INVESTIGATION ON THE EFFECT OF CROP-MACHINE PARAMETERS ON UNIFORMITY OF DISTRIBUTION FOR SMALL SEEDS IN RELATION TO DESIGN OF PNEUMATIC SEED DRILL

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by

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CERTIFICATE

This is to certify that the thesis entitled **INVESTIGATION ON THE EFFECT OF CROP-MACHINE PARAMETERS ON UNIFORMITY OF DISTRIBUTION FOR SMALL SEEDS IN RELATION TO DESIGN OF PNEUMATIC SEED DRILL** submitted in part fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY** in **FARM POWER AND MACHINERY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by Thiru. **V.J.F.KUMAR**, under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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Er.V.J.F. KUMAR

ABSTRACT

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INVESTIGATION ON THE EFFECT OF CROP-MACHINE PARAMETERS ON UNIFORMITY OF DISTRIBUTION FOR SMALL SEEDS IN RELATION TO DESIGN OF PNEUMATIC SEED DRILL

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Crop stand uniformity in the field begins with an appropriate seed metering system that gives the required seed density. At present, developed countries are adopting seed drills operating at high speeds to cover more area. But in our country, this evolution has not taken place fully, though there is pressing demand for such equipment. Hence an attempt was made to develop a high speed pneumatic seed drill for small seeds like sesame, pearl millet and sorghum.

The important physical and aerodynamic properties of these seeds were determined. Three seed metering heads namely parallel disc, closed funnel and streamlined flow distributors were developed. The performance of the distributor was evaluated using a test rig specially developed. The pressure at the blower outlet, distributor head inlet and eductor were measured to study the characteristics of air flow in the head. Determination of the

actual path of the seed traced in the seed conveyance pipe and the distributor was recorded using videographic technique. The experiments on the performance of distributors were statistically designed and executed. The data obtained were analysed and optimised to bring out variable levels yielding the best performance. A prototype pneumatic seed drill was developed and its field performance was evaluated.

The results summarised that pearl millet and sorghum were spherical in shape, while sesame was ellipsoidal. The mean frontal area of sesame, pearl millet and sorghum was found to be 3.34 ± 0.54, 5.14 ± 0.56 and 8.02 ± 1.05 sq. mm. The mean terminal velocity of sesame, pearl millet and sorghum was 2.2 ± 0.13, 4.2 ± 0.08 and 5.6 ± 0.11 ms^{-1} respectively.

The study on the performance of the distributors during dynamic test inferred that streamlined flow distributor gave uniformity of distribution of 97.9 per cent for sesame at an air velocity of 5.5 ms^{-1} and feed rate of 79 g min^{-1}. The same distributor with an air velocity of 6.0 ms^{-1} and feed rate of 273 g min^{-1} was the best combination for distributing pearl millet at 98.39 per cent uniformity. The best performance of 98.5% uniformity for sorghum was obtained with streamlined flow distributor at an air velocity of 8.0ms^{-1} and feed rate of 238$gmin^{-1}$.

The streamlined flow distributor offered least resistance to seed flow since the blower outlet pressure was in the order of 15.5, 25.6 and 30.2 mm of water for sesame, pearl millet and sorghum respectively as compared to other heads. It developed very low pressure of 2.5 mm of water at the head inlet. Highest suction pressure of -16 to -21mm of water was developed at the eductor.

There was no variation between the actual and predicted path of the seed in the vertical column for the three distributors. The path in the distributors showed that there was impact of the seed at 8.0 ms^{-1} air velocity in the parallel disc distributor. However, at lower velocities there was no appreciable impact. The flow of seed in the closed funnel distributor was turbulent in nature. In the streamlined flow distributor, the flow pattern of the seed was quite uniform without undesirable impact.

The uniformity of distribution of seed in streamlined flow distributor remained unaltered even at diferent forward speeds of the power unit.

The field performance of the pneumatic seed drill showed no variation in the number of plants germinated in the individual row. The mean population observed was 87, 78 and 32 per sq.metre for sesame, pearl millet and sorghum respectively. The frequency of plant spacing showed normal distribution with peak aligned along the mean spacing. The mean spacing obtained for sesame and pearl millet was 40 mm, while for sorghum it was 70 mm. The cost of operation of the unit works out to Rs.150 per ha. The saving in cost and time are 55 and 92 per cent respectively as compared to conventional method. The cost of the unit is Rs.20,000/-.

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INTRODUCTION

Seed drill is one of the important farm equipment for mechanized agriculture. Mechanization of post planting operations in the farm very much depend on mechanized seeding in which the crops are planted in rows.

Planting of seeds in the desired fashion is a need based operation in crop production as it aids to maximise yield. Several factors which affect crop stand uniformity includes seed-bed condition, seed metering accuracy, seed drop accuracy, seed germination and plant survival. Thus a uniform crop stand depends on seed metering system that ensures desired sowing density with little seed damage. Drilling of seed is easier, speedier and cheaper than other methods of planting, especially for small seeds. In planting, one or two seeds are dropped in each hill unlike drilling and hence there is a possibility of missing of desired number of plants along the row which can be easily overcome in drilling. But drilled crop may require thinning of the plants to the desired level after germination.

Though there are number of seed drills in the country for handling different types of seed, most of them perform well only for bold seeds and all of them work on any one of the mechanical metering mechanisms. These mechanisms do not work satisfactorily for small seeds such as sesame, pearl millet and sorghum. Hence it is essential to develop a suitable seed metering mechanism for drilling small seeds which has a major share in the total area cultivated. The gross area of sorghum and pearl millet cultivated in India is 134.99 and 102.50 lakh ha. respectively, (Fertilizer statistics, 1992-93) whereas sesame is cultivated in 22.00 lakh ha. (FAO year book, 1990). In Tamil Nadu sorghum, pearl millet and sesame are cultivated in 5.12, 2.46 and 14.9 lakh ha. respectively (Statistical Hand Book of Tamil Nadu, 1993).

1.1. Evolution of seed drills

The use of drill in China dates back to 2800 B.C and in Babylonia between 1700 and 1200 B.C. In Italy the first patent for a seed drill was granted to Camillo Torello. In England, though the first patent was granted to Alexander Hamilton in 1623, the first successful machine that worked was developed in 1701 by the founder of "Drill Husbandry" Jethro Tull. The unit was a fluted force feed device. The cup feed principle was invented by Rev.James Cooke in 1782. The internal force feed drill was developed by Berkford in 1867. In the field of precision seeding, the horizontal plate type with cells on the periphery was the earliest development. The cell drop and picker wheel mechanisms were developed in 1892. The rubber belt type was introduced in 1953 by Stanhay (Ashford) Ltd. of England. To improve planting at high speeds, the vacuum metering mechanism was patented in Germany in 1922 (Datta, 1974). The vacuum planters were susceptible to orifice clogging with dirt and seed residues.

The variation in germination percentage of small seeds is high (Hunt, 1986) and hence the usual practice is to drill the seeds in rows and latter get thinned to desired level of plant stand. In recent years, after the advent of sophisticated chemical selective thinning techniques and machines, developed countries switched over to seed drills capable of travelling at higher speeds and thereby covering more area. In the latter part of 1980's air seeders have been developed and they are becoming popular (Anonymous, 1988).

The major reasons for the popularity of the air seeders are as follows:

* Centralised metering and distribution mechanism eliminates long hoppers and complicated mechanical drives in wider seed drills.
* The design of the unit is flexible and hence it is easier to integrate it with other cultivation machinery.
* Use of collapsible design of wider machinery for easy transportation.

* Elimination of compaction by redistributing the weights between front and rear wheels through front mounted seed hoppers.
* Ease of filling up of seed box
* Ensures high speed operation without sacrificing the quality of work due to reduced mechanical complexities.

1.2 Concept of air seeders

The air seed drill has an air powered distribution and delivery system consisting of a blower driven by the power take off (PTO) of the tractor and a distributor head. The first air seeder was built by "Accord" - a farm equipment firm in England (Anonymous, 1988). The equipment had an air plenum into which the seeds were fed, conveyed and finally distributed to individual furrow openers by a distributor head. The air pressure seed metering device was capable of handling a wide range of seeds irrespective of their size and shape.

In developed countries, air seeders employ the principle of suction force developed by an air stream. However they are meant for bold and hard seed like maize. The research work carried out on the principle of metering small seeds by the pressure of air stream is quite limited and especially the work carried out in India is almost negligible. Hence there is a need to carry out systematic research work on the suitability of such an air force fed seed metering mechanism and the effect of pertinent parameters governing the seed distribution.

1.3 Development of distributor head for air seeder

Though air seeders are in use in western countries, no published literature is available regarding design requirements of air drills. In developing an air assisted seed drill, the physical and aerodynamic properties of the different seeds have a greater role to play. The configuration of the seed distributor head is the nucleus in distributing the seed uniformly to all furrow openers. The studies on the effect of seed feed rate and air velocity on the performance of the distributor head will help to optimise the factors involved in developing pneumatic seed drill for small seeds.

In order to develop a pneumatic drill for small seeds like sesame, pearl millet and sorghum, a study was undertaken with the following specific objectives :

i. To determine the physical and aerodynamic properties of sesame, pearl millet and sorghum in relation to pneumatic conveyance and distribution,

ii. To develop different types of seed distributor head and a test rig for varying air velocity and seed feed rate for experimental investigation,

iii. To investigate the effect of seed feed rate, air velocity and configuration of distributor head on uniformity of seed distribution,

iv. To develop a prototype pneumatic seed drill based on the optimised values and to evaluate its performance characteristics,

v. To evaluate the performance of the pneumatic seed drill in the field and to work out cost economics.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

In this chapter, the review of past work done on physical and aerodynamic properties of seeds is presented. The important literature on the measurement of air pressure and velocity and aerodynamic characteristics of seed in relation to distribution are reviewed and given. The work on development of air assisted seed drills and performance evaluation of seed drills are grouped separately.

2.1. Physical properties

Curray (1951) defined sphericity as the ratio of diameter of largest inscribed circle and diameter of smallest circumscribed circle of any material.

Houston (1957) suggested that the average of orthogonally projected area of the object was taken as the criterion of size and proved the average projected area as :

$$A = KV^{2/3}$$

where,

A = Projected area

V = Volume of the object

K = a constant.

Bilanski *et al* (1962) calculated the frontal area of seeds having ellipsoidal shape as $(\pi L_1 L_2) / 4$ where L_1 and L_2 are length and width respectively. He also determined the size of seeds by measuring the length, width and depth.

Day (1964) developed a device for measuring voids in porous materials. The difference in pressures due to filling up of void space in seed was measured to compute the void volume.

Garrett and Brooker (1965) defined the diameter of a sphere having volume equal to that of particle as :

$$d = \left(6W / \pi \gamma_0 \right)^{1/3}$$

and the cross sectional area of the sphere of equal volume as :

$$A = \pi/4 \, (6W / \pi \gamma_0)^{2/3}$$

where,

W = Particle weight corrected for buoyant force

γ_0 = Particle specific weight

Keck and Goss (1965) found the frontal area of small grains having sphere shape as $\pi d^2/4$, in which 'd' is the diameter of sphere found by taking the geometric mean of the three mutually perpendicular measured seed dimensions.

Prince and Bartok Jr (1966) developed an air flow planimeter to measure irregular areas with speed and accuracy. The unit consisted of a turbo compressor, a pitot tube, a pressure transducer and a strain recording instrument. To support the material a mesh screen was attached at the end of the pipe. Static pressure was measured with a 6 mm pitot tube. Initial calibration was accomplished with static pressure and area of the material. The error using the calculated area and measured with the unit was about 6 per cent.

Thompson and Isaacs (1967) found the equivalent seed diameter of five varieties of grain sorghum to be 3.4 to 3.5 mm based on area. They also measured the porosity of oats, wheat, grain sorghum, soyabeans, barley and yellow corn using air comparison pycnometer. The results concluded that approximately 38.5 to 61.5 per cent of the bulk volume of seed tested was air space. The percentage voids for different varieties of sorghum ranged from 43.26 to 45.75. They compared the relationship between bulk and true density on porosity obtained using pycnometer and concluded that the relationship between bulk density and void space was linear and porosity can be determined approximately by making a simple test-weight measurement.

Whitney and Porterfield (1968) determined the average diameter of soyabean, sorghum and wheat as 6.0, 3.4 and 3.75 mm respectively. They also studied the coefficient of restitution of various plastic balls of 12.7 mm diameter with six different materials. A device to drop the balls from various heights onto the materials fastened horizontally to the base was constructed. Each ball coated with a thin layer of fluorescent shellac, showed the rebounded paths of the balls when photographed by illuminating the rebound area with ultraviolet light.

Wratten *et al* (1969) determined surface area of individual rice by embedding it in wax and the wax and rice matrix was fastened to a wooden block for sectioning by the use of a microtome section cutting machine. They sliced the embedded rice grain into fifteen sections and measured the major and minor axis of each section using precalibrated microscope. They calculated the perimeter (P) of each section using the expression $P = \pi\ [(a^2 + b^2)/2]^{1/2}$ and multiplied it by the thickness between the two consecutive sections to obtain surface area.

Bakker-Arkema *et al* (1971) determined the surface area of certain grains using varnish and nickel powder coating. First the weights of known plastic spheres and unknown grains were measured with an analytical balance. The particles were then coated by dipping them in spar varnish with the excess removed by rolling them over a paper towel. The particles were air dried on a wire screen for about 30 minutes and swirled with nickel powder for about 5 seconds. The particles were again weighed to find the increase in weight. By comparing the weight increase of the unknown with that of known plastic spheres, the surface area of the test particles was calculated. When the grain was at its equilibrium moisture content, the test was sensitive and for other moisture contents error could be about 50 per cent.

Jindal *et al* (1974) determined surface area of seeds by varnish coating and air permeability method. The surface area of unit volume of sorghum by varnish coating method was estimated in the range of 1297.57 - 1335.62 m^2m^{-3}. As the grain size gets smaller, the difference between the surface area values obtained by the coating and the air permeability method seemed to increase. The surface area calculated by the air permeability method was not far off from American Society of Agricultural Engineers' data for most grains under packed condition.

Shellard and MacMillan (1978) measured the dimensions of the wheat grain along three perpendicular axes using a micrometer. The equivalent diameter was taken as the geometric mean of these three dimensions and used to calculate Reynolds number, projected area and drag coefficient. The equivalent diameter of wheat grain was observed as 3.65 mm.

Mohsenin (1980) reported that ideally a great number of measurements in various directions should be taken to determine the average diameter of an agricultural product. However he concluded that three measurements namely major, intermediate and minor diameters were sufficient to determine the size of a material.

Waziri and Mittal (1983) used an overhead projector to trace the outline of the projected boundary to determine the axial measurements using the magnification factor of projection. They placed the seeds in natural rest position and in vertical position to obtain major, minor and intermediate diameters. It was concluded that sorghum and pearl millet kernel were spherical with the average diameter of sorghum and pearl millet as 2.72 ± 0.14 mm and 2.21 ± 0.19 mm respectively. The authors determined the solid density of small objects using specific gravity bottles and reported as 1370 and 1300 kgm^{-3} for sorghum and pearl millet respectively. The porosity of sorghum grain by the porosity tank method was measured as 44 per cent, whereas theoretical porosity calculated was 44.5 per cent. They observed the thousand kernel weight of sorghum and pearl millet as 30.51 ± 1.18 g and 8.51 ± 0.36 g respectively. It was reported that the angle of repose of sorghum and pearl millet was 2.54 ± 0.9 ° and 22.4 ± 0.4 ° respectively.

Sreenarayanan *et al* (1988) measured the length, width and thickness of soyabean using a travelling microscope having a least count of 0.01 mm to determine its size. From the measurements soyabean was approximated to a sphere. The angle of repose of soyabean was calculated by measuring the height of the grain heaped over a circular disc of known diameter. It was observed to be 25.5 °.

Gorial and O'Callaghan (1990) measured the size of seed along three perpendicular axes using a micrometer and concluded that the geometric diameter of sesame, pearl millet and sorghum were 1.66, 2.04 and 3.61 mm respectively. From the geometric diameter and diameter of equivalent sphere, they calculated the sphericity of sesame, pearl millet and sorghum seed as 0.64, 0.95 and 0.80 respectively. The thousand grain weight of sesame, pearl millet and sorghum was reported as 2.41. 6.12 and 31.5 g respectively at 7 per cent moisture (w.b).

Khairwal *et al* (1990) reported that the shape of pearl millet varieties may be either globular, obovate, oblanceolate, pyramidal or cuneiform. They also observed that there was considerable variation in grain weight among pearl millet varieties from as low as 3-4 g per thousand grain to as high as 10-12 g.

Maheswari *et al* (1990) studied the angle of repose of sorghum, pearl millet and sesame and observed that it was 26.57, 27.92 and 30.11 ° respectively.

The thousand grain weight of pearl millet seed was reported to be 8-9 g for WCC variety whereas Co7 had 6.8 to 7.2 g (Crop Production Guide, 1991).

Oje and Ugbor (1991) studied the size of oil bean seed by measuring the major, intermediate and minor diameters on three mutually perpendicular axes using a micrometer. The roundness and sphericity of each seed was observed after tracing the edges of the seed on a graph sheet. They measured the projected area and the diameter of circles inscribing and circumscribing the projected area. The angle of repose of oil bean seed was reported as 17 ° from the measurement of the depths of the free surfaces of the seed at two known horizontal distances from one end of the box. The true density of oil bean seed was determined by water displacement method and surface area by coating the seed surface on a light sensitive flexible paper and then tracing the surface edges on a paper and then to graph paper.

2.2. Aerodynamic properties

Bilanski *et al* (1962) determined the terminal velocity of seeds using an apparatus designed to measure precisely the time of fall of any seed through various distances starting at zero velocity.

They also defined drag coefficient as follows :

$$C_D = 2R / A \rho_f V^2$$

where,

C_D = Total drag coefficient, dimensionless
R = Total drag force = $W(\rho_p - \rho_f)/\rho_p$, kg
A = Frontal area of the particles, m^2
ρ_f = Mass density of fluid, kgs^2m^{-4}
V = Terminal velocity, ms^{-1}
ρ_p = Mass density of particle, kgs^2m^{-4}
W = Weight of particle, kg.

Bilanski and Lal (1965) determined the terminal velocity of wheat grain and straw of various lengths using a vertical air flow pipe. It was concluded that rotation of particles in an air stream caused a higher drag and lower terminal velocities.

Garrett and Brooker (1965) developed a technique for determination of drag coefficient of small particles over a wide range of flow conditions through photography of some portions of the fall of a particle. The technique is limited by the ability of the film to record the trace of the particles. Side drift and spiralling during the fall introduced errors which may be serious for some seeds. They suggested the diameter and area of the sphere of equal volume based on measurement of particle weight and specific weight of seed to quantify the drag coefficient. Hence it was necessary to know the actual projected area to calculate drag coefficient due to seed tumbling.

Keck and Goss (1965) developed an instrumentation to record the free fall time required for an object falling from a predetermined height. They used an electronic interval counter and suitable amplifiers to measure the free fall time. The velocity for each height of drop was computed with the aid of Sterling's rule of approximation. The terminal velocity thus obtained was very close to that computed by Lapple's formula.

Hawk *et al* (1966) reported that terminal velocity increased as the weight of the particle increased, even if the particle volume remain constant. Hence, they concluded that the terminal velocity alone was not a satisfactory aerodynamic characteristic of a particle. They also suggested that the equivalent sphere volume be used as a standard for calculating drag coefficient. The terminal velocity of kernels was determined by suspending it in a vertical airstream. The velocity was measured using pitot tube and manometer.

Menzies and Bilanski (1968) studied the terminal velocity of alfalfa particles in a tapered tunnel of cross section 0.22 m^2, where the fan speed was adjusted until the particle floated at the centre of the tunnel. They measured the height at which the particle crossed the wind tunnel in a horizontal motion by a tape located inside the wind tunnel and determined the suspension velocities from calibration curves of the rpm of the fan and the air velocity at a given height in the wind tunnel. The air velocity was measured with a micromanometer and Prandtl type pitot tube.

Shellard and MacMillan (1978) conducted suspension velocity tests in a duct with a hexagonal cross section each wall being divergent at 1.75 °. They determined suspension velocity with a pitot tube with its tip in the middle of the duct cross section. They also calculated the mean drag coefficient which depended on the geometric mean diameter as a true representative of equivalent diameter.

Smith and Stroshine (1985) studied the terminal velocity of corn residue materials using a wind tunnel of 2.5m long and 0.33m diameter tube made of clear plastic. They measured the air velocity to suspend the particles in a vertical air stream by pitot tube and inclined manometer.

Clarke *et al* (1990) developed a viscometer to measure the flow properties of fluidized bed of beads and grains. He concluded that fluidized suspensions of glass beads of 3mm diameter and five types of seeds of varying properties are markedly non-Newtonian in character.

Gorial and O'Callaghan (1990) measured terminal velocity of sesame, sorghum and pearl millet using a duct of 1.225m long with a rectangular cross section of 0.16 x 0.12m and two walls which diverged at 2 °. They recorded the air velocity using a pitot tube and micromanometer with a resolution of $0.2ms^{-1}$. They found that the terminal velocity of sesame, pearl millet and sorghum as 4.4, 7.6 and $9.7ms^{-1}$ respectively. They calculated the drag coefficient of sesame, pearl millet and sorghum grain as 0.76, 0.56 and 0.59 respectively. From the drag coefficient of spheres they classified that pearl millet and sorghum grain were in the range of spheres and grain with flattershapes had higher drag because they assumed a horizontal position and had larger projected area than other shapes. They also concluded that the drag coefficient of grain depended mainly on shape.

Maheswari *et al* (1990) determined the terminal velocity using a OSAW laboratory model blower and reported the terminal velocity of sorghum, pearl millet and sesame as 5.3, 4.4 and $2.1ms^{-1}$ respectively.

2.3. Air pressure and velocity measurement

Shedd (1953) built a micromanometer containing the manometric fluid in two glass tubes of 45mm diameter connected at the bottom by a rubber tube. He arranged a moving carriage with one of the tubes to adjust for the pressure measured. He reported that the errors due to miniscus was negligible due to larger tube diameter.

Kallen (1961) reported that it was more economical and desirable to use a pitot tube for velocity measurement. The location of the pitot tube should be where there is no possibility of uneven velocity distributions due to fittings or disturbances upstream for about 20 pipe diameters from the location of the tube.

Coulson and Richardson (1970) explained that small difference in pressure was often measured with a two liquid manometer. The difference in pressure,

$$\Delta P = P_2 - P_1 = h_m (\rho_{m1} - \rho_{m2}) g$$

where,

h_m = Difference of height obtained in manometer

ρ_{m1} and ρ_{m2} = Densities of the two manometer liquids

It was mentioned that highest sensitivity was obtained if the density of the liquids used were almost same. He recommended benzyl alcohol and calcium chloride solution at variable concentration as the two liquids. They also suggested pitot tube to measure the difference between the impact and static pressure in a fluid. The pitot tube consisting of two concentric tubes arranged parallel to the direction of flow, measured the impact pressure on the open end of the inner tube and a series of orifices on the sealed curved outer tube gave an accurate indication of the static pressure. They recommended that for flow not to be appreciably disturbed, the diameter of the pitot tube must not exceed one fifth of the diameter of the pipe.

Harwood and Hinkle (1973) developed a single and dual thermistor anemometer to measure micro air flow upto $2.0ms^{-1}$. They concluded that pitot tube could be used in conjunction with a micromanometer to measure velocities above $2.0ms^{-1}$. They successfully used it in the laboratory as a portable unit where air temperature was constant and conditioned air was used.

Sirohi and Radhakrishna (1983) reported that during pressure measurement in a Prandtl pitot tube, the acceleration and stagnation effects will just balance each other at the plane of the pressure holes. This tube utilised eight square edged pressure holes of 1mm diameter placed 45 ° apart in a plane located 8 tube diameters downstream of the nose and 20 tube diameters upstream of the probe stem. It consisted of two tubes of 7mm and 1.7mm diameter positioned one inside the other. The nose surface was curved to the radius of 50 per cent of the outer tube diameter. The probe stem was curved 10 times the radius of the outer tube. It was mentioned that the capabilities of 'U' tube manometers were extended by various types of micromanometer which serves to measure pressure in the range of 5 to 500mm of water. The capillary effects of this manometers were considerably reduced when tubes greater than 20mm diameter were used. They also reported an air micromanometer which was highly sensitive and avoids capillary and meniscus effects. In this device, reference pressure was mechanically amplified by centrifugal action in a rotating disc. Measurement of pressure as small as 0.005mm of water could be made with this manometer with an uncertainty of 1 per cent.

Brundrett and Vermes (1987) measured velocity in polyethylene tubes using the pitot static tube of an Alnor 6000-p velometer. They calibrated the instrument and confirmed the velocity measured by direct comparison to a Prandtl type pitot static probe and Lambrecht sloping tube alcohol manometer.

Sajikumar *et al* (1990) developed a low cost micromanometer to measure very low pressures. They used two manometric liquids namely water and kerosene having different specific gravities for pressure measurement. The manometer kept at an inclined angle of 30 ^{o} gave ten times magnification than that of a 'U' tube manometer with water as manometric liquid.

2.4. Aerodynamic characteristics of seed in relation to distribution

Chancellor (1960) combined air movement measurements with an analytical description of air solid interactions so that pressure and rate of air movement as well as the influences of the air on the solid material may be determined. He explained that once a particle entered the pipe, its movement soon became vertical and analytically considered as :

i. The particle moving upward faster than the air stream or

ii. The air stream moving upward faster than the particle but at a relative velocity less than the terminal velocity of the particle or

iii. The air stream moving upward faster than the particle but at a relative velocity greater than the terminal velocity of the particle.

In the last case,

$$V_r t = (V_s V_r / g) \left[\mathrm{Cot\,h}^{-1} (V_{r0} / V_s) - \mathrm{Cot\,h}^{-1} (V_r / V_s) \right]$$

$$H_t = V_a t - (V_s^2 / 2g) \ln \left[(V_{r0}^2 - V_s^2) / (V_r^2 - V_s^2) \right]$$

where,

V_r = Relative velocity of the particle in the air stream, ms^{-1}

V_s = Terminal velocity, ms^{-1}

t = Time, s

V_a = Velocity of air stream, ms^{-1}

H_t = Height relative to the original point in the pipe, m

g = Acceleration due to gravity, ms^{-2}

V_{r0} = Relative velocity of the particle in the air stream at t=0

He concluded that under most conditions the pressure at the blower outlet was less than that required to overcome pipe friction indicating that the solid material imparted energy to the air stream rather than the reverse, consequently slowing down the solids.

Purser and Greig (1967) investigated the variation of static head along a lateral duct and developed a theory to predict the head variation. They concluded that the static head variation in a lateral duct was a function of the frictional loss and the static head regain. It was found that in a pressure system the highest static head occured towards the distal end of the duct. The variation of the static head along a duct of constant cross section which was discharging air uniformly along its length was determined by an equation of the form :

$$h_L - h_0 = (V_L / 4000)^2 \left[-2K + (f_L / 3D_e) \right]$$

where,

h_L = Static head 'L' m from distal end of duct

h_0 = Static head at distal end of duct

V_L = Velocity, ms^{-1}

K = Velocity head coefficient

f = D'arcy-weisbach friction coefficient

L = Length, m

D_e = Hydraulic mean diameter, m

Chand and Ghosh (1968) developed analytically a general equation for velocity of particles from physical properties of the system when the particles were under pneumatic conveyance. In deriving the equation, they considered the impact and frictional resistance. The velocity of particles under steady state condition of conveyance was given as :

$$U = \sqrt{f_c}\ U_s + \{ [\sqrt{f_0 / gD}\,]\ U_s + 1 \}S$$

where,

U_s = Limiting velocity under free falling condition = $\sqrt{2mg / \rho_a CA}$

f_c = $\sin\theta + \mu_1 f_8 \cos\theta + \mu_2 f_9 \cos\theta$

where,

S = Velocity of particle

D = Particle diameter

g = Acceleration due to gravity

f_0, f_8, f_9 = Constants

θ = Inclination of pipe from horizontal

μ_1 = Coefficient of friction between particles and wall

μ_2 = Coefficient of friction between particles

C = Drag coefficient

A = Projected area of particle

ρ_a = Air density

m = Mass of single particle

The expression was found to be accurate not only for the steady state flow but also for acceleration zones.

Dass and Kashyap (1975) studied the changes in particle trajectory during fall in air stream with respect to variation in initial orientation. They concluded that the effect was more in maize, less in wheat and least in chaff. As the wind velocity was increased, the horizontal distance between the trajectories of chaff and wheat particles went on increasing.

