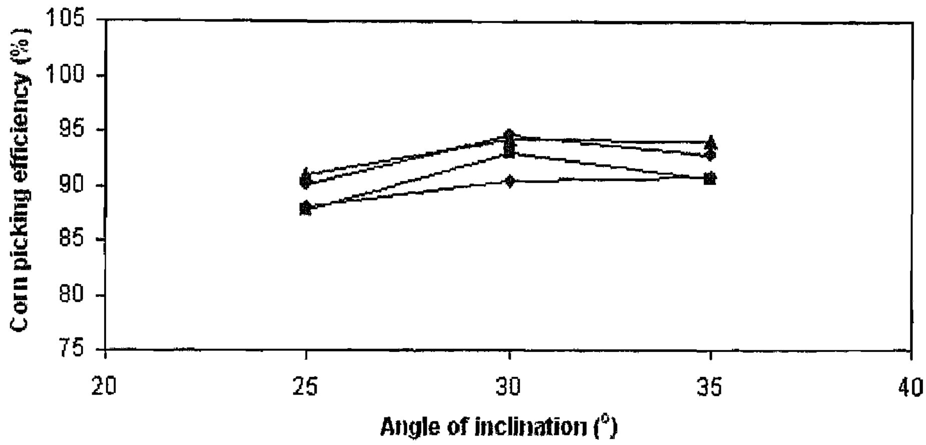
Hurlbut (1955) also reported the snapping roll angle about 30^0 to the row for efficient harvesting of the corn. It is evident from Figure 4.7.a that maximum corn picking efficiency recorded at 30° angle of inclination with peripheral speed of 90 m/min and 25.9 per cent kernel moisture content and 2.0 kmph forward travel speed. Similar trend was also observed at 38.5 per cent kernel moisture content. Figure 4.7.b shows that irrespective of above trends, at 32.7 per cent kernel moisture content, picking efficiency increased up to 35° angle of inclination with peripheral speed of 90 m/min..

Table 4.4 Mean values of corn picking efficiency at different angle of inclination of snapping rolls

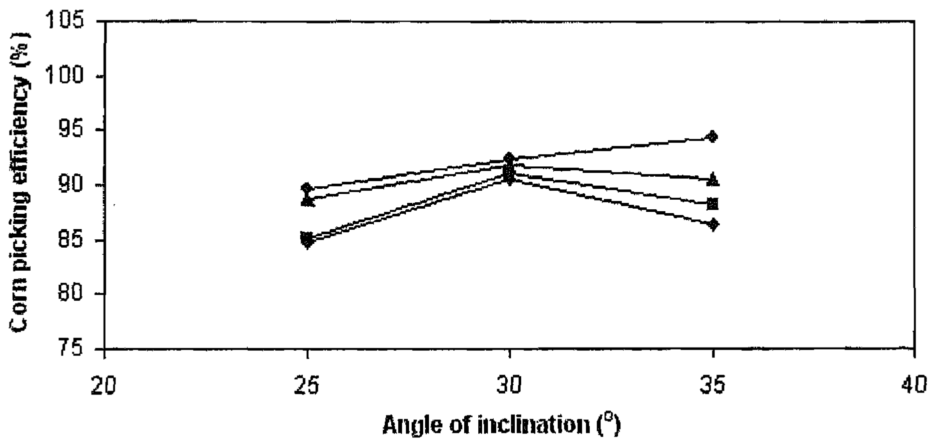
Angle of inclination of snapping rolls (°)	25	30	35
Mean corn picking efficiency (%)	88.26	91.79	89.90

SEm± 0.274 LSD $_{0.05}$ 0.762

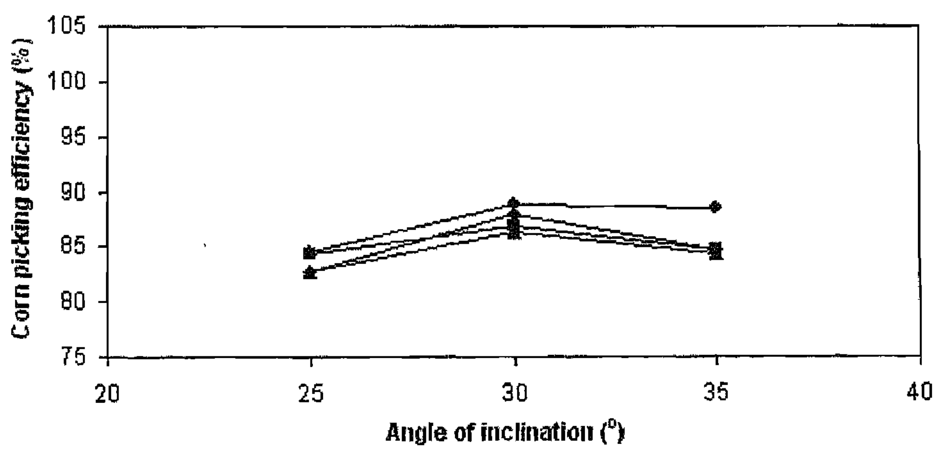
Figure 4.8 shows that at 2.5 kmph forward travel speed and all levels of kernel moisture content, highest picking efficiency was recorded at peripheral speed of 90 m/min



(a) MC 25.9 %



(b) MC 32.7 %



(c) MC 38.5 %

Fig 4.7 Effect of angle of inclination of snapping rolls on corn picking efficiency at different peripheral speed of snapping rolls and kernel moisture content at 2.0 kmph forward travel speed

♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

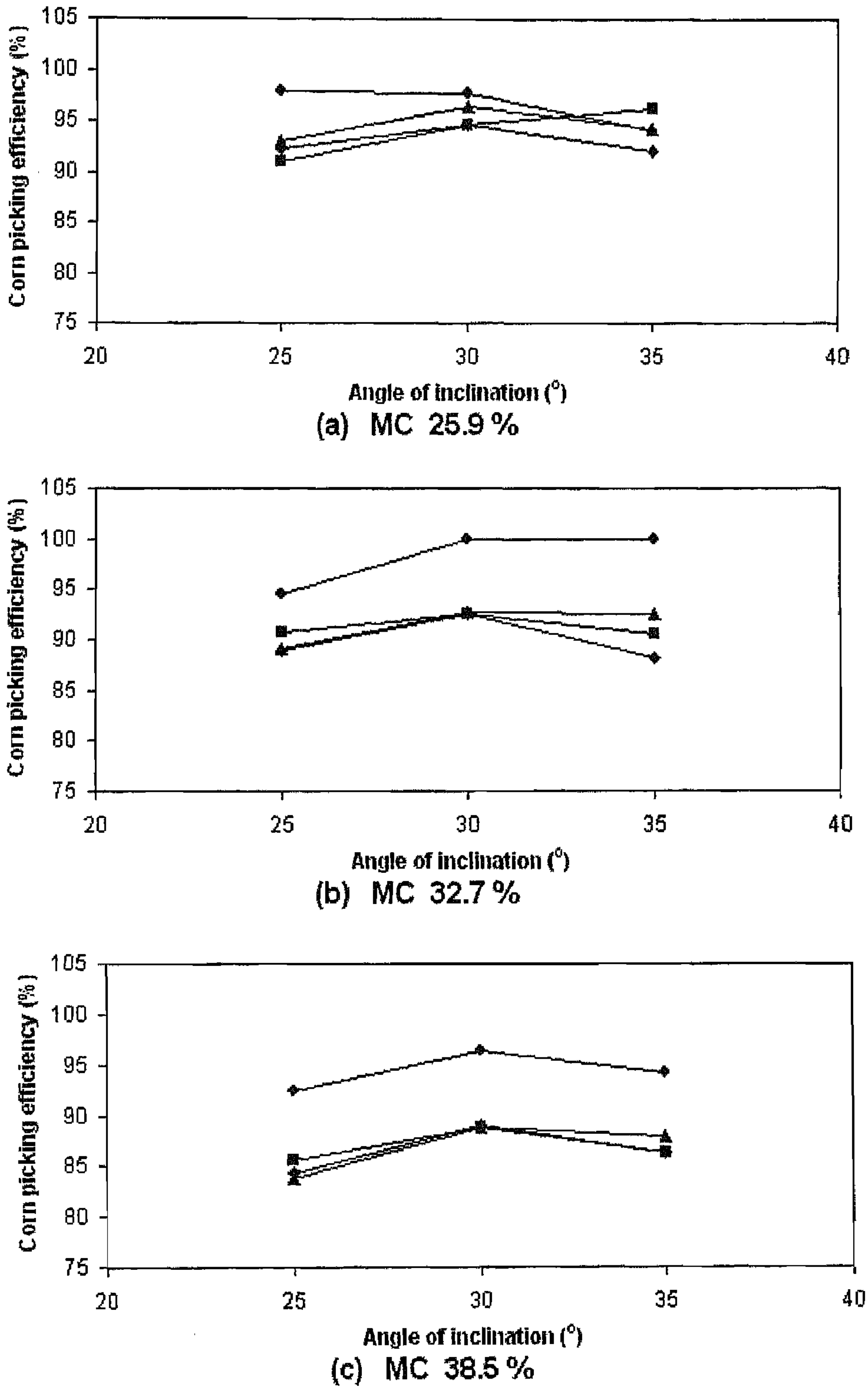


Fig 4.8 Effect of angle of inclination of snapping rolls on corn picking efficiency at different peripheral speed of snapping rolls and kernel moisture content at 2.5 kmph forward travel speed

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

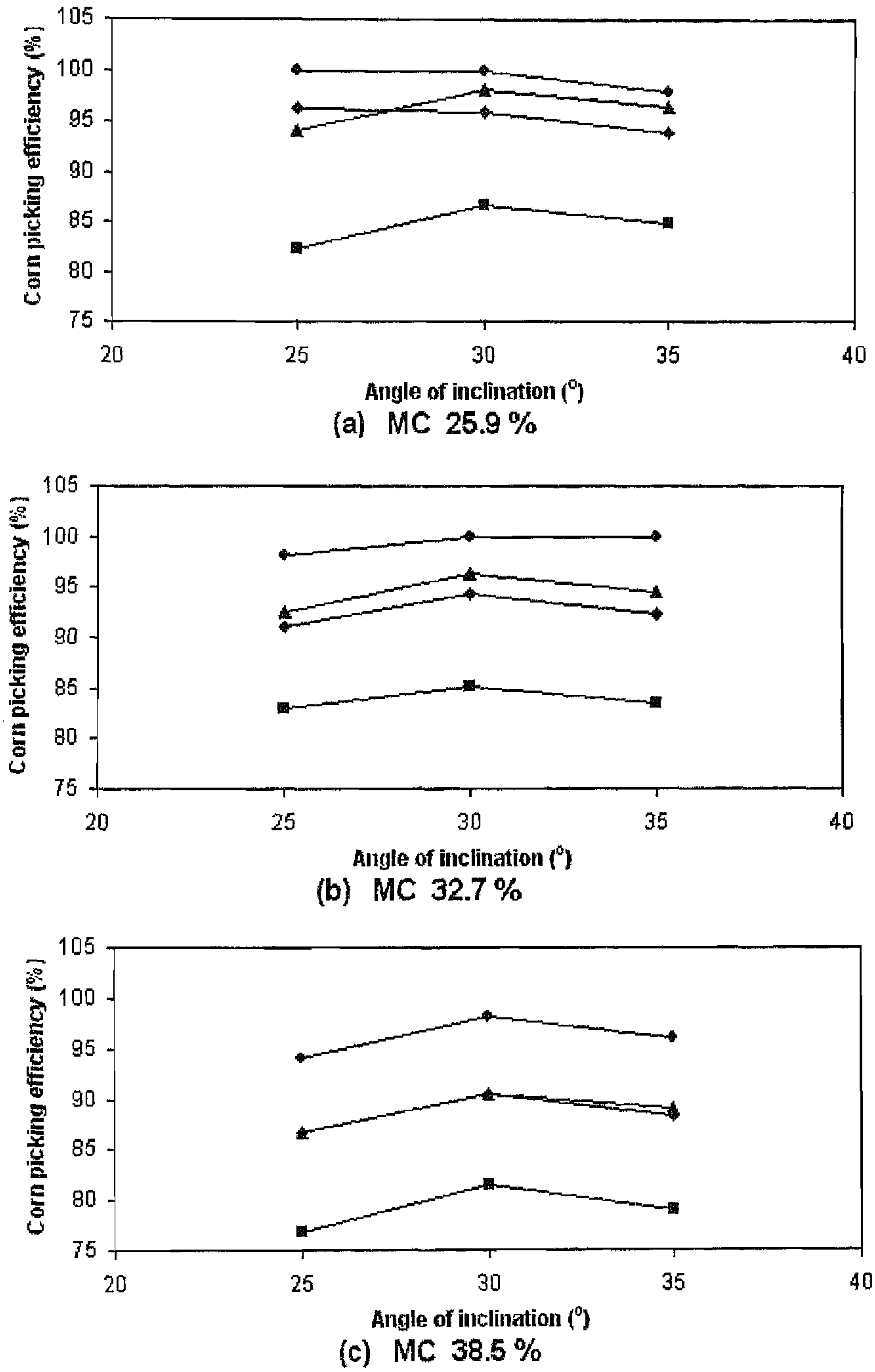
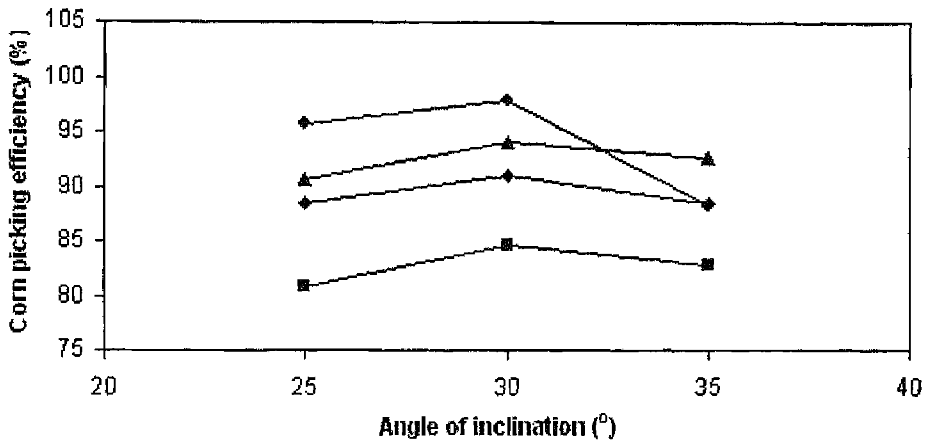
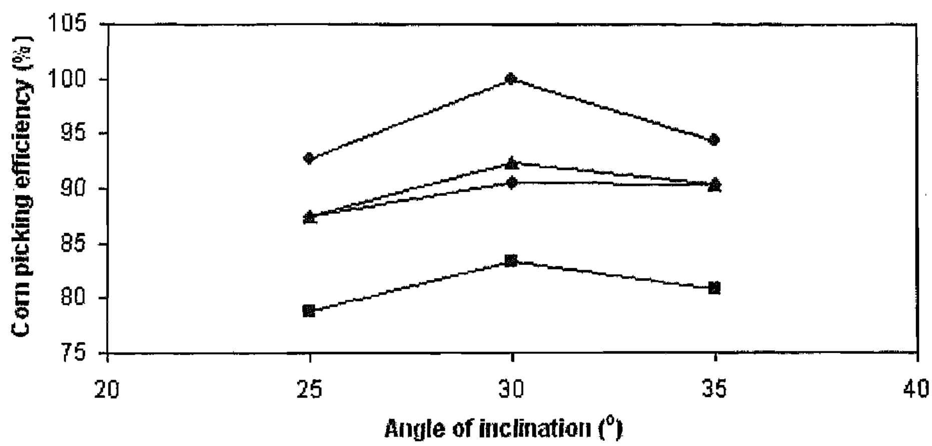


Fig 4.9 **Effect of angle of inclination of snapping rolls on corn picking efficiency at different peripheral speed of snapping rolls and kernel moisture content at 3.0 kmph forward travel speed**

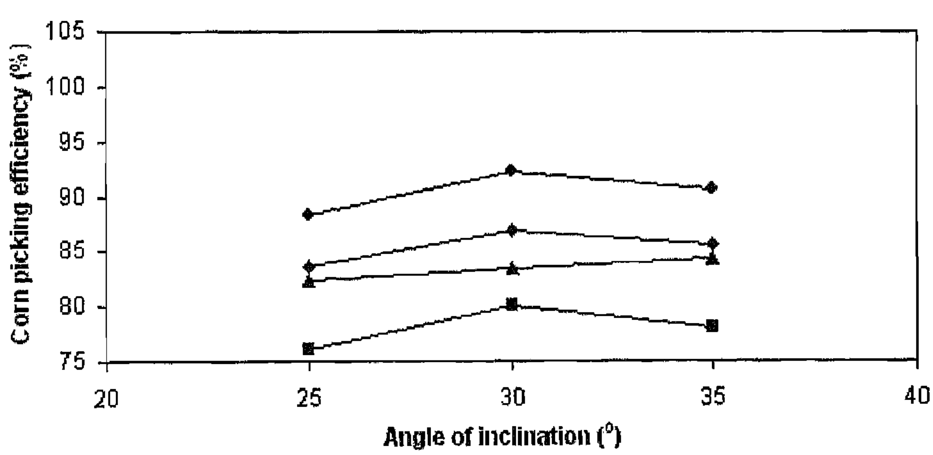
♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) MC 25.9 %



(b) MC 32.7 %



(c) MC 38.5 %

Fig 4.10 Effect of angle of inclination of snapping rolls on corn picking efficiency at different peripheral speed of snapping rolls and kernel moisture content at 3.5 kmph forward travel speed

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

with 30° angle of inclination followed by at peripheral speed 80 m/min. Increasing angle of inclination from 30° to 35° and decreasing from 30° to 25° decreased the cob picking efficiency. At 25.9 per cent moisture content and 70m/min peripheral speed, corn picking efficiency increased with increase in angle of inclination from 25° to 35°. Figure 4.9 revealed that maximum corn picking efficiency was recorded for peripheral speed of 90 m/min followed by 80 m/min at all the three levels of kernel moisture content. Figure 4.10 showed almost similar trend as observed for forward travel speed (Fig. 4.8). Interestingly, at 25.9 per cent kernel moisture content corn picking efficiency drastically decreased above 30° angle of inclination. The highest corn picking efficiency was observed at peripheral speed of 90 m/min.

4.2.4 Effect of kernel moisture content on corn picking efficiency

The results obtained during the study are depicted in Fig.4.11 through Fig. 4.14. The analysis of variance (Table 4.1) showed that effect of kernel moisture content was significant on corn picking efficiency. The mean value of corn picking efficiency for different moisture content of kernel is presented Table 4.5. The Table 4.5 also showed that effect of kernel moisture content was significant on corn picking efficiency. The maximum corn picking efficiency was observed at kernel moisture content of 25.90% and being higher by 1.60 and 6.6 % over 32.70 and 38.50% kernel moisture content, respectively. As moisture content increased in the kernels corn picking efficiency reduced significantly.

Table 4.5 Mean values of corn picking efficiency for different kernel moisture content

Kernel moisture content (%)	25.90	32.70	38.50
Mean corn picking efficiency (%)	92.38	90.92	86.65

SEm± 0.274 LSD $_{0.05}$ 0.762

Johnson *et. al.,* (1963) reported peak harvest efficiency when corn kernel moisture ranged from 20 to 30 per cent depending on the degree of the lodging. Miles (1963) was also of the view that corn would reach full maturity when average kernel moisture was 26 per cent.

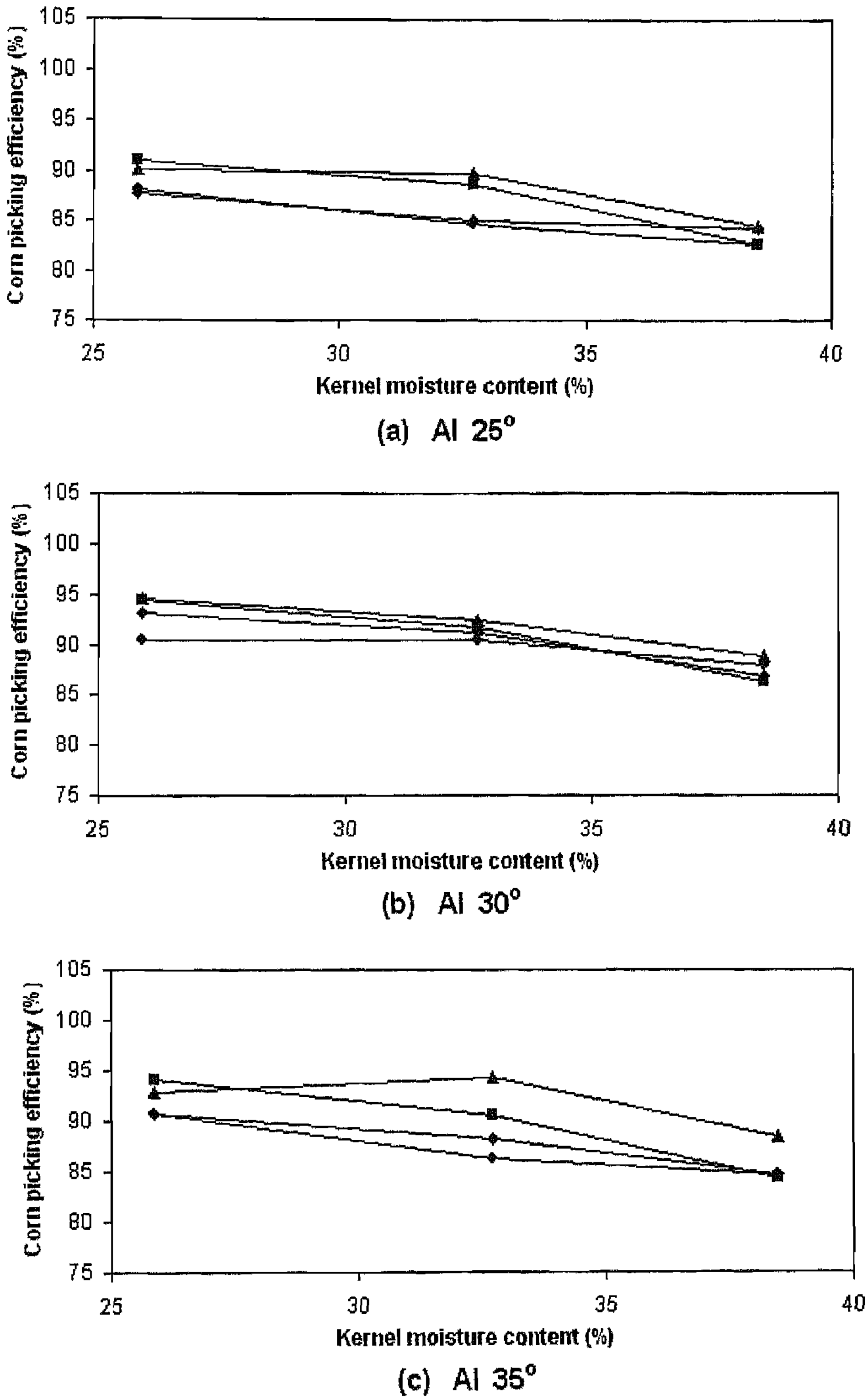


Fig 4.11 Effect of kernel moisture content on corn picking efficiency at different peripheral speed and angle of inclination of snapping rolls at 2.0 kmph forward travel speed

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

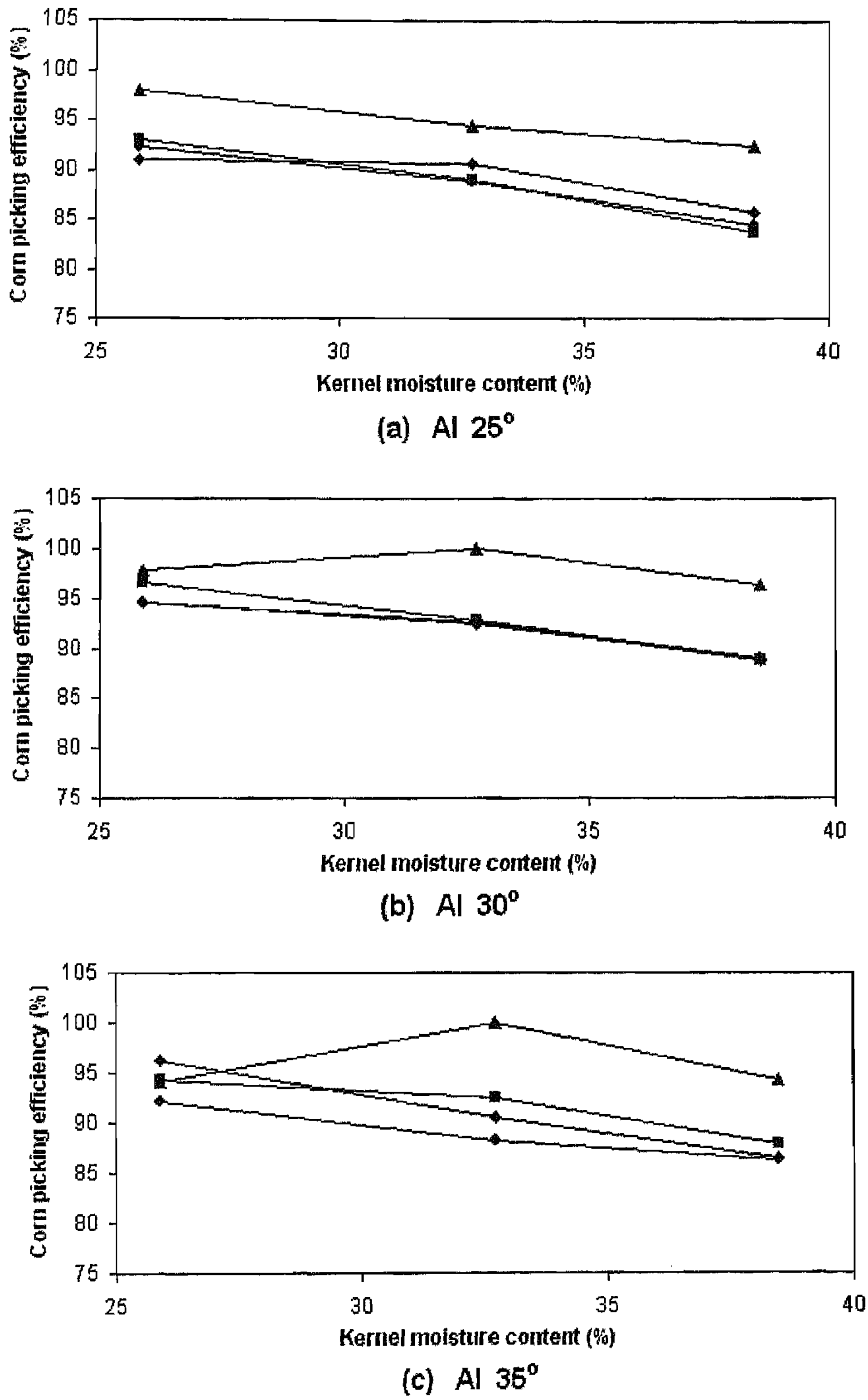


Fig 4.12 **Effect of kernel moisture content on corn picking efficiency at different peripheral speed and angle of inclination of snapping rolls at 2.5 kmph forward travel speed**

♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

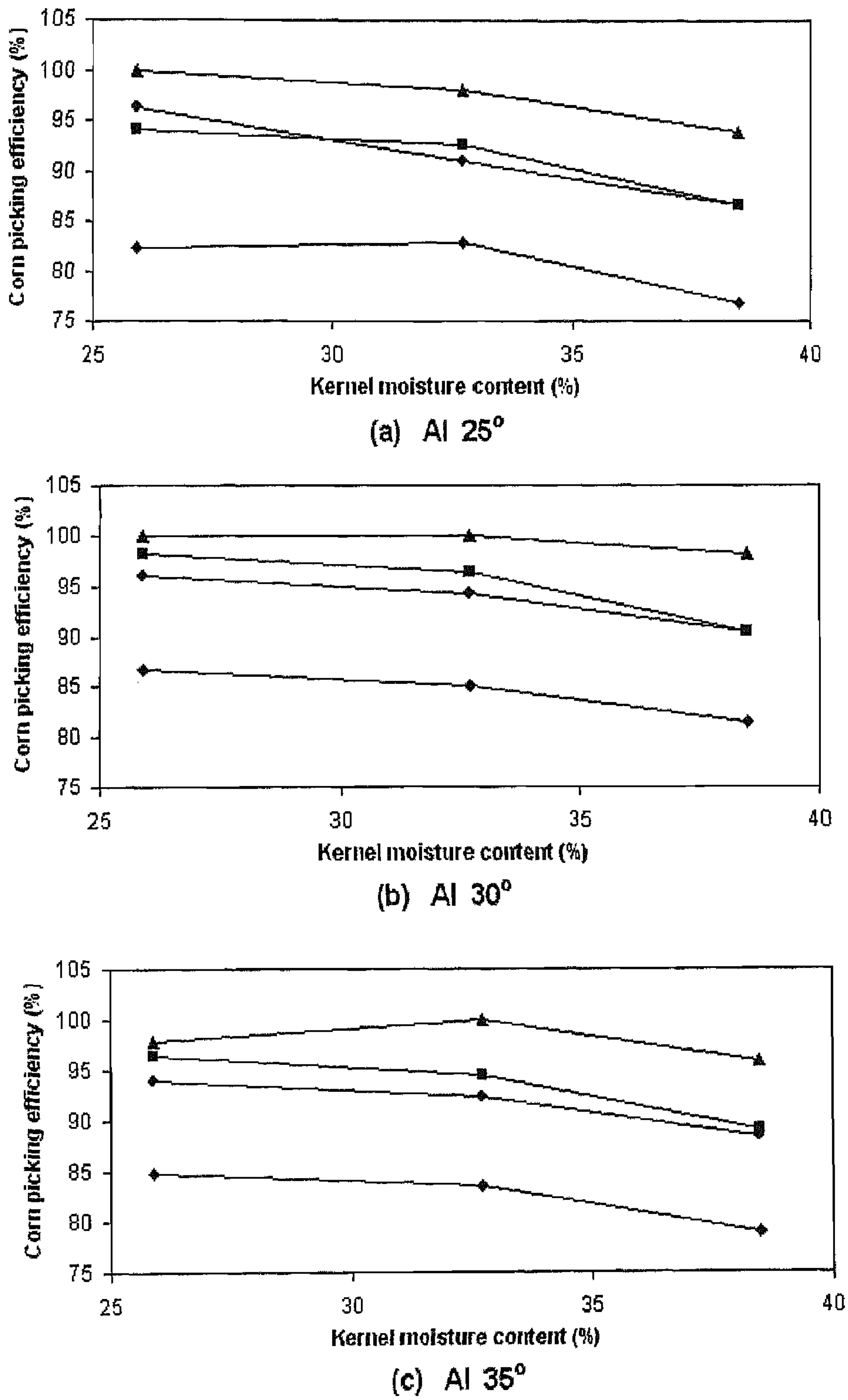
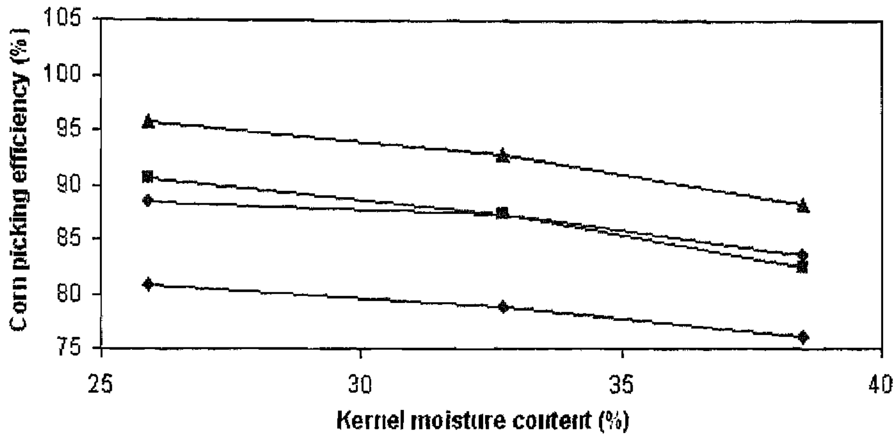
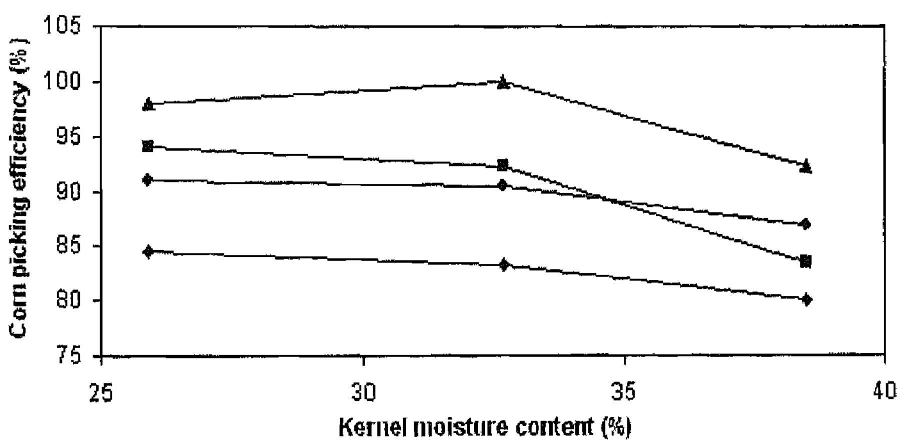


Fig 4.13 Effect of kernel moisture content on corn picking efficiency at different peripheral speed and angle of inclination of snapping rolls at 3.0 kmph forward travel speed

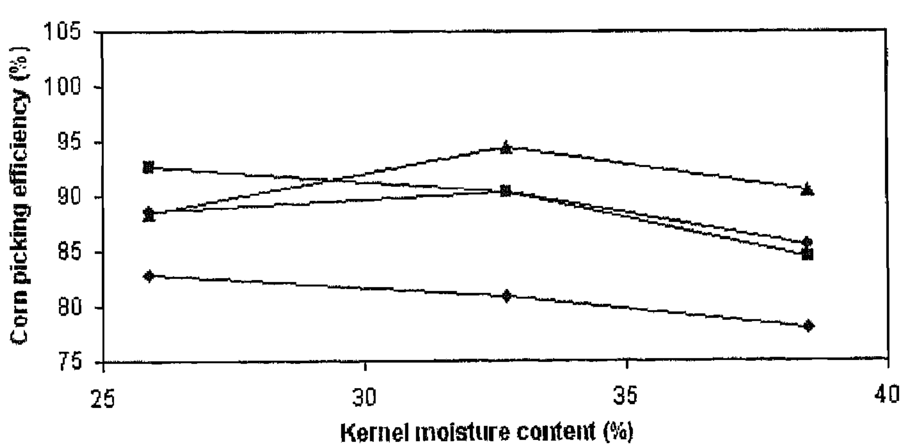
◆,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



(b) AI 30°



(c) AI 35°

Fig 4.14 Effect of kernel moisture content on corn picking efficiency at different peripheral speed and angle of inclination of snapping rolls at 3.5 kmph forward travel speed

◆,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

Figure 4.11 revealed that corn picking efficiency decreased with increasing moisture content in kernels at 2.0 kmph forward travel speed, except at 35° angle of inclination where at peripheral speed of 90 m/min the corn picking efficiency increased with increase in moisture content from 25.9 to 32.7 per cent and there after it decreased with increase in kernel moisture content.