Mizrach *et al* (1984) used density differential for separation of two sizes of spheres in a dry state by creating a state of fluidization and studied their traversing time. After creating a satisfactory fluidized bed, they traced the gravitational motion of the spheres, dropped onto the fluidized bed. They concluded that the terminal velocity and the depth at which it was reached, increased with the mass density of the spheres, which confirmed that there was a separation capability between agricultural products according to the differences in their mass density.

Saini *et al* (1984) conducted studies in an air aspirator on pneumatic separation of agricultural and non agricultural particles. They developed prediction equations using dimensional analysis for the amount of material carried away and observed that the materials carried away increased with increase in the air material mass flow rate ratio, Reynold's number, uniformity coefficient and decreased with increase in Grashoff's number. They found the effect of sphericity to be non significant.

Ishikawa (1985) described the transport characteristics of seed from measurements of air speed within the transport pipe and seed velocity with a high speed camera. He developed a seeding equipment with multi row distribution system and concluded that within the horizontal pipe of 89mm diameter and the bend of the pipe of radius of curvature R=1.2D, the grade of the air speed peaked in the vicinity of the wall of the pipe. He reported that the distribution of the air speed was uniform in the rising pipe section and a high correlation between the air speed transport quantity. He concluded that the minimum air speed required to transport seed constantly was 8 to 15.0 ms^{-1}. When the seed and air mixing ratio was under 0.2, the speed ratio of velocity of seed and air increased with decrease in seed mixing ratio and the value of speed ratio approached to the value of a seed. In the rising pipe, the number of rotation after collisions increased when the air speed was 21.79 ms^{-1}.

Ishikawa (1985) studied the effect of factors on the distribution accuracy of seed within the rising pipe. He recorded the flying tracks of floating seed three dimensionally using a high speed camera. He observed that when air speed was 22.5 - 24.0 ms^{-1}, the seeds larger than wheat were distributed uniformly in the cross section of the rising pipe at transport quantity of 30.0 gs^{-1} and the coefficient of variation of the distribution was below 12 per cent. The gradient of pressure observed around the flat board attached to the top of the rising pipe affected the trajectory of seed except seeds smaller than wheat.

Ishikawa (1985) analysed theoretically the floating mechanism of seed within the rising pipe and concluded that the distribution characteristics of the seed were represented by random variables excepting the phenomenon of the seed distributed at the bend of the pipe by gravity. He approximated the distribution characteristics of the seed in the vicinity of the distributor head by the hypothetical elastic collision theory and repeating the collision trial by random variable. He reported that the axial velocities of wheat and corn in the rising pipe decreased gradually as the seed approached the head of the pipe.

Ishikawa (1985) conducted experiments to predict the effect of the shape of a distributor head and did a mathematical analysis based on probability theory. He concluded that by installing the wavy walls, the distribution of the seed was uniform in comparison with the case of the flat wall, but for small seed the distributions effected by the wavy wall were little.

Chen *et al* (1994) developed a metal-oxide semiconductor linear image sensor to measure the velocity of falling grains. They obtained accurate grain velocity measurements and found that the sensor performed consistently for corn, soyabean and wheat. They measured grain velocity ranging from 3 to 6.7 ms^{-1} with errors less than 7 per cent for three falls. They suggested similar systems could also be developed for flow velocity measurement of granular particles.

2.5. Development of air assisted seed drill

Giannini *et al* (1967) concluded that vacuum systems that pick up individual seeds on the ends of hollow needles were found to work well in the laboratory. But they reported that the pick up needles plugged with dust in the field and the planter performance was unsatisfactory.

Inman (1968) concluded that a vacuum planter achieved excellent results in planting lettuce seed in small trials. The vacuum needles posed serious problems under dusty field conditions.

Anonymous (1971) reported that a seed planter with air powered metering and delivery system was developed, that placed seeds into the ground with amazing accuracy. It consisted of a PTO driven blower, a ground driven drum and rubber cut-off wheels.

Datta (1974) explained about the pneumatic type of metering patented in Germany as early as 1922. He informed that the individual seeds were sucked into an orifice of an evacuated cylinder and were ejected at a predetermined position by the interruption of vacuum. The seed so released was carried to the soil through a discharge tube. The orifice was then cleaned by a blast of air before it picked up a seed again from the seed mass. The pneumatic metering device was capable of handling a wide range of seeds of different size and shape and has a great potential in the field of precision planting.

Yadav (1976) developed a pneumatic paddy planter consisting of a cylindrical drum with seed metering unit in it, equal pressure hopper, an air blower with a small petrol engine and a frame with ground wheels. The cylindrical drum on its periphery contained 10 mm diameter cup with two holes of 2 mm diameter drilled in it for air leakage. Due to the static pressure built inside the cylinder, grains started sealing cup holes and rode over the cup of seed tubes fixed on central shaft beneath the top roof of the drum. The seed fell into the seed tube due to pressure.

Hassan (1981) developed an air assisted nursery precision drum seeder wherein the drum rolls in a hopper filled with seed and rigidly bolted to the frames. The air jet located above the drum surface was applied to blow excess seed off the drum holes leaving single seed. As the drum rolls further, it brought the seed to the seed bed. At that time vacuum was cut off to release the seed.

Ghate *et al* (1981) evolved a design using compressed air to plant seed gel mixture. A solenoid operated poppet valve changed the planting mode to sow tomato and pepper seed accurately at equal distances.

Anonymous (1988) explained about a new Accord DC grain and fertilizer pneumatic seed drill developed and handled in the UK by Ferrag. The unit was designed for use both as a straight grain drill and as a combine drill. The results from yield trials in Scotland on spring sown cereals showed 25 per cent increase in yield when compared with crops sown by conventional straight grain drills.

Morrison Jr. *et al* (1988) developed an air planter consisting of a central seed hopper with a meter that discharged seed into an air distribution and delivery system. They concluded that air seeders could be used for planting small seeds and also for soyabean.

Anonymous (1989) reported that a new air seed drill combination using Ferrag Accord seed drill was developed, consisting of a hopper, metering and blower mechanism mounted on the linkage at the front. The metered seed was blown from the front mounted hopper to the drill mechanism at the rear. A scraper crumble was provided to consolidate the surface after drilling.

Anonymous (1990) reported that Ferrag Rau Rotosem/Accord drill combination with Accord metering system enabled sowing rates of 1 to 350 kg ha^{-1} in 3, 3.6 and 4.0 m working widths. The seed was injected directly into the soil to give accurate depth and distribution. Massey Ferguson tractor mounted fold and go 510 pneumatic drill was reviewed. The system allowed automatic control of tramlining and markers, monitoring the feed shaft, air delivery system and hopper seed level. He also reported about a Supaseeder pneumatic drill matched to the Vicon rotary power harrow and was available in size of 3 and 4 m.

Marshall (1991) reported about the Massey Ferguson's MF510 air drill with a working width of 4m having 32 rows at 125mm spacings. He explained that the hopper capacity was 1573 litres and the seeds were delivered to the coulter through the distributor head by air flow. He also detailed about Simba tilth drill consisting of an Accord pneumatic drill distributor.

Howard (1991) reported that the 'Accord' a'- seed drill consisted of a metering unit fitted at the base of the hopper delivering seed to a pneumatic distributor and thence to the coulters. The fan for the seeding system was powered by the tractor's PTO. He reported that the coverage of 3 and 4m seed drill was 1.6 and 2.0 ha h^{-1} respectively and the tractor sizes needed were 74-104 and 96-126 kW respectively.

Howard (1991) reported that the Concorde combination till and drill was a pneumatic seed metering system based on the Accord mechanism. It consisted of a seed distributor to distribute the seed with air flow and was of 6 and 8 n width having a hopper capacity of 2200 and 2500 litres respectively.

Anonymous (1992) reported a combi pneumatic drill with 1.5t capacity front mounted seed hopper for weight distribution. Two pipes fed the seed from the two pneumatic calibration units for distribution to the coulter bars. The complete drill and power harrow could be quickly folded to 3m width.

Anonymous (1992) reported that a Rau-Rotosem pneumatic seeding aggregate (Accord system) was developed which consisted of a blower, cell wheel for seed metering, injector control valve, corrugated vertical tube for uniform seed and air mixture and distributor head. The system was suitable for all sizes and quantities of seeds from 1 to 360 kg ha^{-1} and had a hopper capacity of 500 litres.

2.6. Performance evaluation of seed drill

Bainer (1947) tested ten planters with vertical and horizontal plates and concluded that the vertical plate planter was the best with field emergence of 55-65 per cent. He also concluded that the proper placement of seed was crucial for maximum emergence.

Bjerkan (1947) while reviewing planting observed slippage of ground driven wheel, high planting speed and size of seed as the parameters causing irregularities in the rate of planting.

Roth and Porterfield (1960) studied the horizontal plate seed metering devices and concluded that the present metering device were inadequate due to the demand for faster planting speeds. They reported that an increase in plate cell speed decreased the cell fill after a certain cell speed was reached.

Brandt and Fabian (1964) reported that increasing the number of cells per plate beyond 16 and reducing the rpm did not increase cell fil' accuracy in proportion to the increase in the number of cells.

Chittey and Perkins (1967) developed a simple system for recording sugar beet plant distribution by perforating paper strip which was then automatically analysed. The use of paper strips provided a permanent record to which reference could be made subsequently if required.

Barmington (1968) determined the degree of precision in seed dropping with all types of planter by simulating a field speed for the planter and passing a greased board on a moving belt beneath the planter at the same speed. He concluded that a large diameter vertical seed plate was good for gentle seed handling.

Wanjura and Hudspeth Jr. (1968) studied the horizontal edge drop plate planter for planting acid delinted cotton seed using greased board technique over long time intervals at ground speed upto 9.66 kph. They reported that the metering variations were caused predominantly by the hopper bottoms followed by plate speed.

Rohrbach *et al* (1969) developed a stochastic model for systems designed to produce uniform spacings of planted seed as a consequence to statistically characterise the plant spacings produced by these systems using horizontal plate seed metering mechanism. He modelled the number of seeds that occupied a seed cell at the time of discharge, the drop error and the survival factor.

Wanjura and Hudspeth Jr. (1969) designed a vacuum wheel to meter single acid delinted cotton seed and tested its performance with an endless belt on the vacuum wheel mounted over the belt. Vacuum was provided to the wheel by a pump. Belt speed, vacuum pressure and wheel speed were varied independently. The results of this study showed that the vacuum-mechanical principle was one method of metering cotton seed at precise intervals.

Hudspeth Jr. and Wanjura (1970) constructed a vacuum wheel to meter single delinted cotton seed where the vacuum port was located on the front side for mechanically assisted pickup. Field tests conducted for comparing the vacuum wheel and a conventional grain drill double run wheel planting had a germination of 90 per cent. Wheel speeds from 20 to 25 rpm and vacuum of 25 mm to 125mm of mercury had only minor influence on the performance of the vacuum wheel, other tests showed that a mechanically assisted vacuum pickup was superior to a system using only suction.

Rohrbach *et al* (1971) evaluated a Monte Carlo planter model with the horizontal cell plate, vertical cell plate, belt type planter, a transplanter and vacuum metering mechanisms. The model contained three random variables viz., selection of a single seed from a large population, discharge of the seed and its placement in the soil and development of the seed into a plant, of which the standard deviation of the drop error was examined as a means of specifying the precision in the row plant spacing. They concluded that the probability density function of the random variable of the Monte Carlo model which characterises seed cell fill could be interpreted as a measure of the precision of metering accuracy and singulation. The plant spacings obtained from the model was described as a folded back normal distribution.

Rohrbach and Kim (1972) concluded that the precision of conventional planting equipment was dependent on the ability of a metering unit and to transport this seed to the furrow.

Chhinnan *et al* (1975) investigated the effect of planting speed, seed size and seed level in the hopper on the metering accuracy and the seed placement accuracy of a inclined plate planter using photo-diode and belt experiments. The levels of planting speed were 1.61, 3.22 and 4.83 kph. Seed sizes were of 7.14 - 7.94mm, 7.94-8.73mm and greater than 7.14mm diameter. He used the seed levels in the hopper as a factor also. He concluded that higher planting speeds resulted more skips, higher seed placement errors and higher average spacings and as the level of seed in the hopper decreased the number of skips increased and average spacings increased.

Speelman (1975) studied the seed and developed a mathematical model simulating the effect of band-width, number of seeds per unit length and transverse seed distribution on the distribution pattern. He did field experiments comparing drilling, band sowing and broadcast sowing and concluded that compared to normal drilling, band sowing had advantage.

Srivastava (1975) tested sowing sugarbeet seed with a stationary hole type metering manual seed drill provided with nylon brush type agitator. He reported that the average seed spacing obtained was 50mm.

Wilkins and Lenker (1981) designed, developed and tested a microprocessor controlled planter to meter small irregularly shaped seed such as lettuce and had multiple plants of 3.7 per cent and lower standard deviation of spacing than other seed drills during field trials.

Snyder and Hummel (1985) studied low pressure air nozzles to remove seeds from the seed cells of a pressurised drum planter for ranges of seed density, seed drum angular velocity and nozzle orifice diameter and supply pressure. They concluded that an 8mm nozzle orifice diameter produced significantly better seed selection than a 6, 7, 9 or 10mm nozzle orifice diameter. The 8mm diameter orifice nozzle supplied with air of 9.7kPa had selection percentage equal to or better than a conventional seed release wheel for seed drum angular velocities between 17 and 83 rpm.

Shafii and Holmes (1990) investigated metering of seed by an air jet flowing through a conical cavity and used spherical balls of various diameters to represent seed. He measured the pressure distribution and forces exerted on the ball for different cone configurations (60, 90, 120, 150 and 180 deg), orifice diameters (0.34, 0.71 and 1.40mm). He showed that a significant retaining force existed between the spherical seeds and the cone for seed cone clearance in the 0.2 to 1.5mm range and force increased as air pressure increased.

Shafii *et al* (1991) developed a new air assisted seed singulation and compared its performance with mechanical singulators. He conducted air jet singulation experiments with three vacuum levels (250, 350 and 450mm of water), three levels of air jet pressure (20.7, 27.6 and 34.5 kPa), three levels of metering plate linear speed (63.6, 130.7 and 240.3 mm s^{-1}) and three different positions of the air jet singulator. He concluded that the systems gave acceptable levels of planting efficiency, singles, skips, doubles and multiples over the parameters used in this study.

Shearer and Holmes (1991) designed and evaluated a device using the submerged turbulent air jet concept for precision metering of seed. He analysed the effect of nozzle diameter, air flow rate and nozzle to seed clearance on singulation and retention of seed for metering. He found the metering accuracy be sensitive to nozzle supply pressures, over the range of rotational speeds of 30 to 50 rpm, operated at nozzle supply pressures of 25 to 40 kPa for corn and 20 to 25 kPa for soyabeans. He reported that the theoretical drop decreased by as much as 40 per cent as the metering speed was increased from 30 to 50 rpm at a constant nozzle supply pressure.

Zulin *et al* (1991) developed a hydropneumatic seeder to singulate and meter primed wet celery seed and metered the seed of 1.53 mm average diameter with planting efficiency in the range of 89.4 to 107.2 per cent as the linear speed of the metering holes was changed from 100 to 500 mms^{-1}. He reported only a few doubles and misses as the linear speed of the metering hole (100-500 mm s^{-1}), applied vacuum level (300-600 mm), air flow rate (170- 230 l min^{-1}) and knock off pressure (13.8 to 69 kPa) were varied over a wide range.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

In this chapter, the methods adopted to measure the physical and aerodynamic properties of seeds selected under the study are mentioned. The method of developing different types of seed distribution head are explained. The development of an experimental set up to change the machine and operational parameters affecting the performance of air assisted seed metering system is explained. The experimental procedure leading to the scientific analysis of the systems interms of the uniformity of seed distribution to the furrow openers and the pressure developed are enumerated. A novel videographic technique to measure the actual path traced by the seed in the system is detailed. The materials and methods of fabricating a field level prototype pneumatic seed drill are given. The procedure of field evaluation of the seed drill for sowing different seeds selected are also discussed.

3.1 Physical properties

The behaviour of the seed metered into the air stream of an air seeder depends on its physical properties. The size and shape, frontal area, density, weight, angle of repose and coefficient of restitution of sesame, pearl millet and sorghum were measured using standard techniques.

3.1.1 Size and Shape

One of the important parameters that influence the conveying of solid materials by air is the shape of the material. The size and shape of the seeds selected viz., TMV6 sesame, Co7 pearl millet and Co26 sorghum were determined by image projection technique (Waziri and Mittal, 1983).

Ten seeds of sesame were selected in random. One of them was placed on an overhead projector and the outline of the projected boundary was traced on the screen. The seed was rotated 90 ° about its longitudinal axis and the projected image traced. From the outline of projected image, the major (L_1), intermediate (L_2) and minor (L_3) axes (Mohsenin, 1980) were measured to determine the size of the seeds by accounting for magnification factor.

Using the projected boundary of seed traced, the diameter of largest inscribed circle (d_i) and diameter of smallest circumscribed circle (d_c) were drawn and the sphericity was calculated as d_i/d_c (Curray, 1951). The observations were recorded. The procedure was repeated for all the ten seeds of sesame, pearl millet and sorghum.

3.1.2 Frontal area

The frontal area of the seed significantly influence the air stream velocity when multiple seeds cluster during conveyance.

Assuming ellipsoidal geometry, the frontal area of sesame was calculated from the following relationship (Bilanski *et al*, 1962).

$$\text{Frontal area} = \pi L_1 L'_2 / 4 \qquad \text{---------} \ 3.1$$

where,

$$L'_2 = L_2 + L_3 / 2$$

The frontal area of pearl millet and sorghum was calculated from the following relationship assuming spherical shape (Keck and Goss, 1965)

$$\text{Frontal area} = \pi d^2 / 4 \qquad \text{---------} \ 3.2$$

where,

$$d = L_1 + L_2 + L_3 / 3$$

3.1.3 Seed weight

Thousand seeds of sesame selected at random were weighed in an electronic weighing balance having sensitivity of 0.01g. The experiment was replicated ten times and the observations were recorded. The procedure was repeated for pearl millet and sorghum.

3.1.4 True density

The true density of pearl millet and sorghum seed was measured by the water displacement method as described by Dutta *et al* (1988).

Pearl millet seed of 250g was weighed and dropped into a transparent measuring cylinder having known volume of water. The volume of water displaced was noted as the volume of seed. The experiment was replicated five times and the values were tabulated. The true density was calculated as the ratio of weight by volume. The same procedure was used to determine the true density of sorghum seed.

The true density of sesame was calculated by measuring its porosity and bulk density since it floated on water. The porosity of sesame seed was measured using the device proposed by Day (1964). Seeds were filled in a tank and air was supplied to a second tank without seed until a suitable manometer displacement was achieved. The steady state pressure P_1 was noted. Then the air was allowed to enter the grain tank and the steady state manometer reading P_2 was recorded. The experiment was replicated five times and the observations were tabulated. The porosity of sesame (P) in fraction was found by the following equation.

$$P = P_1 - P_2 / P_2 \qquad \text{---------} \; 3.3$$

The bulk density of the sesame seed was found by weighing known volume of seed. It was repeated for five samples and the values were recorded. The true density of sesame was calculated by the following relationship adopted by Scheidegger (1957).

$$\rho_t = \rho_b / 1 - P \qquad \text{---------} \; 3.4$$

where,

ρ_t = True density, kgm^{-3}

ρ_b = Bulk density, kgm^{-3}

P = Porosity, fraction

3.1.5 Angle of repose

Angle of repose of the different types of seed was determined by the method suggested by Waziri and Mittal (1983). Sesame seed was heaped over a circular disc of 200mm diameter by allowing it to fall from a height of 300mm until maximum height was reached. The height of the seed heaped was recorded. The experiment was replicated five times and the readings tabulated. The angle of repose was determined by the following relationship.

$$\theta = \tan^{-1} (h / r) \qquad \text{--------- } 3.5$$

where,

θ = Angle of repose, °

h = Height of the cone, m

r = Radius of the cone, m

The same procedure was used for pearl millet and sesame to determine the angle of repose.

3.1.6 Coefficient of restitution

It is used as an indicator of energy absorption of the backstops. A low coefficient represents a high degree of energy absorption capacity.

Sesame seed was dropped from a height of 500mm on 3mm thick acrylic sheet. A graduated scale of 1000mm was kept at the background. The maximum height of rebound of the seed was recorded using high speed videocamera and the height reached was measured in the television monitor using editing unit. This was replicated ten times and the coefficient of restitution was calculated using the following relationship, Whitney and Porterfield (1968).

$$\text{Coefficient of restitution} = \sqrt{h / H} \qquad \text{--------- } 3.6$$

where,

h = Height of rebound, mm

H = Height of drop, mm

The same procedure was adopted to measure the coefficient of restitution of pearl millet and sorghum. The same was repeated for 18 swg mild steel sheet for the three types of seed and the observations were tabulated.

3.2 Aerodynamic properties

The air velocity and energy required for the movement of grain in an air stream are to be studied for pneumatic conveying and distribution of seed. The aerodynamic characteristics measured were the terminal velocity and drag coefficient.

3.2.1 Terminal velocity

The terminal velocity of the seed was measured using a terminal velocity determination apparatus (Hawk *et al*, 1966 and Shellard and MacMillan, 1978). The air velocity required to keep a single sesame seed in suspension without any appreciable vertical movement was measured using an electronic anemometer with gradual adjustment in supply of air. The experiment was replicated for the ten seeds for which the geometry was measured as explained in section 3.1.1 and the readings were tabulated. The same procedure was used for finding the terminal velocity of pearl millet and sorghum.

3.2.2 Drag coefficient

The drag coefficient was calculated from the weight, mass density, projected area and terminal velocity of the seed and mass density of air (1.293 kgm^{-3}) at standard temperature and pressure using the following equation (Bilanski *et al*, 1962).

$$C_D = 2W(\rho_p - \rho_a) / (V_t^2 A_p \rho_p \rho_a) \quad \text{---------} \quad 3.7$$

where,

C_D = Drag coefficient

W = Weight of seed, kg

ρ_p = Mass density of particle, kgs^2m^{-4}

ρ_a = Mass density of air, kgs^2m^{-4}

V_t = Terminal velocity, ms^{-1}

A_p = Projected area, m^2

3.3 Development of seed distributor head

Seed distributor head along with a vertical conveyance pipe forms a critical component that ensures uniform distribution of seed between rows in an air seeder. The principle behind the operation of distributor head and the factors influencing its design has not been investigated and reported. In this study, an attempt was made to fabricate distributor heads based on different principles of distribution and their relative performance was evaluated.

3.3.1 Principle of distributor head

In order to obtain uniform distribution of seed to all furrow openers, the seed suspended in the air stream of the vertical conveyance tube should be divided equally by the distributor head so as to obtain same quantity of seed in all the outlet tubes. This was aimed to be achieved through completely random distribution of seed in each of the outlet. Three distributor heads with different configuration were developed for the study based on the following principles :

i. Random path device

ii. Random sampling device

iii. Streamlined sampling device

The random path device made the seed to impinge on circular plate, held perpendicular to the direction of travel of the air-seed mixture. The seed emerged out around the periphery due to completely randomised path traced by each seed. The seeds were divided from the periphery and directed into seed tubes.

The random sampling device diverged the seed flow pattern into a closed funnel shape. The seed outlet tubes were attached to the closed end of the funnel. As the air entering the head pass through the outlet tube, it carries the seed randomly from the distribution chamber.

In a streamlined sampling device, the seed randomly travelling in the vertical air column were made to diverge into an annular area between the two conical surfaces from where it was divided and made to converge in a streamlined manner towards the seed outlet tubes.

a. Parallel disc distributor

The distributor was developed based on random path device principle. The parallel disc distributor is illustrated in Fig 3.1. It consisted of two concentric discs of 150mm diameter, spaced 18 mm apart. The distributor was fabricated using 3mm acrylic sheet as it is easier to observe the seed flow pattern. The periphery of the disc was divided into nine equal divisions so that the fllow of air seed mixture gets divided into nine streams. The bottom disc was fitted with a 55mm diameter transparent tube for connecting the distributor head to the vertical seed conveyance pipe. The distributor is shown in Plate 3.1.

b. Closed funnel distributor

This distributor was fabricated based on the principle of random sampling device. The construction of the closed funnel distributor is shown in Fig.3.2. It was fabricated with 3mm acrylic sheet. The distributor had an inverted truncated section closed at the wider end. The diameter of the hollow cone at the top and bottom were 180 and 55mm respectively. The wider end of the cone was closed by a concave disc. At the circumference of the concave disc, the flow of air seed mixture was divided into nine equal parts by fitting triangular deflector baffles, Plate 3.2. The air seed mixture thus divided in the distributor was discharged through the tubes of 25mm diameter.

c. Streamlined flow distributor

The streamlined flow distributor was developed based on streamlined sampling device principle. It consisted of two hollow conical sections arranged as shown in Fig 3.3. The nine outlets of the distributor were curved with a radius of curvature of 30mm to have smooth discharge of seed. A 55mm diameter acrylic pipe was fitted at the bottom of the distributor

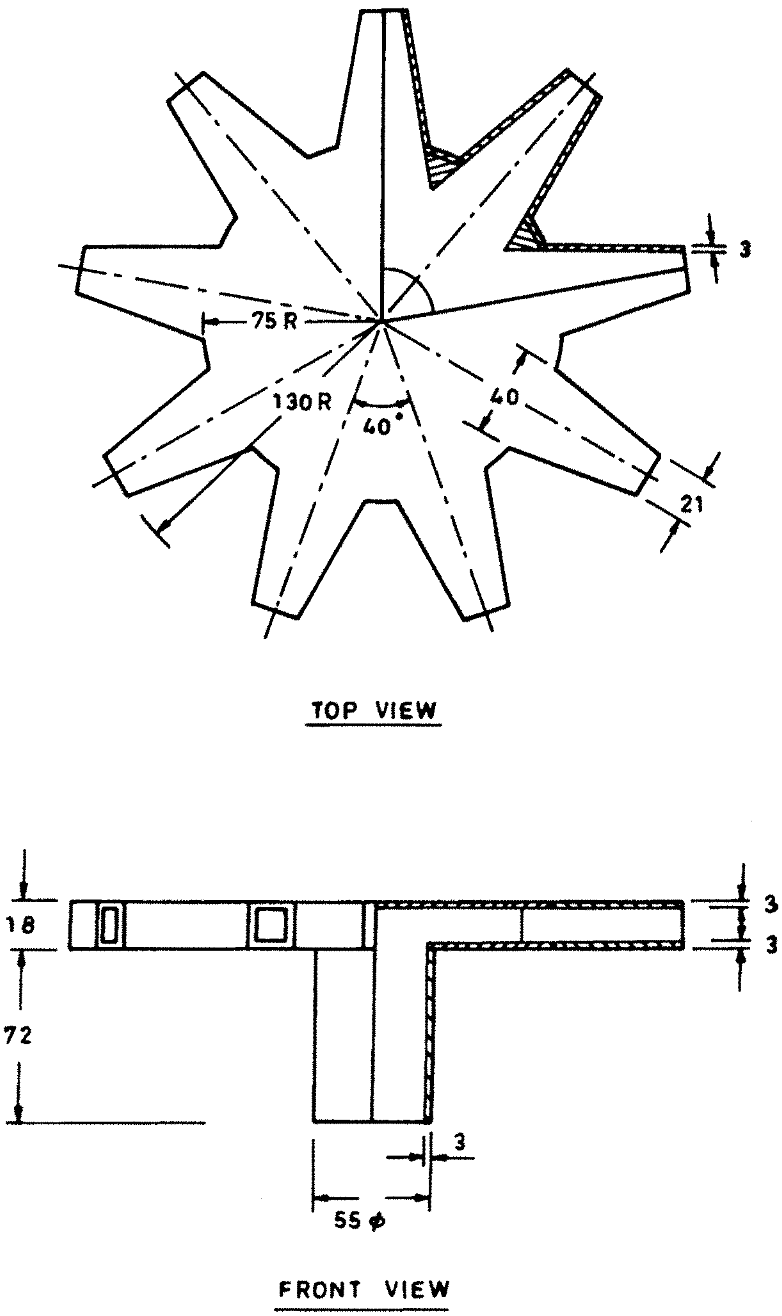


Fig. 3.1. PARALLEL DISC DISTRIBUTOR

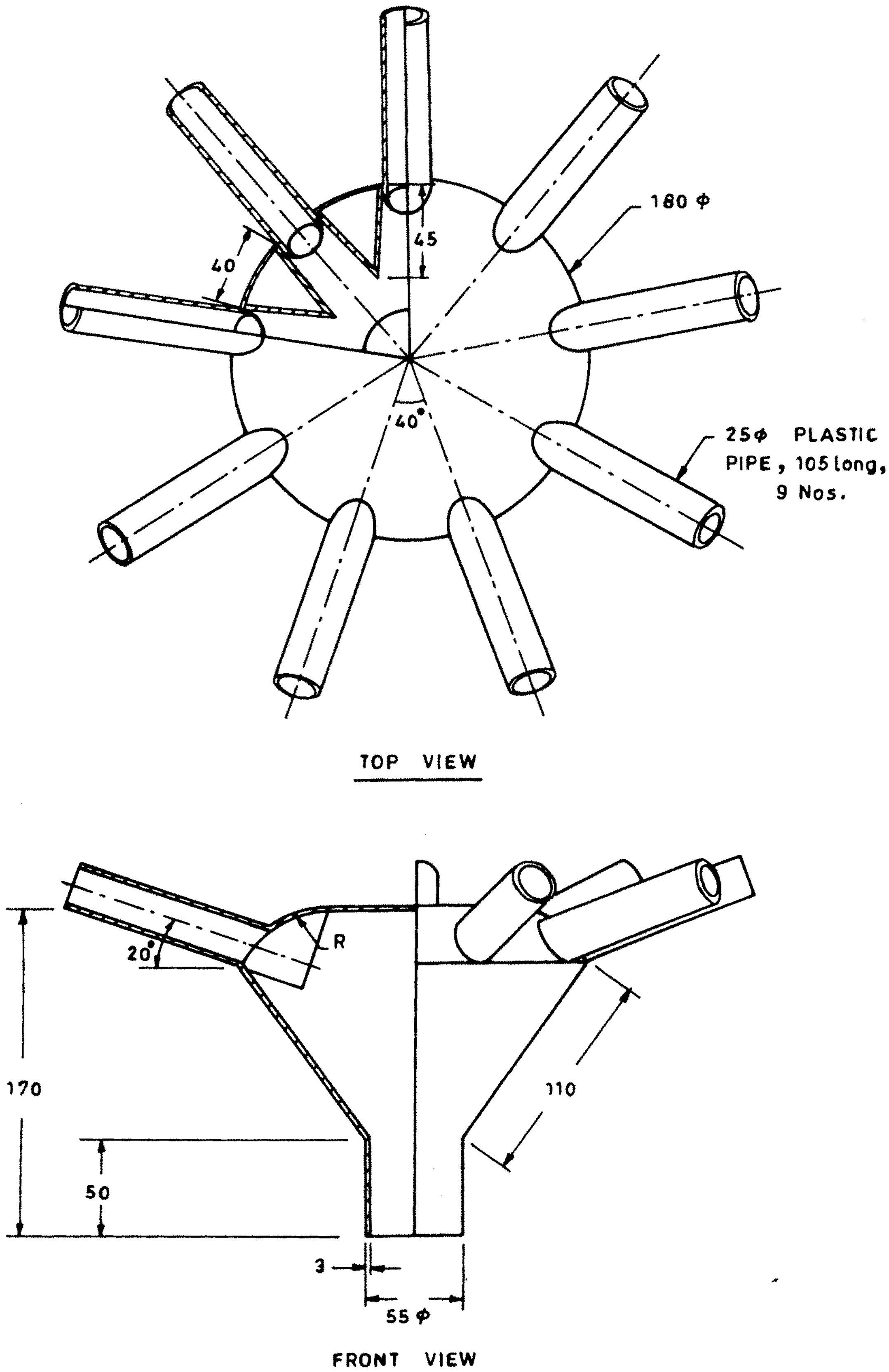


Fig.3.2. CLOSED FUNNEL DISTRIBUTOR

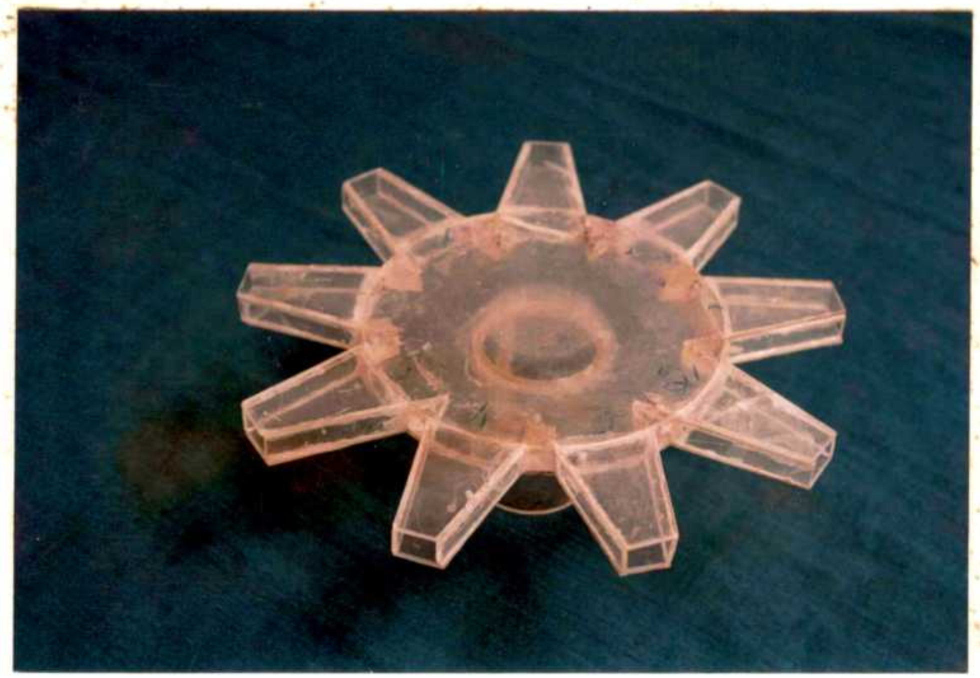


PLATE 3.1. PARALLEL DISC DISTRIBUTOR

PLATE 3.2. CLOSED FUNNEL DISTRIBUTOR

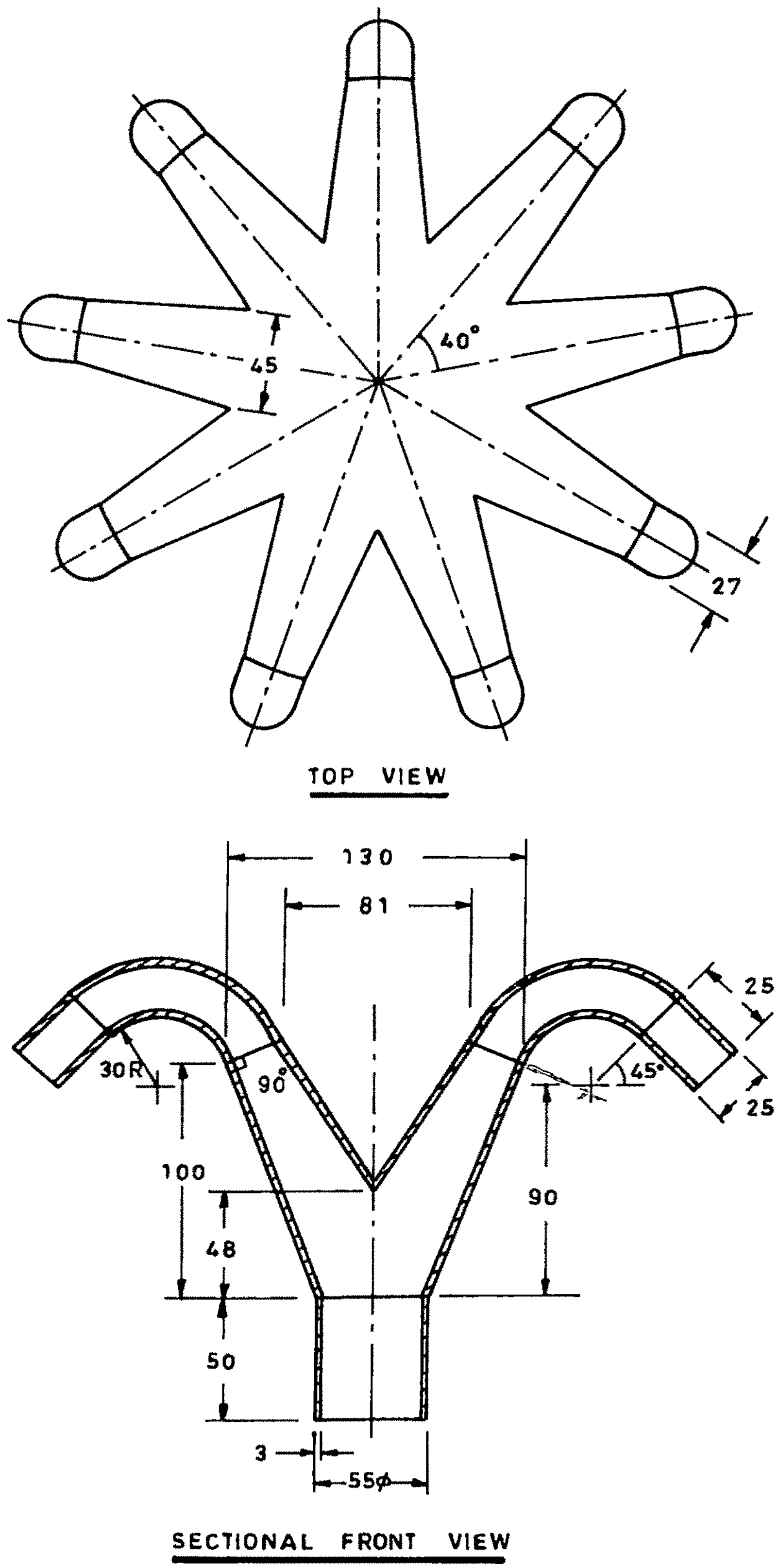


FIG 3·3 STREAMLINED FLOW DISTRIBUTOR

for fixing it easily with the vertical seed conveyance pipe The distributor is shown in Plate 3 3

3.3.2. Development of test rig

It is desired to investigate the effect of crop parameter viz, seed feed rate and machine parameter namely air velocity and the configuration of the distributor head on the uniformity of seed distribution in the outlet pipe It involves various levels of the above mentioned variables and their interactions Hence development of experimental set up in which the above parameters can be varied at will in desired steps for accurately determining the effect of various factors is essential To accommodate change in all the variable levels and to carry out the experiments, a test rig was specially developed and fabricated as shown in Fig 3 4

a. Control of seed feed rate

The unit (Plate 3 4) consisted of a seed hopper of 7kg capacity fitted with internal double run mechanism to feed the seed so that experiment for five treatments could be completed in one filling Provision was made in the feeding mechanism to adjust the seed flow from 3 5 to 9g per revolution of the rotor for sesame seed Pearl millet seeds could be controlled from 4 0 to 8 5g per revolution The same for sorghum seed was 4 0 to 7 5g per revolution The seed feeding unit was driven by a D C motor of 17W By changing the voltage input to the motor using a 10 ohms rheostat, the rpm of the motor could be changed from 0-40 Thus variable drive was obtained precisely to the seed feeding mechanism This arrangement ensured accurate control of seed feed rate The seed on entering the vertical conveyance pipe was resisted because its inside pressure being higher than atmospheric pressure In order to suck the seed inside, partial vacuum was created at the threshold point in the vertical conveyance pipe by fitting an eductor as shown in Fig 3 5

PLATE 3.3. STREAMLINED FLOW DISTRIBUTOR

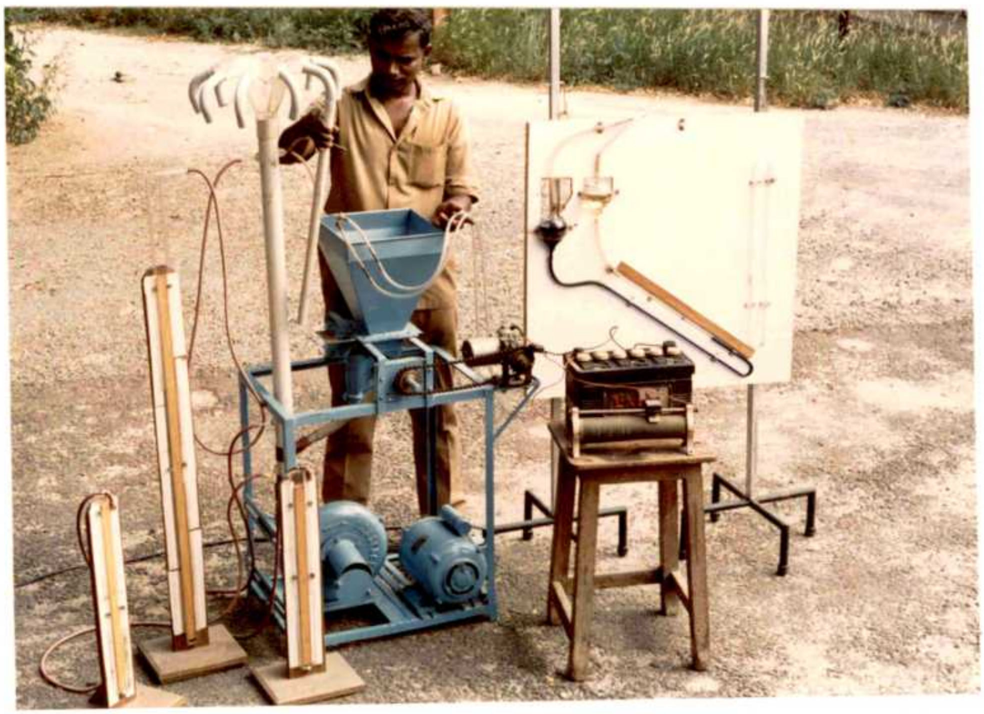


PLATE 3.4. TEST RIG FOR PERFORMANCE EVALUATION OF DISTRIBUTOR

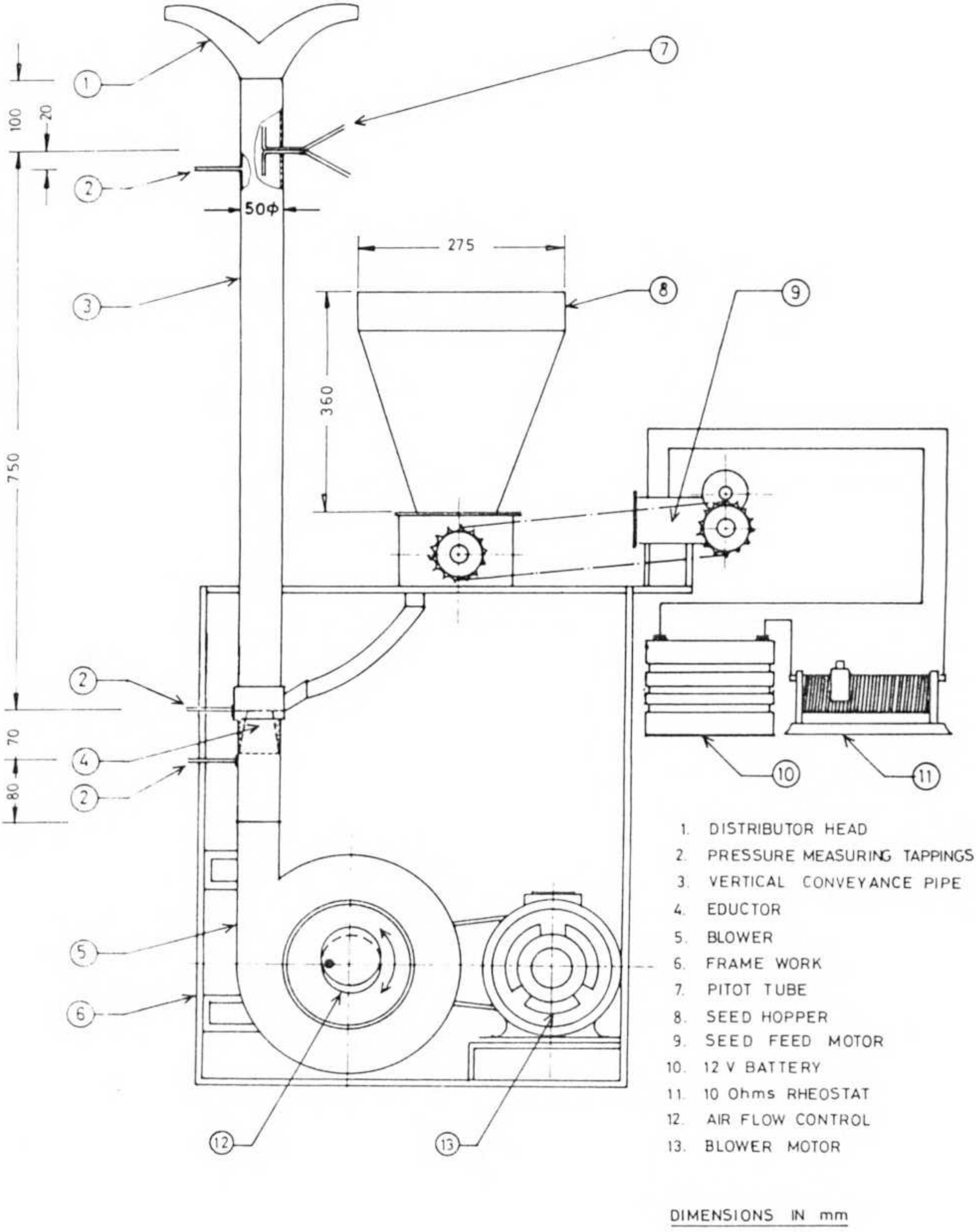


FIG. 3·4 TEST RIG FOR PERFORMANCE EVALUATION OF DISTRIBUTOR

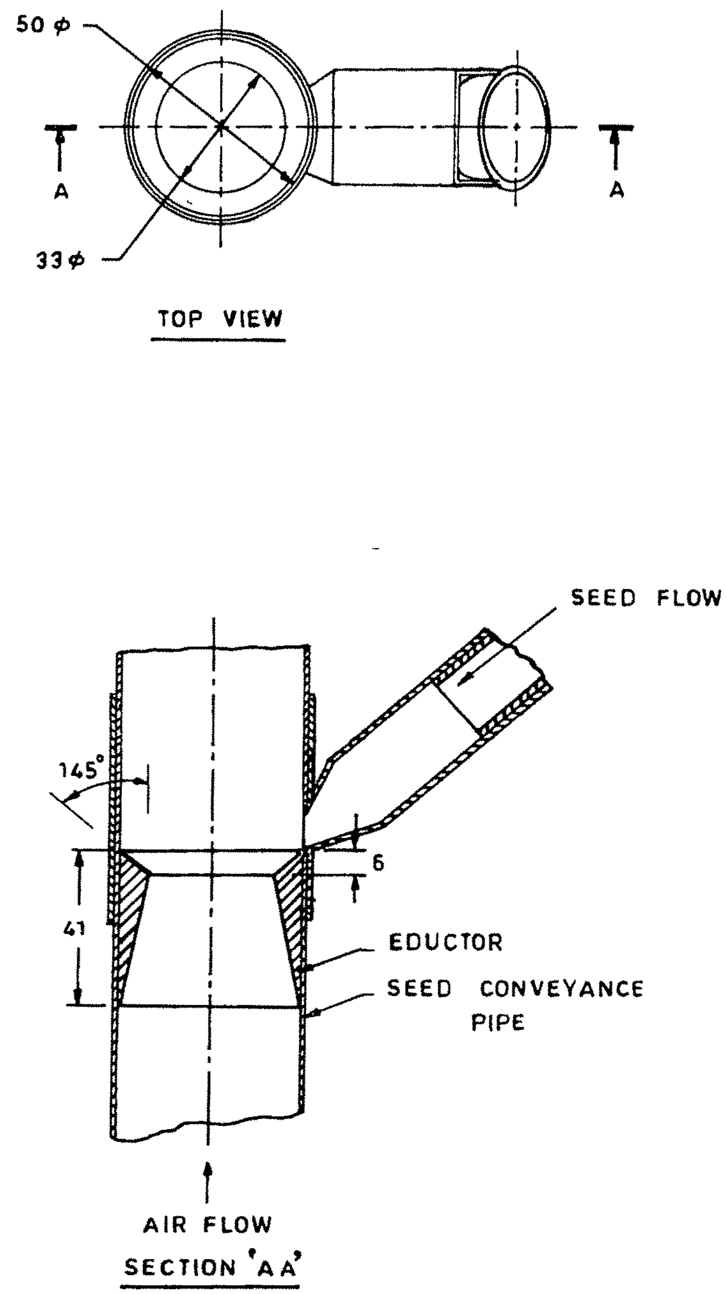


Fig. 3.5. EDUCTOR

b. Control of air velocity

A motorised blower of 373W was fitted with butterfly valve in the inlet to adjust the air flow rate in the vertical conveyance pipe from 0-15 0 ms^{-1} The air velocity was measured with the help of a pitot tube fixed in the vertical conveyance pipe and connected to a micromanometer

The control of seed feed rate and air velocity arrangements in the test rig could supply air seed mixture at different proportions and velocities Pressure measurement tappings were fixed at three places as shown in Fig 3 4 to measure the blower, eductor and head pressure The distributor head could be easily attached and detached from the test rig

3.3.3 Instrumentation for measurement of air velocity

A pitot tube was used to measure the velocity of air in the vertical conveyance pipe and at the outlet of the distributor head The pitot tube is highly sensitive to measure even very low velocity It is very small in size and hence it could be conveniently positioned in the cross section of the pipe to get the velocity pattern very accurately It does not obstruct the seed flow in the air stream

a. Pitot tube

To measure the velocity head, a pitot tube was specially developed The construction of the pitot tube is shown in Fig 3 6C It has two impact orifices pointing in opposite directions, Coulson and Richardson (1970)

Two copper tubes of 1 5mm outer diameter and 0 5mm inner diameter were bent to 'L' shape The construction of the pitot tube confirms to the specifications of a Prandtl pitot tube, Sirohi and Radhakrishna (1983) The tubes were arranged to face opposite direction and soldered together The orifice mouth of both the tube ends was filed without burrs to avoid any disturbance at the inlet

As the air velocity to be investigated ranged from 4 to 8 ms^{-1} in view of the terminal velocity of the three selected seeds, the dynamic head as measured by the pitot tube was in

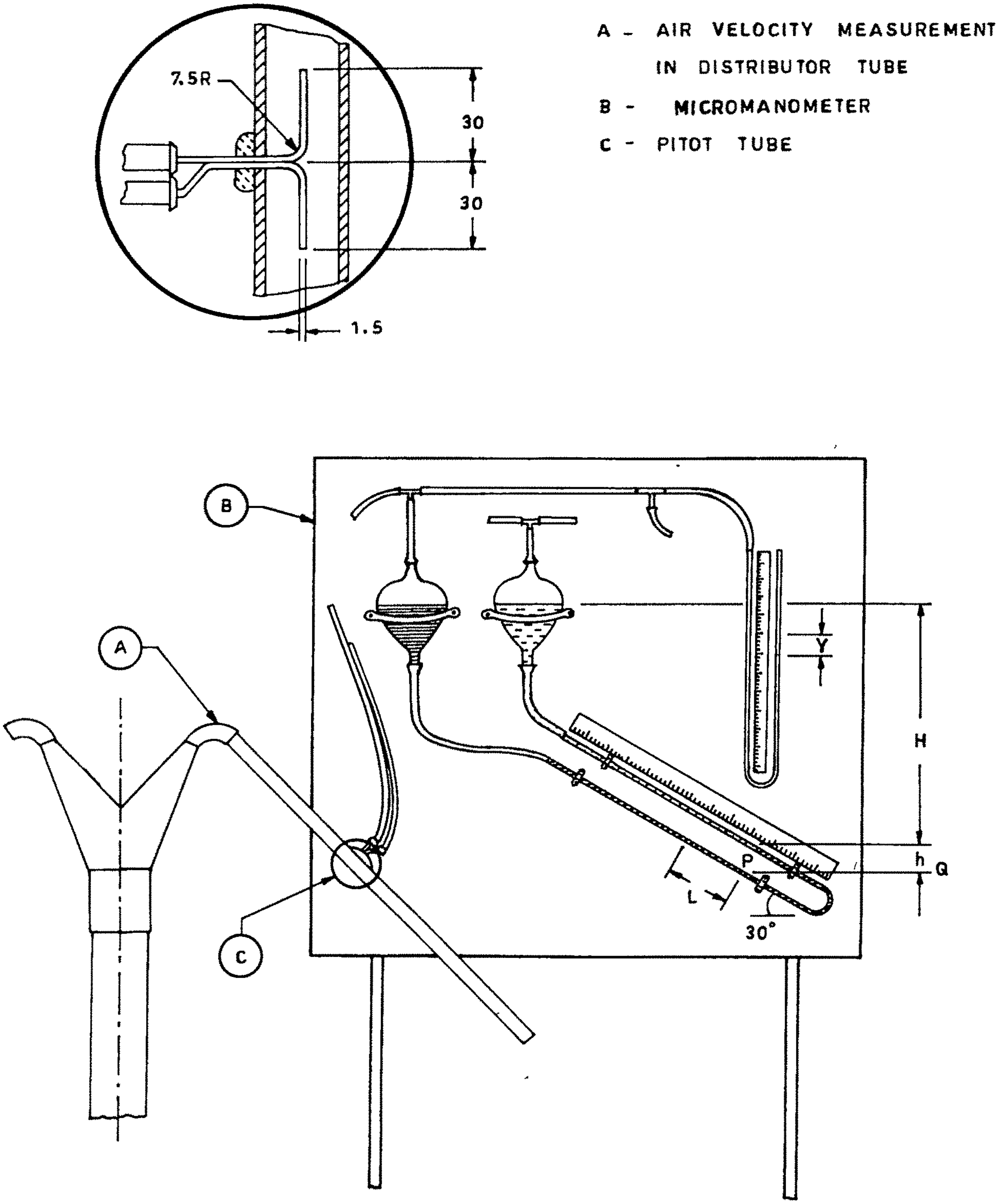


Fig.3.6. INSTRUMENTATION FOR MEASUREMENT OF AIR VELOCITY

the order of 3 to 15mm of water column It is relatively difficult to observe any differential reading owing to fluctuation of the velocity caused by seed movement using an ordinary 'U' tube manometer Hence an accurate micromanometer was required to precisely measure the air velocity

b. Micromanometer

An inclined tube micromanometer Fig 3 6B was used to measure the pressure differential developed across the pitot tube The micromanometer was constructed and used as developed by Sajikumar *et al* (1990) The density differential between the two manometric fluids viz, water and kerosene was utilised to amplify the minute pressure difference sensed by the pitot tube The displacement of the miniscus was further amplified by adopting an inclined tube for measuring the head Equating the pressure head at both limbs of the manometer, with reference to datum line (PQ)

$$Y + H \times 0\,8 + h \times 0\,8 = H \times 0\,8 + h \times 1\,0 \qquad \text{---------} \; 3\,8$$

$$\text{Therefore, } h = 5Y$$

where,

Y = Pressure applied in mm of water column (level difference in vertical manometer)

h = Vertical difference in levels in the inclined manometer

H = Vertical difference in levels from the manometer liquid tank height to inclined manometer

$$L = h / \sin 30$$

where,

L = Inclined level

$$\text{Therefore, } L = 5Y / 0\,5 = 10Y \qquad \text{---------} \; 3\,9$$

c. Calibration of pitot tube and micromanometer

The pitot tube micromanometer system was calibrated for air velocity using an anemometer An electronic anemometer (Machine Control Company Private Ltd), capable of measuring air velocity from 0-15 ms^{-1} was installed on the mouth of the vertical conveyance pipe The air velocity was varied in the range of 3 - 15 ms^{-1} at an interval of 1 ms^{-1} using the blower and adjusting the butterfly valve The corresponding dynamic heads were measured on the micromanometer The calibration chart relating this two parameters was drawn

Air velocity in the individual distributor head outlet tube was measured using a pitot tube micromanometer combination (Fig 3 6A) The air flow from the outlet tube was straightened with a 600mm long 25mm diameter pipe The pitot tube was fitted at the mid point of the pipe for accurate air velocity measurement

3.4 Performance of distributor heads

The function of the distributor head was to uniformly distribute the seed through different seed outlet tubes The pressure drop should be minimum possible so as to maintain the air velocity well above the terminal velocity The variables affecting the performance of the distributor head were the air velocity, seed feed rate and the distributor head configuration

The lower and upper levels for each of the above variables were fixed as follows

i The lower level of air velocity was chosen above the terminal velocity at a value when the particular type of seed begins to get conveyed The upper level was fixed just to avoid violent impact of seed in the distributor In between, 4 levels of air velocity were selected at an interval of 0 5ms^{-1} It is an important variable affecting the performance of the distributor, which requires optimisation It is a continuous variable and can be used for developing analytical relations

ii The seed rate for sowing sesame, pearl millet and sorghum in dry land with a crop spacing of 300 x 150mm was 5, 15 and 15 kg ha^{-1} respectively, Crop Production