It is evident from Figs. 4.12, 4.13 and 4.14 that corn picking efficiency decreased with increase in moisture content in kernels at all the three levels of angle of inclination when forward travel speed ranged from 2.5 to 3.5 kmph, except at peripheral speed of 90 m/min with angle of inclination of 30° and 35° where corn picking efficiency increased up to the kernel moisture content of 32.7 per cent and after that it decreased.

4.2.5 Combined effect of forward travel speed and peripheral speed of snapping rolls on corn picking efficiency

Apart from effect of individual parameters on corn picking efficiency discussed earlier (Section 4.2.1 to Section 4.2.4), Table 4.1 shows that the combined effect of forward travel speed and peripheral speed was significant on corn picking efficiency. A significant interaction between forward travel speed and peripheral speed of snapping rolls on picking efficiency is presented in Table 4.6. Data revealed that forward travel speed of 3.0 kmph along with 90 m/min peripheral speed recorded significantly maximum (98.24 per cent) corn picking efficiency followed by 2.5 kmph forward travel speed and 90 m/min peripheral speed (96.38 per cent). Minimum corn picking efficiency of was obtained at 3.50 kmph forward travel speed and 70 m/min peripheral speed. This indicated that at the same level of forward travel speed, the picking efficiency of cobs showed a variable response with the change of peripheral speed of the snapping rolls.

Table 4.6 Two variable interactions showing effect of forward travel speed with peripheral speed of snapping rolls on mean corn picking efficiency

Peripheral speed of snapping rolls, m/min	Forward travel speed, kmph			
	2.0	2.5	3.0	3.5
70	87.96	90.73	82.49	80.59
80	89.31	90.96	93.13	88.65
90	90.62	96.38	98.24	93.37
100	87.35	89.82	92.13	88.02

SEm± 0.632 LSD $_{0.05}$ 1.762

Interaction effects indicated that with the change of peripheral speed from 90 m/min to 100 m/min, there was a significant decline in the corn picking efficiency. However this trend was different in case of forward travel speed. It indicated that an increase in forward travel speed up to 3.0 kmph, there was a significant increase in corn picking efficiency at the same level of peripheral speed. However, this trend became reverse at 3.5 kmph forward travel speed.

Interaction between peripheral speed and forward travel speed clearly showed that there was a maximum change in picking efficiency at peripheral speed of 70, 80 and 90 m/min. with forward travel speed of 3.0 and 3.5 kmph. However, at a forward travel speed of 3.0 kmph it had a positive effect but at 3.5 kmph, it had negative effect on corn picking efficiency.

4.2.6 Combined effect of peripheral speed of snapping rolls and kernel moisture content on corn picking efficiency

Peripheral speed of snapping roll and kernel moisture content showed an interaction effect on corn picking efficiency. Data presented in Table 4.7 revealed that significant maximum corn picking efficiency (96.53 per cent) was recorded at 90m/min peripheral speed and 32.7 per cent kernel moisture content, whereas minimum (83.50 per cent) corn picking efficiency was obtained for 70 m/min peripheral speed of snapping rolls along with 38.50 per cent kernel moisture content.

Table 4.7 Two variable interactions showing effect of peripheral speed of snapping rolls with kernel moisture content on mean corn picking efficiency

Peripheral speed, m/min	Moisture content, %		
	25.9	32.7	38.5
70	83.50	87.33	85.49
80	88.50	92.13	90.91
90	93.17	96.53	94.26
100	87.86	91.19	88.95

SEm± 0.548 LSD $_{0.05}$ 1.524

Interaction between peripheral speed and moisture content of kernel on corn picking efficiency was found positive from peripheral speed of 70 to 90 m/min at the kernel moisture content of 25.9 per cent and 32.7 per cent. However, beyond peripheral speed of 90 m/min, there was significantly negative effect on corn picking efficiency at all three levels of kernel moisture content. It is interesting to note that moisture content of corn kernels above 32.7 per cent reduced the picking efficiency significantly at all levels of peripheral speed.

For the maximum picking efficiency (96.53 %) a peripheral speed of 90 m/min with kernel moisture content 32.7 per cent was found optimum being significantly higher than the picking efficiency (93.17%) observed at peripheral speed of 90 m/min and kernel moisture content of 25.9 percent.

4.3 Effect of Forward Travel Speed, Peripheral Speed of snapping rolls, Angle of Inclination of snapping rolls and Kernel Moisture Content and their Interaction on Per Cent Cob Damage

The results of effect of forward travel speed, peripheral speed of the snapping rolls, angle of inclination of snapping rolls and moisture content of the kernel on per cent cob damage were statistically analyzed and analysis of variance is presented in Table 4.8. The Table 4.8 shows that effect of all independent parameters, viz., forward travel speed (FS), peripheral speed of the snapping rolls (PS), angle of inclination of snapping rolls (AI) and moisture content of the kernel (MC) were significant on per cent cob damage. The combined effect of forward travel speed (FS) with kernel moisture content (MC), peripheral speed (PS) with kernel moisture content (MC), angle of inclination of snapping rolls (AI) with kernel moisture content (MC), and forward travel speed (FS), angle of inclination (AI) and kernel moisture content (MC) was also found significant on per cent cob damage at 95 per cent confidence level.

Table 4.8 ANOVA table for the effect of forward travel speed, peripheral speed of snapping rolls, angle of inclination of snapping rolls and kernel moisture content on per cent cob damage

Source of variance	Degree of freedom	Sum of Squares	Mean Sum of Squares	Computed F
FS	3	745.287	248.429	285.201*
PS	3	1148.107	382.702	439.350*
AI	2	368.869	184.435	211.735*
MC	2	1593.248	796.624	914.540*
FS X PS	9	9.736	1.082	1.242
FS X AI	6	9.677	1.613	1.852
FS X MC	6	32.550	5.425	6.228*
PS X AI	6	8.187	1.365	1.567
PS X MC	6	13.660	2.277	2.614*
AI X MC	4	66.609	16.652	19.117*
FS X PS XAI	18	9.452	0.525	0.603
FS X PS X MC	18	20.016	1.112	1.277
FS X AI X MC	12	23.921	1.993	2.289*
PS X AI X MC	12	16.450	1.371	1.574
FS X PS X AI X MC	36	27.192	0.755	0.867
Error	288	250.867	0.871	
Total	431			

* Significant at 5 per cent level

4.3.1 Effect of forward travel speed on per cent cob damage

The effect of forward travel speed on per cent cob damage at different peripheral speed, angle of inclination of snapping rolls and kernel moisture content are presented in Fig. 4.15 through Fig. 4.17. The ANOVA Table 4.8 shows that effect of forward travel speed was significant on per cent cob damage. Fig. 4.15 shows that at 25.9 per cent kernel moisture content at all angle of inclination and peripheral speed, per cent cob damage increased with increase in forward travel speed. Similar trends were also obtained for kernel moisture content of 32.7 and 38.5 per cent (Fig. 4.16 and Fig. 4.17).

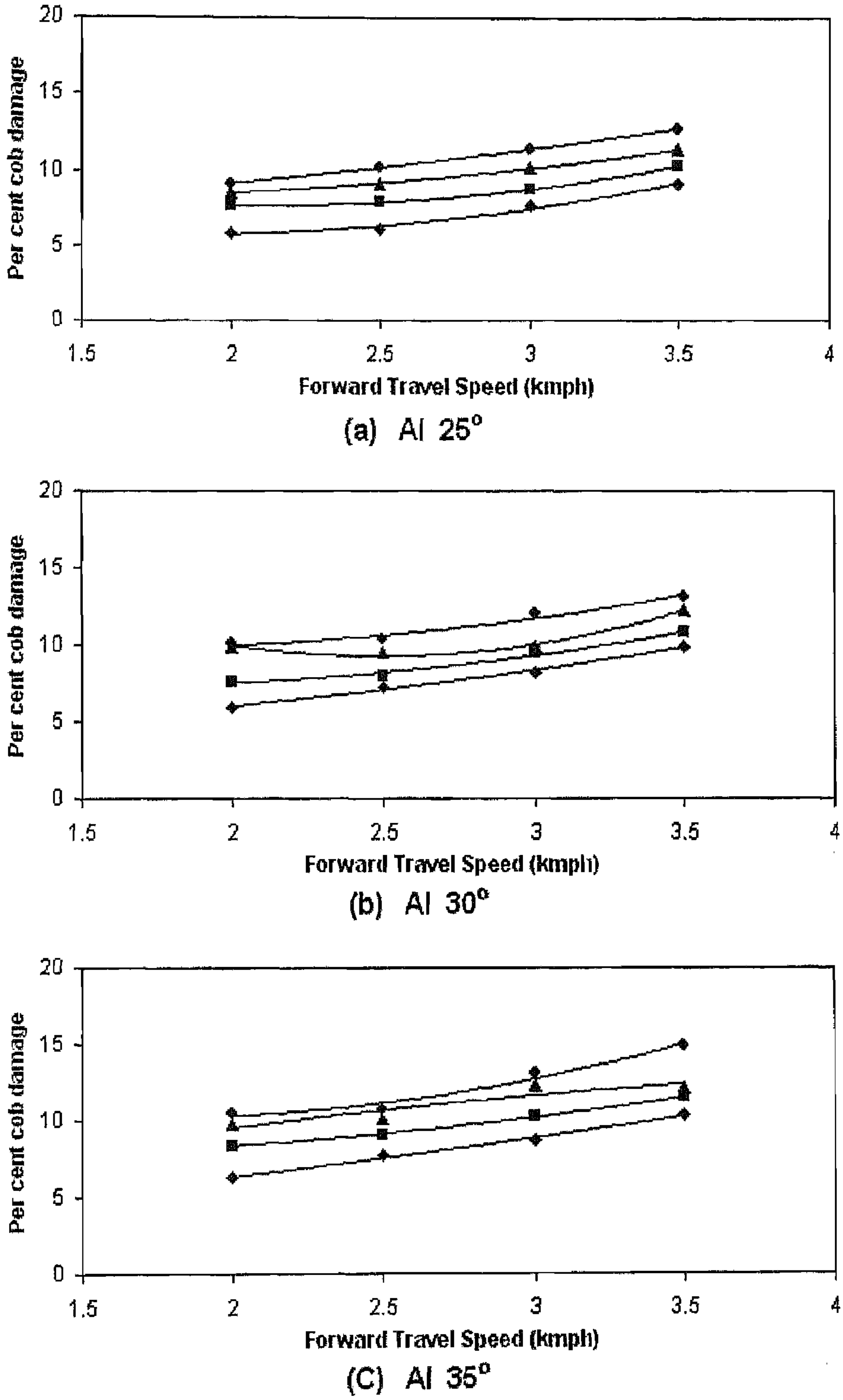


Fig 4.15 **Effect of forward travel speed on per cent cob damage at different peripheral speed and angle of inclination of snapping rolls at 25.9 per cent kernel moisture content**

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

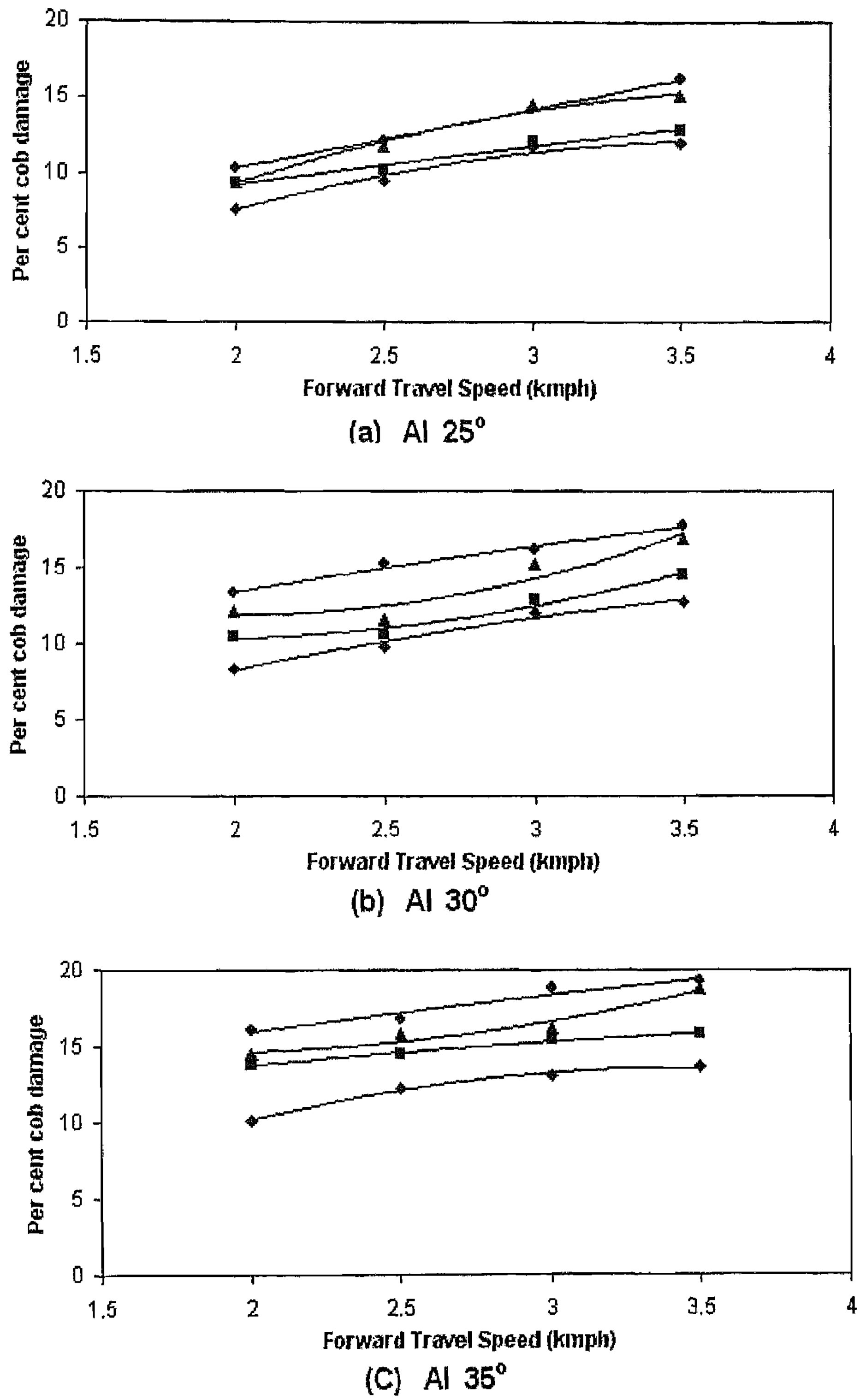
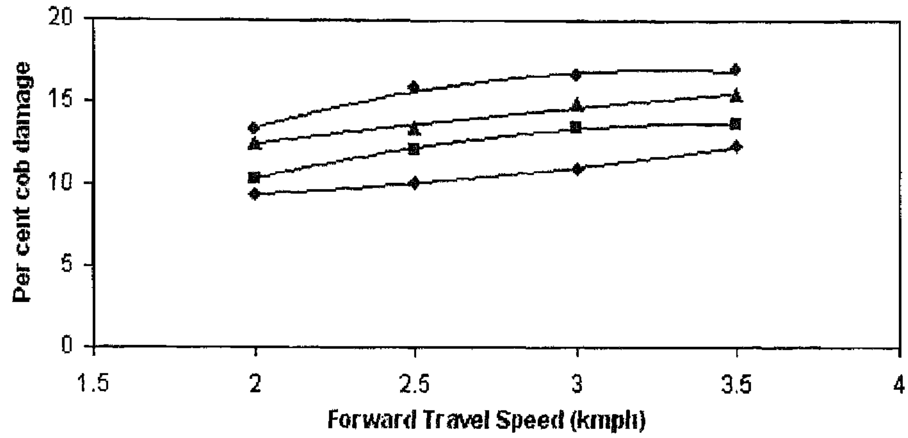
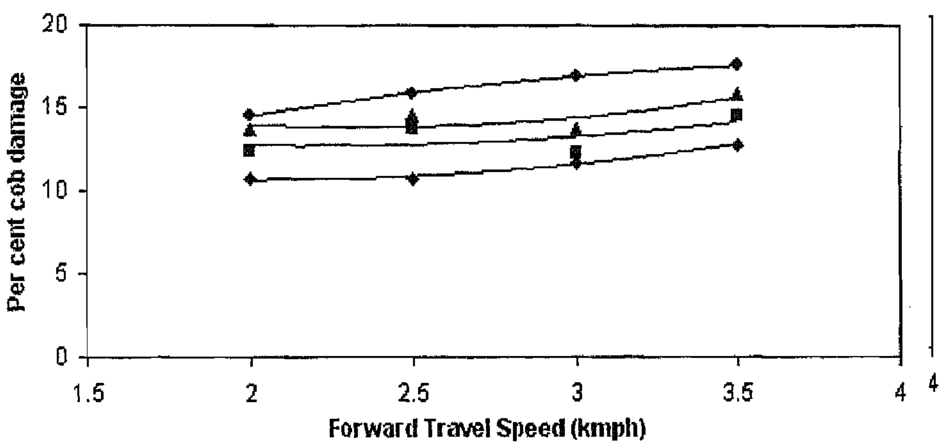


Fig 4.16 **Effect of forward travel speed on per cent cob damage at different peripheral speed and angle of inclination of snapping rolls at 32.7 per cent kernel moisture content**

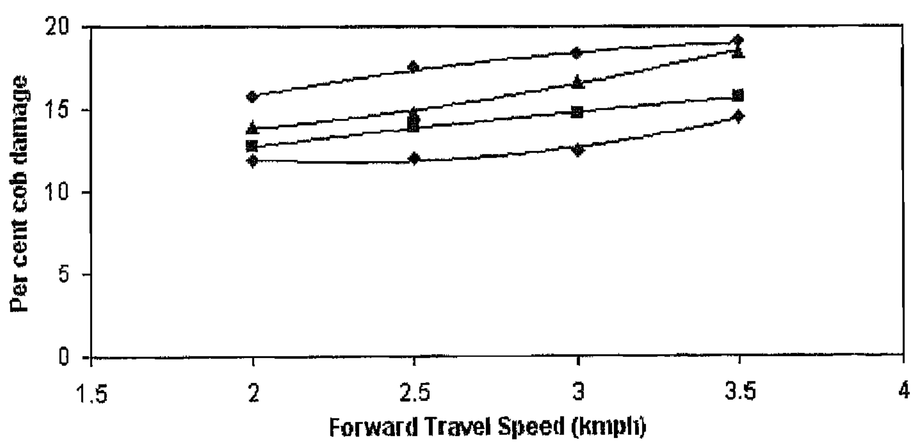
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



(b) AI 30°



(C) AI 35°

Fig 4.17 Effect of forward travel speed on per cent cob damage at different peripheral speed and angle of inclination of snapping rolls at 38.5 per cent kernel moisture content

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

The mean value table for per cent cob damage at different forward travel speed is presented in Table 4.9. It was observed from Table 4.9 that maximum per cent cob damage was obtained at 3.5 kmph. By increasing the forward travel speed from 2.0 to 2.5, 2.0 to 3.0 and 2.0 to 3.5 kmph, per cent cob damage increased to 8.95, 21.08, 32.46 per cent respectively. This might be due to shelling and dehusking of cobs at the point of attachment to the stalks and during conveying and also might be attributed to plugging due to over loaded gathering unit at higher forward travel speed.

Table 4.9 Mean values of per cent cob damage at different forward travel speed

Forward travel speed, kmph	2.0	2.5	3.0	3.5
Cob damage,%	10.72	11.68	12.98	14.20

SEm± 0.090 LSD $_{0.05}$ 0.250

4.3.2 Effect of peripheral speed of snapping rolls on per cent cob damage

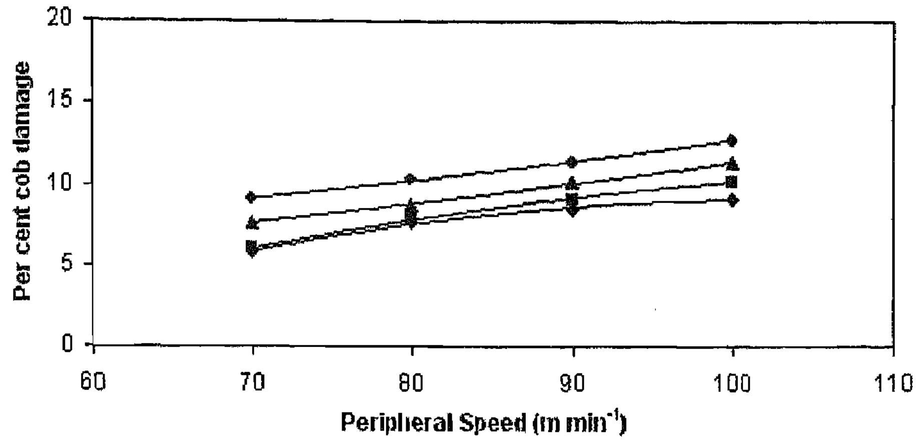
The effect of peripheral speed on per cent cob damage at different forward travel speed for different angle of inclination of snapping rolls and kernel moisture content are presented in Fig. 4.18 through Fig. 4.20. It was observed from Fig. 4.18 that at 25.9 per cent kernel moisture content, at all angle of inclination and forward travel speed per cent cob damage increased with increase in peripheral speed. Similar trends were also obtained for 32.7 and 38.5 per cent kernel moisture content.

The mean value table for per cent cob damage at different peripheral speed is presented in Table 4.10. It was seen from Table 4.10 that peripheral speed had significant effect on per cent cob damage. By increase in the peripheral speed from 70 to 80, 80 to 90 and 90 to 100, per cent cob damage increased by 1.50, 1.47 and 1.33 per cent respectively. This might be due to cob compression in snapping rolls and/or crushing and also due to bouncing off the stalks before the stalks enter the snapping rolls, at higher peripheral speed.

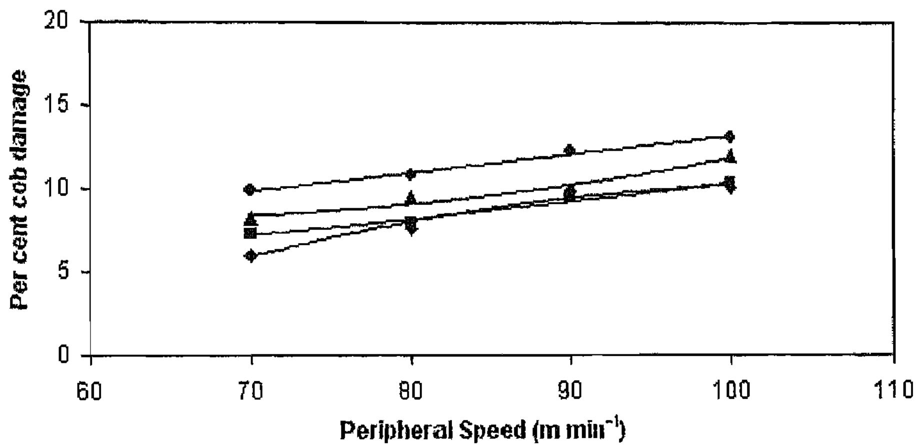
Table 4.10 Mean values of per cent cob damage at different peripheral speed of snapping rolls

Peripheral speed, m/min	70	80	90	100
Cob damage,%	10.15	11.72	13.19	14.52

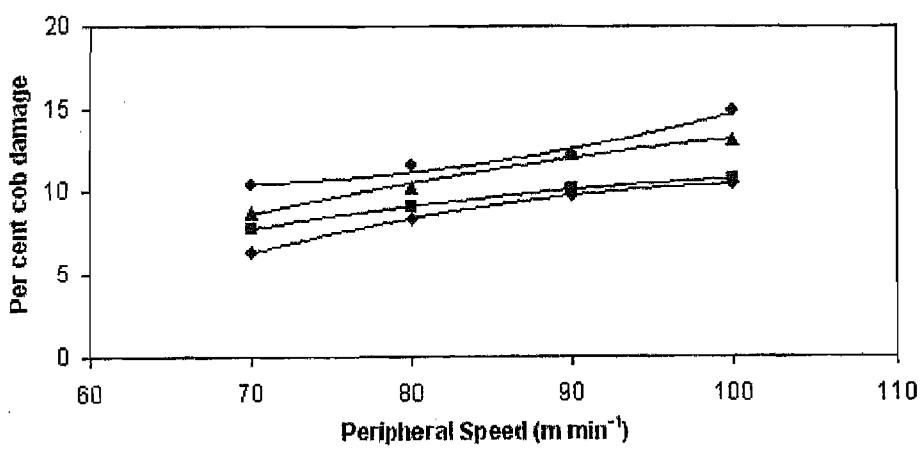
SEm± 0.090 LSD $_{0.05}$ 0.250



(a) AI 25°



(b) AI 30°



(C) AI 35°

Fig 4.18 Effect of peripheral speed on per cent cob damage at different foward travel speed and angle of inclination of snapping rolls at 25.9 per cent kernel moisture content

♦,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph

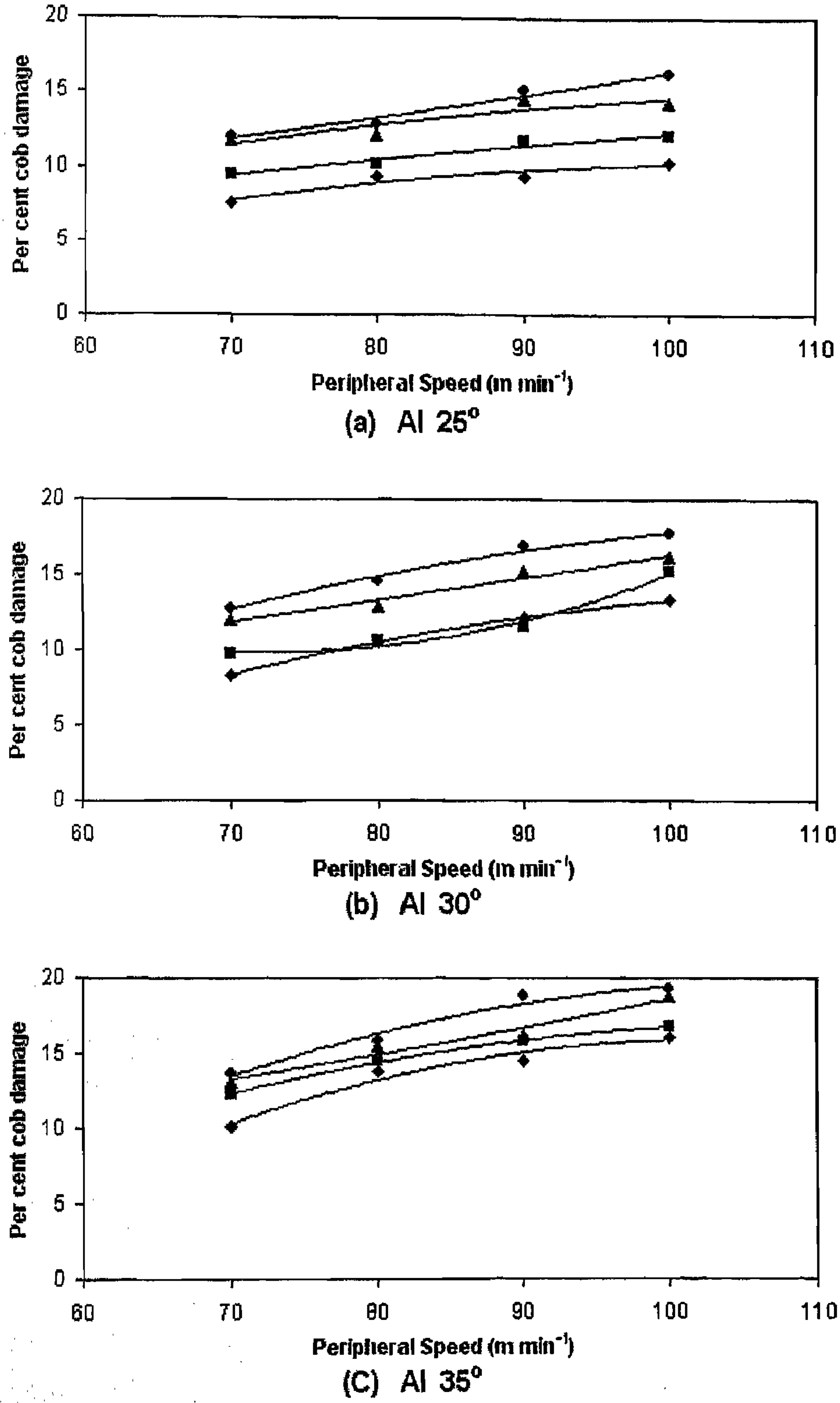


Fig 4.19 Effect of peripheral speed on per cent cob damage at different foward travel speed and angle of inclination of snapping rolls at 32.7 per cent kernel moisture content

♦,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph

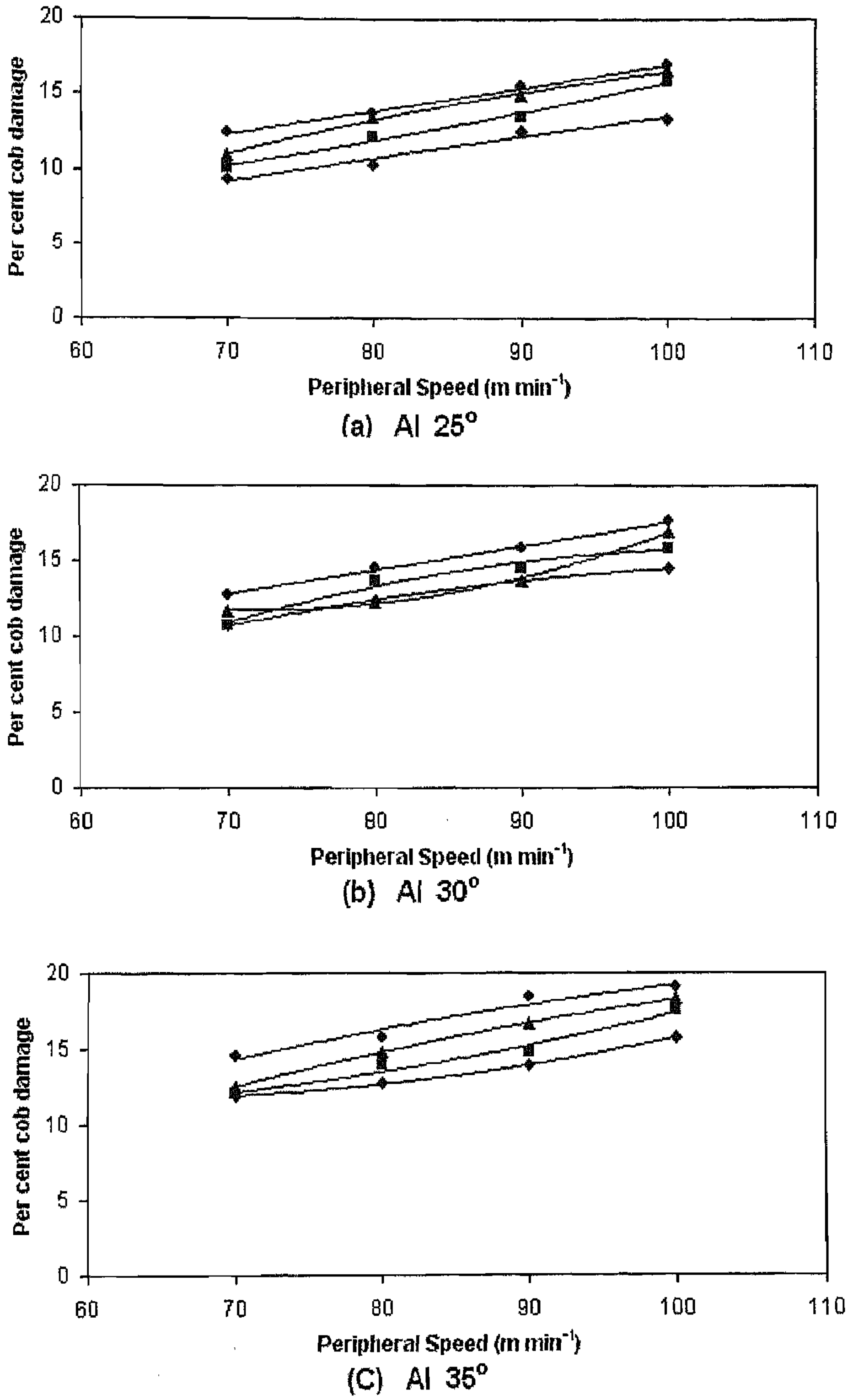


Fig 4.20 Effect of peripheral speed on per cent cob damage at different foward travel speed and angle of inclination of snapping rolls at 38.5 per cent kernel moisture content

♦,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph

4.3.3 Effect of angle of inclination on per cent cob damage

The results obtained during the study are presented in Fig.4.21 through Fig. 4.24. ANOVA Table 4.8 shows that angle of inclination had a significant effect on per cent cob damage. It was seen from Fig. 4.21 that per cent cob damage increased with angle of inclination of snapping rolls at all levels of peripheral speed and kernel moisture content. Almost similar trends were also obtained for forward travel speed ranging from 2.5 to 3.5 kmph (Fig. 4.22 through Fig. 4.24).

The mean value table for per cent cob damage is presented in Table 4.11. It was seen from the Table 4.11 that per cent cob damage increased from 11.37 to 12.20 per cent when angle of inclination was changed from 25° to 30°. Further by changing the angle of inclination from 30° to 35° per cent cob damage further increased from 12.20 to 13.61 per cent. This might be attributed because at higher angle of inclination, mechanism grip the stalk at the lower end and larger portion of the stalk has to be struddle down through pinching off the cob.

Table 4.11 Mean values of per cent cob damage at different angle of inclination of snapping rolls

Angle of inclination,(°)	25	30	35
Cob damage,%	11.37	12.20	13.61

SEm± 0.078 LSD $_{0.05}$ 0.216

4.3.4 Effect of the kernel moisture content on per cent cob damage

The results obtained during the study are presented in Fig. 4.25 through Fig.4.28. ANOVA Table 4.8 shows that kernel moisture content had significant effect on per cent cob damage. It was observed from Fig. 4.25 and from Fig. 4.26 that per cent cob damage increased with increase in kernel moisture content at an angle of inclination of 25^0 and 30^0 up to forward travel speed of 2.5 kmph whereas further increase in inclination angle per cent cob damage decreased when kernel moisture increased from 32.7 to 38.5 at all peripheral speed of snapping rolls. Further increase in forward travel speed increased per cent cob damage up to kernel moisture content of 32.7 per cent, beyond this kernel moisture content per cent cob damage decreased at all angle of inclination and peripheral speeds. The mean value table for the per cent cob damage at different kernel moisture content is present in Table 4.12. The Table 4.12 revealed that effect of kernel moisture

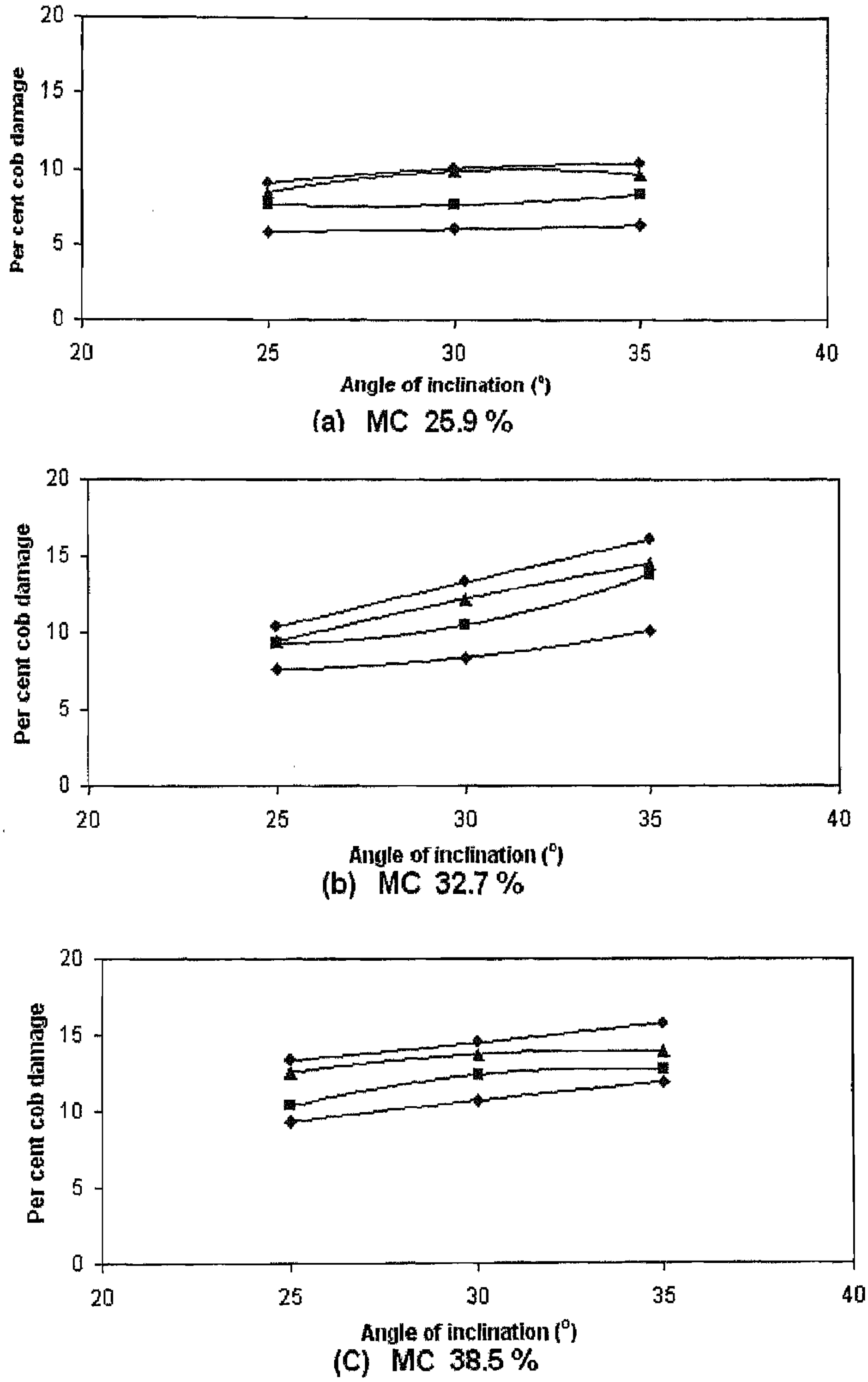
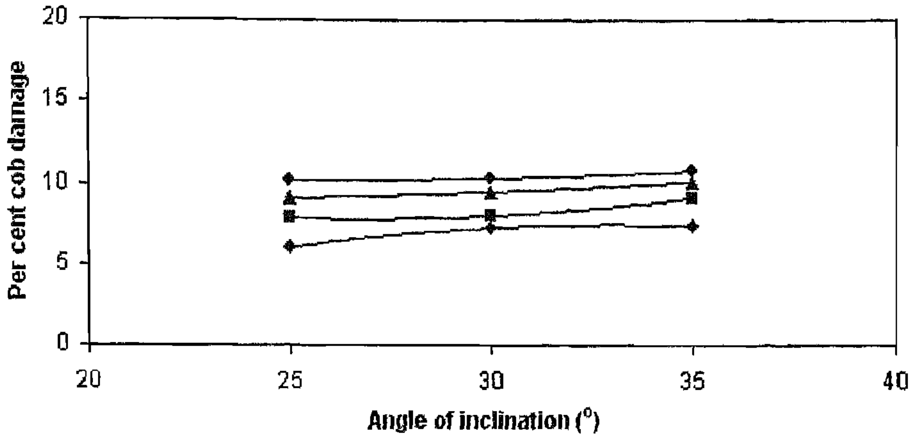
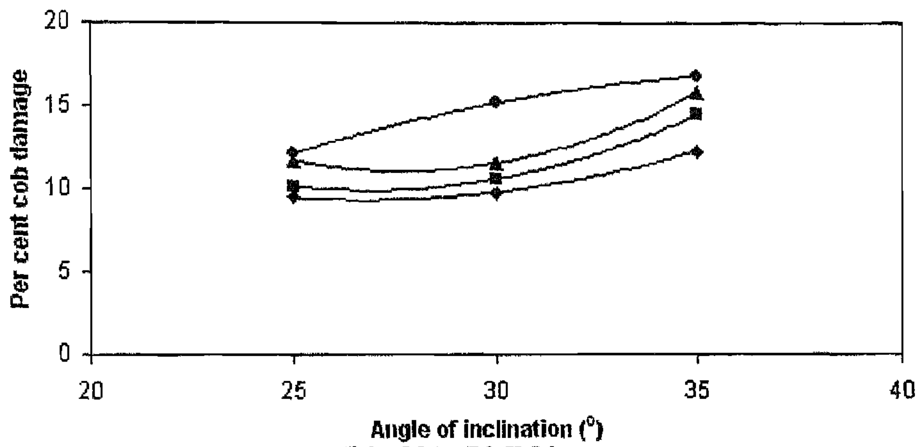


Fig 4.21 **Effect of angle of inclination on per cent cob damage at different peripheral speed and kernel moisture content at 2.0 kmph forward travel speed**

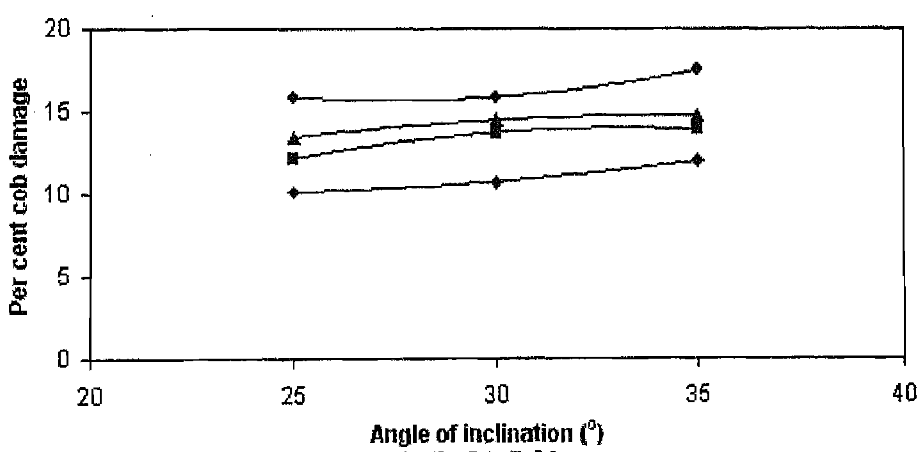
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) MC 25.9 %



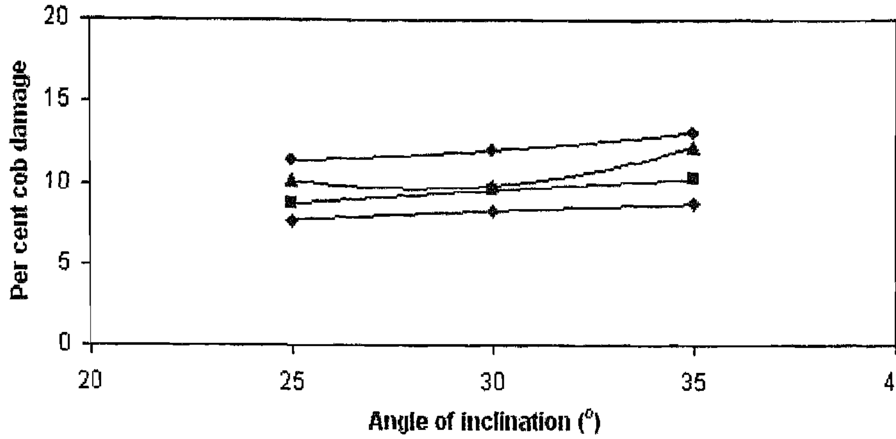
(b) MC 32.7 %



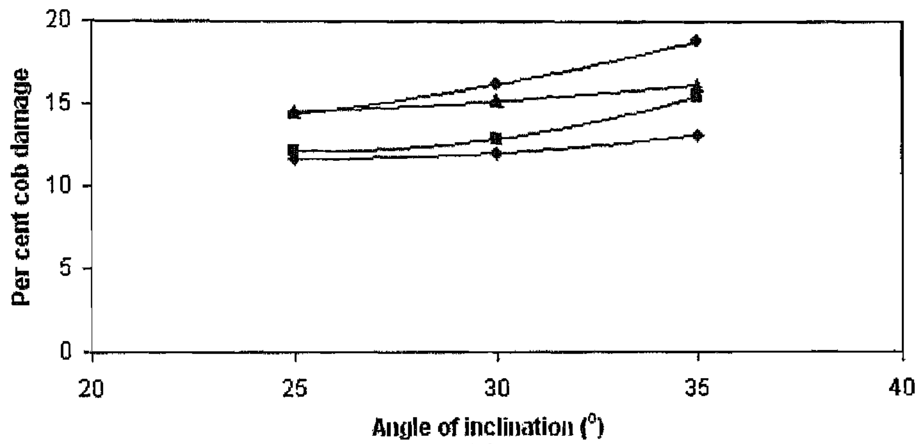
(C) MC 38.5 %

Fig 4.22 **Effect of angle of inclination on per cent cob damage at different peripheral speed and kernel moisture content at 2.5 kmph forward travel speed**

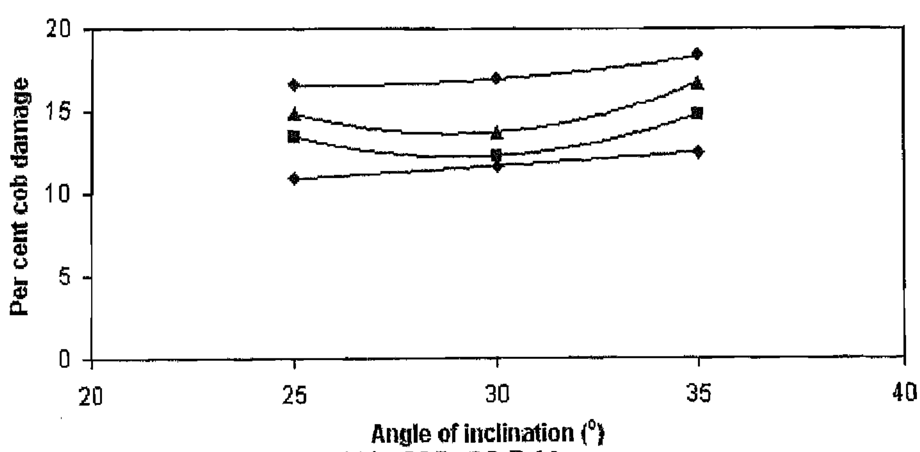
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) MC 25.9 %



(b) MC 32.7 %



(C) MC 38.5 %

Fig 4.23 **Effect of angle of inclination on per cent cob damage at different peripheral speed and kernel moisture content at 3.0 kmph forward travel speed**

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

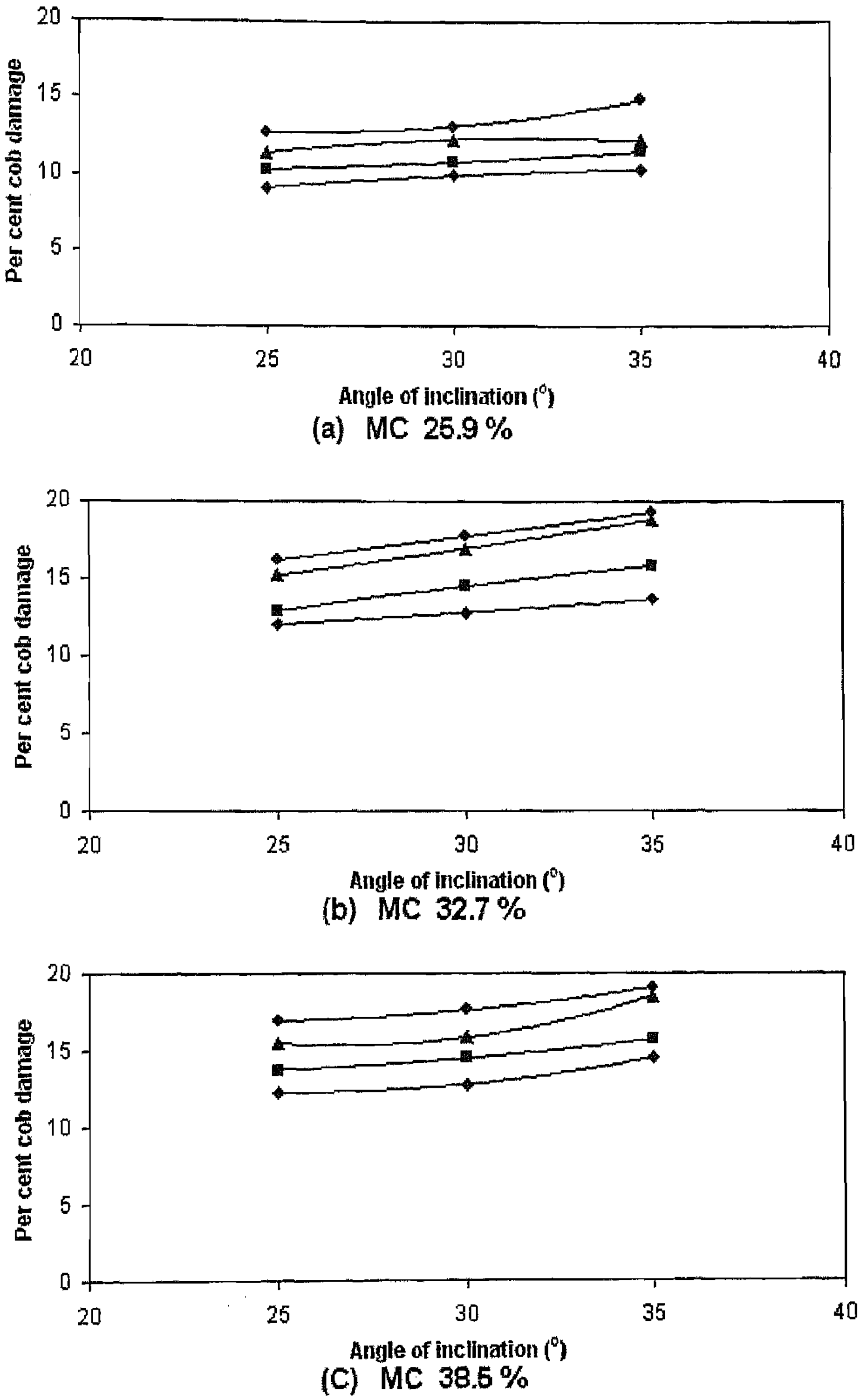
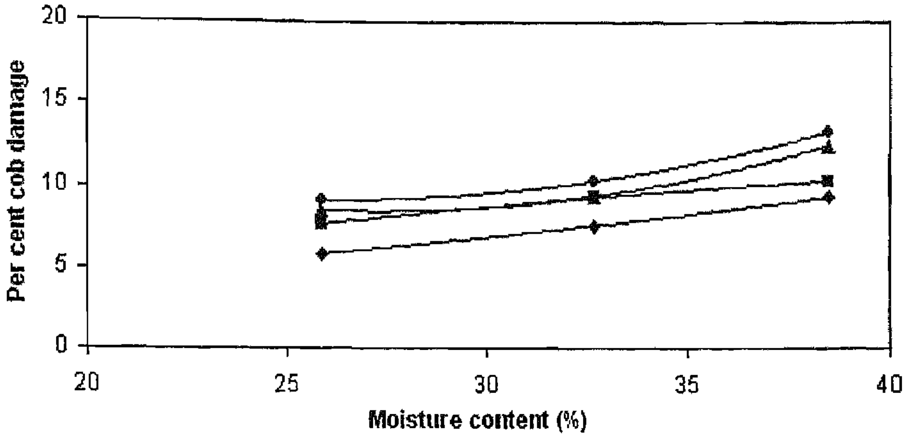
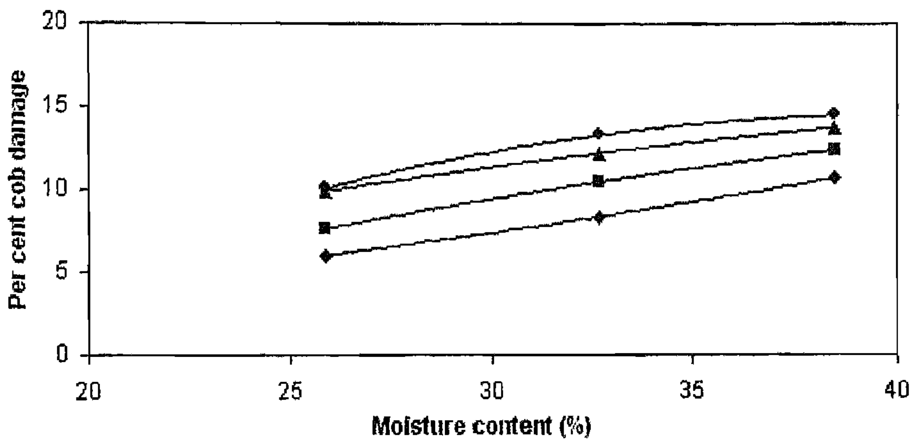


Fig 4.24 Effect of angle of inclination on per cent cob damage at different peripheral speed and kernel moisture content at 3.5 kmph forward travel speed

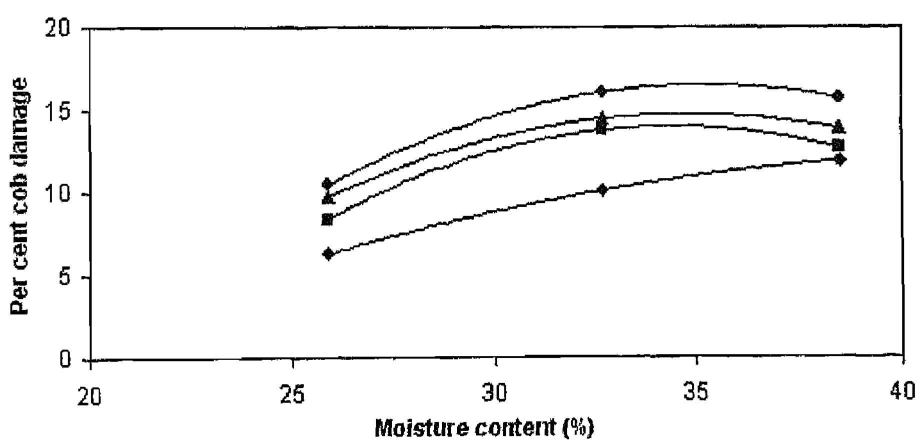
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



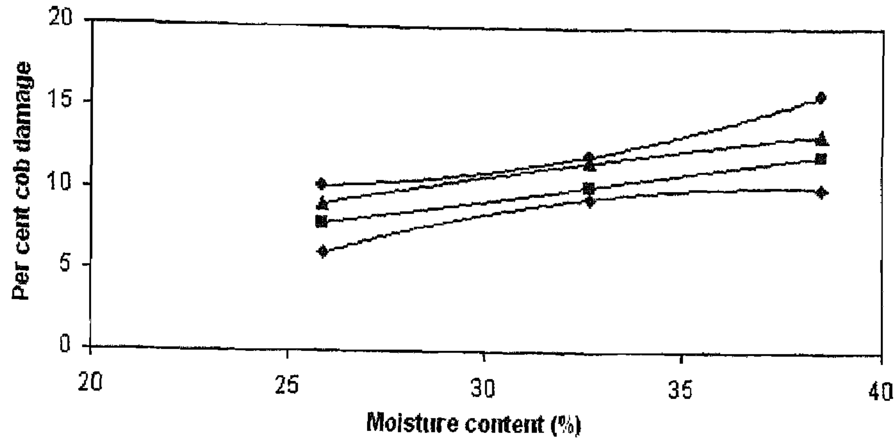
(b) AI 30°



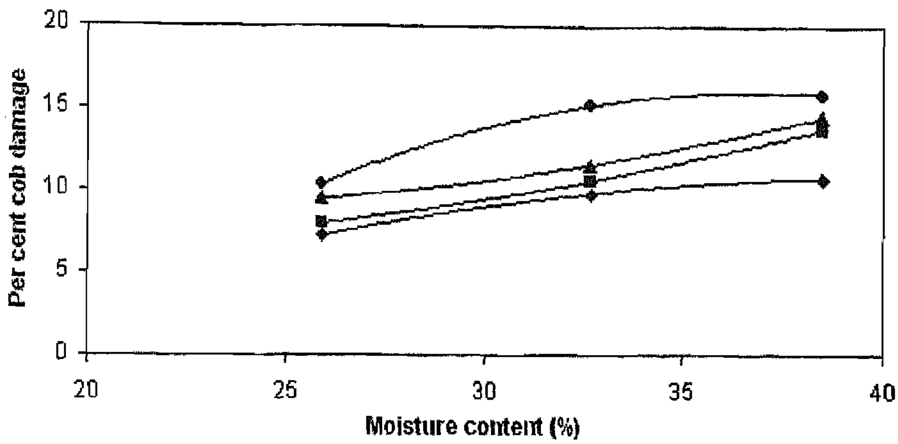
(C) AI 35°

Fig 4.25 Effect of kernel moisture content on per cent cob damage at different peripheral speed and angle of inclination of snapping rolls at 2.0 kmph forward travel speed

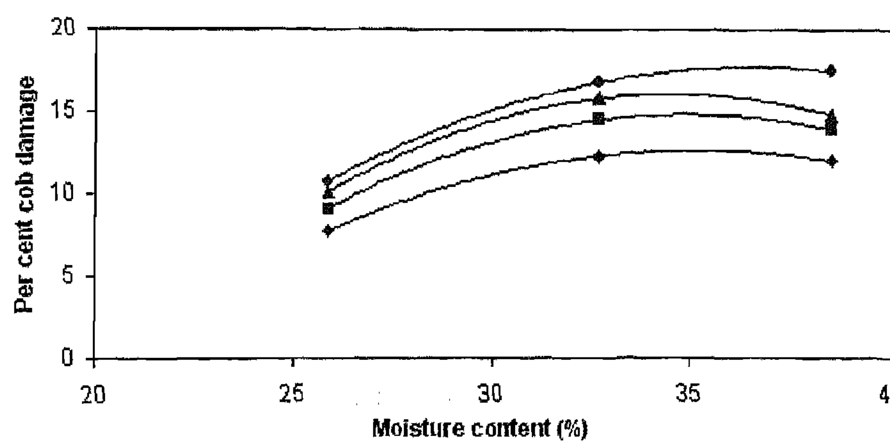
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