Guide (1991) The seed feed rate levels were chosen to obtain the seed rate required for the particular type of seed, when the tractor forward speed was set at 2 5, 3 0, 3 5 and 4 0 kph, Annexure I Moreover the normal sowing speed with mechanical seed metering device is in the range of 2 to 3 kph But an air seed drill may have to cater the higher sowing speed and hence the levels were extended upto 4 0 kph for experimentation The levels of variables for the seeds under study are presented in Table 3 1

Table 3.1 Level of variables for different seeds

Number of distributors = 3

Type of seed	Seed rate kg ha^{-1}	Air Velocity ms^{-1}	Seed feed rate at various operating speeds g min^{-1}			
			2 5kph	3 0kph	3 5kph	4 0kph
Sesame	5 0	4 0, 4 5, 5 0, 5 5	57	68	79	90
Pearl millet	15 0	5 0, 5 5, 6 0, 6 5	168	203	238	273
Sorghum	15 0	6 5, 7 0, 7 5, 8 0	168	203	238	273

3x3x4x4 = 144 Treatments

3.4.1 Experimental procedure

The parallel disc distributor was fitted over the vertical conveyance pipe in the test rig shown in Fig 3 4 Sesame seed was filled in the hopper An air velocity of 4 0 ms^{-1} was set in the vertical conveyance pipe Seed feed rate of 57gmin^{-1} was selected The air velocity in the nine outlet tubes of the distributor head was recorded as shown in Fig 3 6A During the experiment in each outlet tube of the distributor head, net bags were tied to collect the seed for one minute The seed collected was weighed in an electronic balance and the readings were noted This was replicated three times and all the readings were recorded The above experiment was repeated for the closed funnel and streamlined distributor heads Then the air velocity was changed to 4 5, 5 0 and 5 5 ms^{-1} and the observations were noted for the three distributor heads Similarly for the seed feed rate of 68, 79 and 90 g min^{-1} the above procedure was repeated and the observations were recorded and tabulated

The above procedure was followed for pearl millet and sorghum seed for the air velocity and seed feed rates as mentioned in Table 3 1

An experiment with Factorial Completely Randomized Design (FCRD) was laid out The factors considered and their levels are furnished in Table 3 2 IRRISTAT was used to analyse the data This was done to obtain the necessary analysis of variance of the main and interaction effects of variables on the air velocity and seed collected in the outlet tubes of the distributor Standard Duncan's Multiple Range Test (DMRT) results were also obtained with the mean comparison of the effects to know the treatments which were statistically on par in distributing the air velocity and seed between the nine tubes The statistically on par treatments were further analysed to know the deviation of seed flow between the nine tubes to select the best treatment among the lot The means of the outlet tubes of the particular treatment were arranged in descending order and the mean deviation between the 36 combinations were calculated The treatment which gave the least deviation was selected as the best A computer programme shown in Annexure II was written in basic to do the above analysis

Table 3.2 Design layout of FCRD experiment

Factors		
	Type of distributor head	3
	Air velocity	4 levels
	Seed feed rate	4 levels
	Types of seed	3
	Replication	3

Affected response variables

Air velocity in individual outlet

Seed collected in individual outlet

The uniformity of seed distribution by the head was quantified from the quantity of seed collected in the individual outlet The uniformity of distribution was calculated as

$$\text{Uniformity of distribution } (\eta) = 1 - (\sigma_n / \bar{x}) \quad \text{-------- } 3\ 10$$

where,

σ_n = Standard deviation

$\bar{x}$ = Mean

Uniformity coefficient for each distributor was regressed in terms of air velocity and seed feed rate

3.4.2 Measurement of pressure

In the experimental test rig explained in section 3 3 2, the static pressure at blower outlet, eductor and distributor head inlet were measured at the locations shown in Fig 3 4 These pressures were graphically compared to yield an understanding of the effect of the distributor head and the eductor on the overall system pressure

3.4.3 Trajectory of seed

In order to understand the flow behaviour of the seed in the vertical seed conveyance tube and distributor, the path of seed in the system was traced

a. Prediction of seed movement in vertical pipe

The behaviour of seed carried in a vertical air stream as modelled by Chancellor (1960) was used to predict the relative velocity and displacement of seed in the vertical pipe The model is based on the assumption that there is no collision inbetween seeds or seed and the pipe The behaviour of seed in an upward moving air stream with air velocity greater than relative velocity was used for the prediction Here $V_r > V_s$ and V_r is negative

Forces on a unit mass seed are

$$dV_r / dt = g \left\{ [V_r^2 / V_s^2] - 1 \right\} \quad \text{------ } 3\ 11$$

where,

V_r = Relative velocity of seed, ms^{-1}

t = Time, s

g = Acceleration due to gravity, ms^{-2}

V_s = Suspension velocity of seed, ms^{-1}

which resolves to,

$$V_r t = V_s V_r / g \left[\coth^{-1}(V_{ro} / V_s) - \coth^{-1}(V_r / V_s) \right] \text{------ } 3\ 12$$

where,

V_{ro} = Relative velocity of seed at t = 0

$$Ht = V_a t - (V_s^2 / 2g) \ln \left[(V_{ro}^2 - V_s^2) / (V_r^2 - V_s^2) \right] \text{------ } 3\ 13$$

where,

V_a = Air stream velocity, ms^{-1}

The derivation of the prediction equation is shown in Annexure III

The above model was used to derive the relative velocity and displacement of three types of seed in the vertical pipe as affected by time at an air velocity of 4 0, 4 5, 5 0 and 5 5 ms^{-1} for sesame, 5 0, 5 5, 6 0 and 6 5ms^{-1} for pearl millet and 6 5, 7 0, 7 5 and 8 0ms^{-1} for sorghum The seed terminal velocity determined in section 3 2 1 was applied to calculate these parameters for every 1 / 24 (0 0417) second interval using a FORTRAN programme, Annexure IV

b. Tracing the actual path of seed in vertical pipe

The path traced by the seed in a transparent vertical pipe was recorded using a high speed video camera This was done for three types of seed with three distributor heads and four air velocities to compare with the predicted path traced in the vertical pipe The vertical tube of the experimental set up was replaced with a transparent acrylic pipe of identical dimension The motion of seed in the vertical tube is a high speed phenomena The seeds travelled the 850mm height of the vertical pipe in 0 5 second at the highest air velocity

Hence a suitable high speed videographic camera of the following specifications was selected to record the seed path

Make	SONY
Type	'U'matic low band recorder
Model	DXC M3AP three tube
Speed	1/2000 of a second

Recording of the seed path was done with the help of artificial lighting and different backgrounds The reflection of the transparent pipe hindered the location of the seed path while viewing in the television screen Hence the recording was done in natural light The air velocity in the vertical pipe of the experimental set up was set by the pitot tube-micromanometer combination and butterfly valve control in the blower

Preliminary recordings with sesame, pearl millet and sorghum seeds showed that the relative size of sesame and pearl millet as compared to the overall dimension of the vertical tube was very small This made it difficult to locate the path of sesame and pearl millet while viewing in television screen Hence it was proposed to study the general movement of the seed in the vertical pipe using sorghum seed

To record the seed movement the camera was positioned on a tripod at a fixed position The air velocity was set in the vertical conveyance pipe Seeds were individually fed into the air stream through the eductor and the path taken by the seed was recorded as shown in Plate 3 5 It was replicated five times for each treatment

The seed path was viewed on a television monitor using a SONY high quality 'U'matic editing VTRS NO-VO 5800 PS and RM440 edit control units Individual frames of each recording were frozen and projected on the screen The image frozen were advanced at an interval of 1/24 of a second and locations of seed at each movement was marked on a transparent sheet taped to the television screen The measurement was taken from the top of the eductor to the end of the vertical pipe

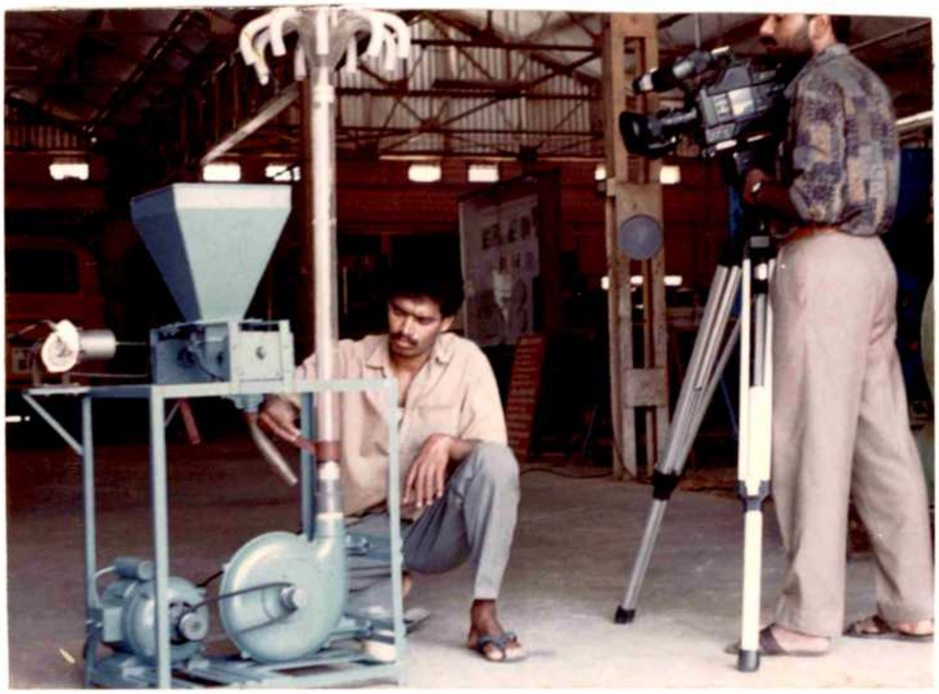


PLATE 3.5. VIDEO RECORDING OF PATH TRACED BY SEED

By this procedure the movement of sorghum seed in the vertical transparent pipe was recorded at 6.5, 7.0, 7.5 and 8.0ms^{-1} air velocity. The traced path was transferred to paper by measuring the X and Y co-ordinates of the loci.

c. Tracing the actual path of seed in the distributor

The movement of seed in the distributor head was recorded by videographic technique adopting procedure similar to that used for recording movement in vertical pipe in section 3.4.3.b. However due to the complex nature of the path traced in the distributor head, the movement was recorded with a close up view of the head for greater magnification. Three replications were done for each treatment.

3.5 Development of pneumatic seed drill

A pneumatic seed drill to sow the seeds selected was developed with the following components.

i. Cutivator frame
ii. Seed hopper and feed regulator
iii. Air blower and drive
iv Seed metering and seed tube assembly
v. Furrow opener and closer

by

The pneumatic seed metering and distribution system was mounted on a nine tyned spring loaded cultivator commonly used the farmers. The blower which supplies air to the seed distributor head was mounted on the right hand side of the cultivator frame and was driven through a side shaft by 'V' belt pulleys. The shaft was driven from the tractor PTO using the standard PTO extension shaft. Air velocity to the vertical conveyance pipe was regulated by a butterfly valve attached to the blower inlet. The air from the outlet of the blower was delivered to the vertical pipe through an elbow. A seed hopper was mounted on the centre of the frame so that it is equally spaced from all the furrow openers. At the bottom of the hopper internal double run seed feeding mechanism with seed rate adjustment was attached to feed the seed into the vertical conveyance pipe. An eductor fixed in the vertical pipe sucked the seeds inside. The drive to the seed feeding mechanism was taken from the ground wheel provided at the rear side of the cultivator frame. The drive sprocket of the ground wheel and feeding mechanism was selected based on the seed rate, slip encountered in the field and the seed feed rate of the feeding mechanism. The seed distributor head which gave the best uniformity of seed distribution was fixed over the vertical conveyance pipe. The seeds metered from the distributor head was conveyed to the furrow openers by transparent plastic tubes. The furrow openers of cup feed cultivator seed drill was adopted here. A plank type furrow closer provided at the rear side of the unit covers the furrows after drilling the seed.

3.5.1. Performance characteristics of the pneumatic seed drill under static condition of the power unit

The prototype was hitched to a 26.11 kW tractor. The engine speed of the tractor was kept constant at 1600 rpm throughout the calibration, yielding PTO rpm of 520. The seed hopper was filled with sesame. The air velocity in the vertical conveyance pipe was adjusted to the required level optimised through laboratory performance studies by regulating the butterfly valve of the blower. The best distribution head was fixed over the vertical conveyance pipe. Seed feed rate was adjusted in the seed feeding mechanism by adjusting the seed control screw. The implement was lifted 15 cm from the ground level. Following the test code IS6316-1971, the seed drill was calibrated. The ground wheel was rotated 25 times and the quantity of seed collected in individual furrow opener was weighed and the observations were recorded. The experiment was replicated three times. The same procedure was repeated for pearl millet and sorghum.

3.5.2 Performance characteristics of the pneumatic seed drill under dynamic condition of the power unit

The selection of appropriate distributor head, the air velocity and seed feed rate for the development of prototype was based on their performance on a static experimental test rig, as already explained in section 3.3.2. But the unit is to perform on a moving tractor during field operation. Under these conditions, there may be significant variation in the distribution of seed due to vibration of the unit, slip of the ground wheel and change in the forward speed of the tractor (Smith and Yoerger, 1975). The air velocity from the blower may be altered due to possible variation in the engine speed of the tractor. This inturn affects the air velocity in the vertical conveyance pipe and the distribution of seed to the furrow openers. If the air velocity is very low in the vertical conveyance pipe, it may clog the pipe. To investigate these effects, experiment was conducted under dynamic condition. The levels of variables used for the study are presented in Table 3.3.

Table 3.3 Levels of variables for different seeds

Type of seed	Air velocity ms^{-1}	Tractor speed kph	Distributor head
Sesame	5.5	2.5, 3.0, 3.5,4.0	Streamlined flow
Pearl millet	6.0	2.5, 3.0, 3.5,4.0	Streamlined flow
Sorghum	8.0	2.5, 3.0, 3.5,4.0	Streamlined flow

3x4x1 = 12 Treatments

a. Experimental procedure

The field was ploughed and harrowed to bring it to good tilth. The streamlined flow distributor head was fitted over the vertical conveyance pipe of the prototype. Sesame seed was filled in the hopper. The throttle setting of the tractor was fixed at 1600 rpm during the experiment. The air velocity in the vertical conveyance pipe was adjusted to 5.5 ms^{-1} using the butterfly control valve of the blower. Tractor forward speed of 2.5 kph was obtained by selecting the appropriate transmission ratio. This automatically fed seed at the rate of 57 g min^{-1} into the vertical conveyance pipe. The seed distributed to individual furrow opener by the distributor head was collected by tieing net bag to the discharge end of the seed tube. The seed collected in each tube was weighed and the observations were recorded. The experiment was replicated three times and the observations were noted. Similarly for the tractor forward speed of 3.0, 3.5 amd 4.0 kph, the above procedure was repeated and the observations were recorded and tabulated. The same procedure was followed for pearl millet and sorghum for the variables mentioned in Table 3.3.

An experiment with FCRD was laid out and the analysis of variance of the main and interaction effects of the variables on the seed collected in the outlet tubes of the distributor was obtained. IRRISTAT was used to analyse the data. The factors considered and their levels are furnished in Table 3.4.

Table 3.4 Design layout of FCRD experiment under dynamic condition

Factors			
	Speed of operation	:	4 levels
	Distribution tubes	:	9
	Type of seed	:	3
	Replications	:	3
Affected response variables			
	Quantity of seed collected in individual outlet		

Standard DMRT results were also obtained with the mean comparison, to know the main effects and the treatments which are statistically on par in discharging the seed between the nine tubes. The statistically on par treatments were further analysed to find the deviation of seed flow between the nine tubes to select the best treatment using the procedure described in section 3.4.1.

3.6 Field performance evaluation

A field size of 65 x 150m was selected, throughly ploughed and harrowed to bring the field to a fine tilth. The area was divided longitudinally into three equal parts to sow, sesame, pearl millet and sorghum. The precalibrated pneumatic seed drill was used to sow sesame seed. After germination, random locations were chosen in the field and marked. The plant population per square metre was counted. A alternate row per pass of the implement was sampled to record the total number of plants (including multiples) per metre row length. Three such replicatory readings were taken on the corresponding treatment rows and the observations were tabulated. The spacing between the consecutive plants germinated were also recorded for one metre length of the row. The above procedure was used to evaluate the performance of the pneumatic seed drill for pearl millet and sorghum in the same field, on the same day.

3.6.1. Cost economics

The total cost of the pneumatic seed drill was arrived and the fixed and variable costs for operating the unit per hour was calculated as per the procedure described by IS:9164-1979. From the field capacity of the unit, the cost of operation per ha was calculated. This cost was compared with conventional cost of sowing one ha. The saving in cost and time using the pneumatic seed drill was also arrived.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, the physical and aerodynamic properties of sesame, pearl millet and sorghum seeds are summarised. The performance of the three types of distributor head interms of uniformity of seed distribution and the resistance to air flow are discussed. The actual and predicted trajectory of seed in the vertical tube and the distributor head are discussed. The performance characteristics of the pneumatic seed drill under static or dynamic condition of the power unit is presented and discussed. The performance of the prototype pneumatic seed drill for sowing sesame, pearl millet and sorghum seeds are presented along with cost economics.

4.1 Physical properties

The physical properties of the seed influence the performance of pneumatic seed drill. The important physical properties are size and shape, frontal area, weight, true density, angle of repose and coefficient of restitution. These properties have been determined for sesame, pearl millet and sorghum seeds.

4.1.1. Size and Shape

The geometry of the three types of seeds viz., sesame, pearl millet and sorghum taken for the study were measured. The typical shapes observed are shown in Fig. 4.1. The associated geometrical measurements are given in Annexure V. The mean values are summarised in Table 4.1.

It was observed that the average length and width of sesame seed were 2.76 $\pm$ 0.21 mm and 1.53 $\pm$ 0.18 mm respectively (95% confidence limits). This showed the existance of considerable non uniformity in the geometrical dimensions of sesame seed.

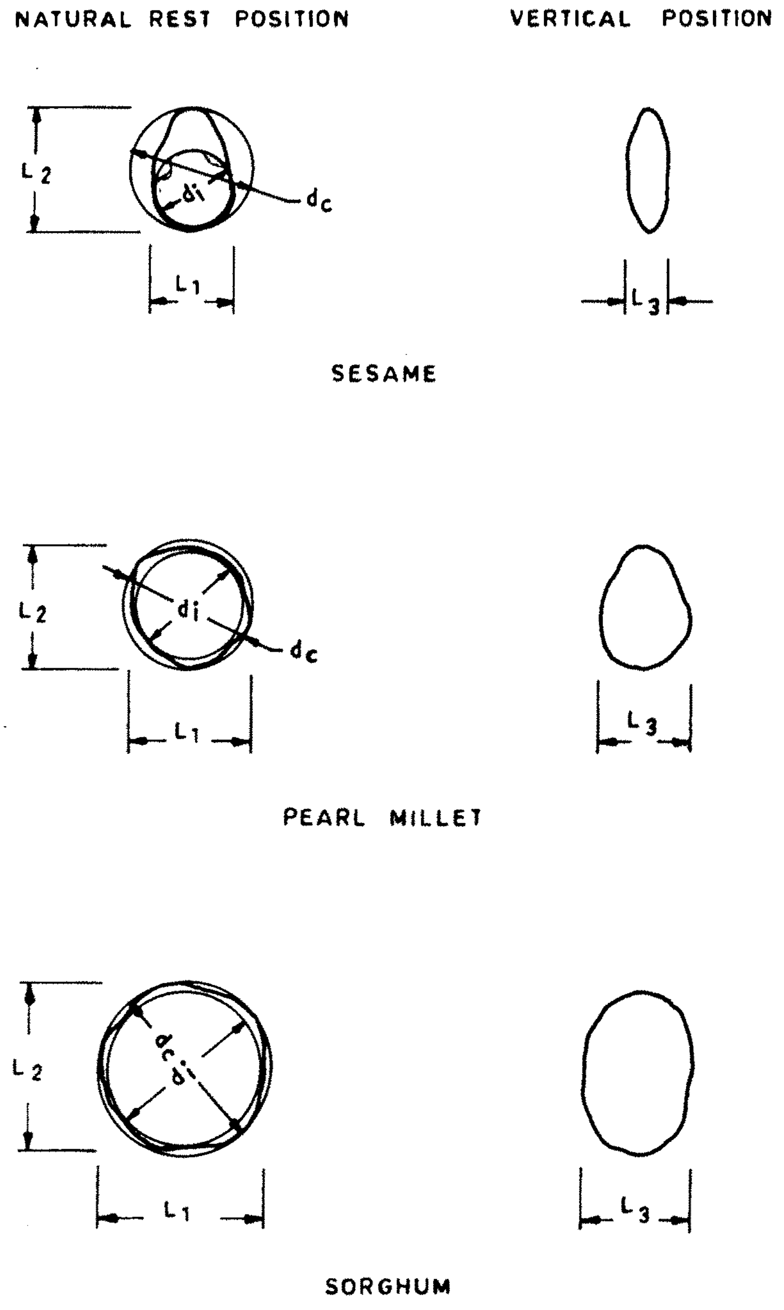


Fig. 4.1. TYPICAL GEOMETRY OF SEEDS

Table 4.1 Size and Shape

a. ~~Sesame~~ Ragi

Particulars	NRP		VP		Sphericity			Length	Width
	D_c mm	D_i mm	D_c mm	D_i mm	NRP	VP	Average	L_1 mm	L'_2 mm
Mean	6.30	4.20	15.20	3.90	0.67	0.26	0.46	1.04 ~~2.76~~	~~1.53~~ 1.05
S.E(m)	0.190	0.257	0.525	0.272	0.035	0.015	0.021	0.095	0.080
95%	6.30±	4.20±	15.20±	3.90±	0.67±	0.26±	0.46±	1.04 ~~2.76±~~	~~1.53±~~ 1.05
confidence limits	0.43	0.58	1.19	0.62	0.08	0.03	0.05	0.21	0.18

b. ~~Pearl millet~~ Cumbu

Particulars	NRP		VP		Sphericity			Diameter			Average diameter
	D_c mm	D_i mm	D_c mm	D_i mm	NRP	VP	Average	L_1 mm	L_2 mm	L_3 mm	mm
Mean	7.45	6.88	6.85	5.88	0.92	0.86	0.89	2.64	2.86	2.15	~~2.55~~ 2.76
S.E(m)	0.131	0.155	0.159	0.191	0.007	0.015	0.008	0.093	0.083	0.084	0.063
95%	7.45±	6.88±	6.85±	5.88±	0.92±	0.86±	0.89±	2.64±	2.86±	2.15±	~~2.55±~~ 2.76
confidence limits	0.30	0.35	0.36	0.43	0.02	0.03	0.02	0.21	0.19	0.19	0.14

~~c~~. Sorghum

Particulars	NRP		VP		Sphericity			Diameter			Average diameter
	D_c mm	D_i mm	D_c mm	D_i mm	NRP	VP	Average	L_1 mm	L_2 mm	L_3 mm	mm
Mean	9.95	9.30	7.40	6.50	0.94	0.88	0.91	3.58	3.59	2.39	3.18
S.E(m)	0.319	0.276	0.243	0.245	0.006	0.013	0.006	0.110	0.103	0.094	0.096
95%	9.95±	9.30±	7.40±	6.50±	0.94±	0.88±	0.91±	3.58±	3.59±	2.39±	3.18±
confidence limits	0.72	0.62	0.55	0.55	0.01	0.03	0.01	0.25	0.23	0.21	0.22

NRP - Natural Rest Position
VP - Vertical Position

The average diameter of pearl millet and sorghum seeds was 2.55 $\pm$ 0.14 and 3.18 $\pm$ 0.22 mm respectively (Thompson and Isaacs 1967, Waziri and Mittal, 1983 and Gorial and O'Callaghan, 1990). The observations indicated that pearl millet and sorghum seeds were more uniform in their geometric dimensions.

The sphericity of sesame, pearl millet and sorghum seeds in natural rest position was 0.67 $\pm$ 0.08, 0.92 $\pm$ 0.02 and 0.94 $\pm$ 0.01 respectively, whereas the same in vertical position was 0.26 $\pm$ 0.03, 0.86 $\pm$ 0.03 and 0.88 $\pm$ 0.03. The sphericity of sesame showed considerable variation while pearl millet and sorghum resulted lesser variation. These observations conclude that pearl millet and sorghum seeds were near spherical in shape (Waziri and Mittal, 1983, Gorial and O'Callaghan, 1990 and Khairwal, 1990). Since sphericity of sesame 0.46 $\pm$ 0.05, it could be considered as an ellipse (Gorial and O'Callaghan, 1990).

The considerable variation in the sphericity of sesame seed imply that individual sesame seed will behave with greater variation when they move through the air stream. The uniform geometrical nature of pearl millet and sorghum will result in uniform behaviour between individual seeds during their movement through air stream.

4.1.2. Frontal area

The frontal area of the seeds were calculated and are shown in Table 4.2. The frontal area of sesame was calculated by assuming an ellipsoidal geometry and for pearl millet and sorghum it was calculated by assuming spherical geometry. The frontal area of sesames, pearl millet and sorghum seeds were observed as 3.34 $\pm$ 0.54, 5.14 $\pm$ 0.56 and 8.02 $\pm$ 1.05 sq.mm respectively (95% confidence limits). The variation in the frontal area of all the three types of seed was higher. Since the frontal area influences the drag coefficient of a seed in the air stream (equation 3.7), the significant variation in the frontal area of the individual seeds may result in considerable variation in the drag coefficient.

Table 4.2 Frontal area

Type of Seed	Mean frontal Area mm^2	S.E(m)	95% confidence limits mm^2
Sesame	3.34	0.238	3.34 ± 0.54
Pearl millet	5.14	0.247	5.14 ± 0.56
Sorghum	8.02	0.466	8.02 ± 1.05

4.1.3. Seed weight

It was found that the average thousand grain weight of sesame, pearl millet and sorghum seed was 2.26 ± 0.08, 8.2 ± 0.11 and 26.0 ± 0.14 g respectively as shown in Table 4.3. These results are similar to those reported by Waziri and Mittal (1983), Gorial and O'Callaghan (1990) and Khairwal (1990). Since the drag coefficient is linearly related to the weight of individual seed, the weight of seed is expected to influence its behaviour in the air stream. High values of thousand seed weight would imply lesser number of seeds sown for a given seed rate and vice versa. The thousand seed weight along with the germination percentage can be used to predict the plant stand for a recommended seed rate.

Table 4.3. Thousand seed weight

Type of seed	Mean weight g	S.E(m)	95% confidence limits g
Sesame	2.26	0.034	2.26 ± 0.08
Pearl millet	8.20	0.050	8.20 ± 0.11
Sorghum	26.0	0.060	26.0 ± 0.14

4.1.4. True density

The true density of different types of seed is shown in Table 4.4. The true density was maximum for sorghum (1350.2 ± 6.31 kg m^{-3}) closely followed by pearl millet (1266.8 ± 8.09 kg m^{-3}). The same for sesame was 961.0 ± 6.28.

Table 4.4. True density

Type of seed	Mean true density kg m^{-3}	S.E(m)	95% confidence limits kg m^{-3}
Sesame	961.0	2.262	961.0 ± 6.28
Pearl millet	1266.8	2.914	1266.8 ± 8.09
Sorghum	1350.2	2.273	1350.2 ± 6.31

The true density affects the drag force of the seed in an air stream. The force of boyancy experienced by a particle in air is due to the difference between the true density and density of air. Hence sesame seed is expected to have lesser terminal velocity than other types of seed.

4.1.5. Angle of repose

The angle of repose of sesame, pearl millet and sorghum seeds were found as 26.25, 21.80 and 24.38 ° respectively. All surfaces on which the seeds are expected to flow by gravity alone like sides of seed hopper, funnel, seed conveyance tube between feeding and eductor were designed to be more than 30 ° to ensure free flow of seed.

4.1.6. Coefficient of restitution

The energy transfer during impact between the walls of the vertical pipe, distributor head and seed is related to the coefficient of restitution of the seed. The coefficient of restitution of the seed for acrylic and mild steel sheet are summarised in Table 4.5. The sesame seed had minimum coefficient of restitution than pearl millet and sorghum. These differences may influence the bouncing action of seed against the internal surfaces of passages during transport through air stream.

Table 4.5. Coefficient of restitution

Type of seed	Coefficient of restitution	
	Acrylic sheet	Mild steel sheet
Sesame	0.14	0.22
Pearl millet	0.22	0.36
Sorghum	0.20	0.40

4.2. Aerodynamic properties

The aerodynamic characteristics considered for this study are the terminal velocity and drag coefficient.