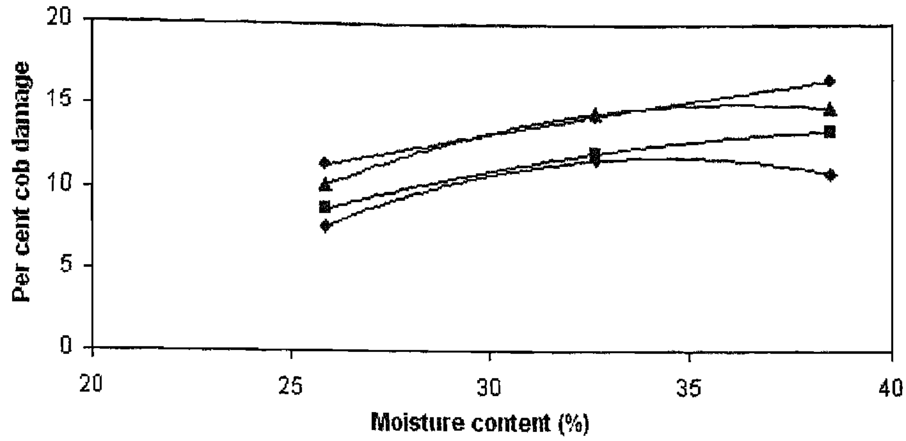
(b) AI 30°



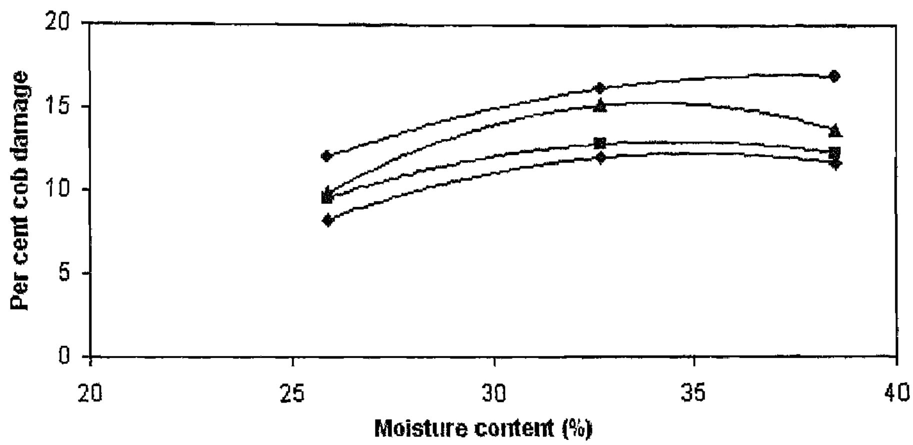
(C) AI 35°

Fig 4.26 Effect of kernel moisture content on per cent cob damage at different peripheral speed and angle of inclination of snapping rolls at 2.5 kmph forward travel speed

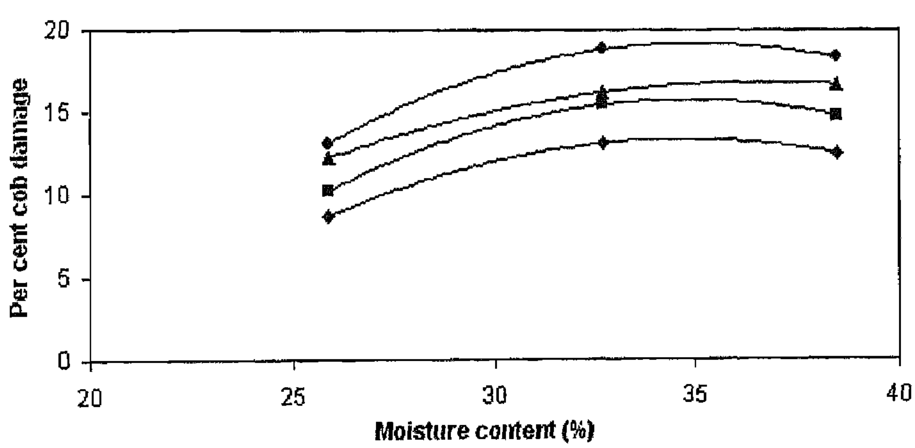
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



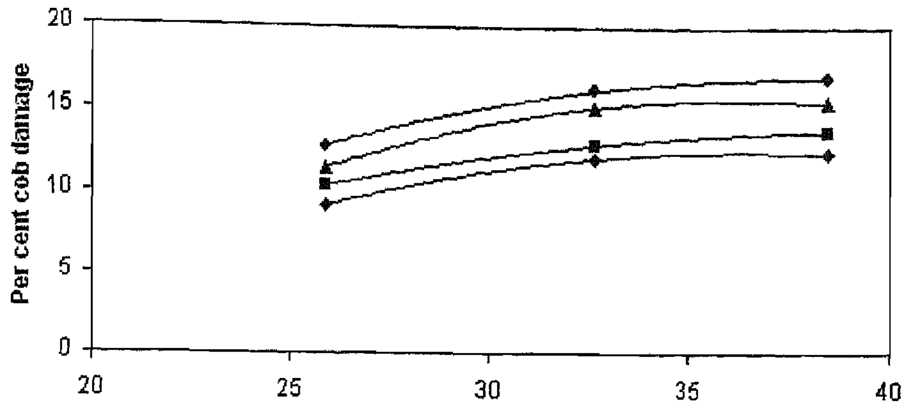
(b) AI 30°



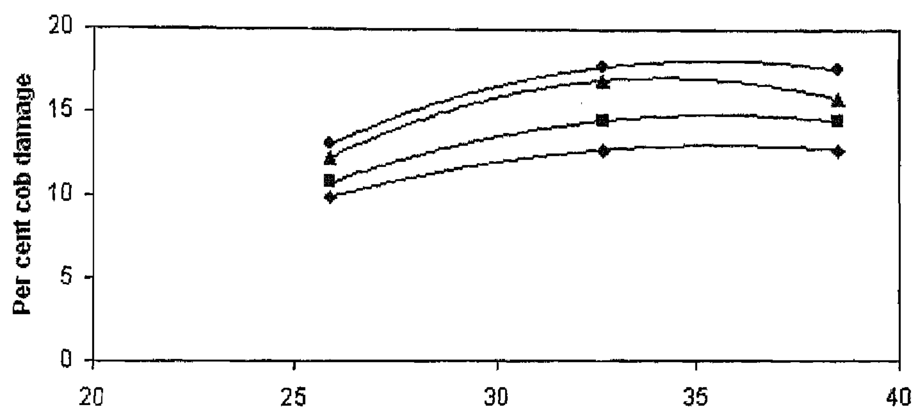
(C) AI 35°

Fig 4.27 Effect of kernel moisture content on per cent cob damage at different peripheral speed and angle of inclination of snapping rolls at 3.0 kmph forward travel speed

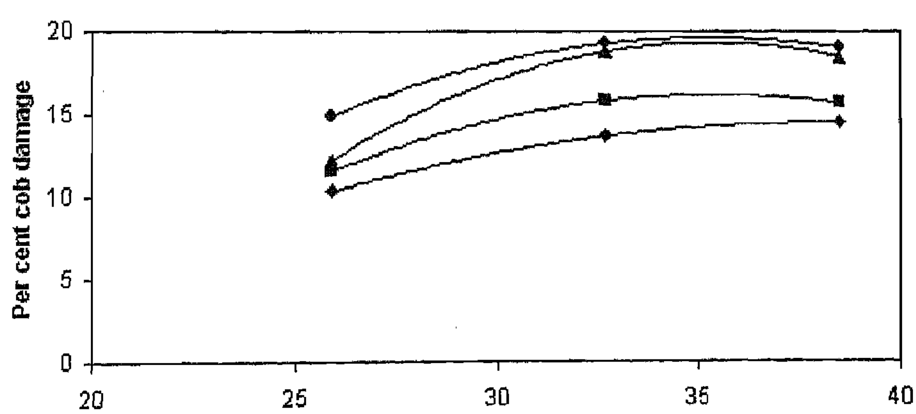
♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



(b) AI 30°



(C) AI 35°

Fig 4.28 Effect of kernel moisture content on per cent cob damage at different peripheral speed and angle of inclination of snapping rolls at 3.5 kmph forward travel speed

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

content was significant on per cent cob damage. By increasing the kernel moisture content from 25.9 to 32.7 and 38.5 per cent, per cent cob damage increased to 38.24 and 45.05 per cent respectively. This might be due to sponginess of the cob at higher moisture content and chances of change in configuration increased even due to little compression during picking and/or conveying. It was interesting to note per cent cob damage increased with further increase forward travel speed and kernel moisture content when angle of inclination of snapping rolls increased from 30^0 to 35^0.

Table 4.12 Mean values of per cent cob damage at different kernel moisture content

Kernel moisture content, %	25.90	32.70	38.50
Cob damage, %	9.70	13.41	14.07

SEm± 0.078 LSD $_{0.05}$ 0.216

4.3.5 Combined effect of forward travel speed and kernel moisture content on per cent cob damage

Table 4.8 (ANOVA) shows that the combined effect of forward travel speed and kernel moisture content was significant on per cent cob damage at 95 per cent confidence level. The results of effect of forward travel speed with kernel moisture content are presented in Table 4.13 and depicted in Fig. 4.29. It was found that with the increase in forward travel speed from 2.0 kmph to 3.5 kmph the per cent cob damage increased from 8.3 to 15.55 per cent. At 25.9 per cent moisture content, per cent cob damage increased from 8.30 to 11.55 per cent when forward travel speed increased from 2.0 to 3.5 kmph. The increase in the per cent cob damage at 32.7 and 38.5 per cent kernel moisture content was 11.28 to 15.47 and 12.58 to 15.65 per cent respectively.

Table 4.13 Two variable interactions showing effect of forward travel speed and kernel moisture content on mean per cent cob damage

Forward travel speed (kmph)	Moisture content (%) / Cob damage (%)		
	25.90	**32.70**	**38.50**
2.0	8.30	11.28	12.58
2.5	8.83	12.5	13.72
3.0	10.16	14.39	14.39
3.5	11.55	15.47	15.55

SEm± 0.156 LSD$_{0.05}$ 0.433

4.3.6 Combined effect of peripheral speed and kernel moisture content on per cent cob damage

The interaction effect between peripheral speed of the snapping rolls with kernel moisture content is presented in Table 4.14 and plotted in Fig. 4.30. It was seen from Table 4.14 that interaction effect was significant at all combinations of peripheral speed and kernel moisture content. Table 4.14 also revealed that at 70 m/min peripheral speed, when kernel moisture content increased from 25.9 to 38.5 per cent, the per cent cob damage increased significantly from 7.75 to 11.64 per cent. Similar increasing trends were observed for peripheral speed of 80, 90 and 100 m/min.

Table 4.14 Two variable interactions showing effect of peripheral speed and kernel moisture content on mean per cent cob damage

Peripheral speed (m/min)	Moisture content (%) / Cob damage (%)		
	25.90	**32.70**	**38.50**
70	7.75	11.08	11.64
80	9.14	12.69	13.31
90	10.42	14.33	14.83
100	11.53	15.53	16.5

SEm$\pm$ 0.156 $LSD_{0.05}$ 0.433

4.3.7 Combined effect of angle of inclination of snapping rolls and kernel moisture content on per cent cob damage

The results obtained during the study are presented in Table 4.15 and depicted in Fig. 4.31. It is revealed from Table 4.15 that interaction effect between angle of inclination and moisture content had significant effect on per cent cob damage. At 25° angle of inclination, when kernel moisture content increased from 25.9 to 38.5 per cent the per cent cob damage increased significantly from 9.10 to 13.20 per cent. The trends for all the three levels of angle of inclination were same. Further at 25.9 per cent kernel moisture content when angle of inclination increased from 25° to 30° and 30° to 35°the per cent cob damage increased significantly and maximum per cent cob damage was 10.35 per cent. Similar trends were observed at 32.7 and 38.5 per cent moisture content.

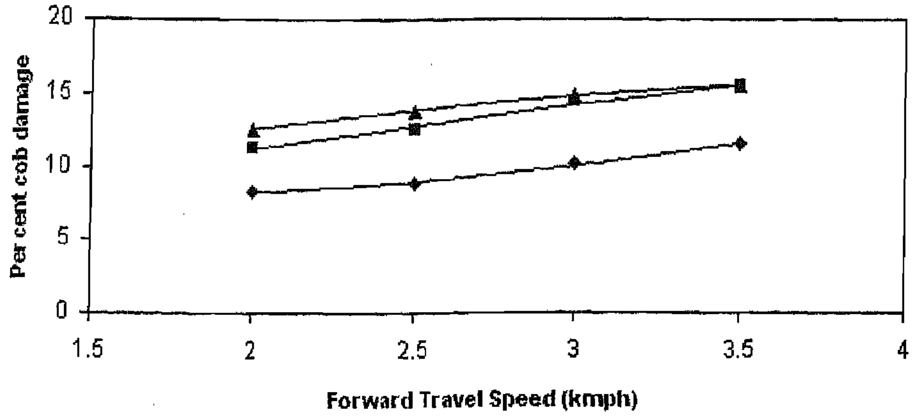


Fig 4.29 Interaction effect of forward travel speed and kernel moisture content on per cent cob damage

♦, MC 25.9 % ■, MC 32.7 % ▲, MC 38.5 %

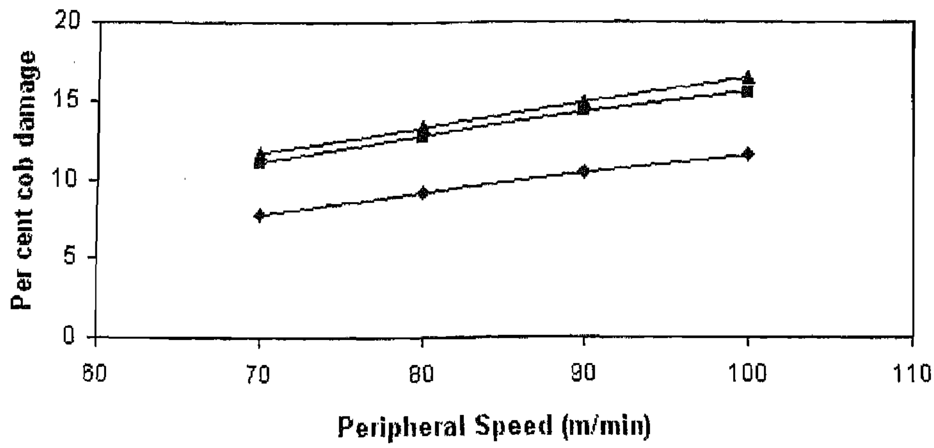


Fig 4.30 Interaction effect of peripheral speed and kernel moisture content on per cent cob damage

♦, MC 25.9 % ■, MC 32.7 % ▲, MC 38.5 %

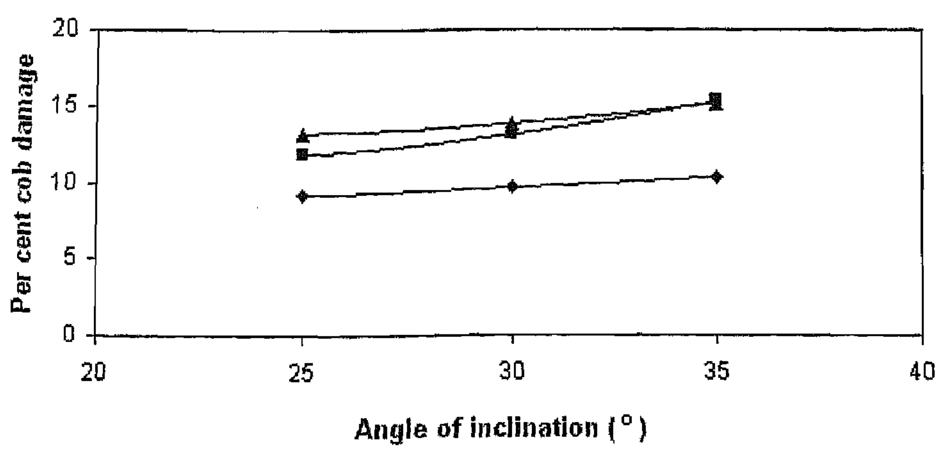


Fig 4.31 Interaction effect of angle of inclination and kernel moisture content on per cent cob damage

♦, MC 25.9 % ■, MC 32.7 % ▲, MC 38.5 %

Table 4.15 Two variable interactions showing effect of angle of inclination of snapping rolls and kernel moisture content on mean per cent cob damage

Angle of inclination(°)	Moisture content (%) / Cob damage (%)		
	25.90	**32.70**	**38.50**
25	9.10	11.81	13.20
30	9.65	13.10	13.83
35	10.35	15.31	15.16

SEm± 0.135 $LSD_{0.05}$ 0.375

4.3.8 Combined effect of forward travel speed, angle of inclination of snapping rolls and kernel moisture content on per cent cob damage

Data on interaction effect of forward travel, angle of inclination and moisture content of cob grain on per cent cob damage are given in Table 4.16 and Fig. 4.32. It was observed from Table 4.16 that with the increase in forward travel speed from 2.0 to 3.5 kmph, per cent cob damage increased from 7.75 to 16.92 at all three levels of moisture content and angle of inclination.

The interaction effect among forward travel speed, angle of inclination of snapping rolls and kernel moisture content on per cent cob damage was found significant. At a forward travel speed of 2.0 kmph and 25° angle of inclination, per cent cob damage increased with increase in moisture content, whereas for 25.9 per cent moisture content increase in angle of inclination per cent cob damage also increased. Similar trends were also observed for all levels of forward travel speed, angle of inclination and moisture content.

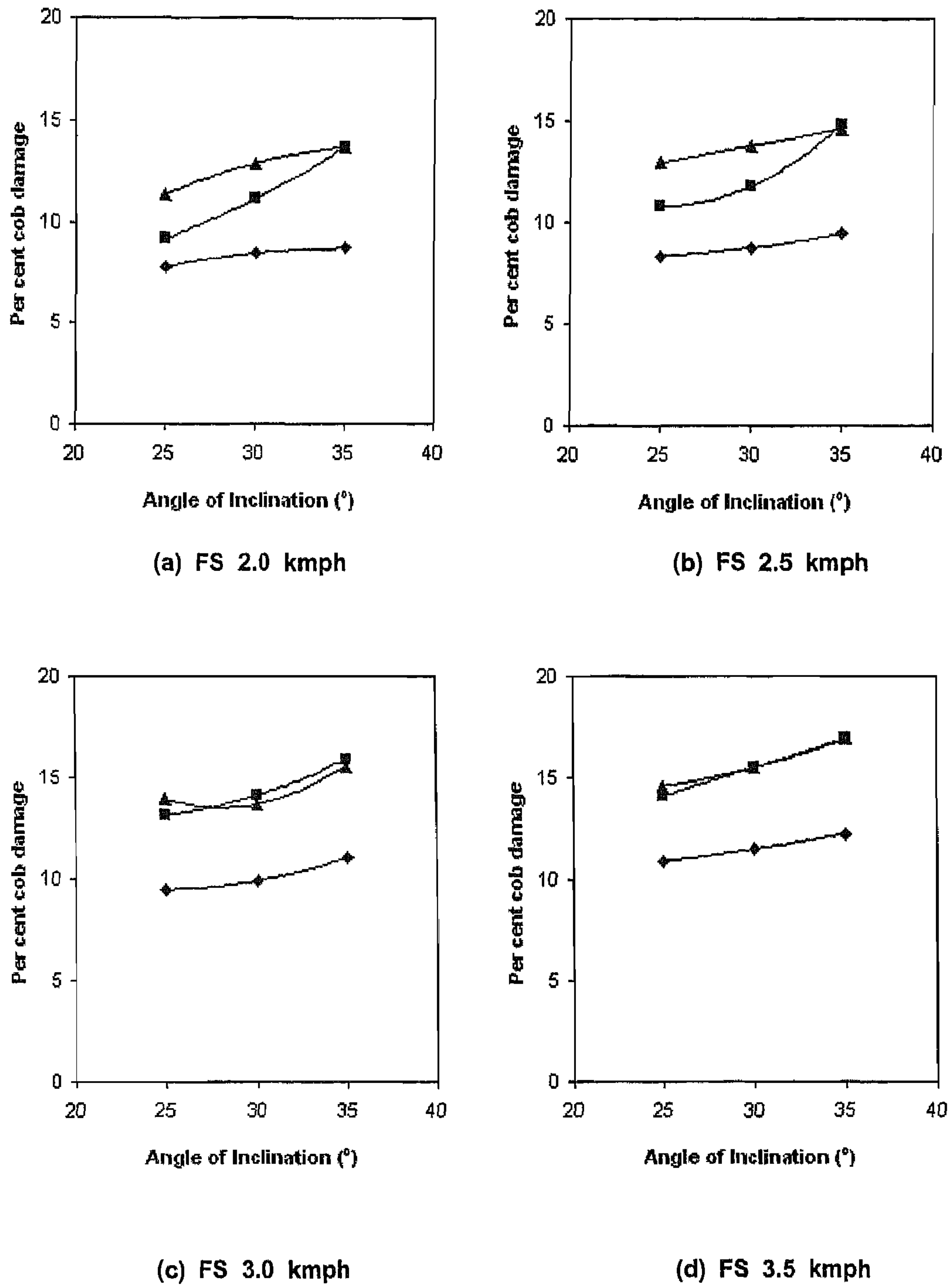


Fig 4.32 Interaction effect of forward travel speed, angle of inclination and kernel moisture content on per cent cob damage

♦, MC 25.9 % ■, MC 32.7 % ▲, MC 38.5 %

Table 4.16 Three variable interactions showing effect of forward travel speed, angle of inclination of snapping rolls and kernel moisture content on mean per cent cob damage

Forward travel speed (kmph)	Angle of inclination(°)	Kernel Moisture content (%) / Per cent Cob damage		
		25.90	32.70	38.50
2.0	25	7.75	9.16	11.33
	30	8.42	11.08	12.83
	35	8.66	13.66	13.66
2.50	25	8.33	10.83	12.92
	30	8.75	11.75	13.75
	35	9.42	14.83	14.58
3.00	25	9.5	13.16	13.92
	30	9.92	14.08	13.67
	35	11.08	15.92	15.58
3.50	25	10.92	14.08	14.58
	30	11.5	15.5	15.5
	35	12.25	16.92	16.92

SEm± 0.269 $LSD_{0.05}$ 0.750

4.4 Effect of Forward Travel Speed, Peripheral Speed of Snapping Rolls, Angle of Inclination of Snapping Rolls and Kernel Moisture Content and their Interaction on Power Requirement of Picking Mechanism

Statistical analysis was performed to see the effect of forward travel speed (FS), peripheral speed of snapping rolls (PS), angle of inclination (AI) and moisture content (MC) on power requirement of picking mechanism. The results of Statistical analysis presented in Table 4.17 (ANOVA). The analysis of variance Table 4.17 indicated that all independent parameters, forward travel speed (FS), peripheral speed of snapping rolls (PS), angle of inclination of snapping rolls (AI) and kernel moisture content (MC) along with their combined effect for forward travel speed with peripheral speed of snapping rolls, angle of inclination with kernel moisture content and forward travel speed, angle of inclination of snapping rolls with kernel moisture content were found significant at 95 per cent confidence level.

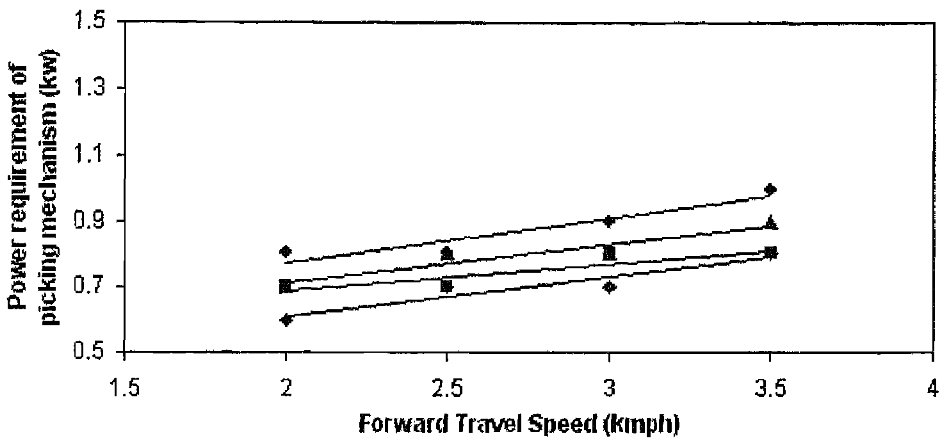
Table 4.17 ANOVA table for the effect of forward travel speed, peripheral speed of snapping rolls, angle of inclination of snapping rolls and kernel moisture content on power requirement of picking mechanism

Source of variance	Degree of freedom	Sum of Squares	Mean Sum of Squares	Computed F
FS	3	1.487	0.496	168.219*
PS	3	2.399	0.800	271.338*
AI	2	1.237	0.619	209.952*
MC	2	2.257	1.129	382.977*
FS X PS	9	0.051	0.006	1.918*
FS X AI	6	0.022	0.004	1.264
FS X MC	6	0.016	0.003	0.920
PS X AI	6	0.018	0.003	1.010
PS X MC	6	0.028	0.005	1.605
AI X MC	4	0.055	0.014	4.698*
FS X PS XAI	18	0.078	0.004	1.477
FS X PS X MC	18	0.045	0.003	0.856
FS X AI X MC	12	0.096	0.008	2.715*
PS X AI X MC	12	0.037	0.003	1.043
FS X PS X AI X MC	36	0.142	0.004	1.341
Error	288	0.849	0.033	
Total	431			

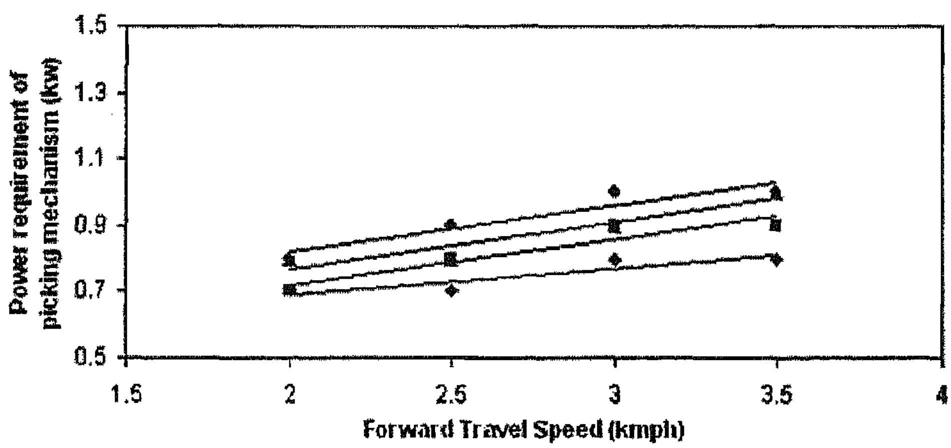
* Significant at 5 per cent level

4.4.1 Effect of forward travel speed on power requirement of picking mechanism

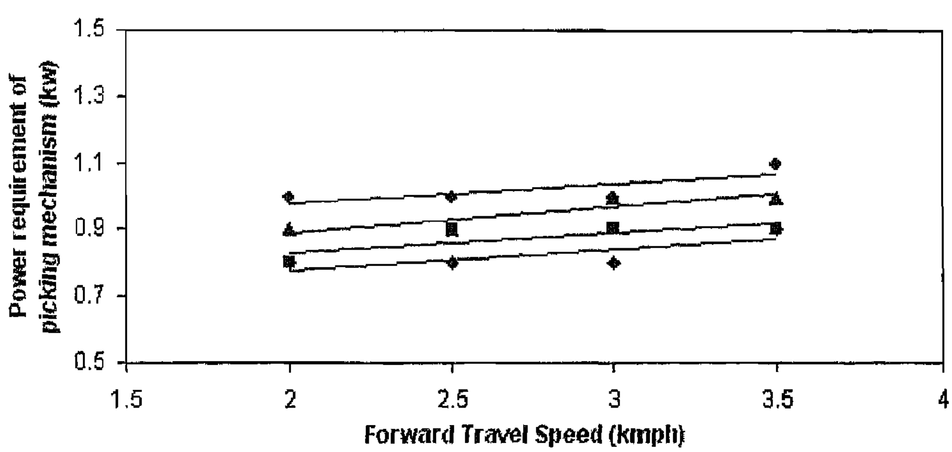
The results obtained during study are presented in Fig. 4.33 through Fig.4.35. The ANOVA Table 4.18 reveals that the forward travel speed had significant effect on power requirement of picking mechanism. Fig. 4.33 revealed that at 25.9 per cent kernel moisture content, power requirement of picking mechanism increased with increase in



(a) AI 25°



(b) AI 30°



(c) AI 35°

Fig 4.33 **Effect of forward travel speed on power requirement of picking mechanism at different peripheral speed and angle of inclination of snapping rolls at 25.9 per cent kernel moisture content**

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

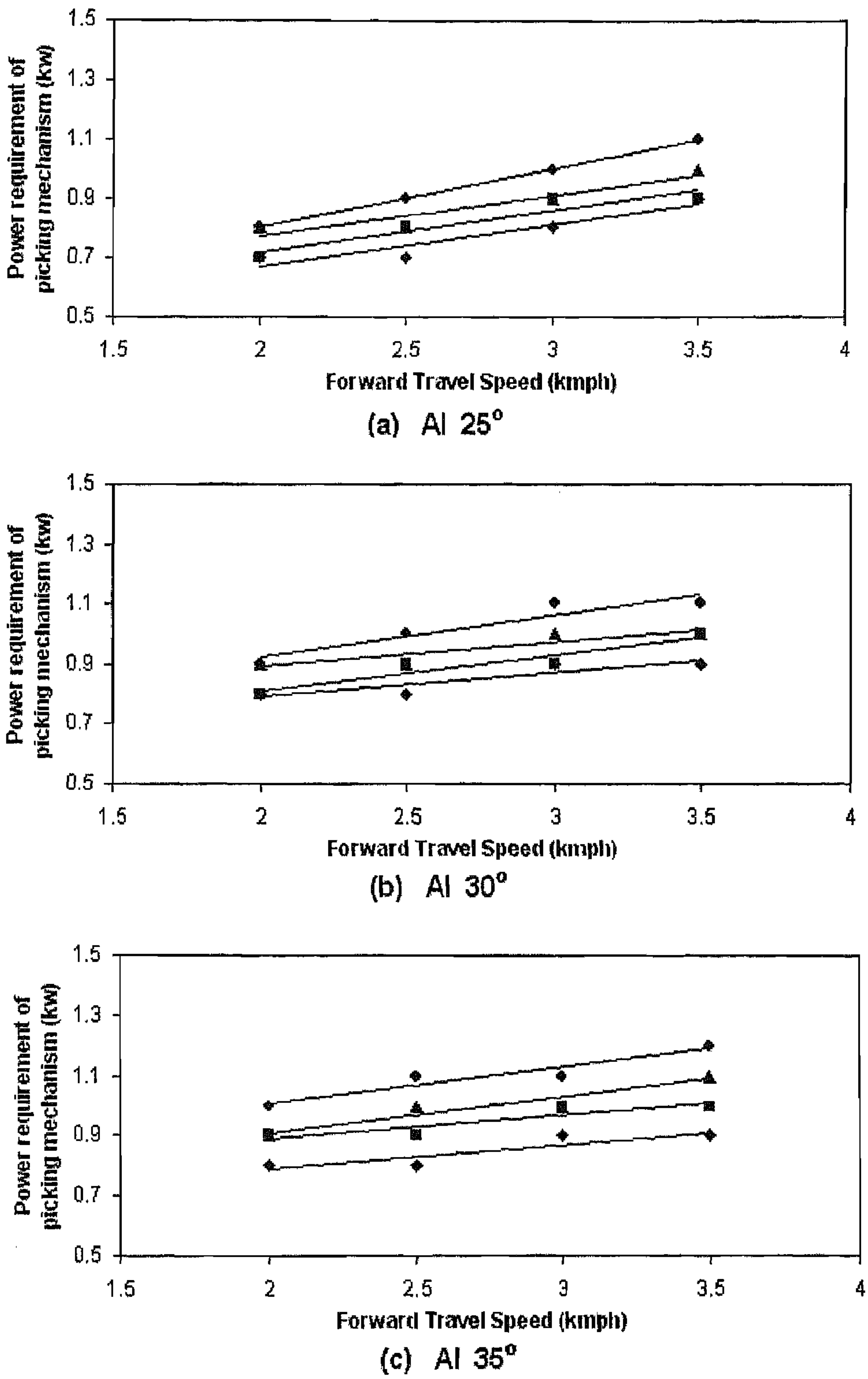


Fig 4.34 Effect of forward travel speed on power requirement of picking mechanism at different peripheral speed and angle of inclination of snapping rolls at 32.7 per cent kernel moisture content