4.2.1. Terminal velocity

The terminal velocity of different seeds are tabulated in Table 4.6. The terminal velocity of sesame, pearl millet and sorghum seeds were observed as 2.2 $\pm$ 0.13, 4.2 $\pm$ 0.08 and 5.6 $\pm$ 0.11 m s^{-1} respectively. The variation in terminal velocity between the types of seed was due to the difference in individual seed weight, frontal area and true density. It was observed that there is minimal variation between the terminal velocity of individual seeds of same type.

Table 4.6. Terminal velocity

Type of seed	Mean terminal velocity m s^{-1}	S.E(m)	95% confidence limits m s^{-1}
Sesame	2.2	0.059	2.2 $\pm$ 0.13
Pearl millet	4.2	0.037	4.2 $\pm$ 0.08
Sorghum	5.6	0.049	5.6 $\pm$ 0.11

4.2.2. Drag coefficient

The drag coefficient of different seeds is shown in Table 4.7. Maximum drag coefficient was obtained for sesame (2.36) while it was least for pearl millet (1.42). The drag coefficient observed for sorghum was 1.65. The higher drag coefficient of sesame inspite of its lower weight of individual seed is due to its lower value of the drag force exerted on the seed.

Table 4.7. Drag coefficient

Type of seed	Mean drag coefficient	S.E(m)	95% confidence limits
Sesame	2.36	0.262	2.36 $\pm$ 0.59
Pearl millet	1.42	0.093	1.42 $\pm$ 0.21
Sorghum	1.65	0.148	1.65 $\pm$ 0.33

4.3. Development of seed distributor head

The principle of random path device, random sampling device and streamlined sampling device is used to fabricate the parallel disc, closed funnel and streamlined flow distributor heads respectively. The inlet pipe of the distributors was 55 mm diameter. The area of each distributor outlet tube was 400 sq.mm. This was kept constant for all the distributors, so that the performance of the head will not vary due to this parameter. The distributors were made of 3 mm acrylic sheat which gives visibility of the seed path in the distributor.

4.3.1. Development of test rig

To investigate the uniformity of seed distribution by the distributor head, an experimental test rig was used. In the experimental set up, air velocity can be regulated from 0 to 14.5 ms^{-1}. The seed feed rate of sesame, pearl millet and sorghum could be controlled precisely from 3.5 to 320, 4.5 to 340 and 4.5 to 300 g min^{-1} respectively by changing the speed of the motor and the seed control screw in the feeding mechanism.

4.3.2. Instrumentation for measurement of air velocity

The air velocity in the test rig was measured using a pitot tube and micromanometer combination. The resolution of the instrument is 0.02 ms^{-1}. The pitot tube and micromanometer was calibrated by measuring the air velocity and the corresponding dynamic head on the micromanometer. The calibration chart is shown in Fig.4.2. The best fit curve obtained was $Y = AX^B$ with R^2 value of 0.997. A look-up table was generated to find out the air velocity for the known manometric head.

4.4. Performance of distributor head

The performance of the three distributor heads namely parallel disc, closed funnel and streamlined flow was tested to determine the uniformity of seed and velocity distribution in the outlet tubes as influenced by different air velocity and seed feed rate.

4.4.1. Analysis of air distribution pattern

The performance of the three distributors were evaluated by measuring the air distribution between the nine outlet tubes for air velocity levels of 3 to 8 ms^{-1} at an increment of 1 ms^{-1}.

The analysis of variance for air velocity distribution between tubes is given in Table 4.8. The main effects of the tube was found to be insignificant which implies that the distributors irrespective of their construction were able to distribute the air evenly. This validated the symmetric construction of the head which ensured uniform radial flow pattern within the head. The velocity in the distributor outlet tubes varied significantly between distributor heads. This was due to the slight difference in the geometry of the outlet from the head. The sum of air flow through the outlet tubes was compared with the measured air flow rate into the head. This showed minimum difference validating the technique adopted for measuring air velocity at inlet and outlet. The interaction effects T x H, T x V and T x H x V were insignificant, whereas H x V interaction was significant. The mean comparison yielded an insignificant difference between any pairs of the three distributor heads. Hence H x V interaction indicated that the highly significant difference in velocity factor interacted with the type of distributor head to cause this effect. This is explained in the mean comparison Table 4.9.

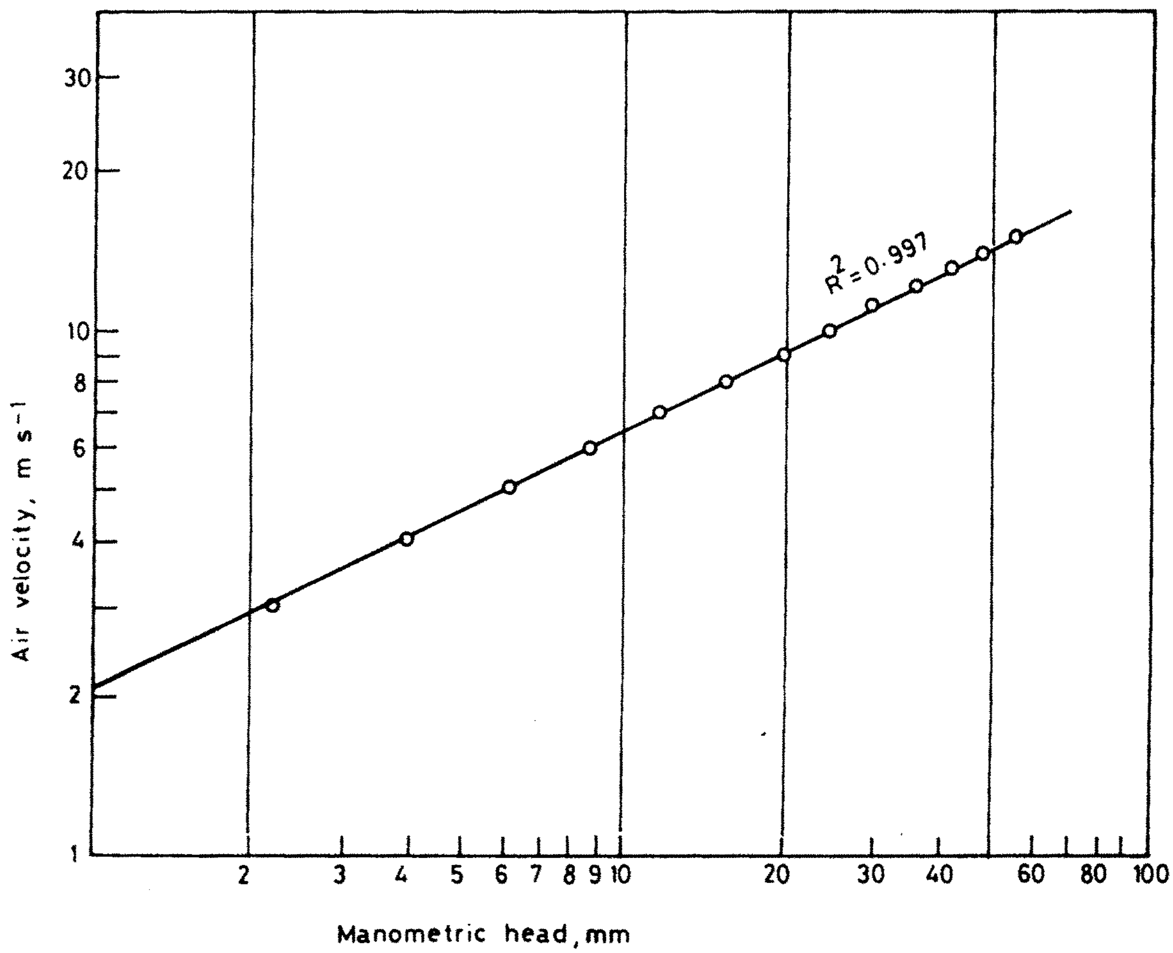


FIG. 4.2 CALIBRATION CHART OF PITOT TUBE

Table 4.8 Analysis of variance for air distribution

SV	DF	SS	MS	F
Treatment	161	281.3003	1.7472	219.80**
Tube (T)	8	0.0151	0.0019	<1
Distributor head (H)	2	0.0580	0.0290	3.65*
Air Velocity (V)	5	280.0117	56.0023	7045.23**
TxH	16	0.0703	0.0044	<1
TxV	40	0.1195	0.0030	<1
HxV	10	0.8540	0.0854	10.74**
TxHxV	80	0.1717	0.0021	<1
Error	324	2.5755	0.0079	
Total	485	283.8758		

C.V. = 3.6%, ** - Significant at 1% level, * - Significant at 5% level

Table 4.9 Interaction of factor means for air velocity

HxV table of means for velocity distribution, ms^{-1}

	Distributor head (H)					
Velocity (V) ms^{-1}	Parallel disc	Closed funnel	Streamlined	Vmean	SED	CD (P=0.05) ms^{-1}
3	1.458f	1.319f	1.480f	1.419		
4	1.720e	1.716e	1.671e	1.702		
5	2.203d	2.291d	2.217d	2.237	0.024	0.048
6	2.784c	2.710c	2.630c	2.708		
7	3.126b	3.131b	3.116b	3.124		
8	3.561a	3.590a	3.579a	3.577		
Hmean	2.475	2.460	2.449	2.461		

$S.E.D_H = 0.007$, CD_H (P=0.05) = 0.019

In a column, means followed by a common letter are not significantly different at 5% level by DMRT

4.4.2. Analysis of air seed mixture distribution pattern

The introduction of seed into the air stream will influence the performance of distributor head since it changes the properties of air. The effect of introducing sesame, pearl millet and sorghum, on the distribution between outlet tubes was analysed. The path of the seed in the distributor head could finally disturb the distribution of seed. Hence for each type of seed both the air velocity and quantity of seed in the distributor outlet tubes were analysed separately.

a. Air - sesame mixture

i. Distribution of air velocity

The effect of air velocity and sesame feed rate on mean air distribution in distributor outlet pipes is illustrated in Fig.4.3. It was observed that as air velocity increased, the air distributed in the outlet tubes increased for the three distributor heads. Also as the seed feed rate increased, air distributed decreased for all seed feed rates and distributor heads. At seed feed rate of 90 g min^{-1}, streamlined flow and parallel disc distributor gave an average of 8.0 and 6.6 per cent higher air distribution than the closed funnel distributor head respectively for the entire range of air velocities. This variation may be due to the choking of the distributor at higher seed feed rates. In other seed feed rates, the variation of air distribution was minimum among the distributor heads.

The analysis of variance for the air distribution in the outlet tubes is illustrated in Table 4.10. There was insignificant variation in air velocity between the tubes when the seeds were transported in the air stream. The main effect of distributor was head is significant. The mean comparison indicated that the distributor head as paired means taken varied significantly. The main effect of the seed feed rate was highly significant. This might be due to the influence of increased seed rate and flow resistance and associated change in pressure.

The H x V, F x V and F x H interaction means are shown in Table 4.11. On comparing the means of the air velocities with respect to the mean feed rate, the mean

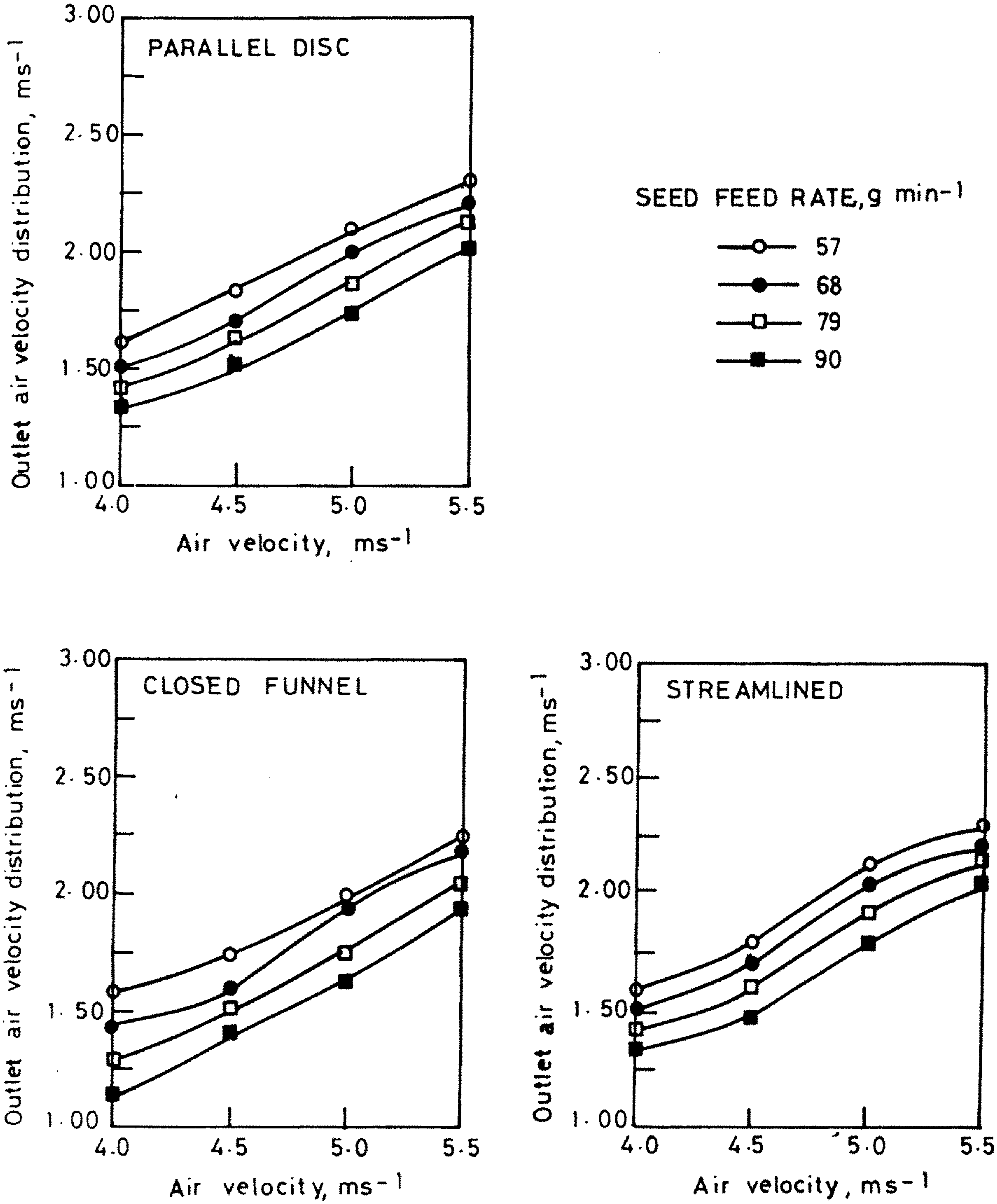


FIG. 4.3 INFLUENCE OF AIR VELOCITY AND SESAME FEED RATE ON OUTLET AIR DISTRIBUTION

Table 4.10 Analysis of variance of air velocity in air-sesame mixture

SV	DF	SS	MS	F
Treatment	431	117.9050	0.2736	39.78**
Tube (T)	8	0.0117	0.0015	<1
Seed feed rate (F)	3	17.6977	5.8992	857.93**
Distributor Head(H)	2	2.6247	1.3123	190.85**
Air Velocity (V)	3	95.2252	31.7417	4616.20**
TxF	24	0.0972	0.0040	<1
TxH	16	0.0431	0.0027	<1
TxV	24	0.1016	0.0042	<1
FxH	6	0.2605	0.0434	6.31**
FxV	9	0.4769	0.0530	7.71**
HxV	6	0.1705	0.0284	4.13**
TxFxH	48	0.1672	0.0035	<1
TxFxV	72	0.2126	0.0030	<1
TxHxV	48	0.2042	0.0043	<1
FxHxV	18	0.1579	0.0088	1.28NS
TxFxHxV	144	0.4540	0.0032	<1
Error	864	5.9410	0.0069	
Total	1295	123.8460		

C.V. = 4.6%, ** - Significant at 1% level, NS - Non significant

Table 4.11 Interaction of factor means for air velocity in air-sesame mixture

HxV table of means for velocity distribution, ms^{-1}

Velocity (V) ms^{-1}	Distributor head (H) Parallel disc	Closed funnel	Streamlined	Vmean	SED	CD (P=0.05) ms^{-1}
4.0	1.465d	1.363d	1.478d	1.435		
4.5	1.637c	1.582c	1.666c	1.640	0.011	0.022
5.0	1.926b	1.851b	1.984b	1.920		
5.5	2.161a	2.100a	2.186a	2.149		
Hmean	1.806	1.724	1.829	1.786		

FxV table of means for velocity distribution, ms^{-1}

Velocity (V) ms^{-1}	Seed feed rate (F), g min^{-1} 57	68	79	90	Vmean	SED	CD (P=0.05) ms^{-1}
4.0	1.587d	1.495d	1.379d	1.280d	1.435		
4.5	1.801c	1.676c	1.602c	1.482c	1.640	0.013	0.026
5.0	2.105b	1.998b	1.848b	1.729b	1.920		
5.5	2.276a	2.187a	2.109a	2.024a	2.149		
Fmean	1.942	1.839	1.735	1.629	1.786		

$S.E.D_F = 0.005$, $CD_F\ (P=0.05) = 0.013$, $S.E.D_V = 0.005$, $CD_V\ (P=0.05) = 0.013$

FxH table of means for velocity distribution, ms^{-1}

Seed feed rate g min^{-1}	Distributor head (H) Parallel disc	Closed funnel	Streamlined	Fmean	SED	CD (P=0.05) ms^{-1}
57	1.953a	1.906a	1.968a	1.942		
68	1.848b	1.788b	1.881b	1.839	0.011	0.022
79	1.767c	1.654c	1.782c	1.735		
90	1.657d	1.547d	1.683d	1.629		
Hmean	1.806	1.724	1.829	1.786		

$S.E.D_H = 0.004$, $CD_H\ (P=0.05) = 0.011$

In a column, means followed by a common letter are not significantly different at 5% level by DMRT.

velocity at 57 g min^{-1} was significantly different from those of 68, 79 and 90 g min^{-1}. Excepting the first order interactions involving the seed feed rate, distributor head and the air velocity, all other interactions were non-significant. When the seed feed rate was at the levels of 57 g min^{-1} and 79 g min^{-1}, the mean velocity between the streamlined flow head and parallel disc head were insignificant, whereas at the other seed feed rates, the effects were significantly different between the heads. Generally at all seed feed rates, the mean velocity was the lowest for closed funnel distributor when compared to the other heads. The above was explained by the significant interactions shown between seed feed rate and distributor head. Similarly the analysis of the interaction between V and H indicated an interesting fact that when the air velocity was maintained below 5 ms^{-1}, there was no difference in magnitude of mean velocity between parallel disc and streamlined flow distributors. The difference in performance between parallel disc and streamlined flow head at air velocity more than 5 ms^{-1} might be due to the sudden change in the air flow in the parallel disc head. The increase in feed rate from 57 g min^{-1} to 90 g min^{-1} caused a gradual decrease in the air velocity in the distributor outlet tubes. This is also evident from Fig.4.3.

ii. Distribution of sesame

The influence of air velocity and sesame seed feed rate on mean distribution of seed in the outlet pipes is shown in Fig.4.4. It was observed that the streamlined flow and parallel disc distributor gave uniform distribution compared to closed funnel distributor. The mean seed distribution in parallel disc and streamlined flow distributors was independent of air velocity. But the closed funnel distributor has not distributed the seed uniformly in the range of air velocity and seed feed rate tested. The seed distribution in closed funnel distributor was different from other distributors for all air velocities and seed feed rates tested except for 5.0 and 5.5 ms^{-1} air velocity and 57 g min^{-1} seed feed rate.

The analysis of variance for the quantity of seed distributed through the outlet pipe of the head is shown in Table 4.12. All the main and interaction effects were found to be

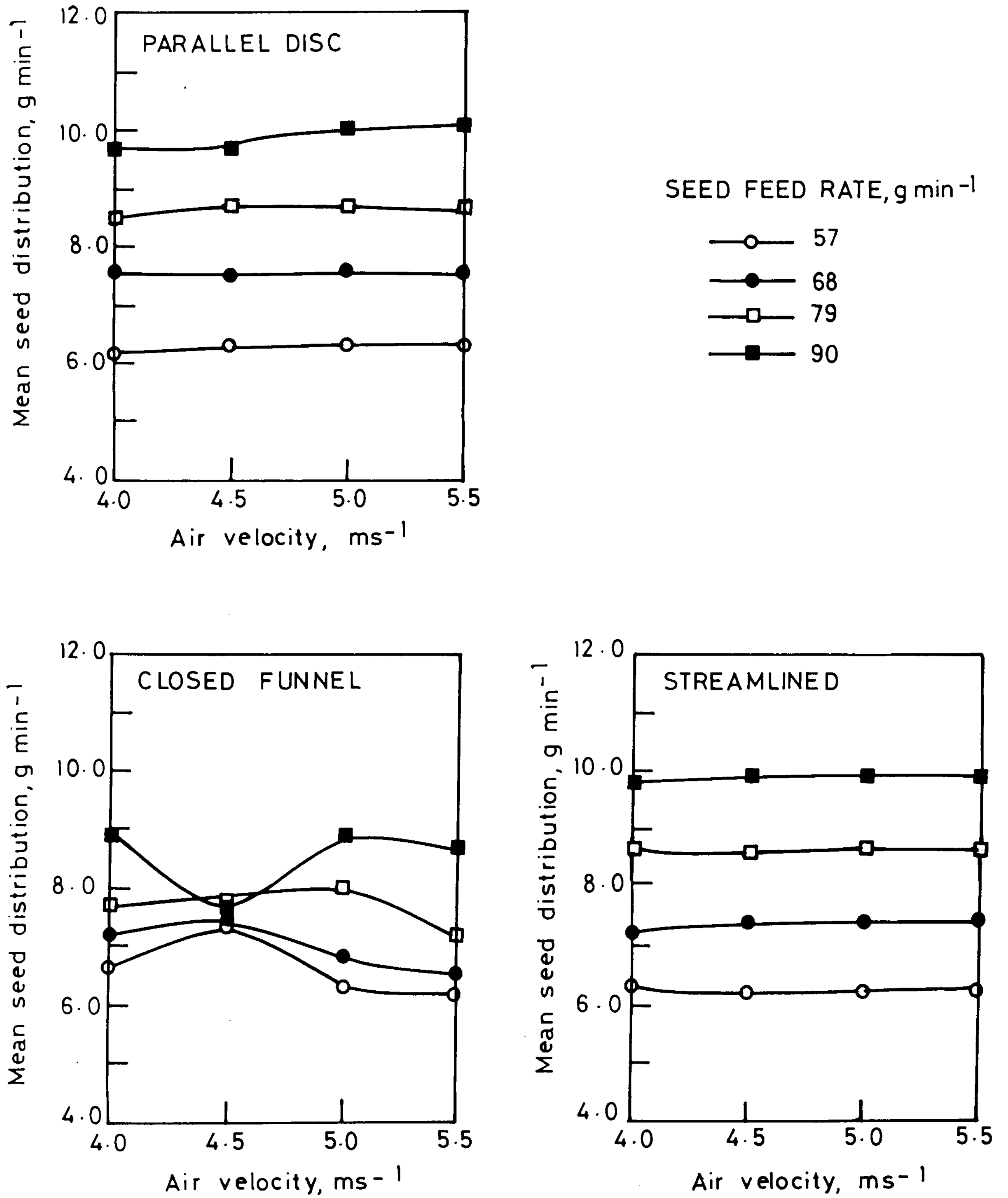


FIG. 4·4 INFLUENCE OF AIR VELOCITY AND SESAME FEED RATE ON SEED DISTRIBUTION

Table 4.12 Analysis of variance for sesame distribution

SV	DF	SS	MS	F
Treatment	431	5873.8304	13.6284	33.00**
Tube (T)	8	86.8588	10.8573	26.29**
Seed feed rate (F)	3	1616.4986	538.8329	1304.73**
Distributor Head(H)	2	118.2751	59.1376	143.20**
Air Velocity (V)	3	3.3146	1.1049	2.68*
TxF	24	257.3288	10.7220	25.96**
TxH	16	144.6046	9.0378	21.88**
TxV	24	273.1640	11.3818	27.56**
FxH	6	115.9205	19.3201	46.78**
FxV	9	25.9037	2.8782	6.97**
HxV	6	13.8483	2.3081	5.59**
TxFxH	48	577.7471	12.0364	29.14**
TxFxV	72	683.6690	9.4954	22.99**
TxHxV	48	591.9306	12.3319	29.86**
FxHxV	18	43.7982	2.4332	5.89**
TxFxHxV	144	1320.9684	9.1734	22.21**
Error	864	356.8183	0.4130	
Total	1295	6230.6487		

C.V. = 8.1%, ** - Significant at 1% level, * - Significant at 5% level significant. The existance of significant third order interactions posed problems in interpreting the analysis. Hence the means of main effects were compared individually to find the best among them. The mean comparison on the quantity of seed distributed in the tubes by the three heads is shown in Table 4.13. The closed funnel distributor behaved differently from parallel disc and streamlined flow distributors. The variation in quantity of seed flow showed that there existed insignificant difference between air velocity at 4, 4.5, 5.0 and 5.5 ms^{-1} for parallel disc and streamlined flow distributors.

From the 48 possible combinations of air velocity, seed feed rate and distributor head, 20 treatments that yielded insignificant variation of seed flow between outlet tubes were selected through DMRT analysis. These treatments were further ranked by analysing the mean deviation between the quantity of seed collected at the outlet tubes and the results are presented in Table 4.14. From the table it was inferred that the streamlined flow distributor at 79 g min^{-1} seed feed rate and 5.5 ms^{-1} air velocity was the best treatment for distributing sesame with mean deviation of 0.1349 between outlet tubes. This is followed by the similar combination of distributor head and air velocity at seed feed rate of 57 g min^{-1} yielding 0.1382 mean deviation between outlets.

The uniformity of seed distribution between outlet tubes was calculated and correlated to air velocity and seed feed rate. Fig.4.5. illustrates the uniformity as a function of air velocity and seed feed rate for the three types of distributor head. It was observed that the streamlined flow and parallel disc distributor head were capable of providing greater uniformity as compared to the closed funnel head. The seed uniformity index at 4.5 ms^{-1} air velocity was 0.899 for parallel disc head and 0.908 for streamlined flow head. Excluding the data point for 4.5 ms^{-1} air velocity and 68 g min^{-1} seed feed rate which lies outside the general trend of the curve, the uniformity index varied from 0.899 to 0.968 in parallel disc head and 0.908 to 0.984 in streamlined flow head for increase in air velocity of 4.0 to 5.5 ms^{-1} and seed feed rate of 57 to 90 g min^{-1}. For a given air velocity, the uniformity

Table 4.13 Interaction of factor means for distribution of sesame

HxV table of means for seed distribution, g min^{-1}

Velocity (V) ms^{-1}	Distributor head (H) Parallel disc	Closed funnel	Streamlined	Vmean	SED	CD (P=0.05) g min^{-1}
4.0	8.000a	7.627a	8.059a	7.895		
4.5	8.077a	7.553a	8.109a	7.913	0.062	0.171
5.0	8.153a	7.516a	8.141a	7.937		
5.5	8.147a	7.144b	8.119a	7.803		
Hmean	8.094	7.460	8.107	7.887		

$S.E.D_V = 0.034$, CD_V (P=0.05) = 0.099

FxV table of means for seed distribution, g min^{-1}

Velocity (V) ms^{-1}	Seed feed rate (F), g min^{-1} 57	68	79	90	Vmean	SED	CD (P=0.05) g min^{-1}
4.0	6.466b	7.372a	8.301a	9.443a	7.895		
4.5	6.682a	7.499a	8.379a	9.091b	7.913	0.071	0.198
5.0	6.320b	7.310a	8.487a	9.630a	7.937		
5.5	6.271b	7.176b	8.226b	9.540a	7.803		
Fmean	6.435	7.339	8.348	9.426	7.887		

$S.E.D_F = 0.036$, CD_F (P=0.05) = 0.099

FxH table of means for seed distribution, g min^{-1}

Seed feed rate g min^{-1}	Distributor head (H) Parallel disc	Closed funnel	Streamlined	Fmean	SED	CD (P=0.05) g min^{-1}
57	6.324d	6.657d	6.324d	6.435		
68	7.546c	6.985c	7.488c	7.339	0.062	0.171
79	8.673b	7.672b	8.700b	8.348		
90	9.834a	8.526a	9.917a	9.426		
Hmean	8.094	7.460	8.107	7.887		

$S.E.D_H = 0.031$, CD_H (P=0.05) = 0.086

In a column, means followed by a common letter are not significantly different at 5% level by DMRT.

Table 4.14 Order of the best treatment for sesame

S.No	Type of distributor head	Air velocity ms^{-1}	Seed feed $g\ min^{-1}$	Mean deviation between nine outlet tubes
1.	Streamlined flow	5.5	79	0.1349
2.	Streamlined flow	5.5	57	0.1382
3.	Streamlined flow	5.5	68	0.1412
4.	Streamlined flow	5.0	68	0.1419
5.	Streamlined flow	5.5	90	0.1471
6.	Streamlined flow	5.0	90	0.1730
7.	Parallel disc	5.0	68	0.1733
8.	Streamlined flow	5.0	57	0.1751
9.	Parallel disc	5.0	57	0.1810
10.	Parallel disc	5.5	57	0.1903
11.	Parallel disc	5.0	90	0.2434
12.	Streamlined flow	5.0	79	0.2469
13.	Parallel disc	5.5	79	0.2854
14.	Parallel disc	5.5	68	0.2924
15.	Parallel disc	5.0	79	0.2984
16.	Streamlined flow	4.5	57	0.3762
17.	Closed funnel	5.5	57	0.3839
18.	Parallel disc	4.5	57	0.4006
19.	Streamlined flow	4.5	79	0.4029
20.	Parallel disc	5.5	90	0.4653

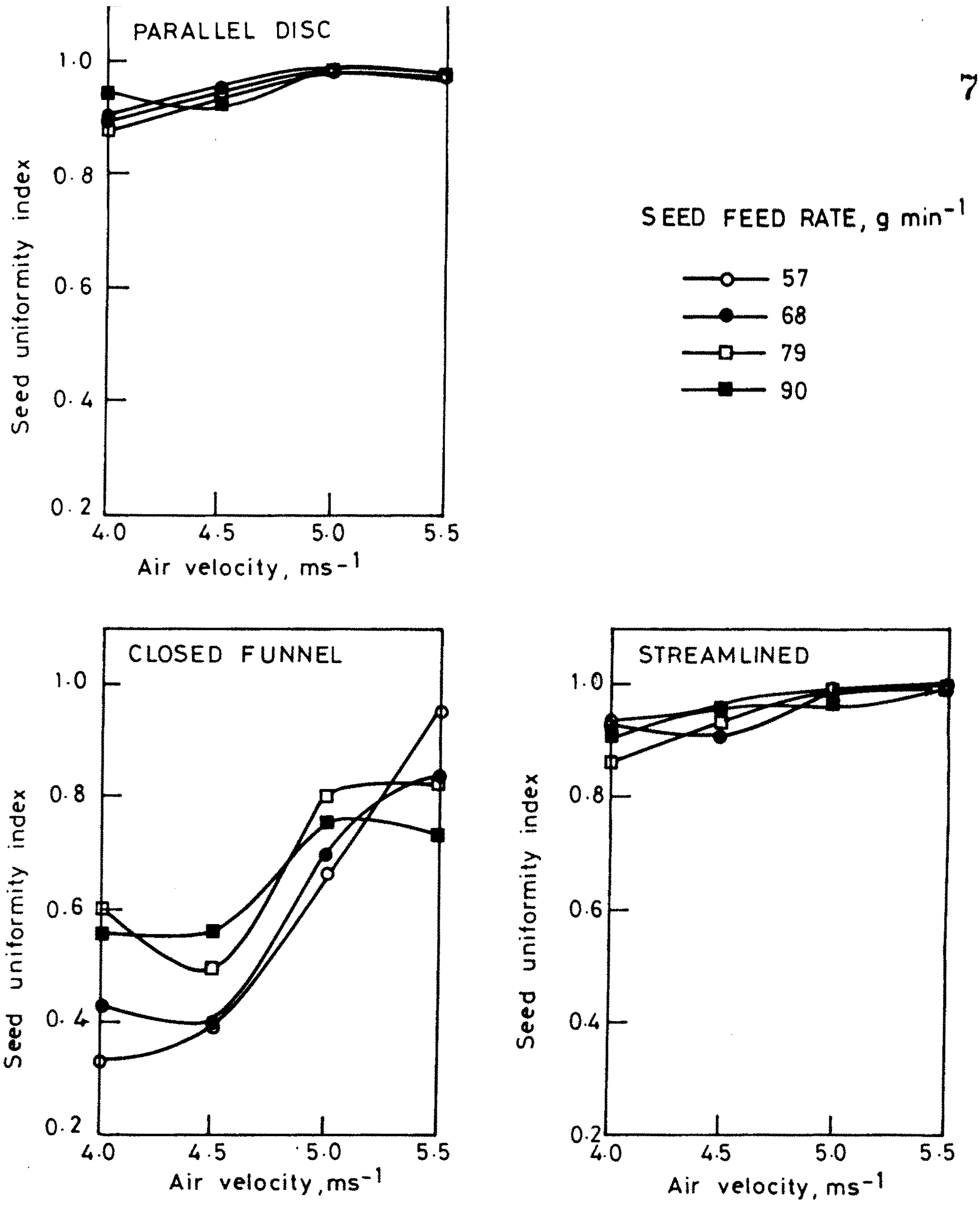


FIG. 4·5 EFFECT OF AIR VELOCITY AND SESAME FEED RATE ON UNIFORMITY showed gradual increase as the seed feed rate decreased. Maximum variation of uniformity was 0.905 $\pm$ 0.035, 0.44 $\pm$ 0.12 and 0.900 $\pm$ 0.025 for parallel disc, closed funnel and streamlined flow head as the seed feed rate varied from 57 to 90 g min^{-1}. The uniformity increased by 6.9, 35.5 and 7.6 per cent as air velocity increased from 4.0 to 5.5 ms^{-1} for parallel disc, closed funnel and streamlined flow head respectively.

The regression equation obtained for the three distributor heads are as follows:

$$\eta_p = -0.477 + 0.516\,V + 0.157\,F - 0.044\,V^2 - 0.033\,VF \qquad R^2 = 0.83^*$$

$$\eta_c = -1.059 - 0.316\,V + 2.723\,F + 0.13\,V^2 - 0.54\,VF \qquad R^2 = 0.87^*$$

$$\eta_s = -0.308 + 0.265\,V - 0.17\,F - 0.026\,V^2 + 0.035\,VF \qquad R^2 = 0.77^*$$

η_p, η_c, η_s - Uniformity of distribution for parallel disc, closed funnel and streamlined flow distributors respectively

* - Significant at 5% level.

On maximising the regression equation of the streamlined flow head, the optimised air velocity was 4.8 ms^{-1}. The mathematically optimised seed feed rate level was -0.44 g min^{-1}, though it gave positive value for other seeds. This value is physically unrealistic and hence the feed rate was selected from minimum mean deviation of seed distribution in outlet tube. The best distribution head and the factor level arrived were as follows :

Distributor head	:	Streamlined flow
Air velocity	:	5.5 ms^{-1}
Seed feed rate	:	79 g min^{-1}

b. Air - pearl millet mixture

i. Distribution of air velocity

The effect of air velocity and seed feed rate on mean air distribution is illustrated in Fig.4.6. As the air velocity increased, the mean air distribution increased in all heads. But

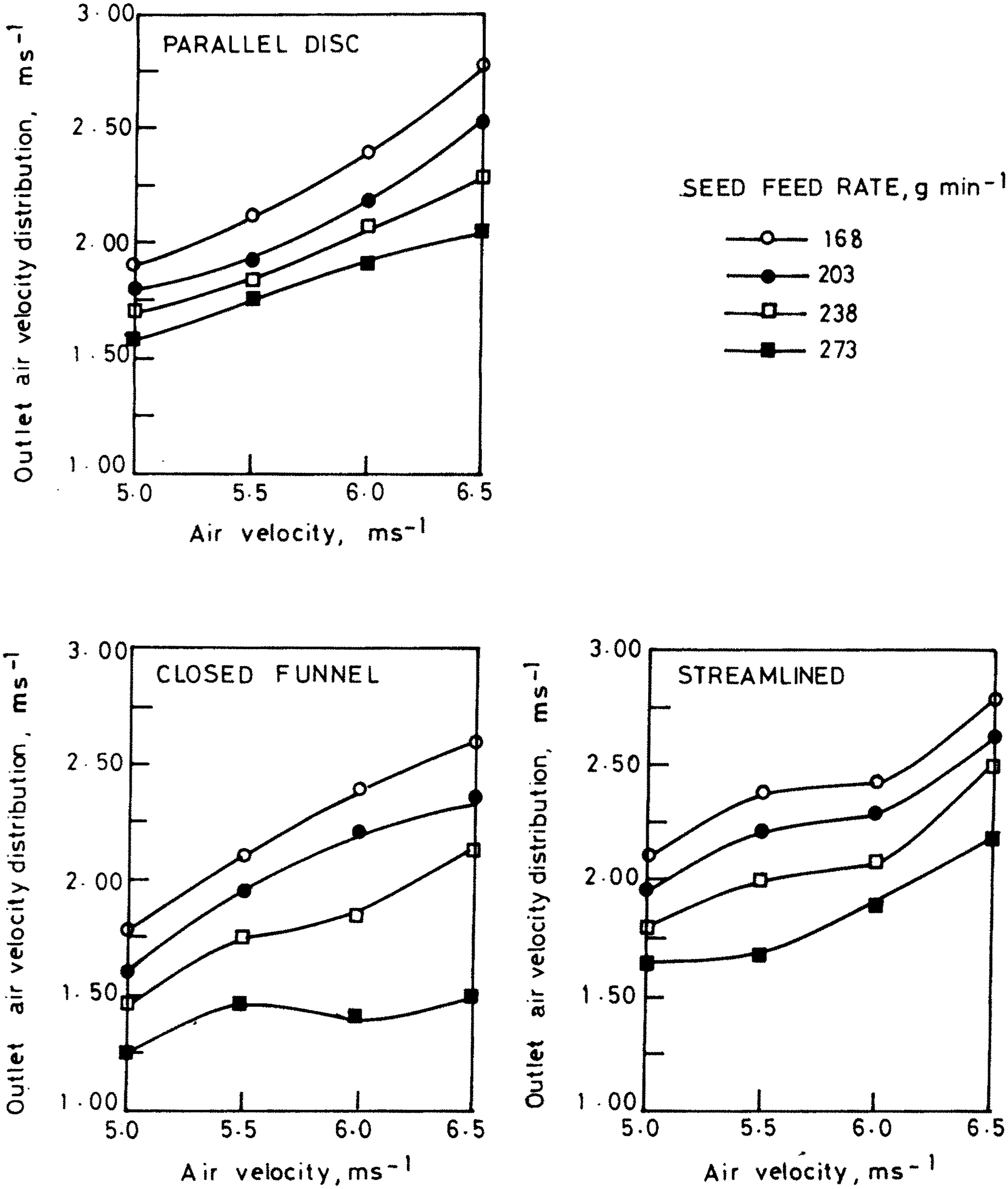


FIG. 4.6 INFLUENCE OF AIR VELOCITY AND PEARL MILLET FEED RATE ON OUTLET AIR DISTRIBUTION

the average rate of increase in streamlined flow and parallel disc distributor at 273 g min^{-1} seed feed rate was 21.86 per cent higher than closed funnel distributor. As the seed feed rate increased the mean air velocity distribution decreased for all distributor heads.

The analysis of variance for the air distribution in the outlet tubes is illustrated in Table 4.15. The behaviour was similar to that when carrying and distributing sesame seed eventhough the range of air velocity, seed feed rate and seed properties differ. The main effects of seed feed rate, distributor head, air velocity and the interactions H x V, F x V and F x H were significant. The rest of the interactions were insignificant. The interaction between the main effects is shown in Table 4.16. The air flow was uniformly distributed among the outlet tubes as seen from the main effect. The main effect showed significant deviation between the distributor heads. The observations were similar to those observed in sesame. The distributor head means showed significant difference between the heads unlike the behaviour during distributing sesame seed. The F x V interaction table showed that the mean air velocity at different feed rates differ significantly. This interaction behaviour is reflected identically in all the three heads could be seen from the F x H interaction table and Fig.4.6.

ii. Distribution of pearl millet

The influence of air velocity and seed feed rate on mean seed distribution is shown in Fig 4.7. It was clearly observed that the mean seed distribution in closed funnel distributor varied considerably from the other two distributors. At 5.0ms^{-1} air velocity and 168, 203, 238 and 273g min^{-1} seed feed rate, the mean seed distribution was 65, 62, 38 and 28 per cent higher for streamlined flow and parallel disc distributor than the closed funnel distributor. This might be due to accumulation of seeds inside the closed funnel distributor at lower velocity. There was no variation in the mean seed distribution for parallel disc and streamlined flow distributors between 6.0 and 6.5 ms^{-1} air velocity. At 168 and 203 $gmin^{-1}$

Table 4.15 Analysis of variance of air velocity in air-pearl millet mixture

SV	DF	MS	SS	F
Treatment	431	179.5564	0.4166	33.15**
Tube (T)	8	0.1456	0.0182	1.45NS
Seed feed rate(F)	3	68.1008	22.7002	1806.03**
Distributor Head(H)	2	22.9983	11.4991	914.87**
Air Velocity (V)	3	72.8817	24.2939	1932.82**
TxF	24	0.1924	0.0080	<1
TxH	16	0.2024	0.0127	1.01NS
TxV	24	0.1461	0.0061	<1
FxH	6	4.3684	0.7281	57.93**
FxV	9	3.4609	0.3845	30.59**
HxV	6	1.8607	0.3101	24.67**
TxFxH	48	0.3697	0.0077	<1
TxFxV	72	0.6265	0.0087	<1
TxHxV	48	0.3665	0.0076	<1
FxHxV	18	2.6743	0.1486	11.82**
TxFxHxV	144	1.1621	0.0081	<1
Error	864	10.8597	0.0126	
Total	1295	190.4161		

C.V. = 5.5%, ** - Significant at 1% level, NS - Non significant

Table 4.16 Interaction of factor means for air velocity in air-pearl millet mixture

HxV table of means for velocity distribution, ms^{-1}

Velocity (V) ms^{-1}	Distributor head (H) Parallel disc	closed funnel	Streamlined	Vmean	SED	CD (P=0.05) ms^{-1}
5.0	1.753d	1.509d	1.896d	1.719		
5.5	1.917c	1.815c	2.083c	1.938	0.011	0.030
6.0	2.143b	1.963b	2.187b	2.098		
6.5	2.418a	2.139a	2.552a	2.370		
Hmean	2.058	1.856	2.179	2.031		

$S.E.D_H = 0.005$, $CD_H (P=0.05) = 0.015$

FxV table of means for velocity distribution, ms^{-1}

Velocity (V) ms^{-1}	Seed feed rate (F), g min^{-1} 168	203	238	273	Vmean	SED	CD (P=0.05) ms^{-1}
5.0	1.937d	1.779d	1.667d	1.494d	1.719		
5.5	2.199c	2.037c	1.880c	1.637c	1.938	0.012	0.035
6.0	2.407b	2.237b	2.012b	1.735b	2.098		
6.5	2.733a	2.514a	2.305a	1.926a	2.370		
Fmean	2.319	2.142	1.966	1.698	2.031		

$S.E.D_V = 0.006$, $CD_V (P=0.05) = 0.017$, $S.E.D_F = 0.006$, $CD_F (P=0.05) = 0.017$

FxH table of means for velocity distribution, ms^{-1}

Seed feed rate g min^{-1}	Distributor head (H) Parallel disc	closed funnel	Streamlined	Fmean	SED	CD (P=0.05) ms^{-1}
168	2.297d	2.218d	2.441d	2.319		
203	2.115c	2.014c	2.296c	2.142	0.011	0.030
238	1.987b	1.793b	2.118b	1.966		
273	1.831a	1.400a	1.863a	1.698		
Hmean	2.058	1.856	2.179	2.031		

In a column, means followed by a common letter are not significantly different at 5% level by DMRT.

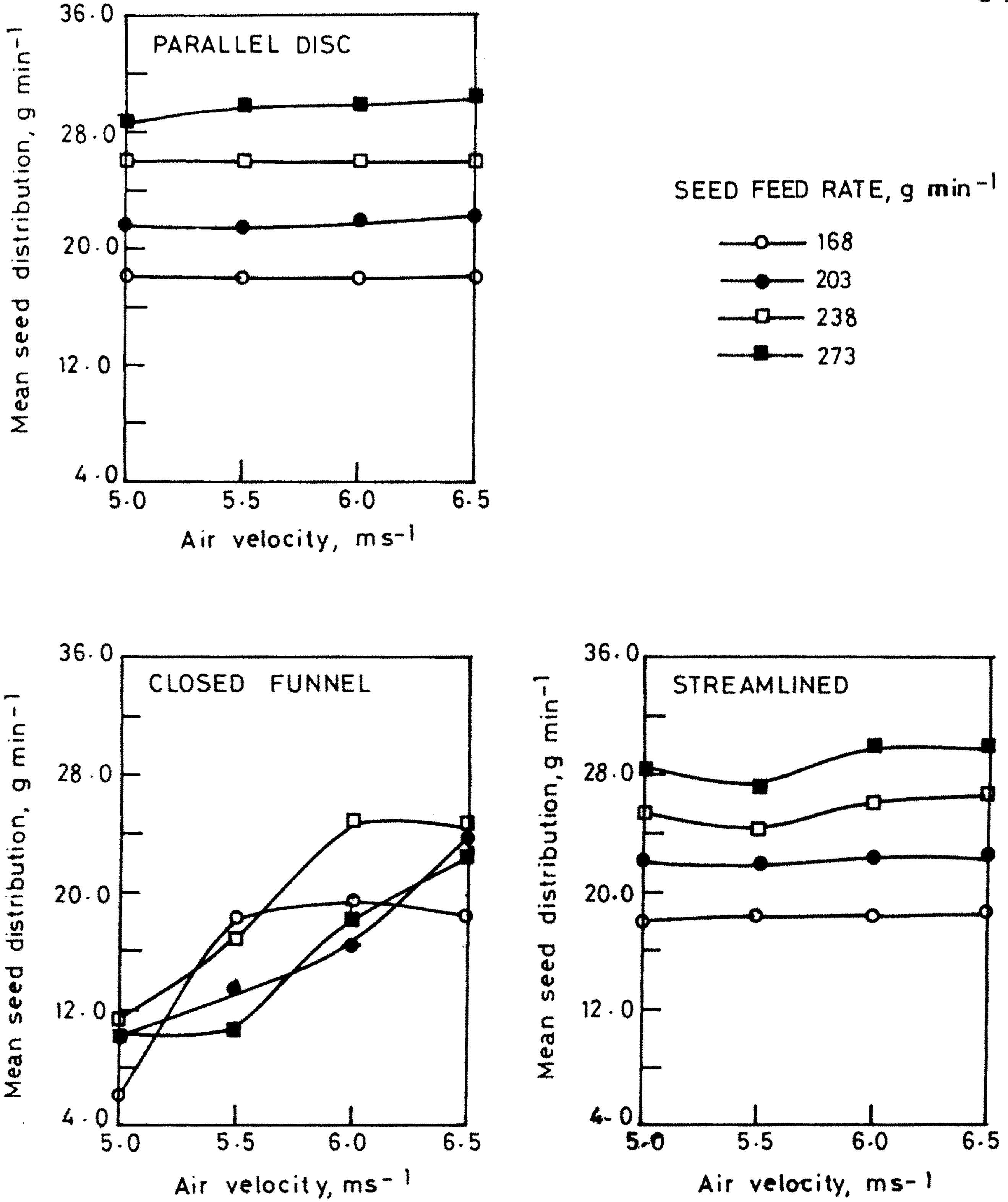


FIG. 4.7 INFLUENCE OF AIR VELOCITY AND PEARL MILLET FEED RATE ON SEED DISTRIBUTION

seed feed rates, the parallel disc and streamlined flow distributors gave identical mean seed distribution in the entire range of velocities.

As seen from the analysis of variance Table 4.17, all the main and interaction effects were significant in their influence on the mean seed flow rate in the outlet tubes. The significant variation between the seed distributor outlet tubes is of main concern. The mean comparison of the quantity of seed (Table 4.18) showed significant difference between the three distributor heads. It was clearly observed that the performance of the closed funnel distributor differed widely from parallel disc and streamlined flow distributors. There was significant variation of mean quantity of seed flow in the outlet tubes with change in air velocity. This behaviour was evident observed from Fig 4.7. The second and third order interactions could not be interpreted due to its significance interms of physical behaviour.

The DMRT analysis showed only ten treatments that yielded insignificant variation of seed flow between outlet tubes among the 48 possible combinations. These treatments were further ranked by analysing the mean deviation between outlet tubes and shown in Table 4.19. The streamlined flow distributor head with air velocity of $6 ms^{-1}$ and seed feed rate of $168 g\ min^{-1}$ was chosen as the best combination with least mean deviation of 0.3103 between outlet tubes. This was followed by the same combination of distributor head and air velocity with $273 g\ min^{-1}$ seed feed rate.

The uniformity of seed distribution between the outlet tubes was calculated and correlated to air velocity and seed feed rate. Fig 4.8 illustrates the uniformity as a function of air velocity and seed feed rate for the three distributor heads. It was observed that the streamlined and parallel disc distributor heads provided greater uniformity than closed funnel distributor. The seed uniformity index at $5.0 ms^{-1}$ air velocity was 0.866, 0.698 and 0.870 for parallel disc, closed funnel and streamlined flow distributors respectively. The uniformity did show gradual increase as the seed rate decreased. Maximum variation in uniformity index was 0.855 ± 0.035, 0.69 ± 0.22 and 0.88 ± 0.07 for the parallel disc, closed funnel and

Table 4.17 Analysis of variance for pearl millet distribution

SV	DF	SS	MS	F
Treatment	431	51036.9796	118.4153	188.96**
Tube (T)	8	88.9187	11.1148	17.74**
Seed feed rate(F)	3	10394.0996	3464.6999	5528.86**
Distributor Head(H)	2	14970.4924	7485.2462	11944.72**
Air Velocity (V)	3	4785.9716	1595.3239	2545.77**
TxF	24	609.2746	25.3864	40.51**
TxH	16	287.8452	17.9903	28.71**
TxV	24	683.3167	28.4715	45.43 **
FxH	6	4588.2639	764.7106	1220.30**
FxV	9	1054.2097	117.1344	186.92**
HxV	6	6237.9577	1039.6596	1659.06**
TxFxH	48	874.8786	18.2266	29.09**
TxFxV	72	1431.5175	19.8822	31.73**
TxHxV	48	917.6731	19.1182	30.51**
FxHxV	18	1430.1844	79.4547	126.79**
TxFxHxV	144	2682.3758	18.6276	29.73**
Error	864	541.4321	0.6267	
Total	1295	51578.4117		

C.V. = 3.7%, ** - Significant at 1% level.

Table 4.18 Interaction of factor means for distribution of pearl millet

HxV table of means for seed distribution, g min^{-1}

Velocity (V) ms^{-1}	Distributor head (H) Parallel disc	Closed funnel	Streamlined	Vmean	SED	CD (P=0.05) g min^{-1}
5.0	23.738c	9.407d	23.591b	18.912		
5.5	23.978b	14.923c	22.108c	20.336	0.076	0.211
6.0	24.230a	20.025b	24.297a	22.851		
6.5	24.419a	22.264a	24.460a	23.715		
Hmean	24.091	16.655	23.614	21.453		

$S.E.D_V = 0.044$, $CD_V (P=0.05) = 0.122$

$S.E.D_H = 0.038$, $CD_H (P=0.05) = 0.106$

FxV table of means for seed distribution, g min^{-1}

Velocity (V) ms^{-1}	Seed feed rate (F), g min^{-1} 168	203	238	273	Vmean	SED	CD (P=0.05) g min^{-1}
5.0	14.253c	17.916d	21.070c	22.410c	18.912		
5.5	18.368b	18.973c	22.547b	21.456d	20.336	0.088	0.244
6.0	18.918a	20.420b	25.871a	26.195b	22.851		
6.5	18.469b	22.900a	25.836a	27.653a	23.715		
Fmean	17.502	20.052	23.831	24.429	21.453		

$S.E.D_F = 0.044$, $CD_F (P=0.05) = 0.122$

FxH table of means for seed distribution, g min^{-1}

Seed feed rate g min^{-1}	Distributor head (H) Parallel disc	Closed funnel	Streamlined	Fmean	SED	CD (P=0.05) g min^{-1}
168	18.449d	15.691c	18.366d	17.502		
203	21.884c	15.940b	22.333c	20.052	0.076	0.211
238	26.214b	19.570a	25.709b	23.831		
273	29.819a	15.418d	28.048a	24.429		
Hmean	24.091	16.655	23.614	21.453		

In a column, means followed by a common letter are not significantly different at 5% level by DMRT.

streamlined flow distributors as the seed feed rates varied from 168 to 273g min^{-1}. The increase in uniformity was 11.55, 15.95 and 11.17 per cent as air velocity increased from 5 to 6.5 ms^{-1} for parallel disc, closed funnel and streamlined flow head respectively. The parallel disc and streamlined flow distributors exhibited maximum uniformity of 98.0 and 98.1 per cent at 6.0 and 6.5 ms^{-1} air velocity respectively. The regression equation obtained for the three distributor heads were as follows :

Table 4.19 Order of the best treatment for pearl millet

S.No.	Type of distributor head	Air velocity ms^{-1}	Seed feed rate g min^{-1}	Mean deviation between nine outlet tubes
1.	Streamlined flow	6.0	168	0.3103
2.	Streamlined flow	6.0	273	0.3149
3.	Parallel disc	6.0	168	0.3217
4.	Parallel disc	6.5	273	0.3946
5.	Streamlined flow	6.5	168	0.3965
6.	Streamlined flow	6.5	273	0.4425
7.	Streamlined flow	6.5	238	0.4748
8.	Parallel disc	6.5	168	0.4926
9.	Parallel disc	6.5	238	0.5457
10.	Streamlined flow	6.0	238	0.5521

$$\eta_p = -1.558 + 0.714\,V + 0.124\,F - 0.052\,V^2 - 0.010\,F^2 - 0.008\,VF \qquad R^2 = 0.92^*$$

$$\eta_c = -4.386 + 1.560\,V + 0.235\,F - 0.105\,V^2 + 0.019\,F^2 - 0.067\,VF \qquad R^2 = NS$$

$$\eta_s = -0.005 + 0.383\,V - 0.191\,F - 0.034\,V^2 + 0.002\,F^2 + 0.027\,VF \qquad R^2 = 0.7^*$$

NS - Non significant

* - Significant at 5% level.