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

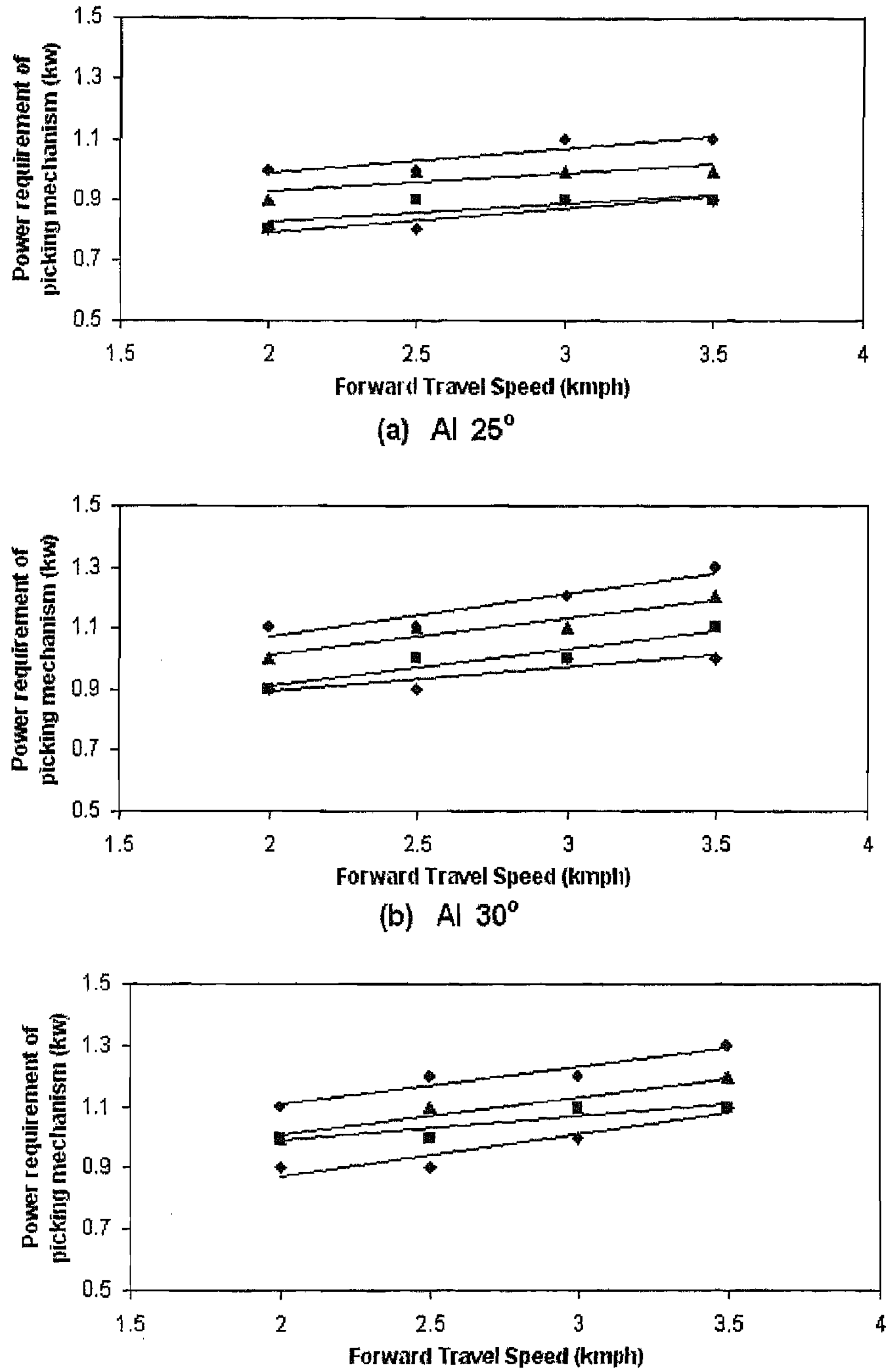


Fig 4.35 **Effect of forward travel speed on power requirement of picking mechanism at different peripheral speed and angle of inclination of snapping rolls at 38.5 per cent kernel moisture content**

◆,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} ●, PS 100 m min^{-1}

forward travel speed at all levels of peripheral speed and angle of inclination. Similar trends were also observed for kernel moisture content of 32.7 and 38.5 per cent (Fig. 4.34 and Fig. 3.35).

The mean value table for power requirement of picking mechanism at different forward travel speed is presented in Table 4.18. The Table 4.18 shows that the effect of forward travel speed was significant on power requirement of corn picking mechanism. The table 4.18 also indicated that minimum power requirement was observed at 2.0 kmph forward travel speed. When forward travel speed increased from 2.0 to 3.5 kmph, power requirement increased to 17.44 %. The increase in power requirement by increasing forward travel speed from 2.0 to 2.5, 2.5 to 3.0 and 3.0 to 3.5 kmph was 0.04, 0.06 and 0.05 k respectively.

Table 4.18 Mean values of power requirement of picking mechanism at different forward travel speed

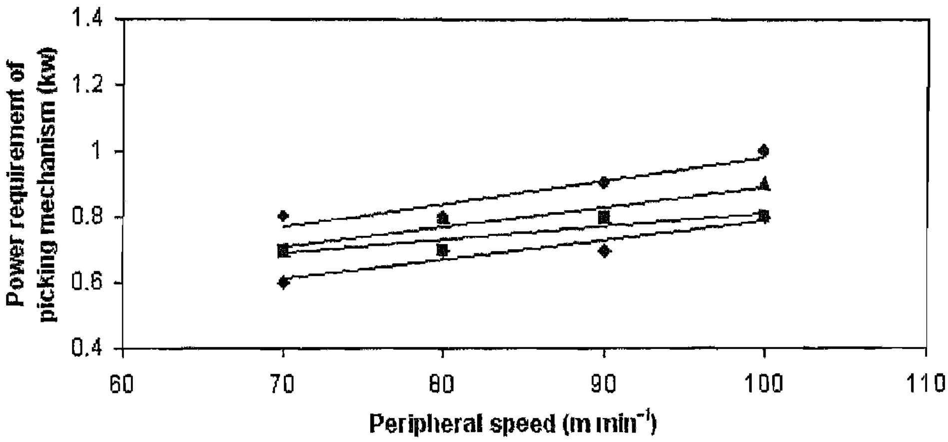
Forward travel speed, kmph	2.0	2.5	3.0	3.5
Power requirement of picking mechanism, kw	0.86	0.90	0.96	1.01

SEm± 0.005 LSD $_{0.05}$ 0.015

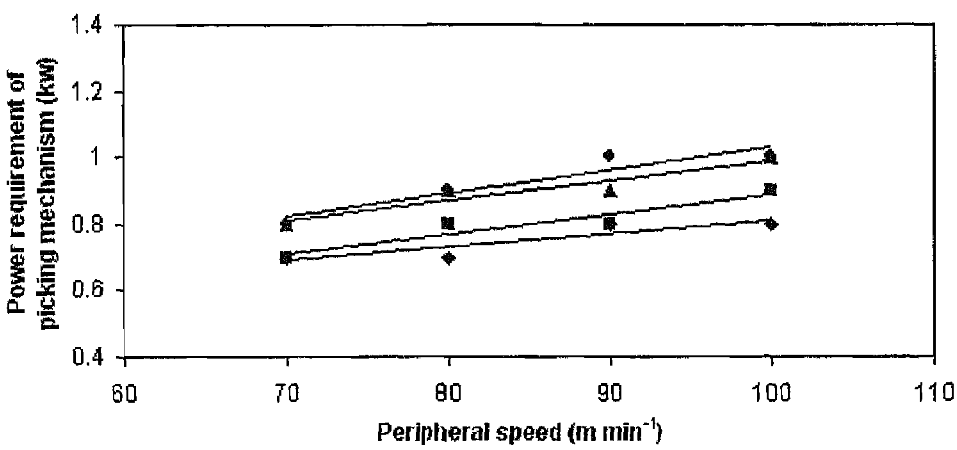
4.4.2 Effect of peripheral speed on power requirement of picking mechanism

The results obtained during the study are presented in Fig. 4.36 through Fig.4.38. Figure 4.36 showed that at kernel moisture content of 25.9 per cent, power requirement of picking mechanism increased with increase in peripheral speed at all four levels of forward travel speed and angle of inclination of snapping rolls. Similar trends were also observed for kernel moisture content of 32.7 and 38.5 per cent (Fig. 4.37 and Fig.4.38).

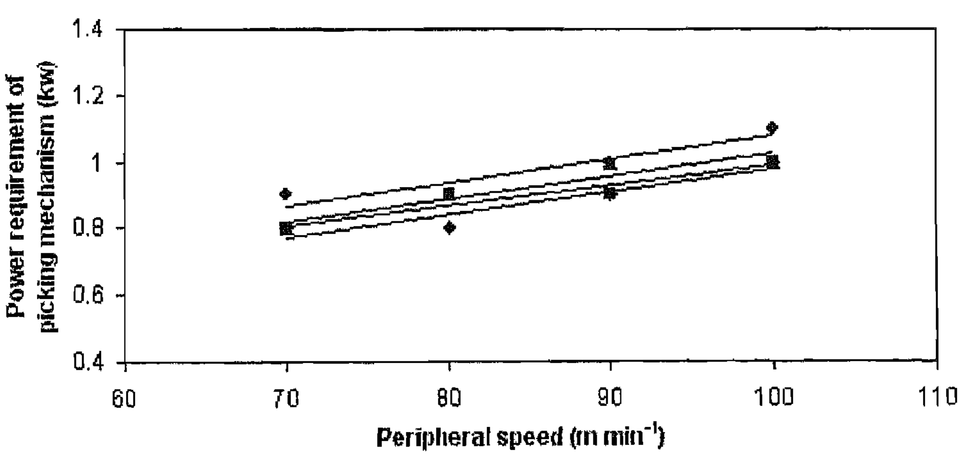
The mean value table for power requirement of corn picking mechanism at all four levels of peripheral speed is presented in Table 4.19. It was seen from Table 4.19 that the effect of peripheral speed was significant on power requirement of picking mechanism. Minimum and maximum of power 0.84 and 1.04 kW was obtained at 70 and 100 m/min peripheral speed of snapping rolls respectively. This might be due to fact that at higher peripheral speed, per cent cob damage was more. At higher peripheral speed more per cent cob damage was observed due to compression of cob in snapping rolls or bounce off the stalks before stalks enter on the snapping rolls.



(a) AI 25°



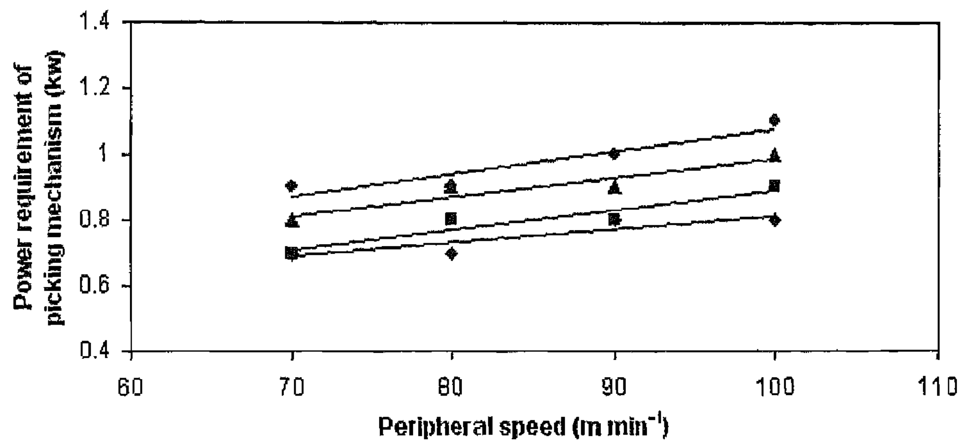
(b) AI 30°



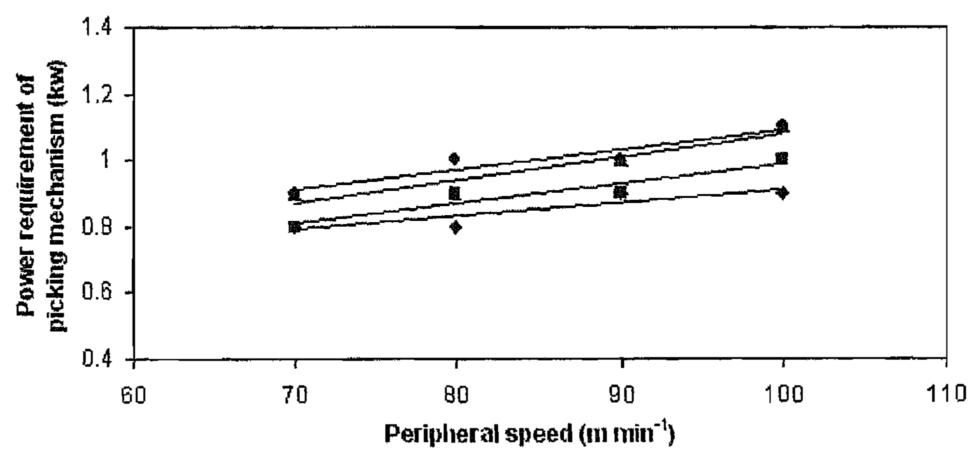
(c) AI 35°

Fig 4.36 **Effect of peripheral speed on power requirement of picking mechanism at different forward travel speed and angle of inclination of snapping rolls at 25.9 per cent kernel moisture content**

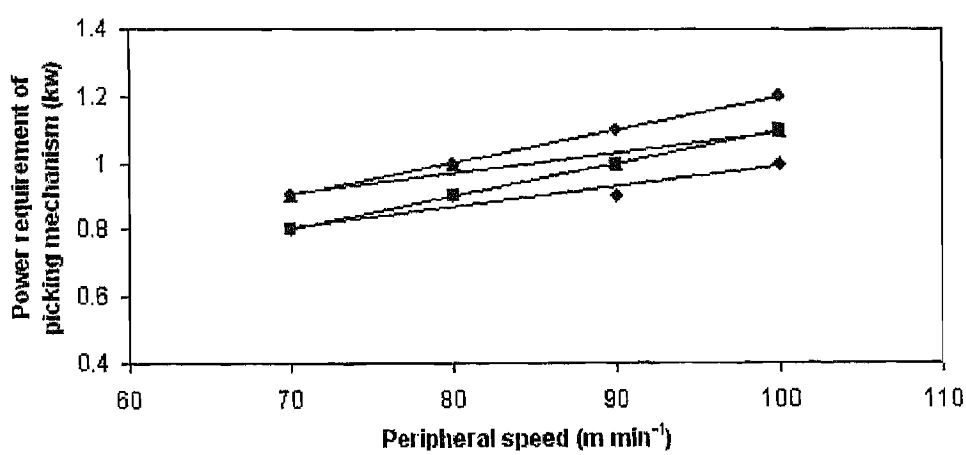
♦,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph



(a) AI 25°



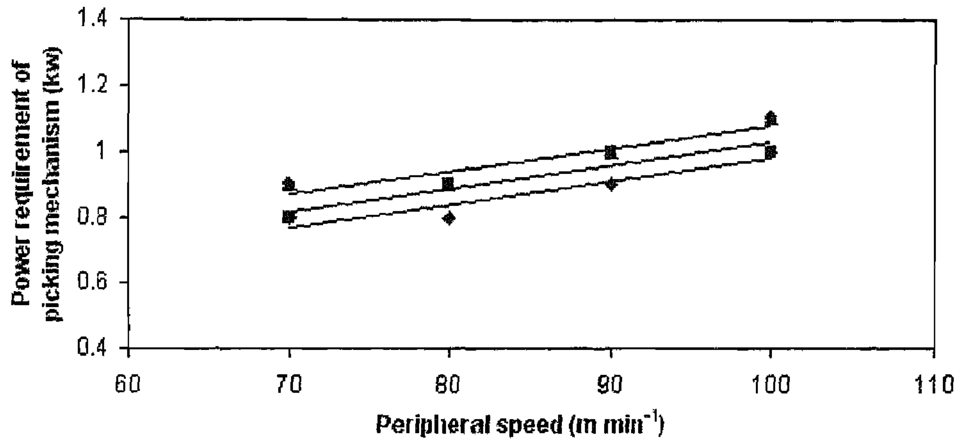
(b) AI 30°



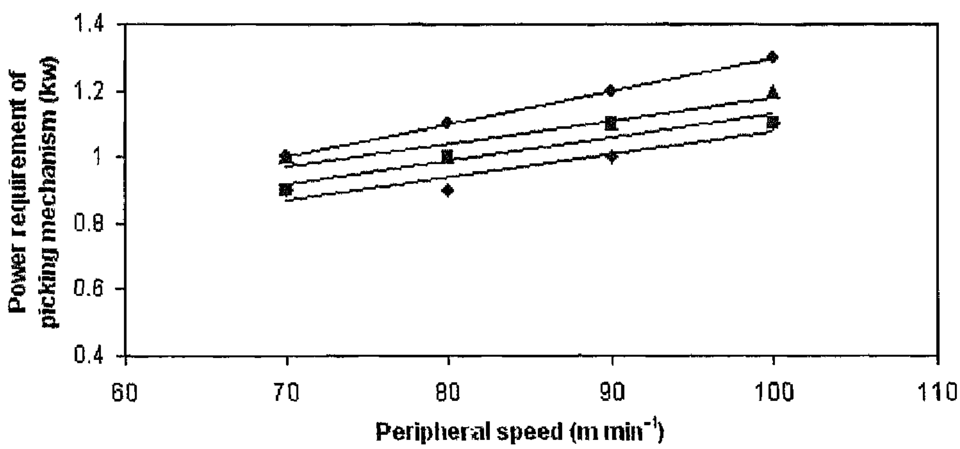
(c) AI 35°

Fig 4.37 Effect of peripheral speed on power requirement of picking mechanism at different forward travel speed and angle of inclination of snapping rolls at 32.7 per cent kernel moisture content

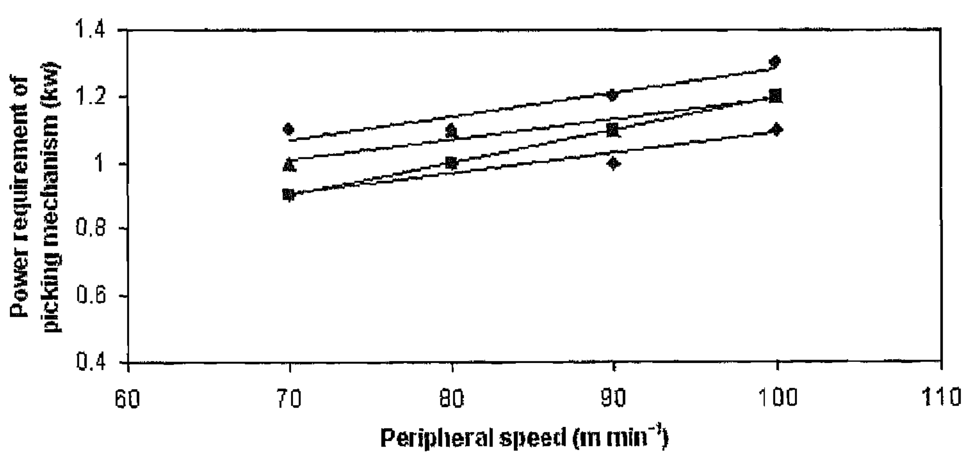
◆,FTS 2 kmph ■, FTS 2.5 kmph ▲, FTS 3.0 kmph •, FTS 3.5 kmph



(a) AI 25°



(b) AI 30°



(c) AI 35°

Fig 4.38 Effect of peripheral speed on power requirement of picking mechanism at different forward travel speed and angle of inclination of snapping rolls at 38.5 per cent kernel moisture content

♦, FTS 2 kmph   ■, FTS 2.5 kmph   ▲, FTS 3.0 kmph   •, FTS 3.5 kmph

Table 4.19 Mean values of power requirement of picking mechanism at different peripheral speed of snapping rolls

Peripheral speed, m/min	70	80	90	100
Power requirement of picking mechanism, kw	0.84	0.90	0.96	1.04

SEm± 0.005 LSD $_{0.05}$ 0.015

4.4.3 Effect of angle of inclination on power requirement of picking mechanism

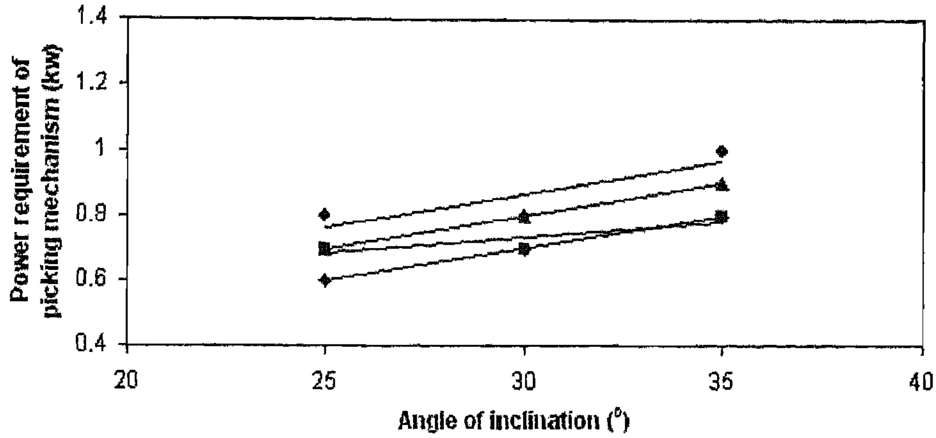
The results obtained during study are presented in Fig. 4.39 through Fig. 4.42. Fig. 4.39 shows that at 25.9 per cent kernel moisture content and 2.0 kmph forward travel speed increase in angle of inclination, power requirement of picking mechanism increased significantly at all levels of angle of inclination and kernel moisture content. Similar trends were also observed for forward travel speed of 2.5, 3.0 and 3.5 kmph (Fig. 4.40, Fig. 4.41 and Fig. 4.42).

The mean table for power requirement of picking mechanism at different angle of inclination is presented in Table 4.20. The Table 4.20 revealed that effect of angle of inclination of snapping rolls was significant on power requirement of con picking mechanism. Results also indicated that minimum power was required when snapping rolls were operated at 25^0 angle of inclination. Increase in the angle of inclination from 25^0 to 30^0 and 30^0 to 35^0, increased power requirement of picking mechanism from 0.86 kW to 0.94 kW and 0.94 kW to 0.99 kW respectively. Maximum power requirement was 0.99 kW for angle of inclination of 35^0.

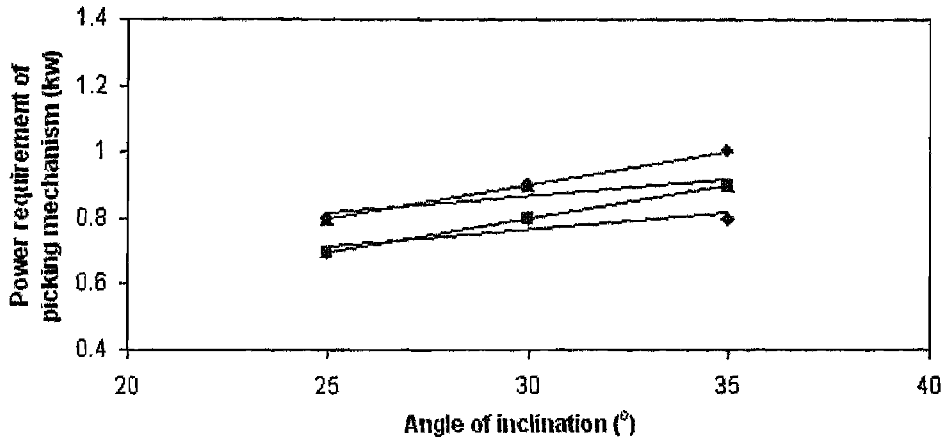
Table 4.20 Mean values of power requirement of picking mechanism at different angle of inclination of snapping rolls

Angle of inclination, ^{0}	25	30	35
Power requirement of picking mechanism, kw	0.86	0.94	0.99

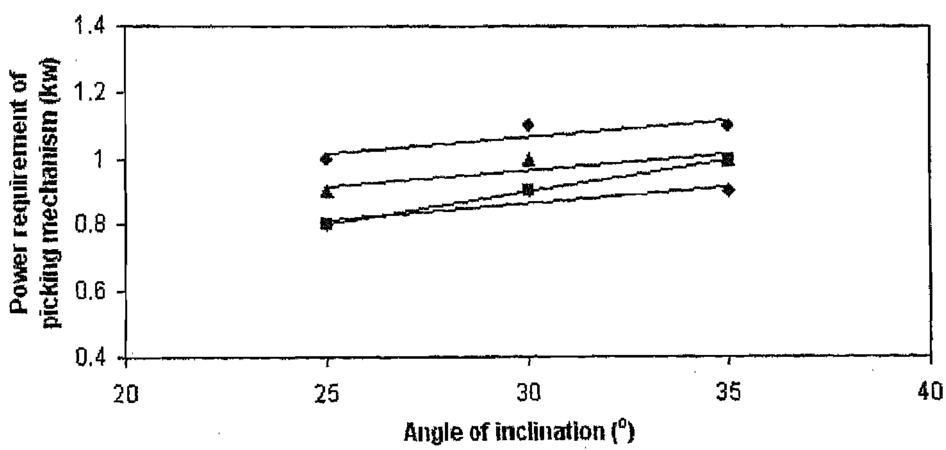
SEm± 0.005 LSD $_{0.05}$ 0.013



(a) MC 25.9 %



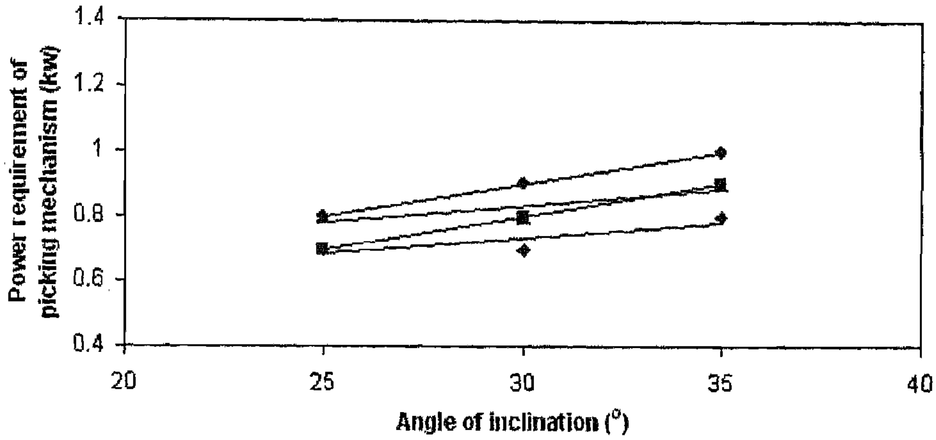
(b) MC 32.7 %



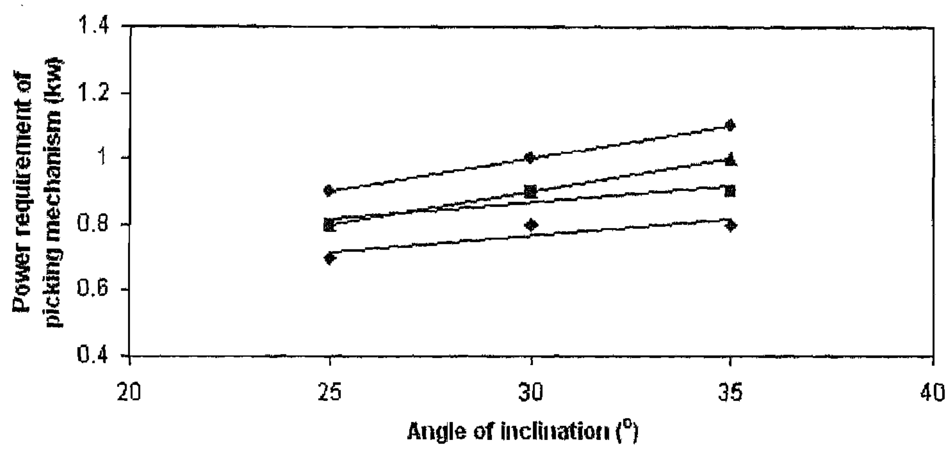
(c) MC 38.5 %

Fig 4.39 Effect of angle of inclination on power requirement of picking mechanism at different peripheral speed and kernel moisture content at 2.0 kmph forward speed

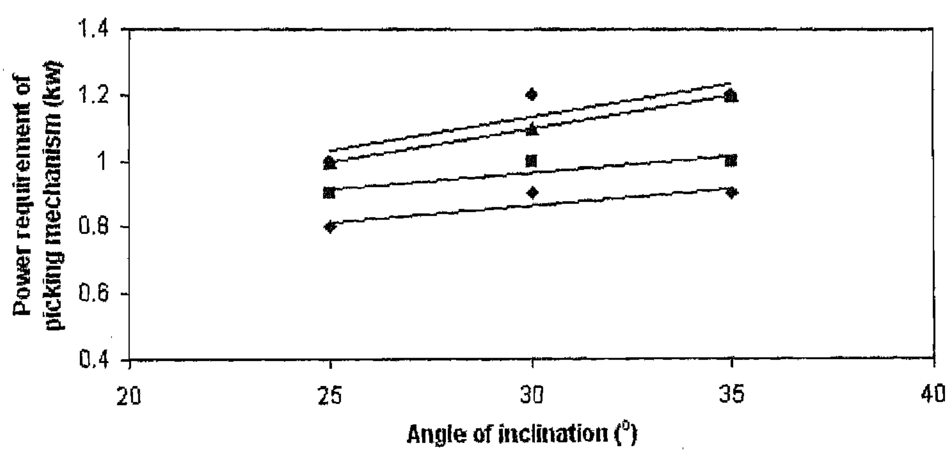
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) MC 25.9 %