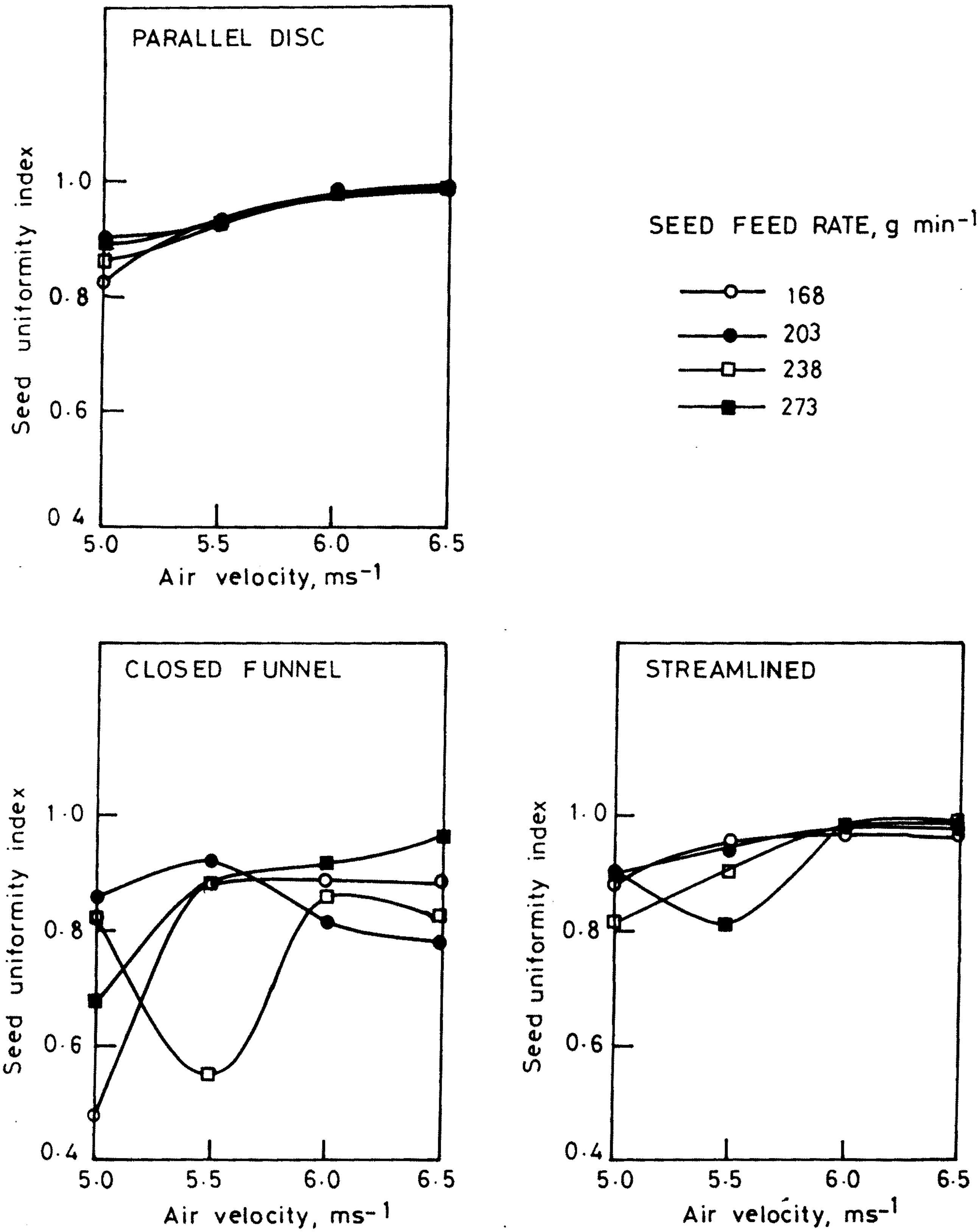


FIG. 4·8 EFFECT OF AIR VELOCITY AND PEARL MILLET FEED RATE ON UNIFORMITY

On maximising the regression equation for streamlined flow distributor, the optimised air velocity was 6.69 ms^{-1} and the seed feed rate was 168 g min^{-1}. This conclusion was perfectly in agreement with the selection of best head from the deviation analysis. The streamlined flow head at 6.0 ms^{-1} air velocity and 168 g min^{-1} seed feed rate gave minimum deviation of 0.3103 in seed distribution between outlet tubes. The same head at 6.0 ms^{-1} air velocity and 273 g min^{-1} feed rate yielded minimum deviation of 0.3149. Since the difference between the two treatments was negligible and the seed feed rate of 273 g min^{-1} envisages operation of the implement at 4.0 kph, this combination was selected as the best. Hence the best combination for sowing pearl millet were as follows.

Distributor head	:	Streamlined flow
Air velocity	:	6 ms^{-1}
Seed feed rate	:	273 g min^{-1}

c. Air-sorghum mixture

i. Distribution of air velocity

The effect of air velocity and seed feed rate on air distribution is shown in Fig.4.9. As the air velocity increased, the mean air distribution increased. The increase in seed feed rate decreased the mean air distribution. All the heads distributed air uniformly except closed funnel at 168 g min^{-1} seed feed rate and 7.5 ms^{-1} air velocity.

The analysis of variance for mean air velocity during distribution of sorghum seed is illustrated in Table 4.20. The results obtained were similar to that when conveying pearl millet and sesame seed, eventhough the range of air velocity, seed feed rate and seed properties differ. The three heads varied significantly in their performance as could be seen from the wide range of difference between the mean air velocity in the outlet tubes while distributing sorghum. This behaviour was identical as that of pearl millet distribution. Table 4.21 shows the mean comparison of main effects. The air flow was uniformly distributed among the outlet tubes of the distributor as seen from the main effect. The main

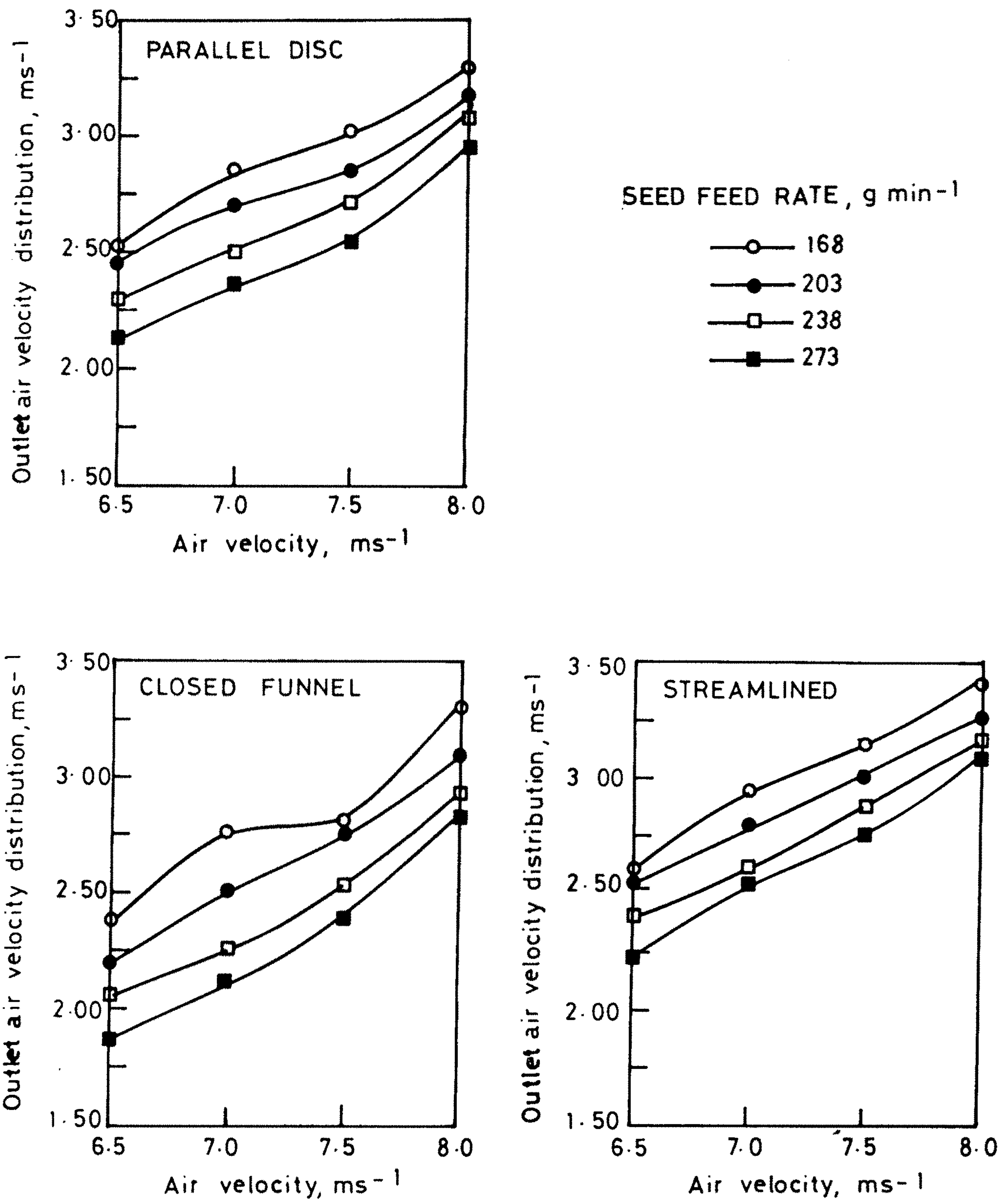


FIG. 4·9 INFLUENCE OF AIR VELOCITY AND SORGHUM FEED RATE ON OUTLET AIR DISTRIBUTION

Table 4.20 Analysis of variance of air velocity in air-sorghum mixture

SV	DF	MS	SS	F
Treatment	431	175.4493	0.4071	133.30**
Tube (T)	8	0.0267	0.0033	1.09NS
Seed feed rate(F)	3	36.0537	12.0179	3935.22**
Distributor Head(H)	2	18.6471	9.3235	3052.96**
Air Velocity (V)	3	117.2390	39.0797	12796.50**
TxF	24	0.0652	0.0027	<1
TxH	16	0.0337	0.0021	<1
TxV	24	0.0322	0.0013	<1
FxH	6	0.5041	0.0840	27.51**
FxV	9	0.6925	0.0769	25.19**
HxV	6	1.1612	0.1935	63.37**
TxFxH	48	0.0950	0.0020	<1
TxFxV	72	0.1203	0.0017	<1
TxHxV	48	0.0814	0.0017	<1
FxHxV	18	0.4461	0.0248	3.12**
TxFxHxV	144	0.2510	0.0017	<1
Error	864	2.6386	0.0031	
Total	1295	178.0879		

C.V. = 2.0%, ** - Significant at 1% level, NS - Non significant

Table 4.21 Interaction of factor means for air velocity in air-sorghum mixture

HxV table of means for velocity distribution, ms^{-1}

Velocity (V) ms^{-1}	Distributor head (H) Parallel disc	closed funnel	Streamlined	Vmean	SED	CD (P=0.05) ms^{-1}
6.5	2.377d	2.136d	2.458d	2.324		
7.0	2.614c	2.410c	2.746c	2.590	0.005	0.015
7.5	2.801b	2.625b	2.952b	2.793		
8.0	3.142a	3.059a	3.242a	3.148		
Hmean	2.734	2.558	2.850	2.714		

$S.E.D_V = 0.003$, CD_V (P=0.05) = 0.009

$S.E.D_H = 0.003$, CD_H (P=0.05) = 0.007

FxV table of means for velocity distribution, ms^{-1}

Velocity (V) ms^{-1}	Seed feed rate (F), g min^{-1} 168	203	238	273	Vmean	SED	CD (P=0.05) ms^{-1}
6.5	2.544d	2.412d	2.258d	2.081d	2.324		
7.0	2.855c	2.680c	2.477c	2.348c	2.590	0.006	0.017
7.5	3.006b	2.883b	2.709b	2.572b	2.793		
8.0	3.341a	3.201a	3.070a	2.979a	3.148		
Fmean	2.937	2.794	2.629	2.495	2.714		

$S.E.D_F = 0.003$, CD_F (P=0.05) = 0.009

FxH table of means for velocity distribution, ms^{-1}

Seed feed rate g min^{-1}	Distributor head (H) Parallel disc	closed funnel	Streamlined	Fmean	SED	CD (P=0.05) ms^{-1}
168	2.954d	2.811d	3.045d	2.937		
203	2.819c	2.652c	2.911c	2.794	0.005	0.015
238	2.653b	2.458b	2.776b	2.629		
273	2.509a	2.310a	2.666a	2.495		
Hmean	2.734	2.558	2.850	2.714		

In a column, means followed by a common letter are not significantly different at 5% level by DMRT.

effect of distributor showed significant variation between them in the air flow at the outlet tubes. The distributor means showed significant difference between the heads unlike the behaviour during distributing sesame. The F x V interaction table showed that the mean air velocity at different seed feed rates varied significantly. This interaction behaviour is reflected identically in all the three heads as seen from the F x H interaction table and Fig.4.9.

ii. Distribution of sorghum

The influence of air velocity and seed feed rate on mean seed distribution is shown in Fig.4.10. The streamlined flow distributor uniformly distributed the seeds at all seed feed rates and air velocities than parallel disc distributor. The streamlined distributor at 6.5 ms^{-1} air velocity resulted 7.7 per cent higher average seed distribution than parallel disc head. The seed distribution in streamlined and parallel disc distributor at 6.5 ms^{-1} air velocity was 40 per cent higher than the closed funnel distributor. At 168, 203 and 238 $gmin^{-1}$ seed feed rates the parallel disc and streamlined flow distributors yielded same mean seed distribution in the outlet tubes for the entire range of air velocity.

The analysis of variance for sorghum seed distributed in the outlet tubes is shown in Table 4.22. The main and interaction effects were significant. It was observed that there existed significant difference between the seed distribution outlet tubes. The mean comparison of the quantity of seeds distributed as shown in Table 4.23 evinced highly significant difference in performance between the three heads. The closed funnel distributor varied significantly from parallel disc and streamlined flow distributors. There was significant variation of mean quantity of seed flow in the outlet tubes with change in air velocity. This behaviour was evident from Fig. 4.10. The second and third order interactions could not be interpreted due to its significance interms of physical behaviour.

The DMRT analysis showed only 17 treatments that yielded insignificant variation of seed flow between outlet tubes among the 48 possible combinations. The treatments were further ranked by analysing the mean deviation between outlet tubes, Table 4.24. From the

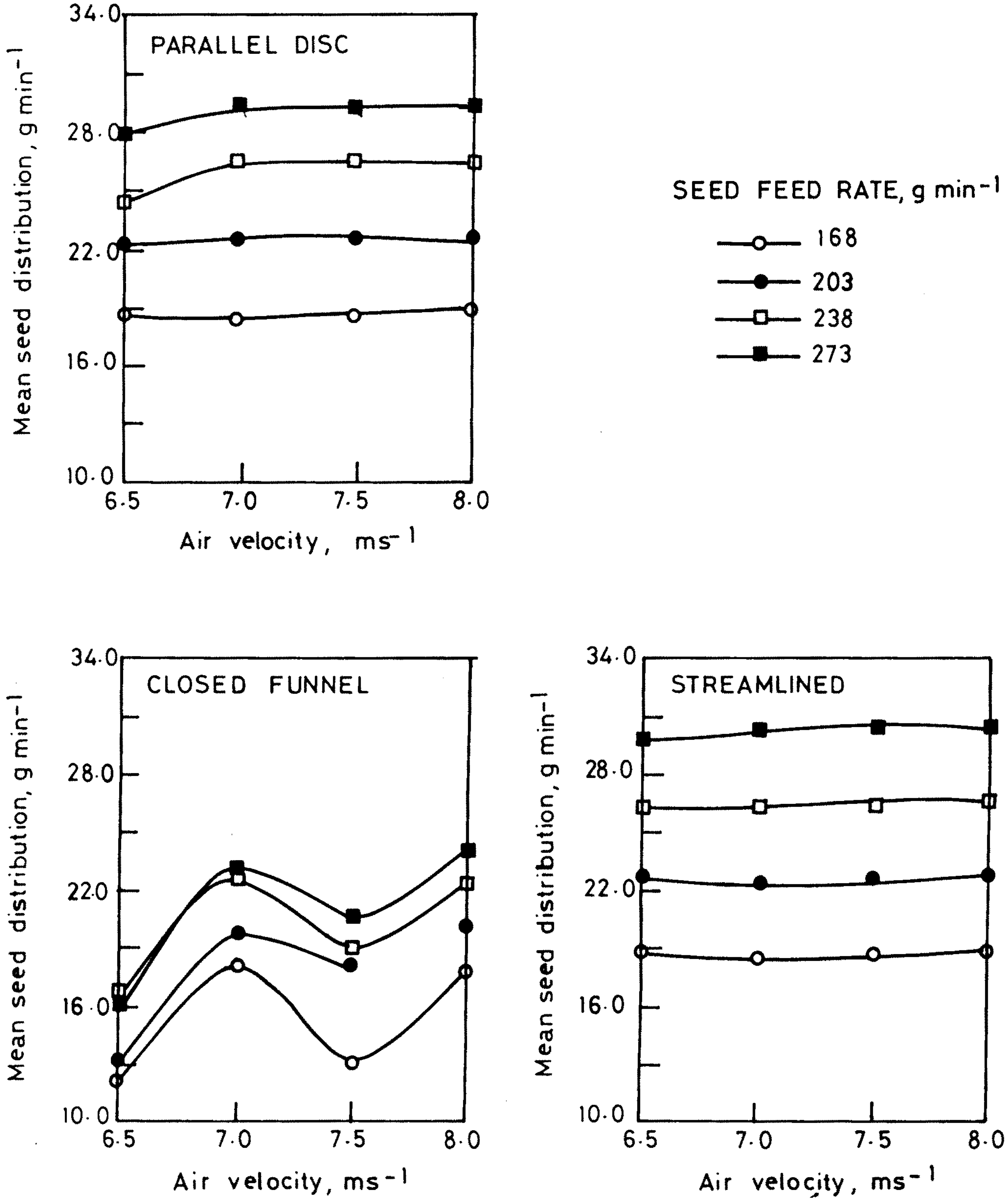


FIG. 4·10 INFLUENCE OF AIR VELOCITY AND SORGHUM FEED RATE ON SEED DISTRIBUTION

Table 4.22 Analysis of variance for sorghum distribution

SV	DF	SS	MS	F
Treatment	431	38851.8014	90.1434	98.77**
Tube (T)	8	335.8309	41.9789	46.00**
Seed feed rate(F)	3	16230.4231	5410.1410	5927.75**
Distributor Head(H)	2	9447.6881	4723.8441	5175.79**
Air Velocity (V)	3	1418.7174	472.9058	518.15**
TxF	24	334.1946	13.9248	15.26**
TxH	16	764.0054	47.7503	52.32**
TxV	24	521.7304	21.7388	23.82**
FxH	6	1257.1376	209.5229	229.57**
FxV	9	144.2279	16.0253	17.56**
HxV	6	1951.8993	325.3166	356.44**
TxFxH	48	829.3295	17.2777	18.93**
TxFxV	72	1518.1000	21.0847	23.10**
TxHxV	48	1129.2066	23.5251	25.78**
FxHxV	18	154.9911	8.6106	9.43**
TxFxHxV	144	2814.3195	19.5439	21.41**
Error	864	788.5556	0.9127	
Total	1295	39640.3570		

C.V. = 4.3%, ** - Significant at 1% level.

Table 4.23 Interaction of factor means for distribution of sorghum

HxV table of means for seed distribution, g min^{-1}

Velocity (V) ms^{-1}	Distributor head (H)			Vmean	SED	CD (P=0.05) g min^{-1}
	Parallel disc	Closed funnel	Streamlined			
6.5	23.416a	14.490d	24.421a	20.776		
7.0	24.402a	20.976b	24.350a	23.242	0.092	0.255
7.5	24.460a	17.626c	24.449a	22.178		
8.0	24.444a	21.233a	24.495a	23.391		
Hmean	24.180	18.581	24.429	22.397		

S.E.D_V = 0.053, CD_V (P=0.05) = 0.147, S.E.D_H = 0.046, CD_H (P=0.05) = 0.127

FxV table of means for seed distribution, g min^{-1}

Velocity (V) ms^{-1}	Seed feed rate (F), g min^{-1}				Vmean	SED	CD (P=0.05) g min^{-1}
	168	203	238	273			
6.5	16.617b	19.363d	22.463c	24.659d	20.776		
7.0	18.308a	21.463b	25.145a	28.053b	23.242	0.106	0.294
7.5	16.803b	21.048c	23.821b	27.041c	22.178		
8.0	18.388a	21.865a	24.999a	28.311a	23.391		
Fmean	17.529	20.935	24.107	27.016	22.397		

S.E.D_F = 0.053, CD_F (P=0.05) = 0.147

FxH table of means for seed distribution, g min^{-1}

Seed feed rate g min^{-1}	Distributor head (H)			Fmean	SED	CD (P=0.05) g min^{-1}
	Parallel disc	Closed funnel	Streamlined			
168	18.577d	15.325d	18.685d	17.529		
203	22.402c	17.908c	22.494c	20.935	0.092	0.255
238	25.943b	19.992b	26.385b	24.107		
273	29.799a	21.098a	30.151a	27.016		
Hmean	24.180	18.581	24.429	22.397		

In a column, means followed by a common letter are not significantly different at 5% level by DMRT.

Table 4.24 Order of the best treatment for sorghum

S.No.	Type of distributor head	Air velocity ms^{-1}	Seed feed rate $g\ min^{-1}$	Mean deviation between nine outlet tubes
1.	Streamlined flow	8.0	238	0.1777
2.	Streamlined flow	7.5	168	0.1844
3.	Streamlined flow	8.0	168	0.2222
4.	Streamlined flow	7.5	238	0.2653
5.	Parallel disc	8.0	168	0.2738
6.	Parallel disc	7.5	168	0.3709
7.	Streamlined flow	8.0	203	0.3731
8.	Streamlined flow	7.5	203	0.4003
9.	Streamlined flow	8.0	273	0.4124
10.	Parallel disc	8.0	238	0.4454
11.	Streamlined flow	7.5	273	0.4558
12.	Parallel disc	7.5	203	0.4736
13.	Parallel disc	8.0	203	0.4892
14.	Parallel disc	7.5	238	0.5757
15.	Parallel disc	7.5	273	0.5810
16.	Parallel disc	8.0	273	0.5955
17.	Streamlined flow	7.0	238	0.6177

table the streamlined flow distributor at 8.0 ms^{-1} air velocity and 238 g min^{-1} seed feed rate was chosen as the best combination with minimum mean deviation of 0.177 between the outlet tubes. This was followed by the same head at 7.5 ms^{-1} air velocity and 168 g min^{-1} seed feed rate.

The uniformity of seed distribution between the outlet tubes was calculated and correlated to air velocity and seed feed rate. Fig.4.11 illustrates the uniformity as a function of air velocity and seed feed rate for the three distributors. It was clearly observed that the streamlined and parallel disc distributors provided maximum uniformity than closed funnel head at all air velocities and seed feed rates. The uniformity showed gradual increase as the seed feed rate decreased. The seed uniformity index at 6.5 ms^{-1} air velocity was 0.928, 0.818 and 0.920 for parallel disc, closed funnel and streamlined flow distributors respectively. Maximum variation of uniformity was 0.925 $\pm$ 0.025, 0.725 $\pm$ 0.125 and 0.950 $\pm$ 0.025 for parallel disc, closed funnel and streamlined flow distributor as the feed rate varied from 168 to 273 g min^{-1}. The increase in uniformity was 5.6 and 7.0 per cent as air velocity increased from 6.5 to 8.0 ms^{-1} for parallel disc and streamlined flow heads respectively. It was also observed that above 7.5 ms^{-1} air velocity, for both parallel disc and streamlined flow heads, the uniformity was independent of seed feed rate and the effect of air velocity was almost negligible. This indicated that either of the head at air velocity in the above range would perform with consistent level of distribution uniformity.

The regression equation obtained for the three distributor heads were as follows :

$$\eta_p = 0.379 + 0.103\ V + 0.04\ F - 0.007\ V^2 - 0.018\ F^2 + 0.012\ VF \qquad R^2 = 0.80^{**}$$

$$\eta_c = 6.241 - 1.283\ V - 0.39\ F + 0.083\ V^2 + 0.041\ F^2 + 0.012\ VF \qquad R^2 = NS$$

$$\eta_s = -0.636 + 0.4\ V - 0.011\ F - 0.024\ V^2 + 0.001\ F^2 + 0.0003\ VF \qquad R^2 = 0.80^{**}$$

** - Highly significant, NS - Non Significant.

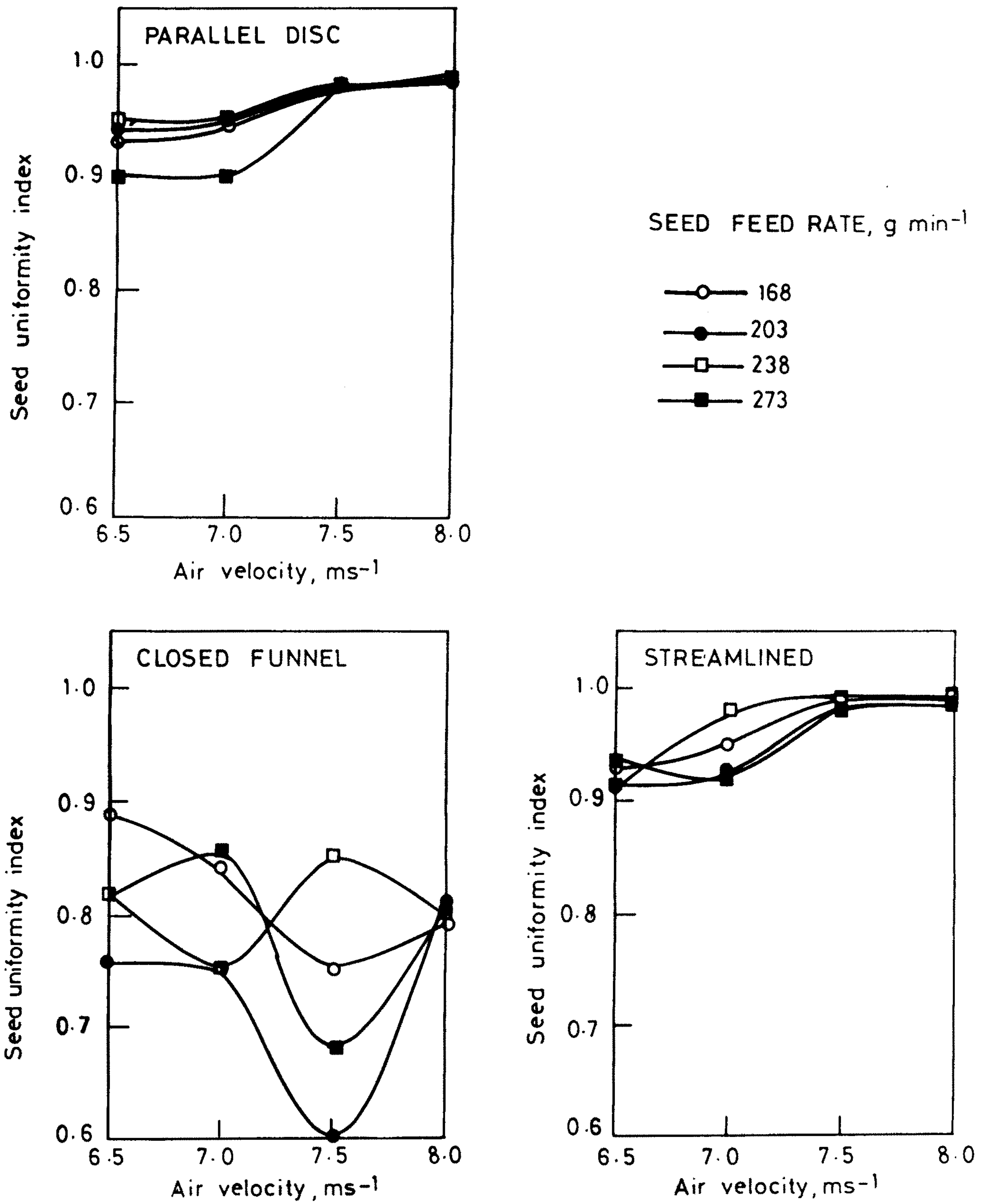


FIG. 4·11 EFFECT OF AIR VELOCITY AND SORGHUM FEED RATE ON UNIFORMITY

On maximising the regression equation for streamlined flow distributor, the optimised air velocity was 8.35 ms^{-1} and the seed feed rate was 250 g min^{-1}. This conclusion was in agreement with the selection of best head from the deviation analysis.

4.4.3. Measurement of pressure

The static pressure at different points along the flow path from the blower to the inlet of the distributor head provided valuable information on the aerodynamic resistance provided by different components of the conveyance and distribution system.

a. Air pressure developed by the blower.