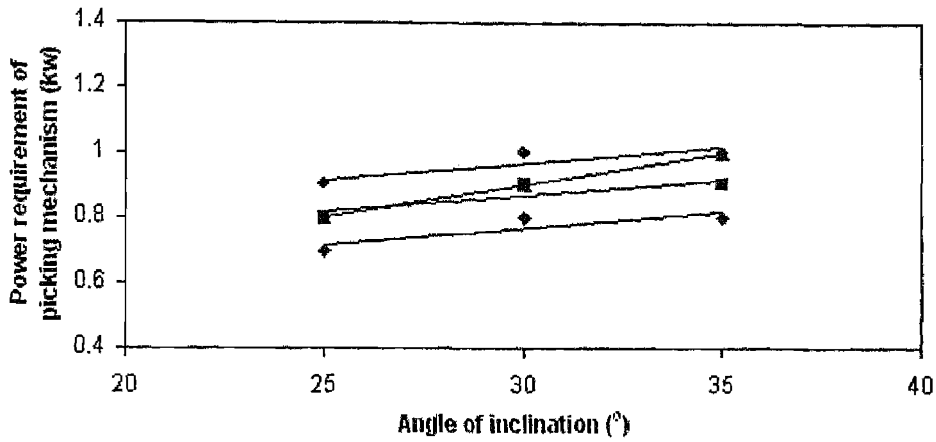
(b) MC 32.7 %



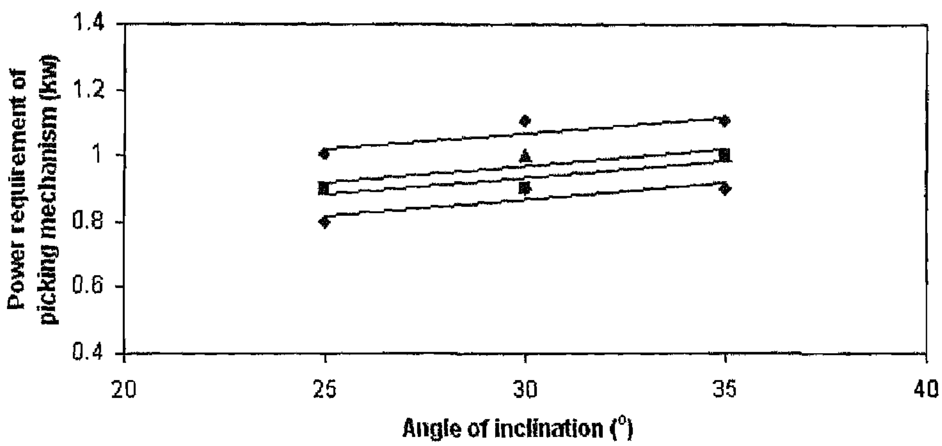
(c) MC 38.5 %

Fig 4.40 Effect of angle of inclination on power requirement of picking mechanism at different peripheral speed and kernel moisture content at 2.5 kmph forward speed

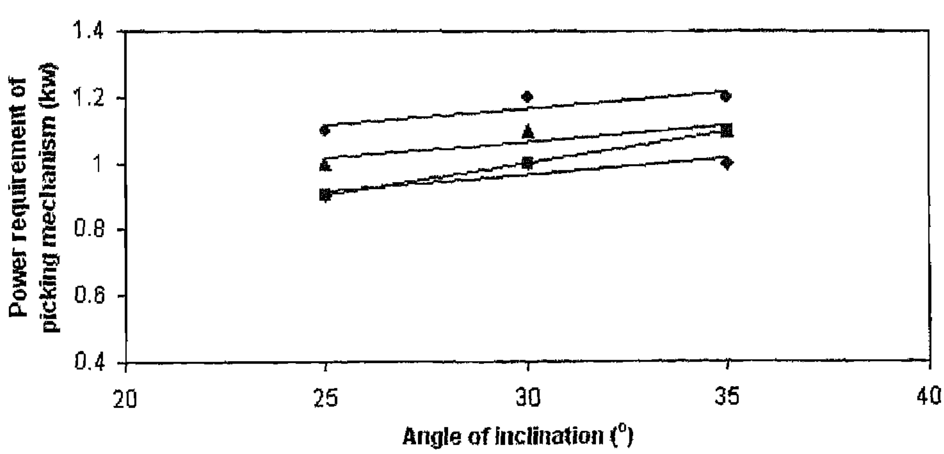
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) MC 25.9 %



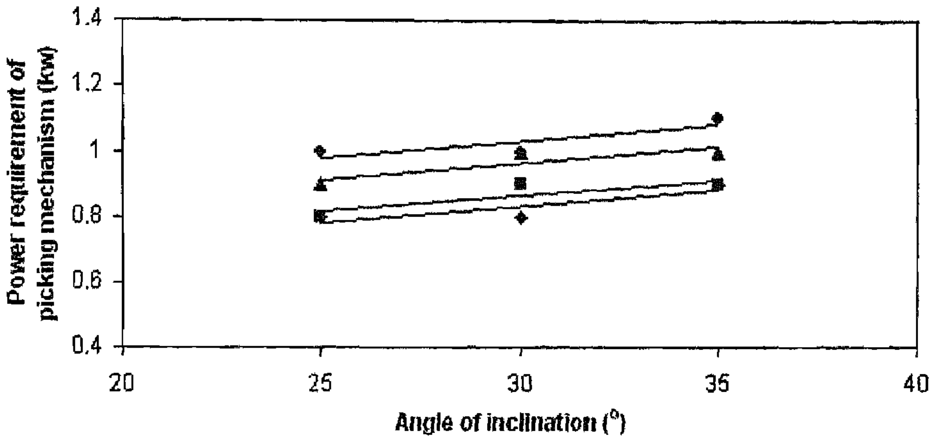
(b) MC 32.7 %



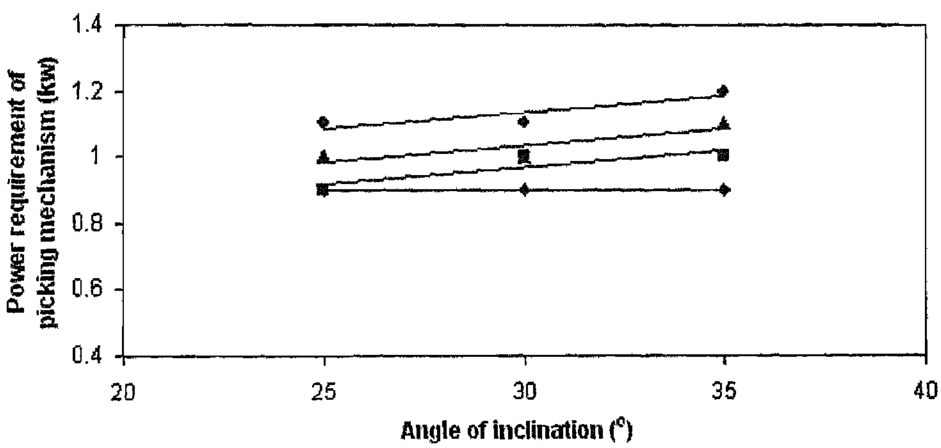
(c) MC 38.5 %

Fig 4.41 Effect of angle of inclination on power requirement of picking mechanism at different peripheral speed and kernel moisture content at 3.0 kmph forward speed

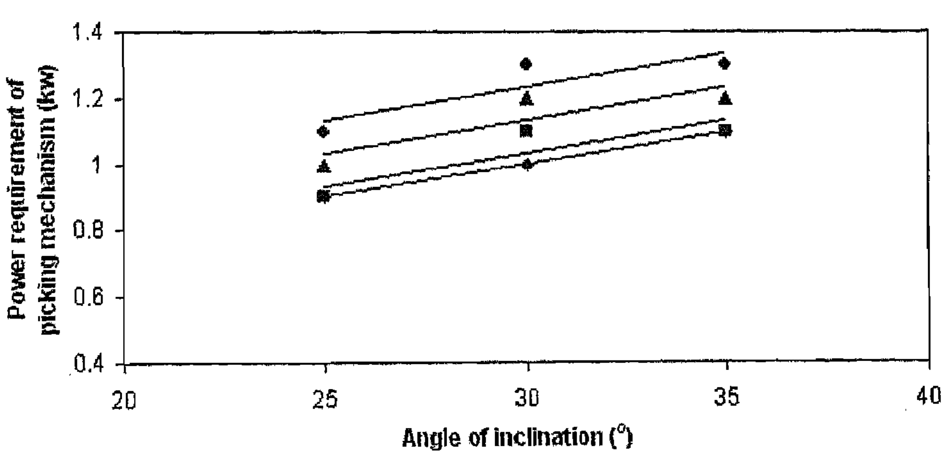
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) MC 25.9 %



(b) MC 32.7 %



(c) MC 38.5 %

Fig 4.42 **Effect of angle of inclination on power requirement of picking mechanism at different peripheral speed and kernel moisture content at 3.5 kmph forward speed**

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

4.4.4 Effect of kernel moisture content on power requirement of picking mechanism

The results obtained during study depicted in Fig. 4.43 through Fig 4.46. The ANOVA Table 4.17 revealed that effect of kernel moisture content was significant on power requirement of picking mechanism.

The mean value for power requirement of picking mechanism at different kernel moisture content is presented in Table 4.21. The Table 4.21 revealed that kernel moisture content had significant effect on power requirement of picking mechanism. This might be attributed to the fact that at higher moisture content, stalk stiffness increases and at higher stiffness more power is required to detach the cob from stalk. Richey *et. al.,* (1961) also suggested that early picking of green corn requires much more power than picking after stalks have been dried, when ears snap more easily.

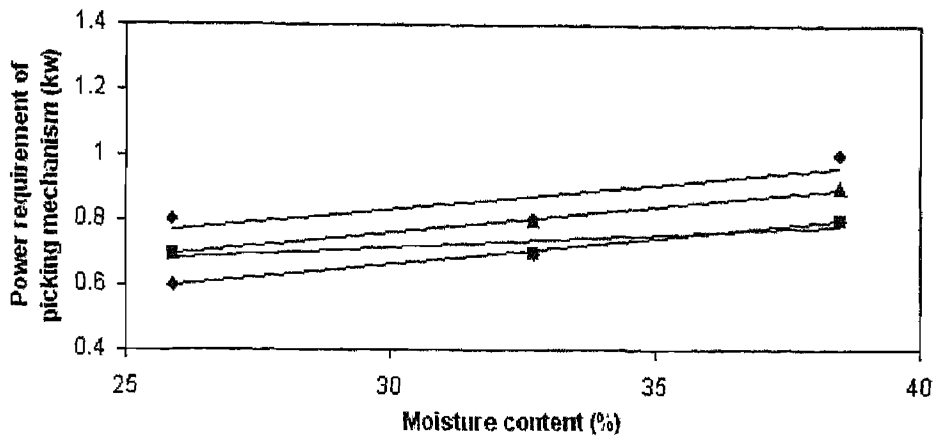
Table 4.21 Mean values of power requirement of picking mechanism at different kernel moisture content

Moisture content, %	25.90	32.70	38.50
power requirement of picking mechanism, kw	0.85	0.92	1.03

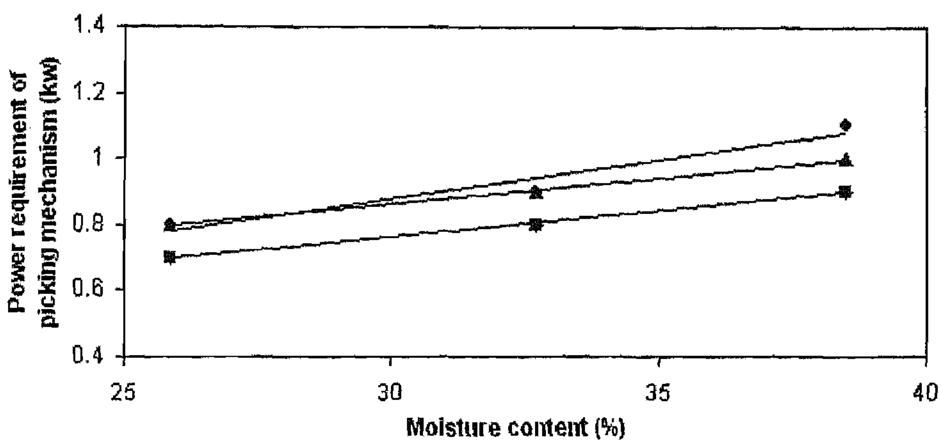
SEm± 0.005 LSD $_{0.05}$ 0.013

4.4.5 Combined effect of forward travel speed and peripheral speed of snapping rolls on mean power requirement of picking mechanism

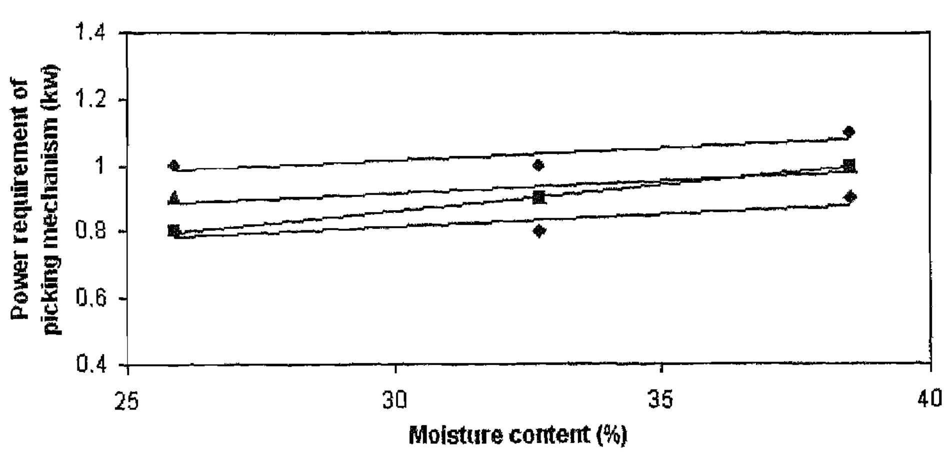
Two variable interaction table showing the effect of forward travel speed and peripheral speed of snapping rolls on power requirement of corn picking mechanism is presented in Table 4.22 and depicted in Fig. 4.47. The Table 4.22 revealed that two variable interactions between forward travel speed and peripheral speed of snapping rolls had significant effect on power requirement of picking mechanism. At 2.0 kmph forward travel speed, when peripheral speed increased from 70 to 80, 80 to 90 and 90 to 100 m/min power requirement increased by 0.03, 0.08 and 0.07 kw respectively. Similar trends have also been observed for 2.5, 3.0 and 3.5 kmph forward travel speed.



(a) AI 25°



(b) AI 30°



(c) AI 35°

Fig 4.43 Effect of moisture content on power requirement of picking mechanism at different peripheral speed and angle of inclination of snapping rolls at 2.0 kmph forward speed

♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

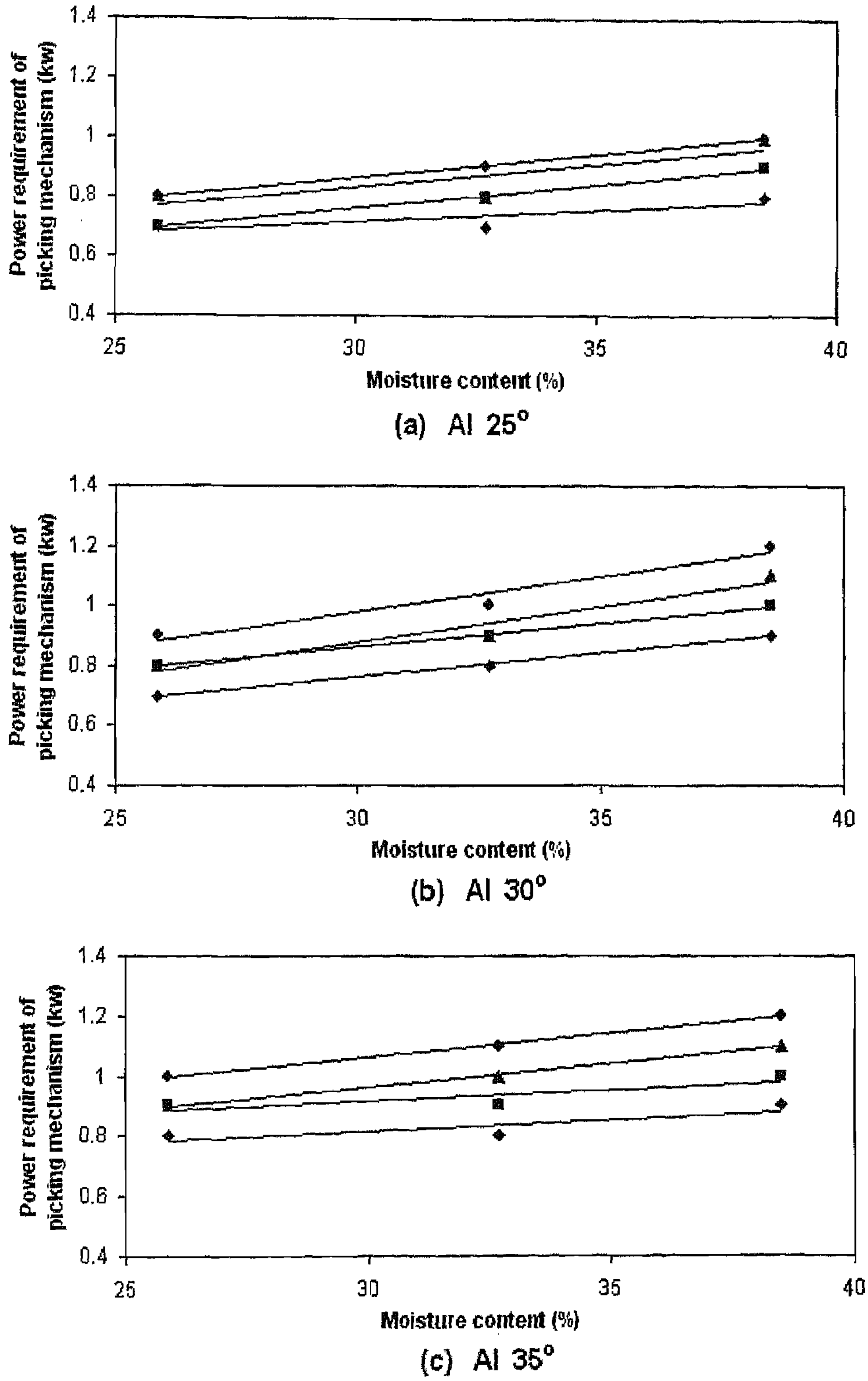
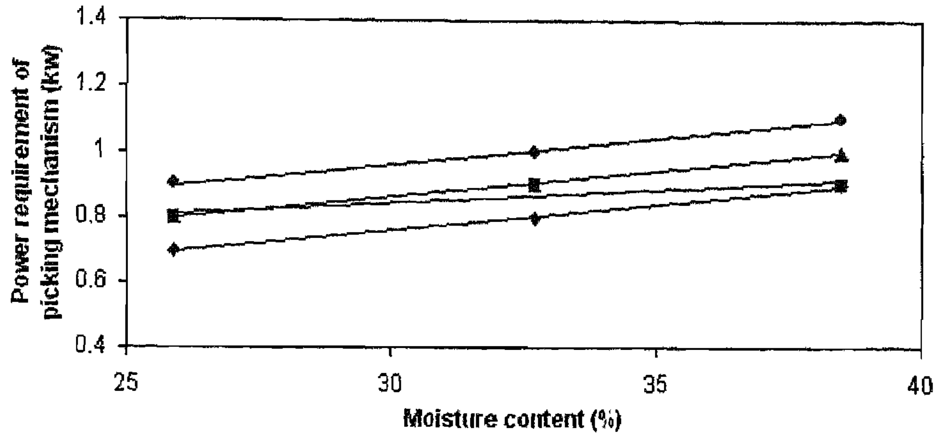
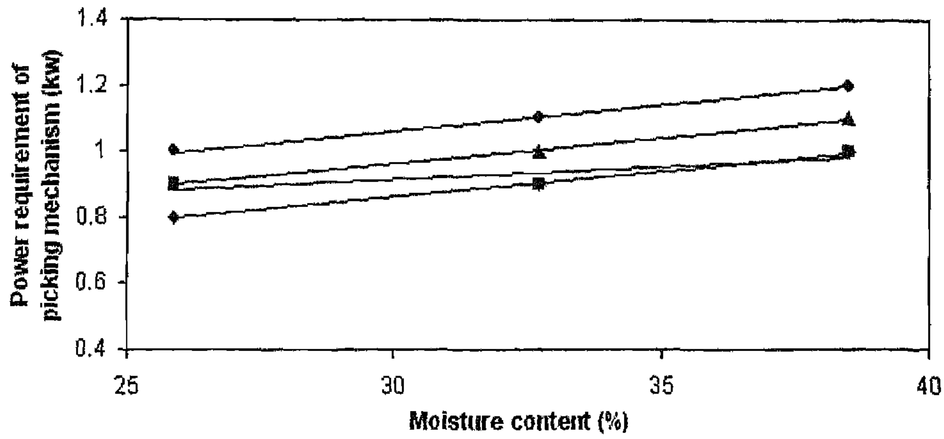


Fig 4.44 **Effect of moisture content on power requirement of picking mechanism at different peripheral speed and angle of inclination of snapping rolls at 2.5 kmph forward speed**

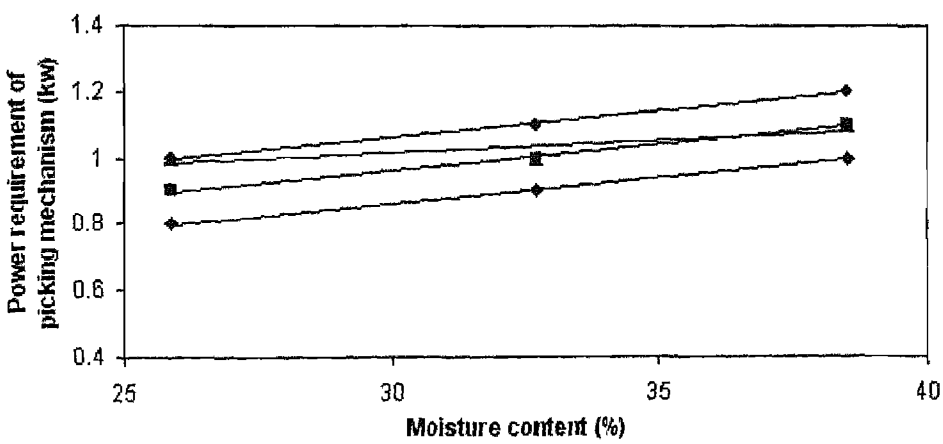
♦, PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



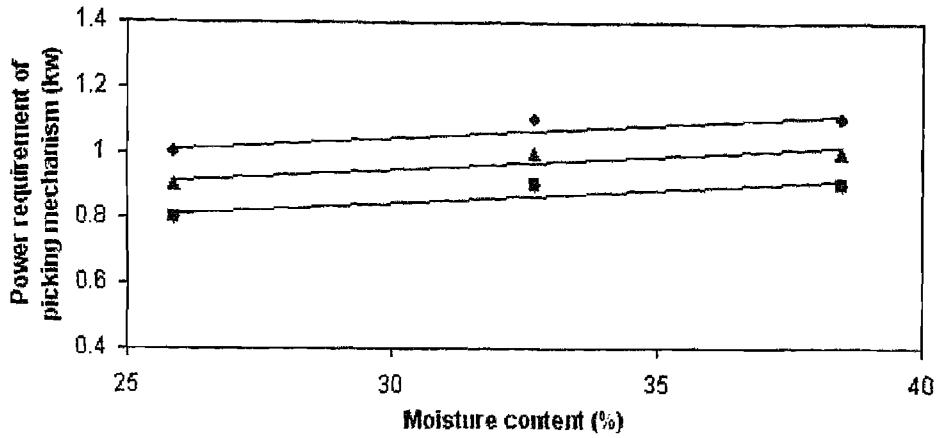
(b) AI 30°



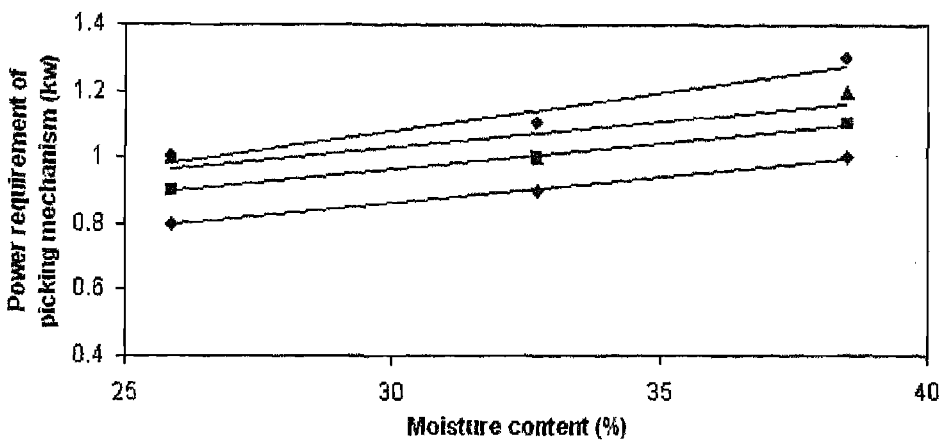
(c) AI 35°

Fig 4.45 **Effect of moisture content on power requirement of picking mechanism at different peripheral speed and angle of inclination of snapping rolls at 3.0 kmph forward speed**

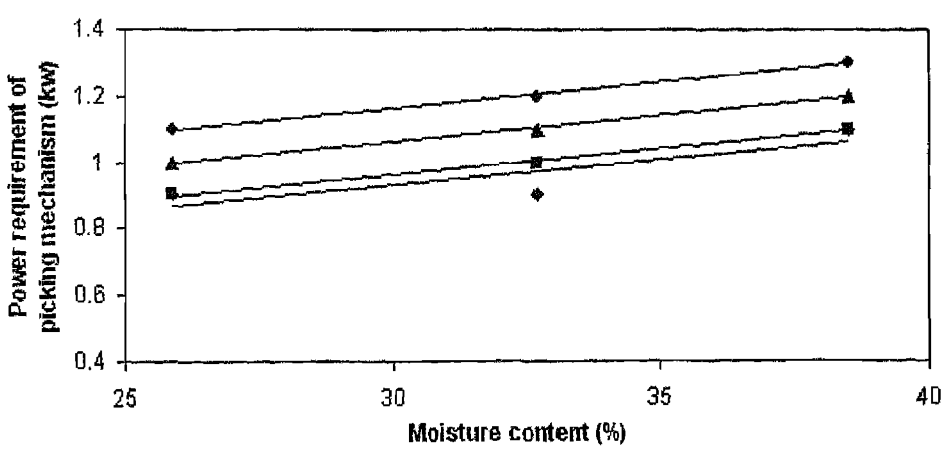
♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}



(a) AI 25°



(b) AI 30°



(c) AI 35°

Fig 4.46 Effect of moisture content on power requirement of picking mechanism at different peripheral speed and angle of inclination of snapping rolls at 3.5 kmph forward speed

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

Table 4.22 Two variable interactions showing effect of forward travel speed and peripheral speed of snapping rolls on mean power requirement of picking mechanism

Forward travel speed, kmph	Power requirement of picking mechanism, Kw/ Peripheral speed, m/min			
	70	**80**	**90**	**100**
2.0	0.78	0.81	0.89	0.96
2.5	0.78	0.89	0.93	1.0
3.0	0.85	0.93	0.97	1.07
3.5	0.93	0.96	1.08	1.15

SEm± 0.010 LSD $_{0.05}$ 0.029

Further at 70 m/min peripheral speed, when forward travel speed increased from 3.0 to 3.5 kmph power requirement of picking mechanism increased whereas no change was observed when forward travel speed increased from 2.0 to 2.5 kmph. However to 80, 90 and 100 m/min peripheral speed of snapping rolls the power requirement increased with increase forward travel speed. Maximum power 1.15 kw was obtained when corn picking mechanism was operated at 3.5 kmph forward travel speed of 100 m/min whereas, minimum power 0.78 kw was obtained at 70 m/min peripheral speed of snapping rolls for 2.0 and 2.5 kmph forward travel speed.

4.4.6 Combined effect of angle of inclination and kernel moisture content on power requirement of picking mechanism

Two variable interaction showing effect of angle of inclination of snapping rolls on kernel moisture content and mean power requirement of corn picking mechanism is presented in Table 4.23 and depicted in Fig.4.48. Data revealed that interaction effect between angle of inclination of snapping rolls and moisture content of kernel had significant effect on power requirement of picking mechanism (Table 4.23). The power requirement of picking mechanism increased with increase in kernel moisture content at all level of angle of inclination. Further at 25.9 per cent kernel moisture content, increase in angle of inclination from 25^0 to 30^0 and 30^0 to 35^0, power requirement also increased significantly. Similar trends were also observed for 32.7 and 38.5 per cent kernel

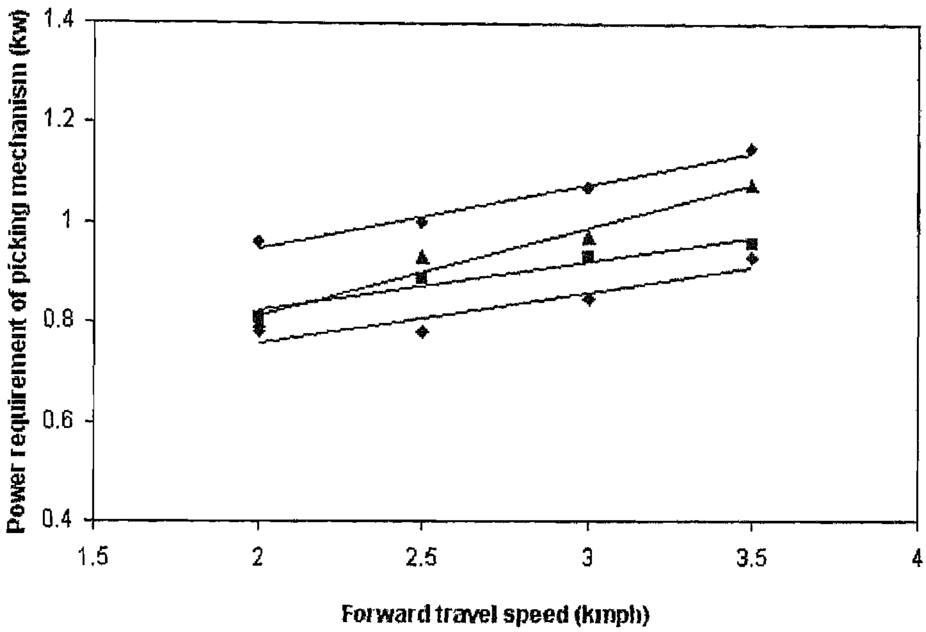


Fig 4.47 Interaction effect of forward travel and peripheral speed on power requirement of picking mechanism

♦,PS 70 m min^{-1} ■, PS 80 m min^{-1} ▲, PS 90 m min^{-1} •, PS 100 m min^{-1}

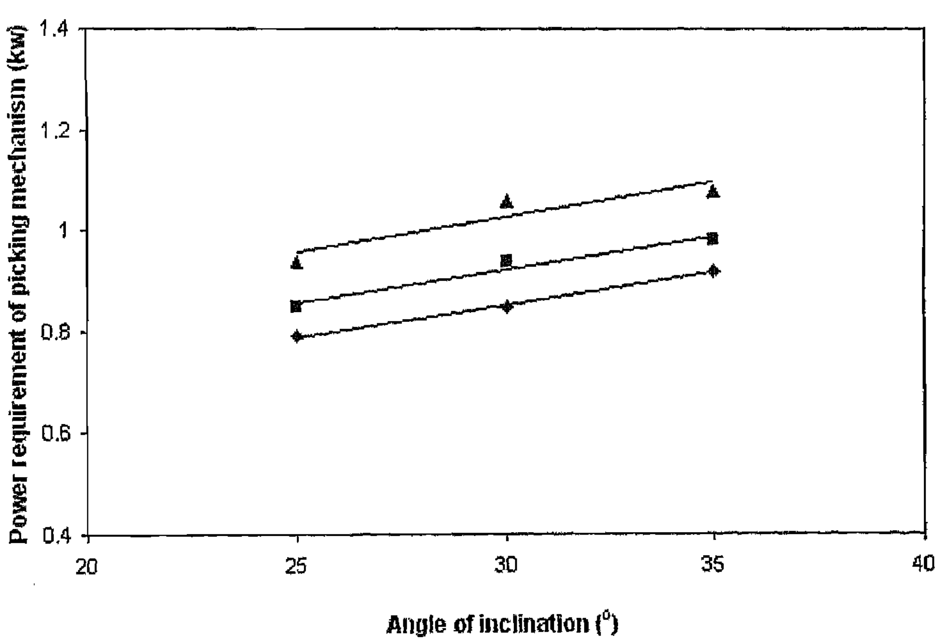


Fig 4.48 Interaction effect of angle of inclination and kernel moisture content on power requirement of picking mechanism

♦,MC 25.9 % ■, MC 32.7 % ▲, MC 38.5 %

moisture content. Maximum power requirement of 1.08 kw was observed when corn picking mechanism was operated at 35^0 angle of inclination and 38.5 per cent kernel moisture content. Minimum power requirement of 0.79 kw was recorded when corn picking mechanism was operated at 25^0 angle of inclination and at 25.9 per cent kernel moisture content.

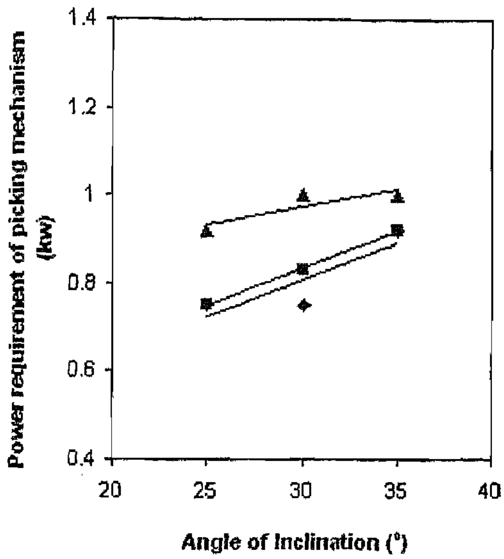
Table 4.23 Two variable interactions showing effect of angle of inclination of snapping rolls and kernel moisture content on mean power requirement of picking mechanism

Angle of inclination(°)	Power requirement of picking mechanism, Kw /Moisture content (%)		
	25.90	32.70	38.50
25	0.79	0.85	0.94
30	0.85	0.94	1.06
35	0.92	0.98	1.08

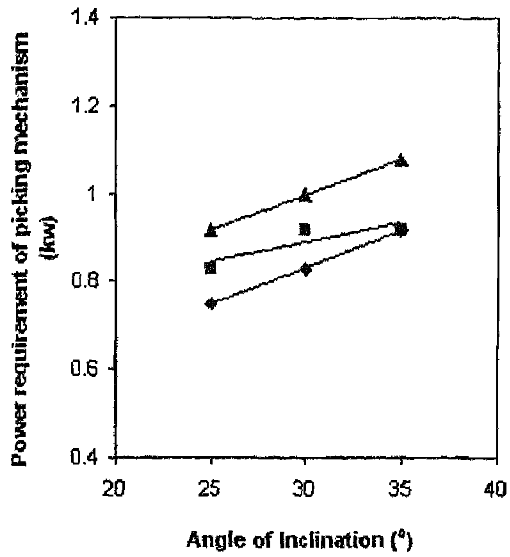
SEm± 0.008 $LSD_{0.05}$ 0.022

4.4.7 Combined effect of forward travel speed, angle of inclination of snapping rolls and kernel moisture content on power requirement of picking mechanism

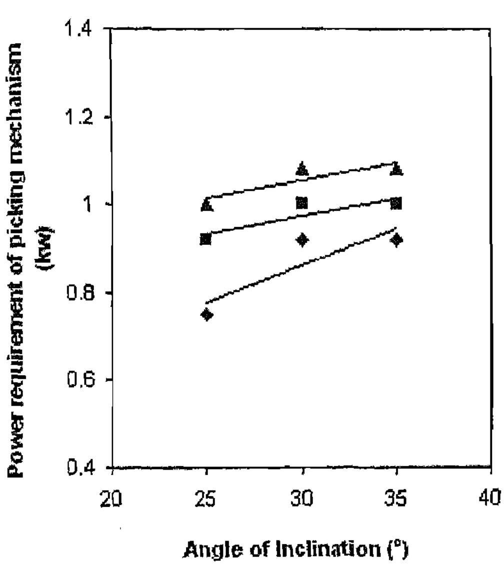
Interaction effect among forward travel speed, angle of inclination and moisture content is presented in Table 4.24 and depicted in Fig. 4.49. Data reveals that the forward travel speed, angle of inclination and moisture content had significant effect on power requirement of picking mechanism (Table 4.24). At 25^0 angle of inclination of snapping rolls for 2.0 kmph forward travel speed, power requirement was 0.75 kw at 25.9 per cent kernel moisture content. At 30^0 and 35^0 angle of inclination for 2.0 kmph forward travel speed, power requirement of corn picking mechanism increased with increase in moisture content (Fig. 4.49.a). Fig 4.49(b) represents the interaction effect when corn picking mechanism was operated at 2.5 kmph at all three levels of angle of inclination. The power requirement increased by 0.08 kW and 0.09 kW when kernel moisture content increased from 25.9 to 32.7 and 32.7 to 38.5 respectively at 25^0 angle of inclination. However increase trends were also observed form 30^0 and 35^0 angle of inclination of snapping rolls. Maximum power of 1.17 kW was observed for 3.5 kmph when corn picking mechanism was operated at 35^0 angle of inclination and 38.5 per cent kernel moisture content.



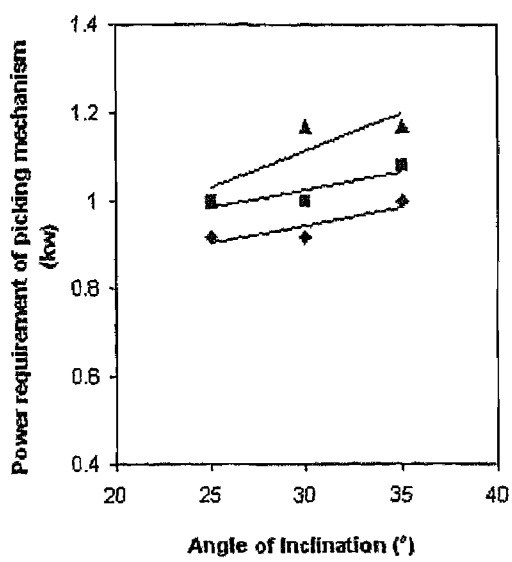
(a) FS 2.0 kmph



(b) FS 2.5 kmph



(c) FS 3.0 kmph



(d) FS 3.5 kmph

Fig 4.49 Interaction effect of forward travel speed, angle of inclination and kernel moisture content on power requirement of picking mechanism

♦, MC 25.9 % ■, MC 32.7 % ▲, MC 38.5 %

Table 4.24 Three variable interactions showing effect of forward travel speed, angle of inclination of snapping rolls and kernel moisture content on power requirement of picking mechanism

Forward travel speed (kmph)	Angle of inclination(°)	Power requirement of picking mechanism, Kw Moisture content (%)		
		25.90	**32.70**	**38.50**
2.0	25	0.75	0.75	0.92
	30	075	0.83	1.0
	35	0.92	0.92	1.0
2.50	25	0.75	0.83	0.92
	30	0.83	0.92	1.0
	35	0.92	0.92	1.08
3.00	25	0.75	0.92	1.0
	30	0.92	1.0	1.08
	35	0.92	1.0	1.08
3.50	25	0.92	1.0	1.0
	30	0.92	1.0	1.17
	35	1.0	1.08	1.17

SEm$\pm$ 0.016 $LSD_{0.05}$ 0.044

4.5 Analytical Modeling of Results

The influence of each individual parameter was studied (Section 4.2 through Section 4.4). Further the analysis was carried out to develop a relation among forward travel speed (FS), peripheral speed (PS), angle of inclination of snapping rolls (AI) and moisture content of kernel (MC). A step wise linear regression was performed to find out significant and non significant terms and only significant terms were included in the regression model.

4.5.1 Regression analysis for corn picking efficiency

The relationship for picking efficiency was found to be of following form

$$CPE = -54.60 - 3.98 \times 10^{-04} (MC)^3 - 1.82 \times 10^{-04}(PS)^3 + 2.06 \times 10^{-02}(PS)^2 - 0.86(FS)^3 + 0.22(FS)(PS) - 1.15 \times 10^{-03} (AI)^3 + 3.30 (AI) + 0.81 (MC) \quad \text{--(4.1)}$$

Where,

CPE = Corn picking efficiency

FS = Forward travel speed

PS = Peripheral speed

AI = Angle of inclination

MC = Moisture content

Predicted values of corn picking efficiency were calculated using Equation 4.1. A curve between observed and predicted values of corn picking efficiency is presented in Fig. 4.50. The summary of the developed model is given in Tables 4.25.

Table 4.25 Model summary for corn picking efficiency

R	R Square	Std. Error of Estimate	Computed F
0.882	0.778	2.5987	59.200**

** Significant at 99 per cent confidence level

Table 4.25 and Fig 4.5 showed that Equation 4.1 predicted the corn picking efficiency well within acceptable limits and is statistically significant at 99 per cent confidence level.

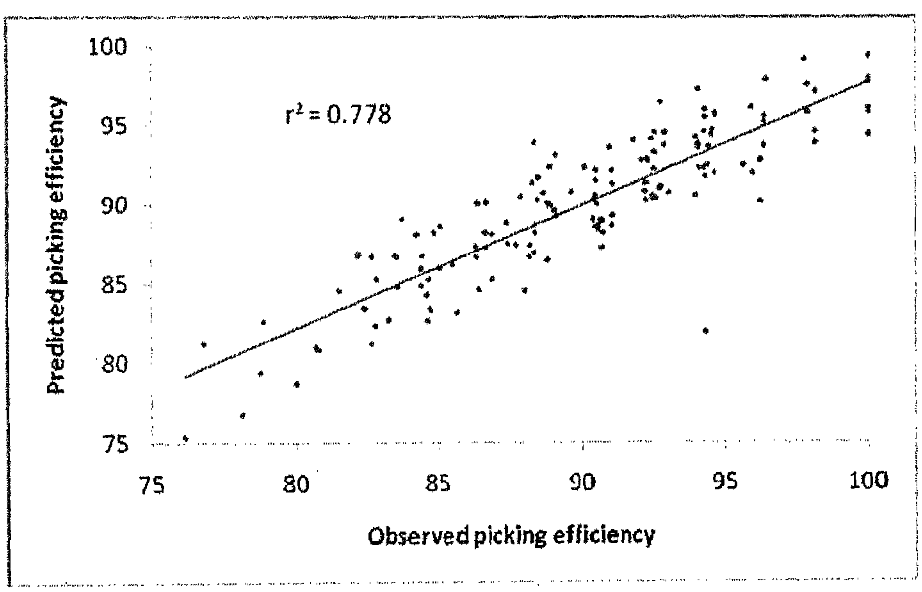


Fig. 4.50 Relationship between observed and predicted values of corn picking efficiency

4.5.2 Regression analysis for per cent cob damage

The relationship obtain for per cent cob damage is given as follows:

$$\text{Cob damage (\%)} = -14.93 + 2.21\times10^{-03}\,(MC)\,(PS) - 7.69\times10^{-04}\,(MC)^3 + 3.96\times10^{-02}\,(MC)^2 + 9.05\times10^{-04}\,(AI)(FS)(PS) \quad \text{----(4.2)}$$

Where,

FS = Forward travel speed

PS = Peripheral speed

AI = Angle of inclination

MC = Moisture content

Predicted values of per cent cob damage were calculated using Equation 4.2. A curve between observed and predicted values of per cent cob damage is depicted in Fig. 4.51. The summary of the developed model is given in Tables 4.26 respectively.

Table 4.26 Model summary for per cent cob damage

R	R Square	Std. Error of Estimate	Computed F
0.968	0.936	0.7928	509.409**

** Significant at 99 per cent confidence level

The Table 4.26 and Fig.4.51 showed that Equation 4.3 predicts the per cent cob damage of picking mechanism well within acceptable limits and is statistically significant at 99 per cent confidence level.

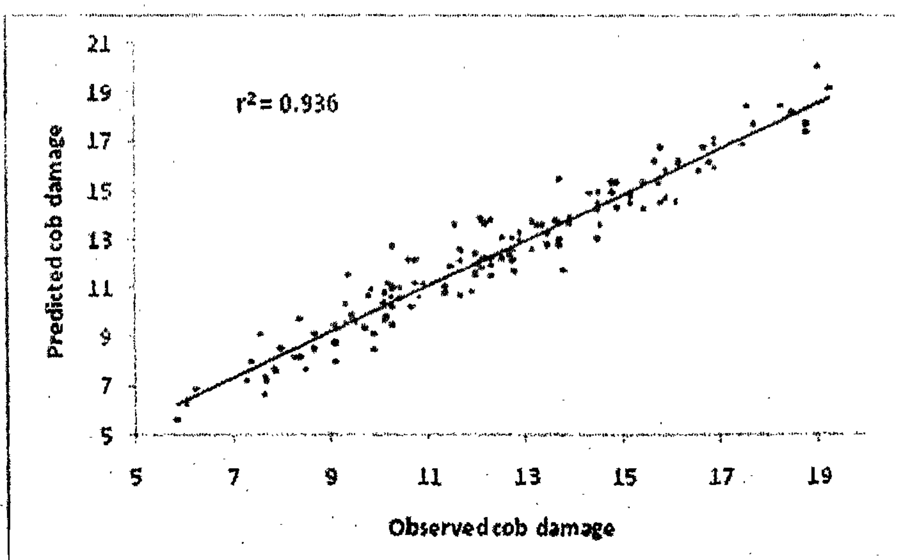


Fig.4.51 Relationship between observed and predicted values of per cent cob damage

4.5.3 Regression analysis for power requirement of picking mechanism

The relationship obtain for power requirement of picking mechanism is as follows:

$$PR = -0.21 + 3.45\times10^{-06}(MC)(AI)(PS) + 1.24\times10^{-03}(FS)(PS) + 6.50\times10^{-06}(MC)^3 + 5.15\times10^{-02}(AI) - 7.91\times10^{-04}(AI)^2 - 1.49\times10^{-02}(MC) \quad \text{----(4.3)}$$

Where,

PR = Power requirement of picking mechanism, kw
FS = Forward travel speed
PS = Peripheral speed
AI = Angle of inclination
MC = Moisture content

Predicted values of power requirement of snapping rolls were calculated using Equation 4.3. A curve between observed and predicted values of power requirement of picking mechanism is depicted in Fig. 4.52. The summary of the developed model is given in Tables 4.27.

Table 4.27 Model summary for power requirement of picking mechanism

R	R Square	Std. Error of Estimate	Computed F
0.966	0.932	3.716E-02	314.678**

** Significant at 99 per cent confidence level

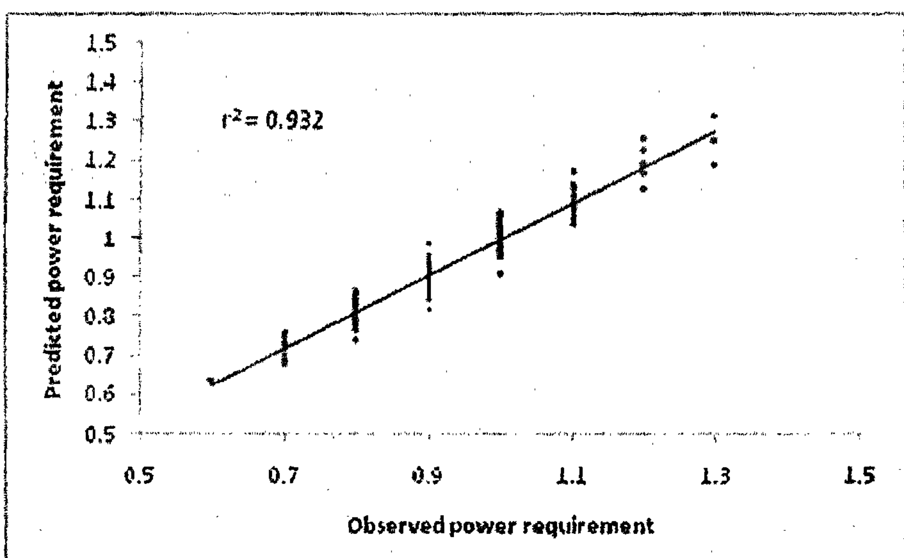


Fig.4.52 Relationship between observed and predicted values of power requirement of picking mechanism

The Table 4.27 and Fig.4.52 showed that Equation 4.3 predicts the power requirement of picking mechanism well within acceptable limits and is statistically significant at 99 per cent confidence level.

CHAPTER -V

SUMMARY AND CONCLUSIONS

Maize (*Zea mays*.L.) is the second most important cereal crop of the world accounting 18 per cent of world's cereal acreage and 25 per cent of production. Maize production in India has increased 4.5 folds since fifties i.e. from 3.7 million tonnes to 16.78 million tonnes in recent years. Maize is the major staple food crop of south Rajasthan.

Maize cultivation in southern districts of the Rajasthan totally depends on manual labour due to small and fragmented land holding size, undulating topography, lack of knowledge, poor economic condition, etc. Mechanization in maize cultivation is limited to only field preparation, sowing, intercultural operation and threshing. There is no machine is available for maize harvesting.

The practice of maize harvesting is totally manual. There are two popular methods of harvesting of the grain from maize crop viz.; removal of ears when the grain have dried and do not have more than 20 per cent moister in them. At this stage almost all the plants remain very green and after removal of the ears they may be used for fodder. In second method of harvesting when the crop gets matured (leaves dried and kernel moisture content is about 25 to 40 per cent plants are cut by sickle and laid on the field. During cutting of the plants, the man walks along a row and cuts single plant at the height of 15-20 cm above the ground. This is very cumbersome method. Harvested plants are bundled and heaped together known as "shucks". Cobs are picked manually from individual plant when moisture content in cobs reaches upto 15-20 per cent. This is also very time and labour consuming method. During storage in shucks the cobs are damaged due to insects-pests attack. Cobs are sun dried and dehusked and threshed by beating with heavy wooden stick or by maize thresher.

In western countries corn harvesters are being used to harvest the maize. In India these machineries are not suitable to small land holding and high cost of maize harvester's as a result they do not have much prospects. Therefore, an alternative strategy of mechanizing small and marginal land holding is by introduction of the small machines that would be more appropriate for the present land holding in India.

Based on the available literature and existing designs of maize harvesters, a corn picking mechanism was designed and developed to pick up the cobs from standing maize plants with minimum damage of cobs. While designing and development of corn picking mechanism, power and cost factor was considered without sacrificing its performance, durability and safety and maximum picking efficiency. The experimental set up consisted of a test track, a mounting trolley, a pipe frame assembly, a corn picking mechanism, power transmission system. The corn picking mechanism consisted of snapping unit, a gathering unit, guiding points, a gear box and discharge pan. The power transmission was controlled by two control panel.

The performance of the corn picking mechanism was assessed and evaluated on the basis of corn picking efficiency, per cent cob damage and power requirement of picking mechanism. On the basis of preliminary testing of mechanism, it was observed that peripheral speed of snapping rolls should be proportional to forward travel speed. If snapping rolls operate too slow, the machine run by putting cobs down before they were pulled through. With increasing the forward travel speed along with low peripheral speed, picker rolls overload and break the stalks causing plugging at the back of the rolls. Therefore, mechanism was evaluated for forward travel speeds (2.0, 2.5, 3.0 and 3.5 kmph) peripheral speeds of snapping rolls (70, 80, 90 and 100 m/min) at angle of inclination of snapping rolls (25, 30, and 35^0) and three different kernel moister content of 25.9, 32.7 and 38.5 per cent were selected for performance evaluation of the developed corn picking mechanism. The experiments were carried out with independent parameters and their combined effects and replicated thrice following statistical design factorial CRD.

Statistical analysis was done to study the effect of individual parameters and their combined effects on corn picking efficiency, per cent cob damage and power requirement of corn picking mechanism. The results of analysis revealed that effect of forward travel speed, peripheral speed, angle of inclination and kernel moisture content on picking efficiency, per cent cob damage and power requirement of picking mechanism were significant at 95 per cent level of confidence. Two variable interactions between forward travel speed and peripheral speed of snapping rolls, and peripheral speed and kernel moisture content were also found significant effect on corn picking efficiency. The results of corn picking mechanism are summarized as under:

Corn Picking Efficiency

The results of effect of forward travel speed, peripheral speed of snapping rolls, angle of inclination of snapping roll and kernel moisture content was significant on Corn picking efficiency. The combined effect of forward travel speed with peripheral speed of snapping roll and peripheral speed of snapping roll with kernel moisture content was also found significant on corn picking efficiency at 95 per cent confidence level. The following results were observed.

1. Maximum corn picking efficiency of 91.97 per cent was observed with forward travel speed of 2.5 kmph followed by forward travel speed of 3.0 kmph (91.50 per cent).
2. Maximum corn picking efficiency (94.65%) was observed at peripheral speed of 90 m/min followed by peripheral speed of 80 m/min (90.51%).
3. Maximum corn picking efficiency 91.79 per cent was observed at 30° angle of inclination.
4. At 25.9 per cent kernel moisture content corn picking efficiency was maximum (92.38 per cent) followed by 32.7 per cent kernel moisture content (90.92 per cent).

Cob Damage

The results of the effect of forward travel speed, peripheral speed of snapping rolls, angle of inclination of snapping roll and kernel moisture content was significant on per cent cob damage. The combined effect of forward travel speed with kernel moisture content, peripheral speed of snapping rolls with kernel moisture content, angle of inclination with kernel moisture content and forward travel speed, angle of inclination of snapping roll with kernel moisture content was also found significant on per cent cob damage at 95 per cent confidence level. The following results were observed.

1. Minimum per cent cob damage 10.72 per cent was observed at 2.0 kmph forward travel speed.
2. Minimum per cent cob damage 10.15 per cent was observed at 70 m/mim peripheral speed.
3. Minimum per cent cob damage 11.37 per cent was observed at 25° angle of inclination.

4. In respect of kernel moisture content, 25.9 per cent moisture was found optimum for minimum per cent cob damage.

5. Combined effect of parameters also showed significant variation in per cent cob damage. Further, treatment combination forward travel speed 2.0 kmph, 25° angle of inclination and 25.9 per cent moisture content in grains had significant effect in minimizing per cent cob damage.

Power Requirement of Picking Mechanism

The results of effect of forward travel speed, peripheral speed of snapping rolls, angle of inclination of snapping roll and kernel moisture content was significant on power requirement of picking mechanism. The combined effect of forward travel speed with peripheral speed of snapping rolls, angle of inclination with kernel moisture content and forward travel speed, angle of inclination of snapping roll with kernel moisture content was also found significant on power requirement of picking mechanism at 95 per cent confidence level. The following results were observed.

1. Minimum corn picking mechanism power of 0.86 kW was observed at 2.0 kmph forward travel speed.

2. Minimum corn picking mechanism power was observed at 70 m/mim peripheral speed.

3. Minimum corn picking mechanism power of 0.85 kW was observed at 25.9 kernel moisture content.

4. Combined effect of parameters also affected power requirement of the mechanism. Further at forward travel speed of 2.0, 2.5 and 3.0 kmph and 25.9 per cent moisture, at 25^0 and 30° angle of inclination alongwith 32.70 per cent kernel moisture content, power requirement was only 0.7 kw.

Conclusions

1. Forward travel speed, peripheral speed of snapping rolls, angle of inclination of snapping rolls and kernel moisture content significantly influences the corn picking efficiency, per cent cob damage and power requirement of picking mechanism.

2. Corn picking efficiency was about 92 per cent at 2.5 kmph forward travel speed, 90 m/min peripheral speed of the snapping rolls, 30° angle of inclination of

snapping rolls 25.9 per cent kernel moisture content. The percent cob damage (9.47) was within acceptable limits.

3. Minimum per cent cob damage of 5.83 was observed at 2.0 kmph forward travel speed, 70 m/min peripher al speed of snapping rolls, 25° angle of inclination of snapping rolls and 25.9 per cent kernel moisture content.

4. Minimum power for operating corn picking mechanism was 0.6 kW at 2.0 kmph forward travel speed, 70 m/min peripheral speed of snapping rolls, 25° angle of inclination of snapping rolls and 25.9 per cent kernel moisture content.

5. The following prediction equations were developed to predict the performance of corn picking mechanism with forward travel speed of 2.0 to 3.5 kmph, peripheral speed of snapping rolls of 70 to 100 m/min, angle of inclination of 25° to 35° and at kernel moisture contents of 25.9,32.7 and 38.5 per cent.

a) Prediction of corn picking efficiency.

$$CPE = -54.60 - 3.98\times10^{-04}(MC)^3 - 1.82\times10^{-04}(PS)^3 + 2.06\times10^{-02}(PS)^2 - 0.86(FS)^3 + 0.22(FS)(PS) - 1.15\times10^{-03}(AI)^3 + 3.30(AI) + 0.81(MC)$$

b) Prediction of per cent cob damage

$$\text{Cob damage (\%)} = -14.93 + 2.21\times10^{-03}(MC)(PS) - 7.69\times10^{-04}(MC)^3 + 3.96\times10^{-02}(MC)^2 + 9.05\times10^{-04}(AI)(FS)(PS)$$

c) Prediction for power requirement of corn picking mechanism

$$PR = -0.21 + 3.45\times10^{-06}(MC)(AI)(PS) + 1.24\times10^{-03}(FS)(PS) + 6.50\times10^{-06}(MC)^3 + 5.15\times10^{-02}(AI) - 7.91\times10^{-04}(AI)^2 - 1.49\times10^{-02}(MC)$$

The research findings will provide help to the scientist/ research workers working in the field of corn harvesting machines.

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ABSTRACT

Maize (*Zea mays*.L) is the second most important cereal crops of the world. It is also widely cultivated in the tribal districts of south Rajasthan as a staple food. In India maize harvesting operation is performed manually by picking cobs from standing plant or by harvesting ear bearing plants with sickle and then picking cobs manually. This operation is arduous and consume more time and labour. Therefore, there exists a felt need for a suitable corn picker in Rajasthan and in Indian Agriculture. Majority of the land holding are small in size where big machines do not have more prospects. Therefore a mechanism to pick the cobs from the standing corn plants may have more potentiality

A Corn Picking Mechanism was designed and developed from mechanical considerations. In order to achieve this, laboratory set up was established which consisted of a test track, a mounting trolley, snapping rolls, gathering unit, pipe frame assembly and a discharge pan. A power transmission system was incorporated to impart power to the mounting trolley, snapping rolls and gathering chain. A plant holder was fixed on the test track to hold the healthy corn plants. Experiments were carried out to evaluate the effect of forward travel speed (2.0, 2.5, 3.0 and 3.5 kmph), peripheral speed of snapping rolls (70, 80, 90 and 100 m/min), angle of inclination of snapping rolls (25^0, 30^0 and 35^0) and kernel moisture content (25.9, 32.7 and 38.5 per cent) on corn picking efficiency, per cent cob damage and power requirement of picking mechanism. Mathematical models were also developed for corn picking efficiency, per cent cob damage and power requirement of picking mechanism

From the experimental results minimum power requirement of 0.6 kW was obtained to operate the picking mechanism and per cent cob damage of 5.83 was observed at the forward travel speed of 2.0 kmph, peripheral speed and angle of inclination of snapping rolls 70 m/min and 25^0 respectively and at 25.9 per cent kernel moisture content. Corn picking efficiency with forward travel speed of 2.5 kmph, peripheral speed of snapping rolls of 90 m/min and 30^0 angle of inclination at 25.9 per cent kernel moisture content was about 92 per cent. At these values the performance of the corn picking mechanism was satisfactory with acceptable limits of percent cob damage and reasonable power to operate the mechanism.

The investigation carried out indicate that the developed single row corn picking mechanism is a viable proposition and useful in reducing time, labour and drudgery during the operation.

Key Words: picking mechanism, corn picking efficiency, per cent cob damage, kernel moisture content, peripheral speed, forward travel speed, snapping rolls, angle of inclination.

अनुक्षेपण

मक्का का विश्व में मोटे अनाज वाली फसलों में दूसरा महत्वपूर्ण स्थान है। दक्षिणी राजस्थान के आदिवासी बाहुल्य जिलों में खाद्यान्न के लिये मक्का का व्यापक रुप से उत्पादन किया जाता है। मक्का कटाई के लिये मनुष्यों द्वारा पहले भुट्टे तोड़ने के उपरान्त दराती से तने को काटा जाता है अथवा भुट्टे लगे हुए पौधों को पहले दराती से काटकर बाद में भुट्टों को अलग किया जात है। इन दोनों ही विधियों में समय, श्रम एवं बैगारी अधिक होती है। अतः राजस्थान एवं भारतीय कृषि में एक उपयुक्त भुट्टे तोड़ने वाली मशीन की आवश्यकता है जो छोटे एवं सीमान्त किसानों की जोत एवं उपयोग सम्भावना के आधार पर बनाई गई हो।

भुट्टे तोड़ने की क्रियाविधि का यांत्रिक आधारों पर विकास एवं निर्माण किया गया है। इसके प्राचल प्रभुता के निष्पादन अध्ययन हेतु एक प्रयोगशाला स्थापित की गई है जिसमें ट्रेक, ट्रोली, स्नेपिंग रोल, पाईप एसेम्बली एवं भुट्टा संग्रहण का समावेश किया गया। स्वस्थ पोधों को सीधे एवं मजबुती से पकड़े रखने के लिये "तना पकड़" बनाया गया। क्रियाविधि के निष्पादन की प्राचल प्रभुता का अध्ययन आगे की और बढ़ने की गति दर (2.0, 2.5, 3.0 एवं 3.5 किमी./प्रति घंटा), कर्तक गति दर (70, 80, 90 एवं 100 मीटर/मिनट), झुकाव कोण (25^0, 30^0 एवं 35^0) एवं दानों में नमी (25.9, 32.7 एवं 38.5 प्रतिशत) मानकों पर किया गया। भुट्टा तोड़ने की क्रियाविधि के निष्पादन के मूल्यांकन का आधार क्रियाविधि की भुट्टे तोड़ने की कार्यकुलशता, भुट्टों को क्षति एवं ऊर्जा की आवश्यकता है। गणितीय प्रतिरुप भी भुट्टे चयन की कार्यकुशलता, भुट्टों को क्षति, एवं शक्ति की आवश्यकता के लिये विकसित किये गये।

प्रयोगों के परिणामों से निष्कर्ष प्राप्त हुआ है कि सबसे कम शक्ति की आवश्यकता 0.6 किलोवाट एवं भुट्टों को क्षति 5.83 प्रतिशत रही, जब भुट्टे तोड़ने की क्रियाविधि का निष्पादन आगे की और बढ़ने की गति दर 2.0 किमी./प्रति घंटा, कर्तक गति दर 70 मीटर/मिनट, झुकाव कोण 25^0 एवं दानों में नमी 25.9 प्रतिशत पर किया गया। भुट्टे तोड़ने कि क्रियाविधि के निष्पादन की कार्यकुशलता लगभग 92 प्रतिशत रही जब इसका संचालन 2.5 किमी./प्रति घंटा आगे की और बढ़ने की गति दर, 90 मी./मिनट की कर्तक गति, 30^0 के झुकाव कोण एवं दानों में नमी 25.9 प्रतिशत थी। इन मानकों पर भुट्टों को क्षति स्वीकार्य मानदण्डो के भीतर एवं शक्ति की आवश्यकता तर्क संगत रही।

किये गये प्रयोगों से यह संकेत मिलता है कि भुट्टे तोड़ने की विकसित क्रियाविधि व्यवहार्य एवं उपयोगी है एवं इससे समय की बचत तथा श्रम एवं प्रचालन के दौरान बेगारी से निजात प्राप्त हो सकती है।

प्रभावी बिंदु : भुट्टे तोड़ने की क्रियाविधि, निष्पादन मूल्यांकन आधार, क्रियाविधि, प्राचल की प्रभुता, भुट्टों को प्रतिशत क्षति, दानों में प्रतिशत नमी, आगे की ओर बढ़ने की गति, कर्तक गति, स्नेपिंग रोल एवं झुकाव कोण।

APPENDIX A

A.1 Gear design

Gears are defined as the toothed wheels which transmit power and motion from one shaft to the other shaft by means of successive engagement of teeth. In spur gear the teeth are cut parallel to the axis of the shaft. The profile of the gear tooth is in the shape of an involutes curve and it remains identical along the entire width of the gear wheel. As the teeth are parallel to the axis of the shaft, spur gears are used only when the shafts are parallel. (Bhandari, 1994)

Bevel gears have the shape of a truncated cone. The size of the gear tooth including the thickness and height decreases towards the apex of the cone. Bevel gears are normally used for shafts which are at right angles to each other.

The first step in the design of the gear drive is the selection of a proper type of gear for a given application. The factors that are considered for deciding the type of gears are general layout of shafts, speed reduction, power to be transmitted, input speed and cost. Based on the requirement the gear was designed to transmit 7.5 hp. Top and bottom of the gear box was fabricated by 8 mm MS plate. (Figs. A-1,A-2)

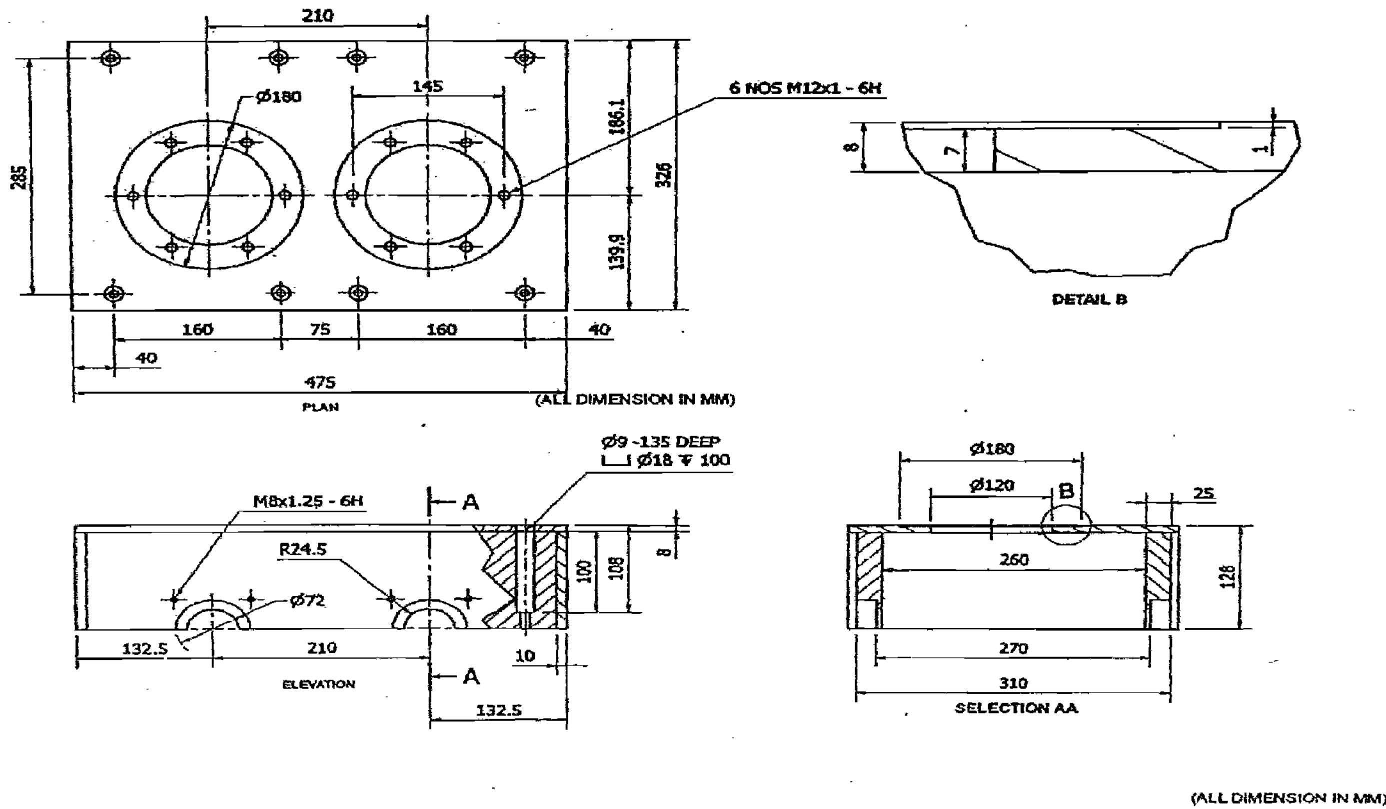

Fig. A-1. Schematic view of gear box top

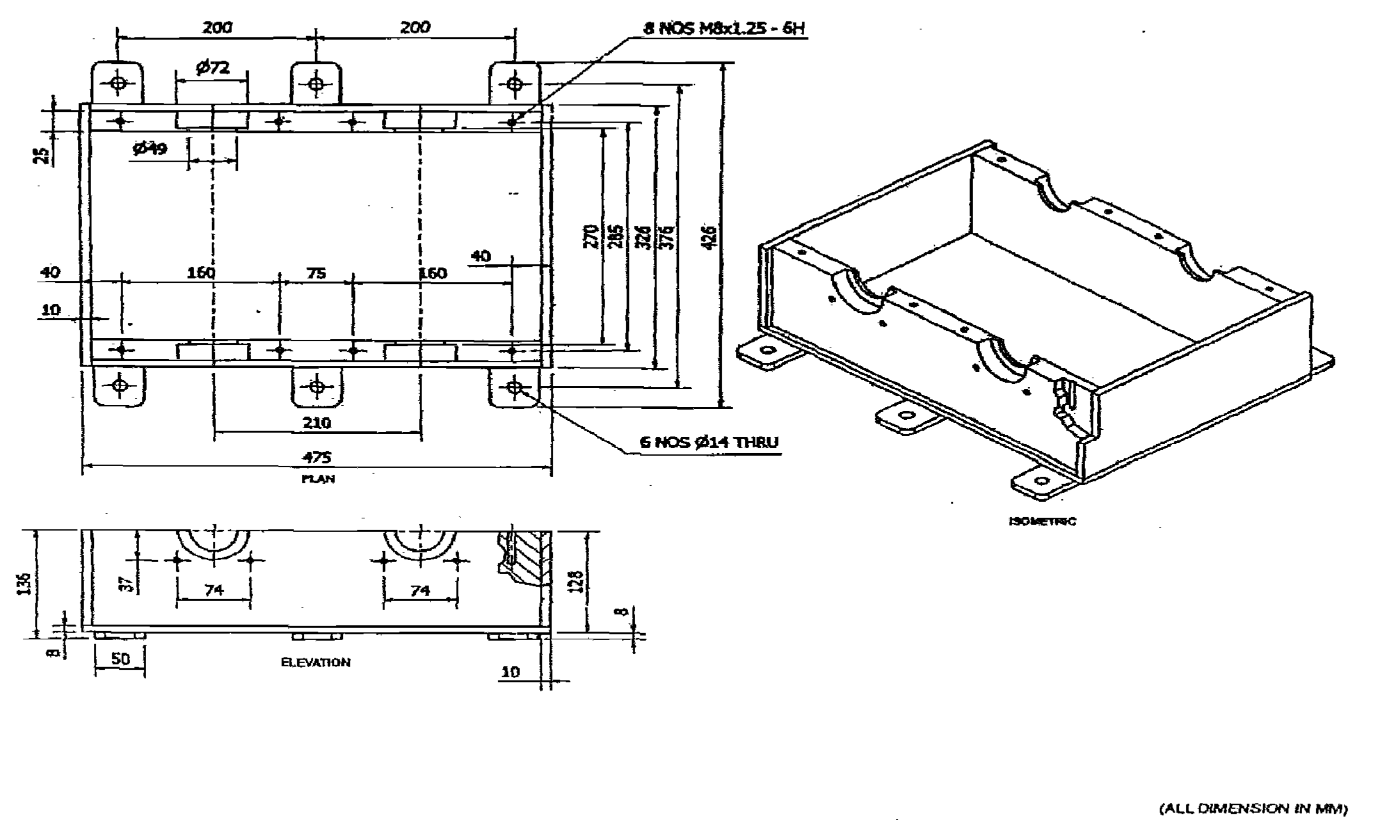

Fig. A-2 Schematic view of gear box bottom

A.2 Design of spur and bevel gear shaft

Design for both gears was made for input power of 7.5 HP and maximum 200 m/min peripheral speed of snapping roll. Further peripheral speeds are 160m/min to 200m/min, which are to be converted in RPM as follows -

Effective diameter of the snapping rolls

= Diameter of snapping rolls + 2 × diameter of spiral rod

$= 0.075 + 2 \times 0.015$

$= 0.105$ m

Peripheral speed of snapping rolls

$V = \omega r$ .....(1)

= 2□Nr = □ND

where V = peripheral speed m/min

ω = angular velocity radians/s

N = rpm of snapping rolls

D = Diameter of snapping rolls

ω = 200 / □D

$= 200/3.14 \times 0.105$

= 606 rpm

≈ 600 rpm

It is prefer to determine the diameter of the shaft by both the maximum shear and maximum normal stress theory and the larger of two are used.

The torque to be transmitted through shaft is determined as

hp = 2□ NT / 4500 ..... (2)

where,

hp = horse power

N = RPM

T = Torque Kg-m

Therefore, T = 7.5 × 4500/2 × □ × 600

= 8.95 kg-m

The diameter of the shaft is determined from the empirical relation

$$d = \sqrt[3]{16 \times T \times 1000/fs \times \square} \qquad \text{..... (3)}$$

where,

fs = shear stress, 5.6kg-mm²

$$= \sqrt[3]{16 \times 8.95 \times 100/5.6 \times 3.14}$$

= 21.12 mm

Bending moment on the shaft considering fixed beam and concentrated load at the centre

$$Mt = W \times L/8 \qquad \text{.....(4)}$$

where,

Mt = Bending Moment

W = Weight of shaft

L = Length of shaft

Mt = 3.8 × 0.42/8

= 0.2 kg-m

Torque equivalent by considering shock for bending and shock factor for torsion is determined as

$$Te = \sqrt{(km \times Mt)^2 + (kt \times T)^2} \qquad \text{..... (5)}$$

where,

Te = equivalent torque

km = shock factor for bending, 1.5

kt = shock factor for torsion, 2.0

$$Te = \sqrt{(1.5 \times 0.2)^2 + (2.0 \times 8.95)^2}$$

= 17.90 mm

Higher value 21.12 mm was taken into consideration. Considering 1.5 factor of safety, the diameter of shaft comes out be 32 mm. However considering unavoidable load during operation diameter of shaft was taken as 35mm.(Figs. A-3 and A-4)

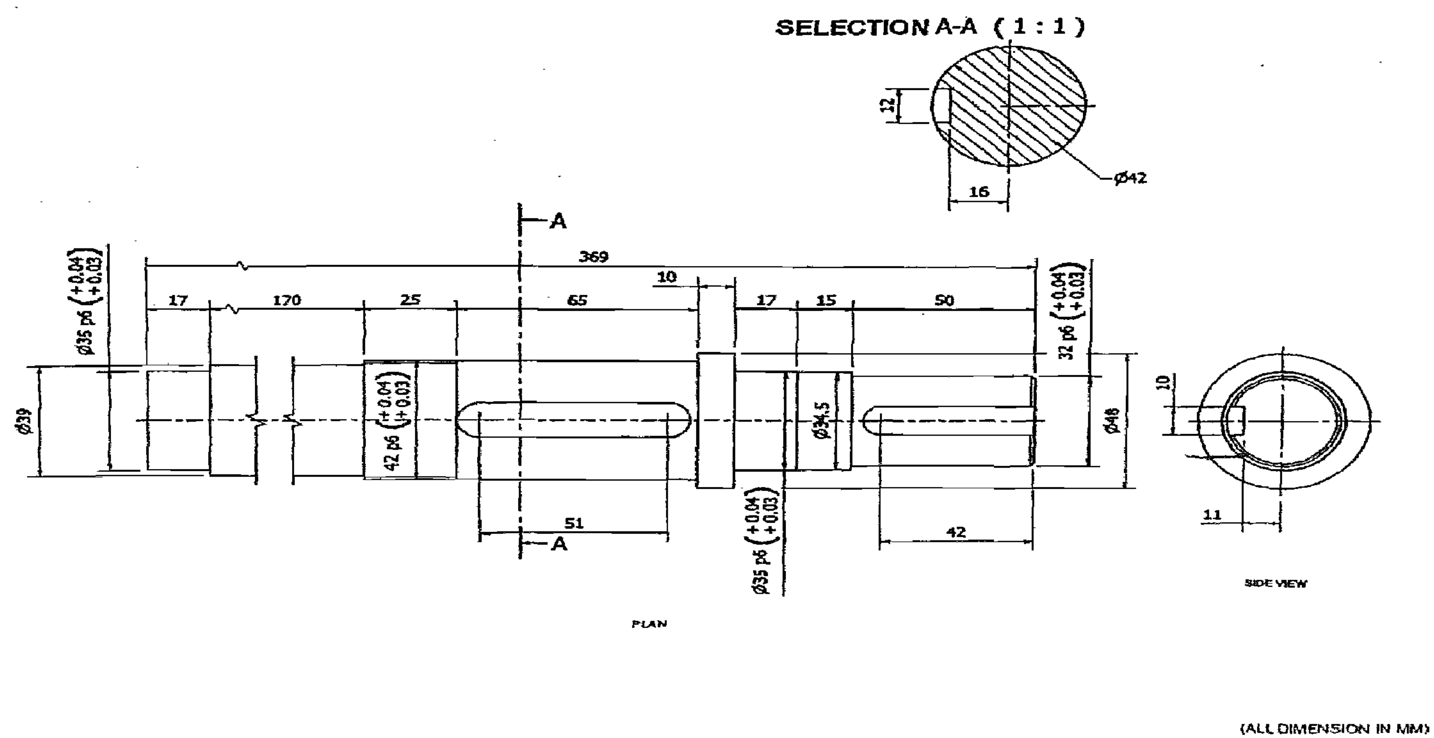

Fig. A-3 Sectional view of gear shaft

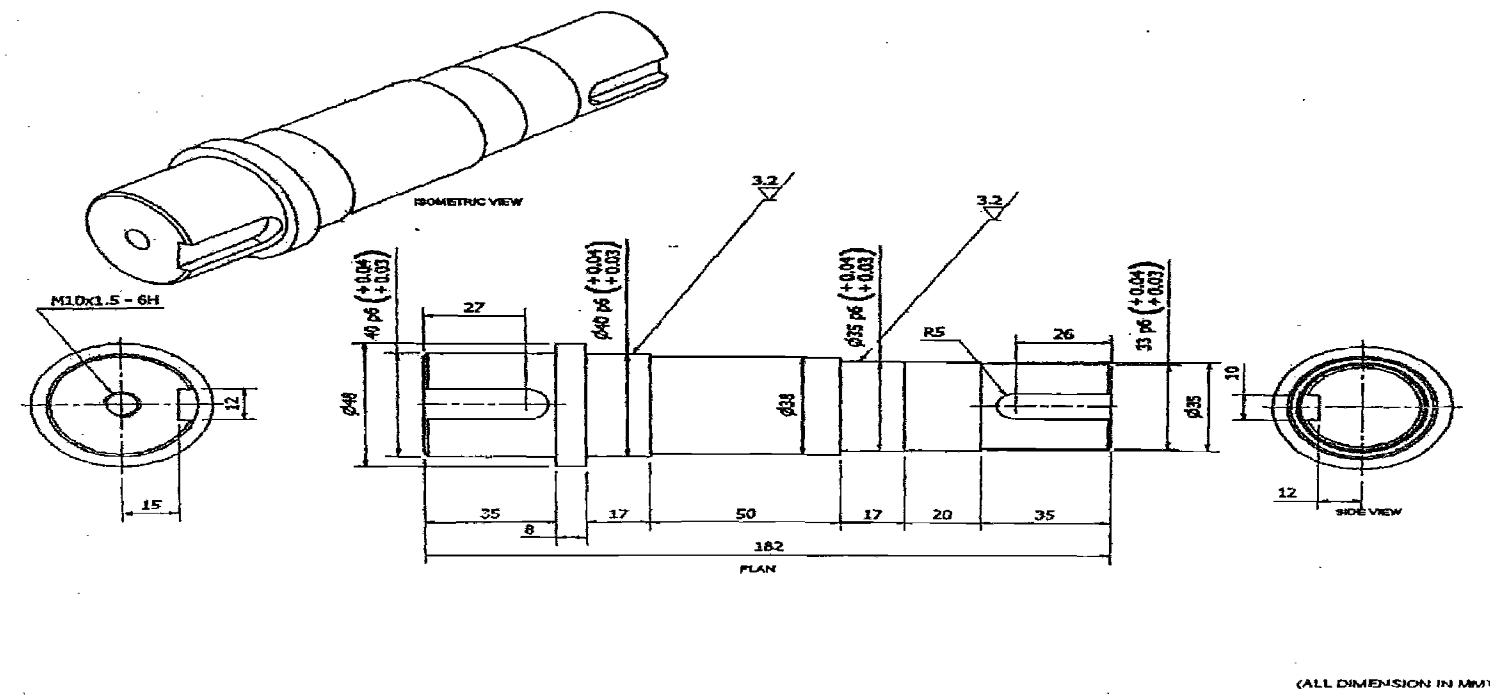

Fig. A-4 Sectional view of bevel gear shaft

A.3 Spur gear design

Two parallel shafts are to be placed at 210 mm and pitch of the spur gear must be same as that of the bevel gear in order to have perfect meshing. The module of the gear to bear given torque is determine by

$$m^3 = 1.5 \times T \times 2000 \times 9.81/12 \times fb \times y \times z \quad \ldots\ldots (6)$$

where ,

m = module in mm

T = torque in kg-m

fb = bending stress, for EN-8, 250-350 N/mm²

y = Lewis form factor

z = number of teeth

For the bevel pinion recommended minimum numbers of teeth at 20° pressure angle are 17. Therefore, 20 number teeth are considered in design.

$$y = 0.154 - .0912/z \quad \ldots\ldots (7)$$

$$= 0.154 - .0912/20$$

$$= 0.108$$

Therefore,

$$m^3 = 1.5 \times 8.95 \times 2000 \times 9.81/12 \times 300 \times 0.108 \times 20$$

$$= 33.87$$

or

$$m = 3.24\text{mm}$$

Hence 5 mm module was considered in gear design.

Number of teeth of spur gear = a/m ….. (8)

where, a = centre to centre distance between two gears, cm

= 210/5

= 42

Other dimensions are calculated by the empirical relations as

(i) addendum = m = 5 mm ….. (9)

(ii) dedundum = 1.25 m = 6.25 mm ..... (10)

(iii) clearance = 0.25 m = 1.25 mm ..... (11)

(iv) tooth thickness = 1.5708 m = 7.85 mm ..... (12)

(v) Fillet radius = 0.4 m = 2.0 mm ..... (13)

Two spur gears of 42 teeth 5 mm module (Fig. A-5) each meshed together in order to transmit the power from driven pulley to snapping rolls through universal shaft.

A.4 Bevel gear design

Power to the bevel gears is transmitted by the spur gear through bevel pinion. Two bevel pinions are used to change the direction of rotation of the output shaft on which chain sprockets are mounted so that gathering chains can run inward. The module of the bevel gear must be same as that of the bevel pinion i,e 5 mm for perfect meshing of the gears. For proper operation chain speed must be somewhat faster than peripheral speed and assumed that it is 5 per cent higher. Numbers of teeth on bevel gears are calculated by gear chain theory as below:

$$N_1T_1 = N_2T_2 = N_3T_3$$

Where,

N_1 = RPM of the spur gear

T_1 = Number of teeth on spur gear, 42

N_2 = RPM of the bevel pinion

T_2 = Number of teeth on bevel pinion, 20

N_3 = RPM of bevel gear, 1.05 N1

T_3 = Number of teeth on bevel gear

Therefore, $N_2 = N_1T_1/T_2 = N_1 x42/20 = 2.1 N_1$

$N_2T_2 = N_3T_3$ or, $T_3 = N_2T_2/N_3 = 2.1N_1 x20/1.05N_1 = 40$

Bevel pinion 20 teeth 5 mm module (Fig. A-6) and bevel gear 40 teeth 5 mm modules (Fig. A-7) was used for transmission of the power. This power is used for gathering chain through chain sprocket system.

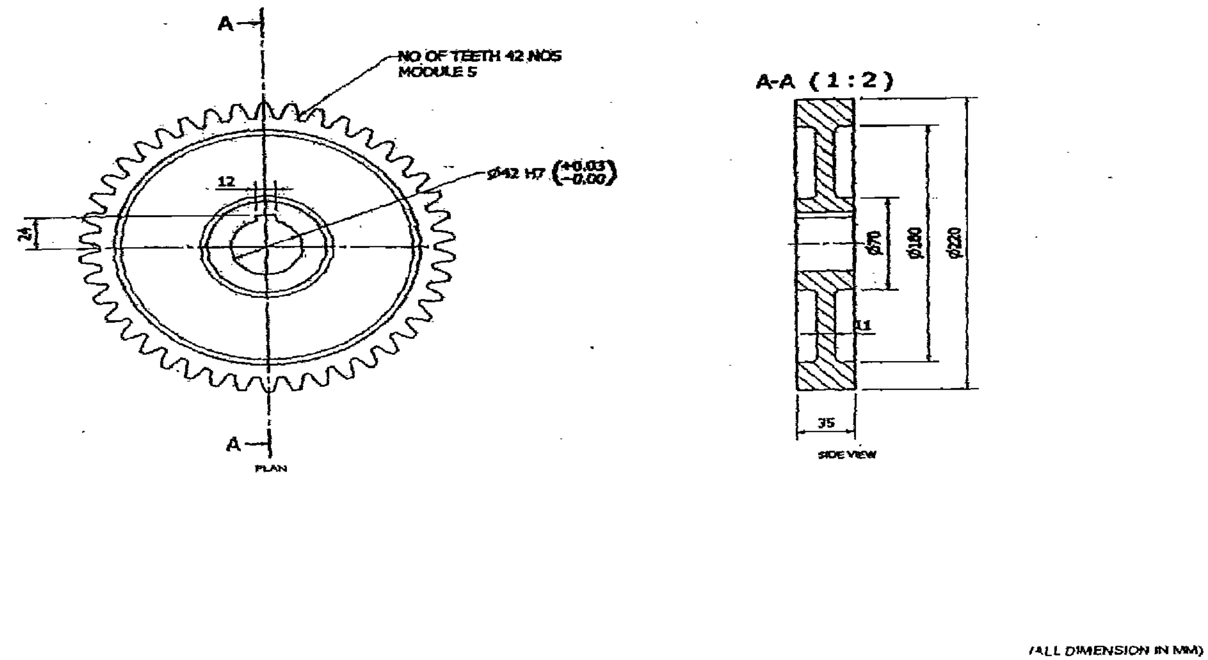

Fig. A-5. Schematic view of spur gear

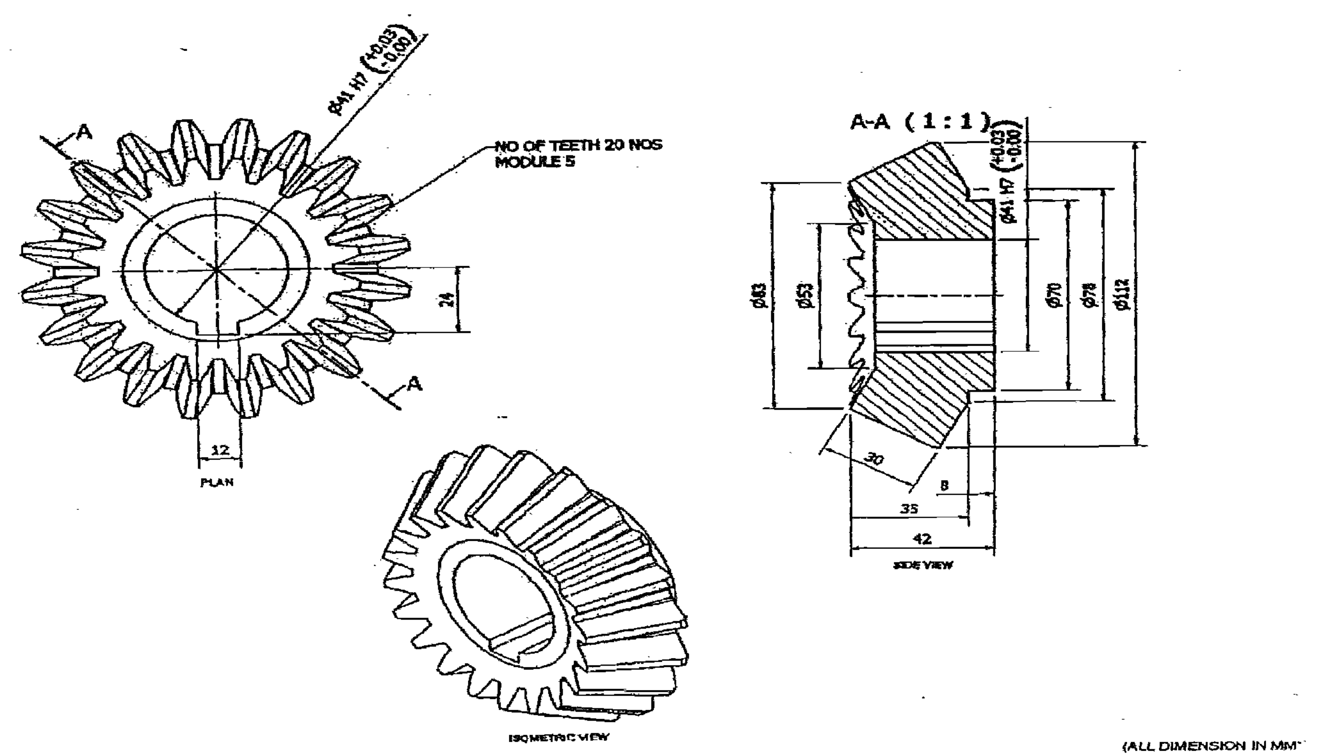

Fig. A-6 Sectional view of bevel pinion 20 teeth 5 module

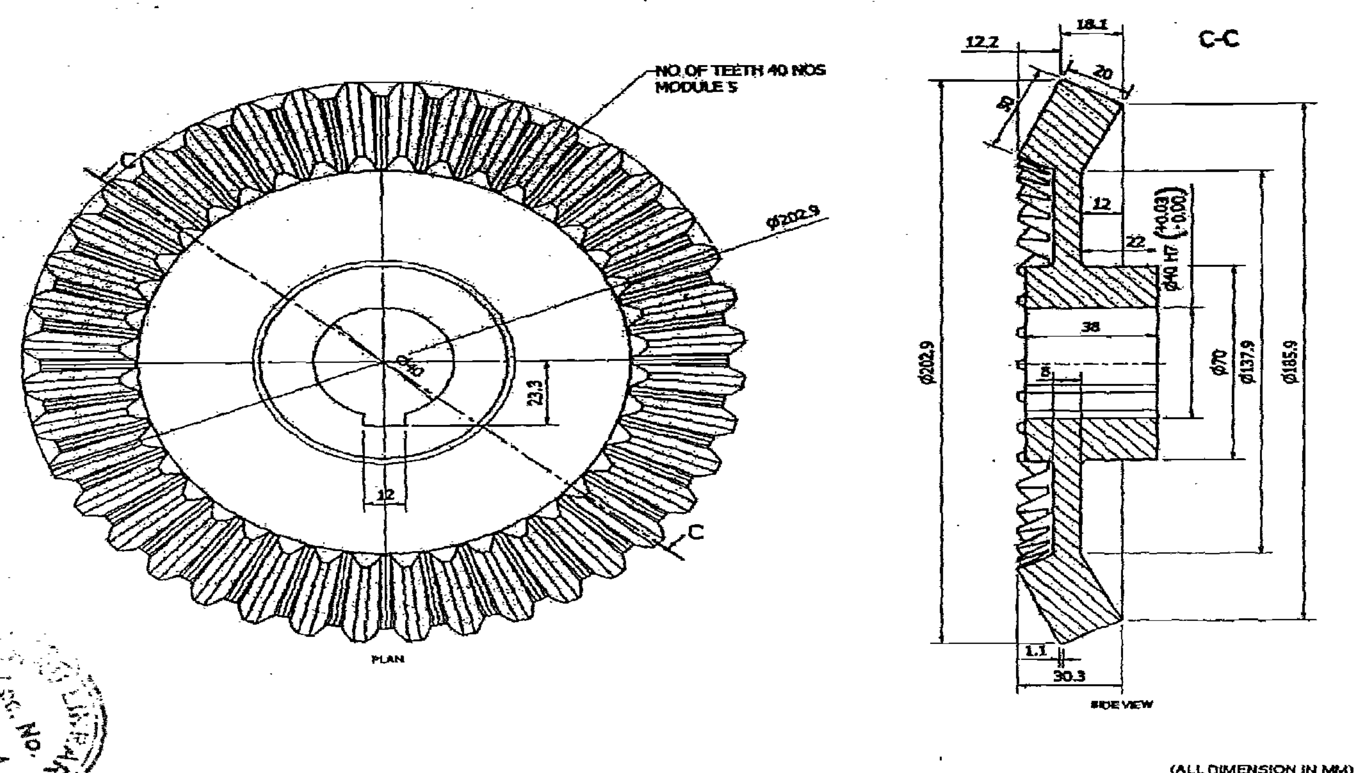

Fig. A-7 Sectional view of bevel gear