The static pressure measured at the outlet of the blower indicated the total resistance offered by the seed during conveyance and distribution. The effect of air velocity in the vertical conveyance tube and seed feed rate on the blower outlet pressure for the different types of distributor head and the three types of seed are shown in Fig.4.12 - 4.14. The blower outlet pressure for all the distributor heads and seed types increased with the increase in air velocity. Comparing the blower pressure and air velocity relation between distributor heads, the closed funnel head resulted highest pressure of 23, 44 and 45 mm of water closely followed by the parallel disc distributor for 5.5 ms^{-1}, 90 g min^{-1} combination for sesame, 6.5 ms^{-1}, 273 g min^{-1} combination for pearl millet and 8.0 ms^{-1}, 273 g min^{-1} combination for sorghum respectively. The streamlined flow distributor resulted in 15.5, 25.6 and 30.2 mm blower outlet pressure for the above combination. The minimum blower outlet pressure observed with streamlined flow distributor was obviously due to the basic design of this head which resulted minimum disturbance to air flow. This was ensured due to uniform flow path without sudden contractions, expansions and abrupt change in flow directions. Comparing air velocity versus blower pressure relation for similar heads irrespective of the type of seed being fed, it was observed that the relationship between air velocity and blower pressure did not change appreciably. The figures also showed that increase in seed feed rate had a definite influence on the blower pressure and air velocity. The blower pressure

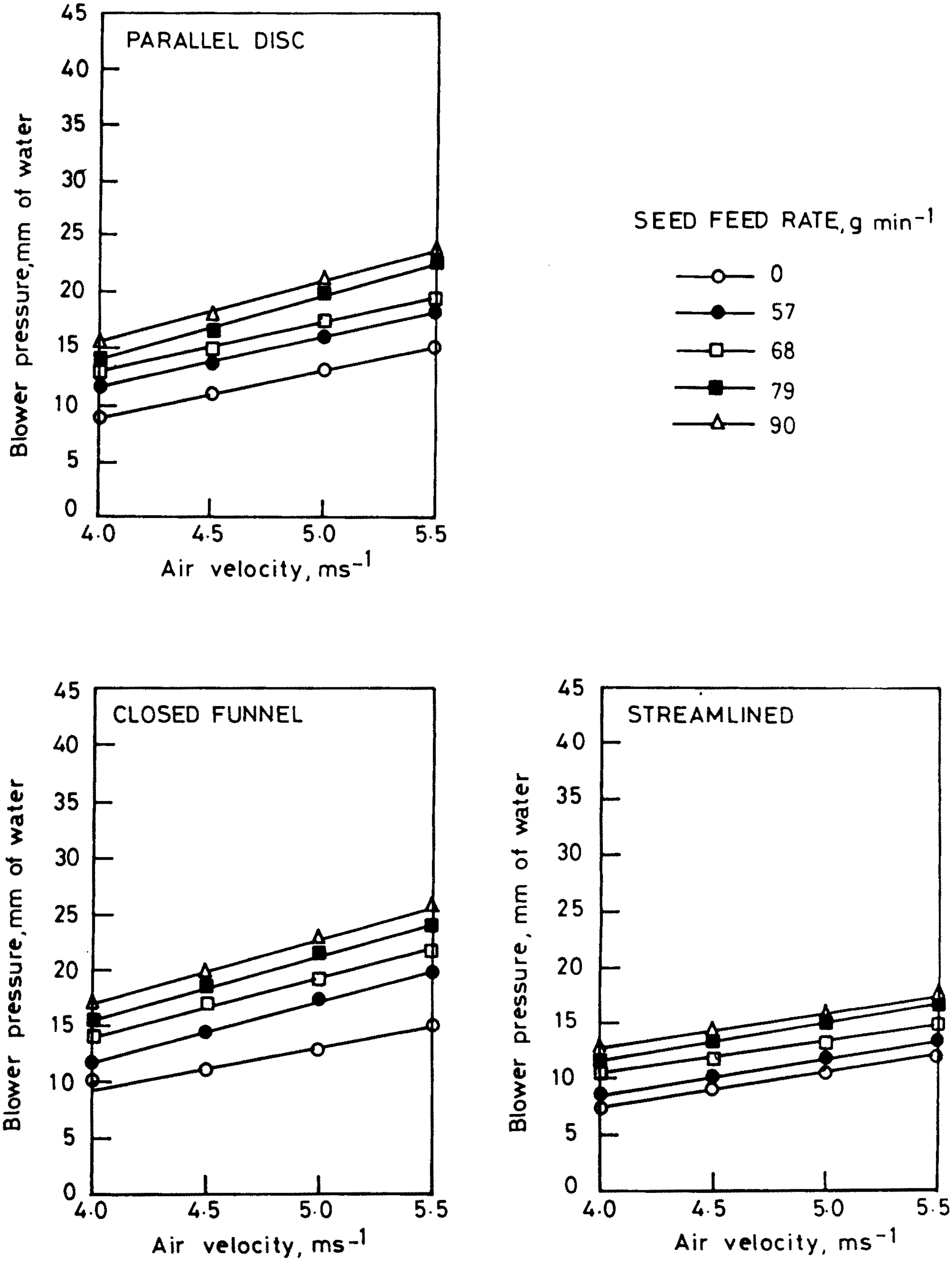


FIG. 4·12 EFFECT OF AIR VELOCITY AND SESAME FEED RATE ON BLOWER PRESSURE

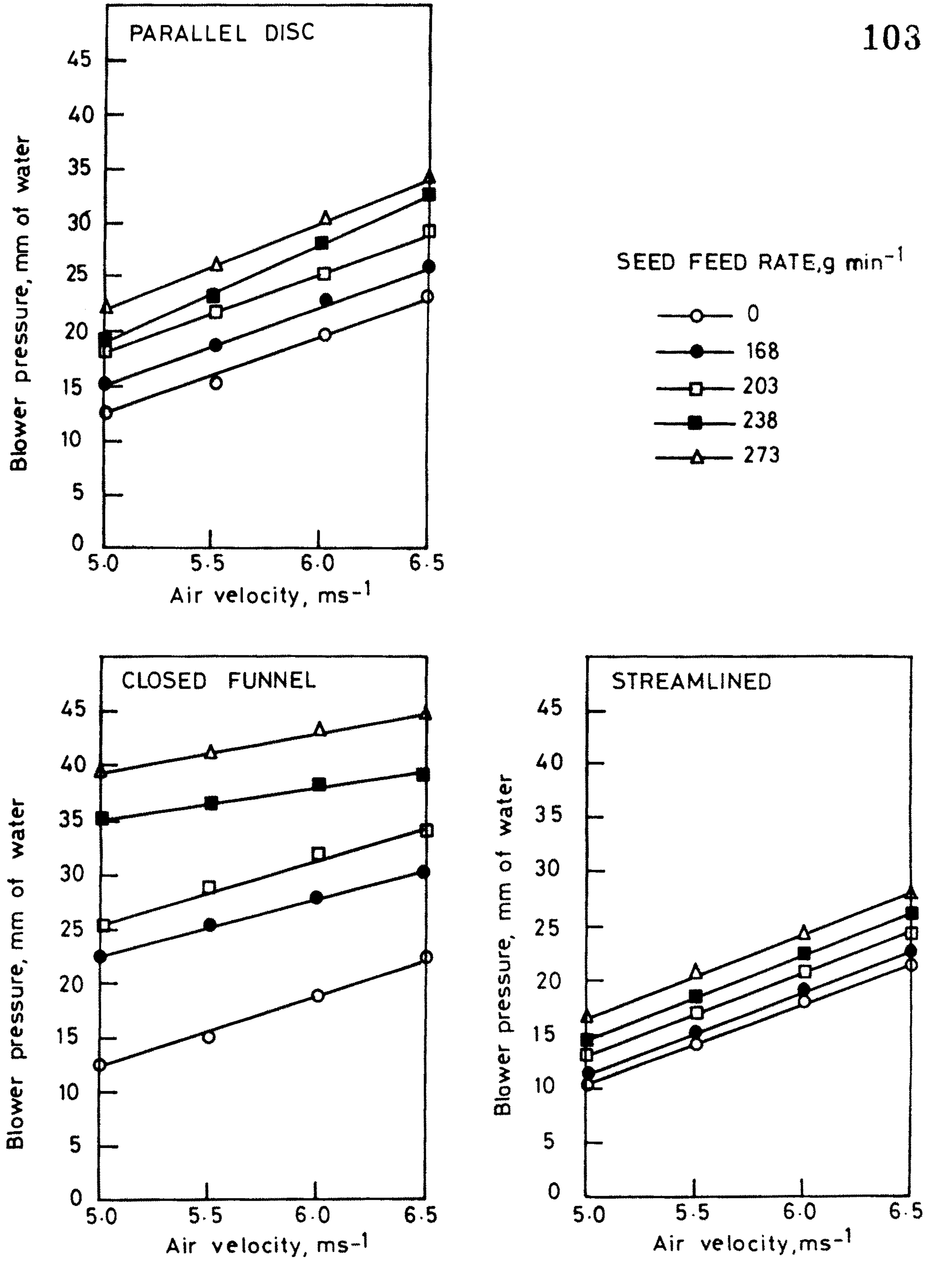


FIG. 4·13 EFFECT OF AIR VELOCITY AND PEARL MILLET FEED RATE ON BLOWER PRESSURE

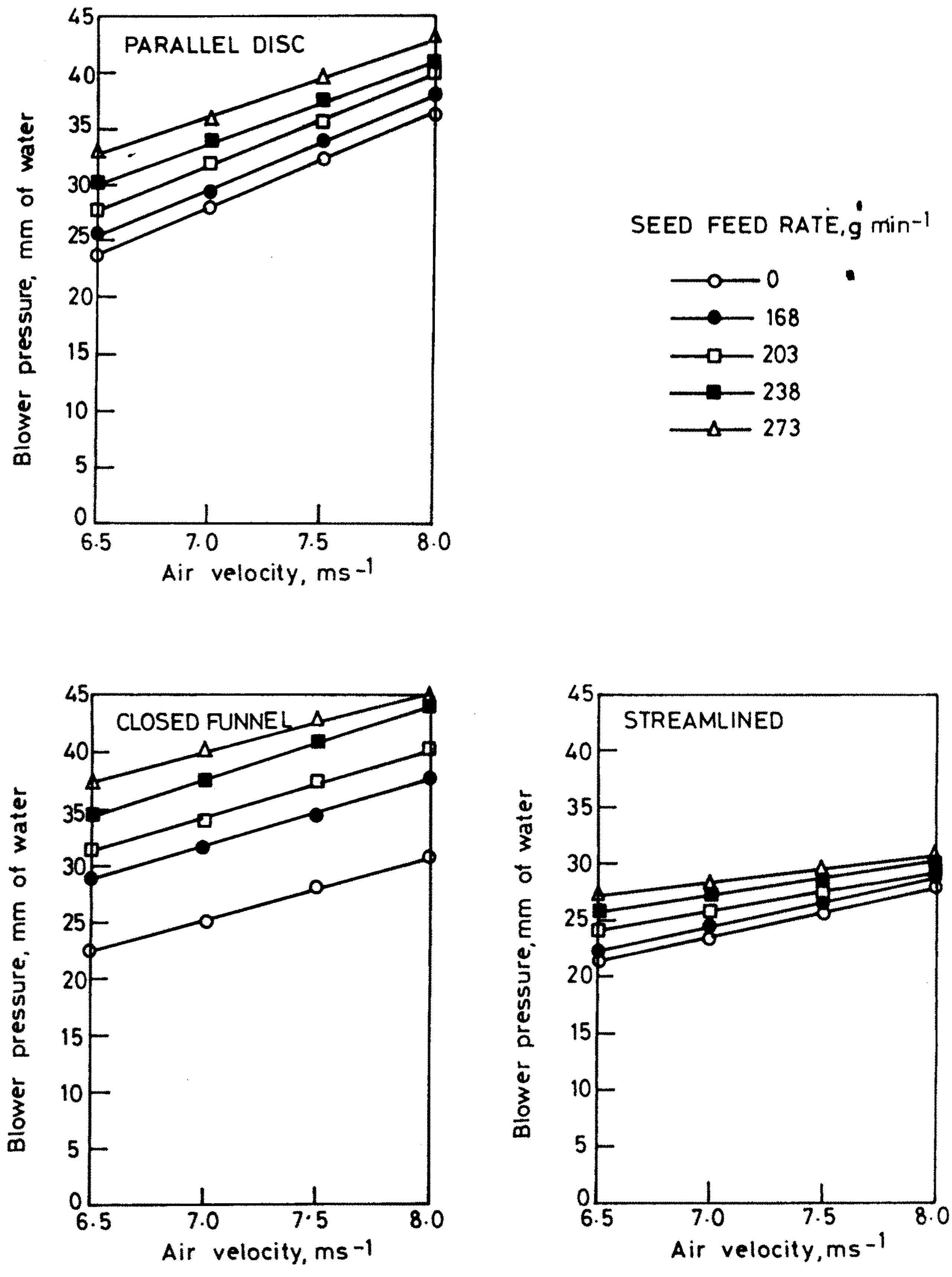


FIG. 4·14 EFFECT OF AIR VELOCITY AND SORGHUM FEED RATE ON BLOWER PRESSURE increased with increase in seed feed rate. It was also observed that the closed funnel distributor exhibited highest rate of increase in air pressure of 10, 22.5 and 14 mm for sesame, pearl millet and sorghum respectively with increase in seed feed rate.

b. Pressure at inlet of distributor head

The pressure measured at the inlet of the distributor head for different seed feed rates and seed type is shown in Fig.4.15-4.17. The head pressure reflected the amount of head loss due to the fluidised air-seed mixture. Combining Fig.4.12 to 4.14 it could be seen that the trend of increase in blower pressure and air velocity was a continuous function over the entire range. When seeds were introduced into the air stream, the pressure drop by the head varied due to the resistance offered by the seed and restriction of passage due to seed accumulation and choking. The highest head pressure was observed in parallel disc distributor. Fig.4.15 represents sesame which was fed at a comparatively very low seed feed rate than other types of seed. Introduction of seed into the air stream increased the flow resistance to 13 mm and 10 mm of water column in parallel disc and closed funnel distributor. But in the case of streamlined flow distributor, it was very meagre (2.5 mm of water column) representing free flow of air seed mixture. The effect due to flow of pearl millet and sorghum which are identical in seed feed rate varied due to the difference in the number of seeds traversing the air stream per unit time.

c. Eductor pressure

The suction created in the eductor for all the three distributor heads and types of seed are shown in Fig.4.18-4.20. The parallel disc head recorded a minimum eductor suction from -1.5 mm to - 10 mm of water column for the different ranges of air velocity and seed feed rate tested compared to the other two types of head. The streamlined flow head recorded -15 to -29 mm of water column for the same range. The sudden change in direction of air flow in the parallel disc head had caused this effect. The increase in seed rate resulted in consistent decrease in suction pressure for the seeds. This was due to the increase in

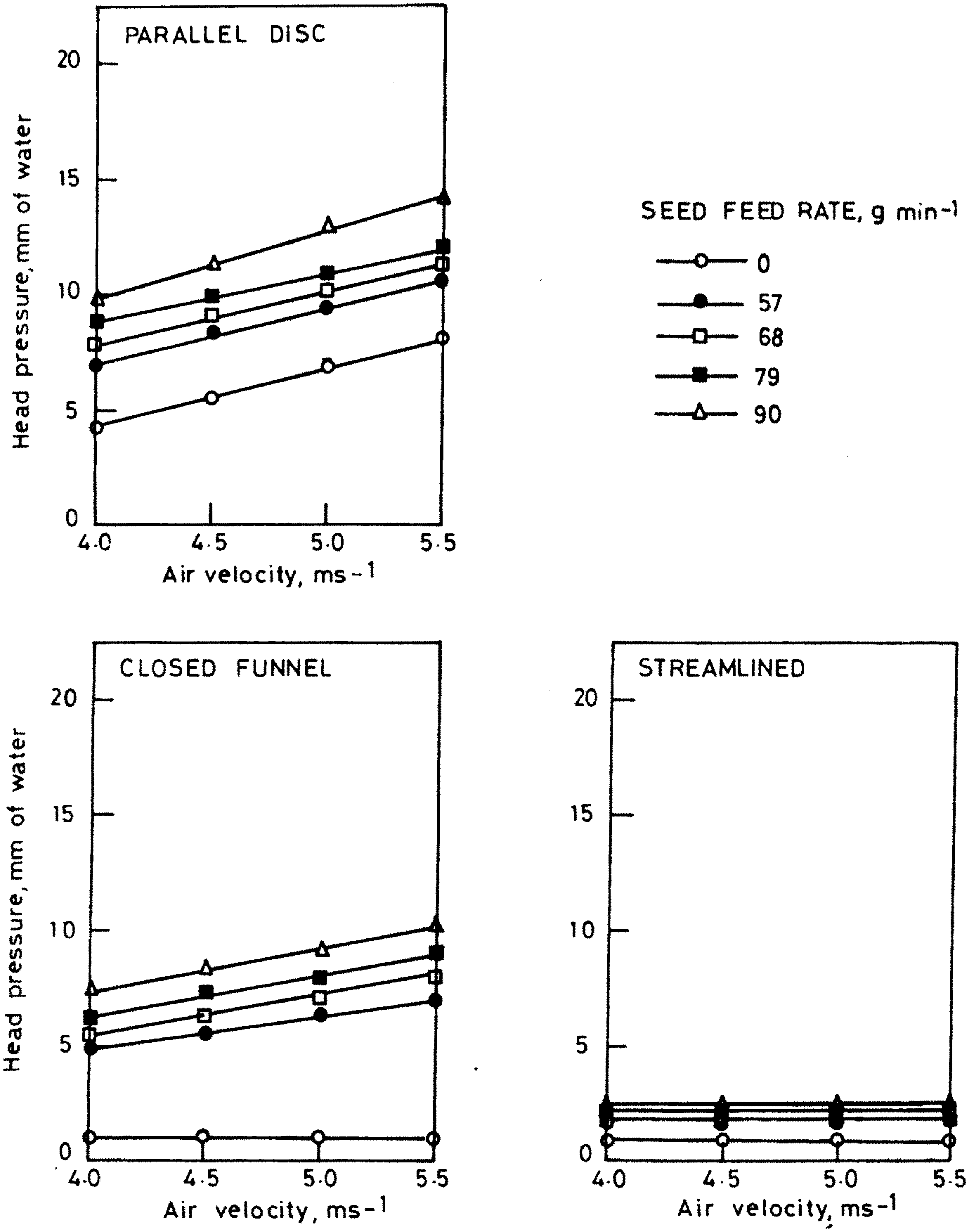


FIG. 4·15 INFLUENCE OF AIR VELOCITY AND SESAME FEED RATE ON HEAD PRESSURE

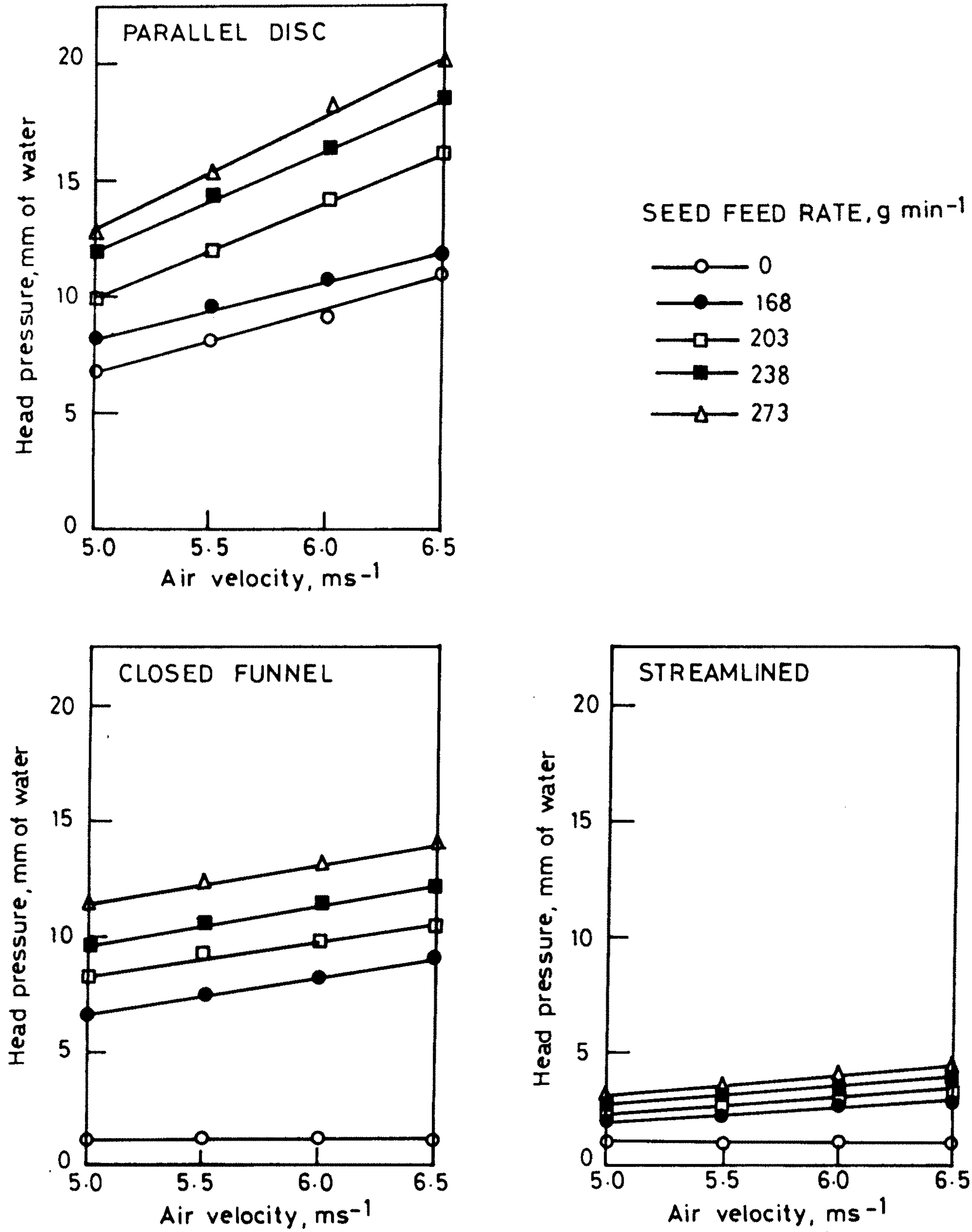


FIG. 4·16 INFLUENCE OF AIR VELOCITY AND PEARL MILLET FEED RATE ON HEAD PRESSURE

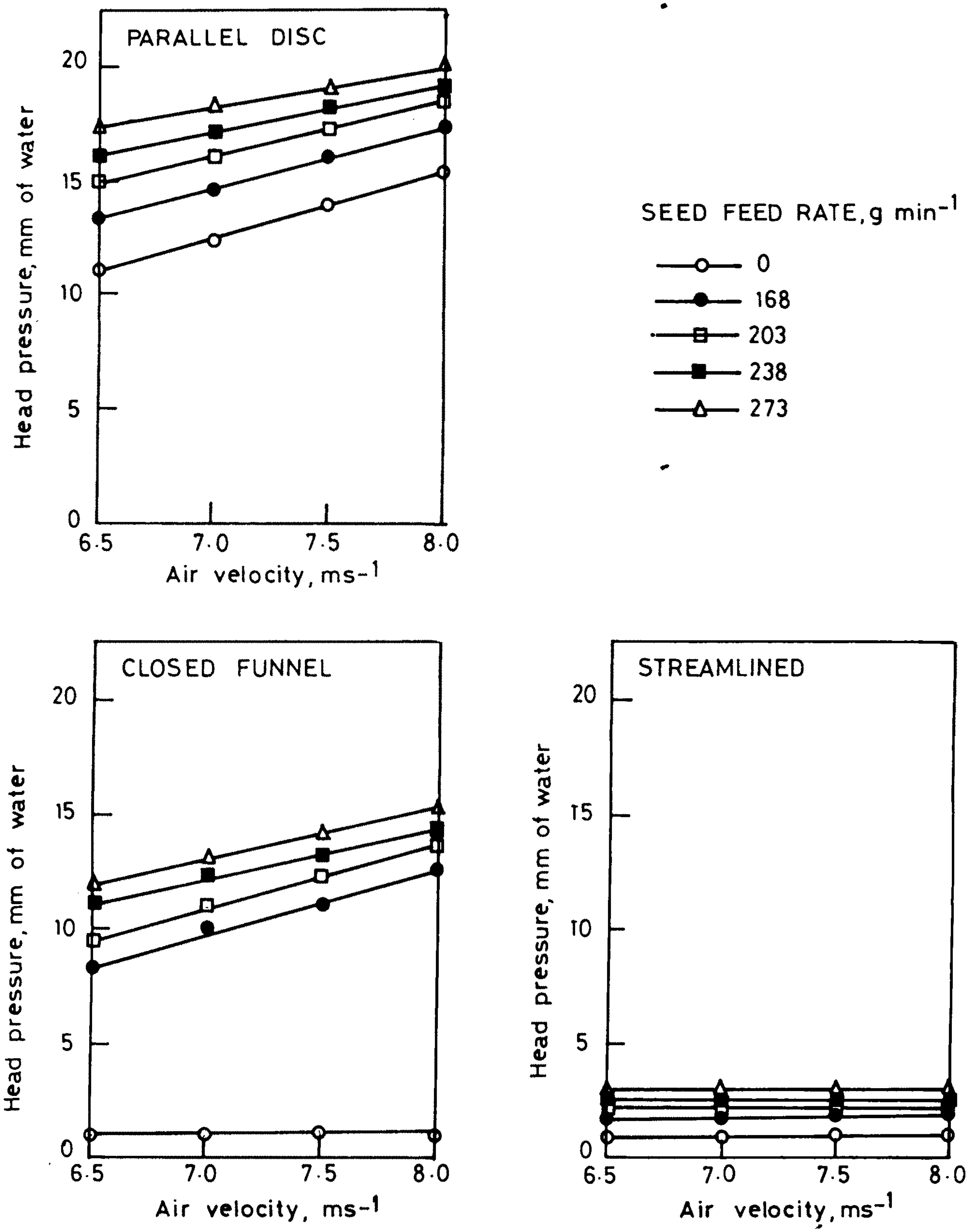


FIG. 4·17 INFLUENCE OF AIR VELOCITY AND SORGHUM FEED RATE ON HEAD PRESSURE

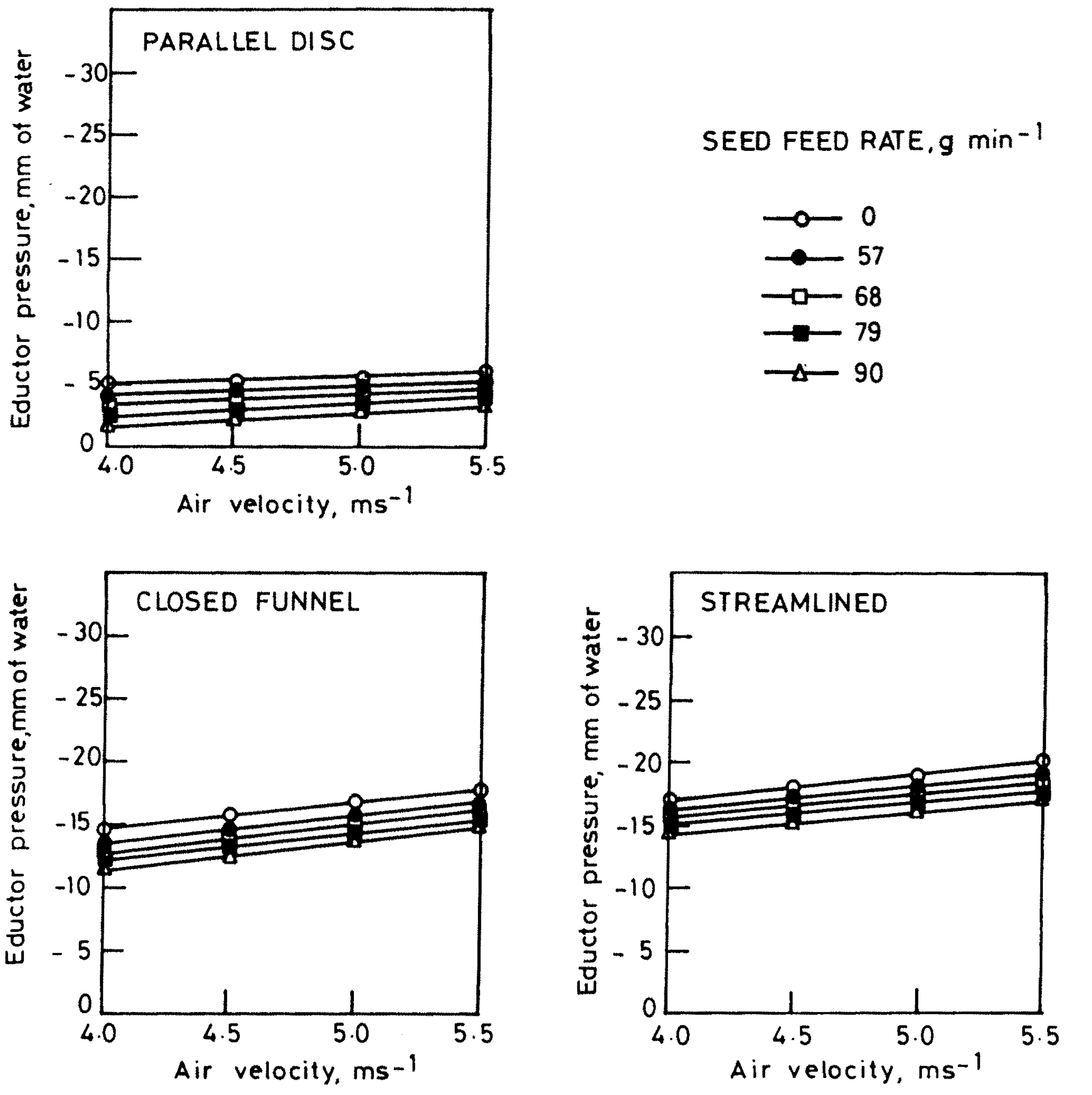


FIG. 4·18 EFFECT OF AIR VELOCITY AND SESAME FEED RATE ON EDUCTOR PRESSURE

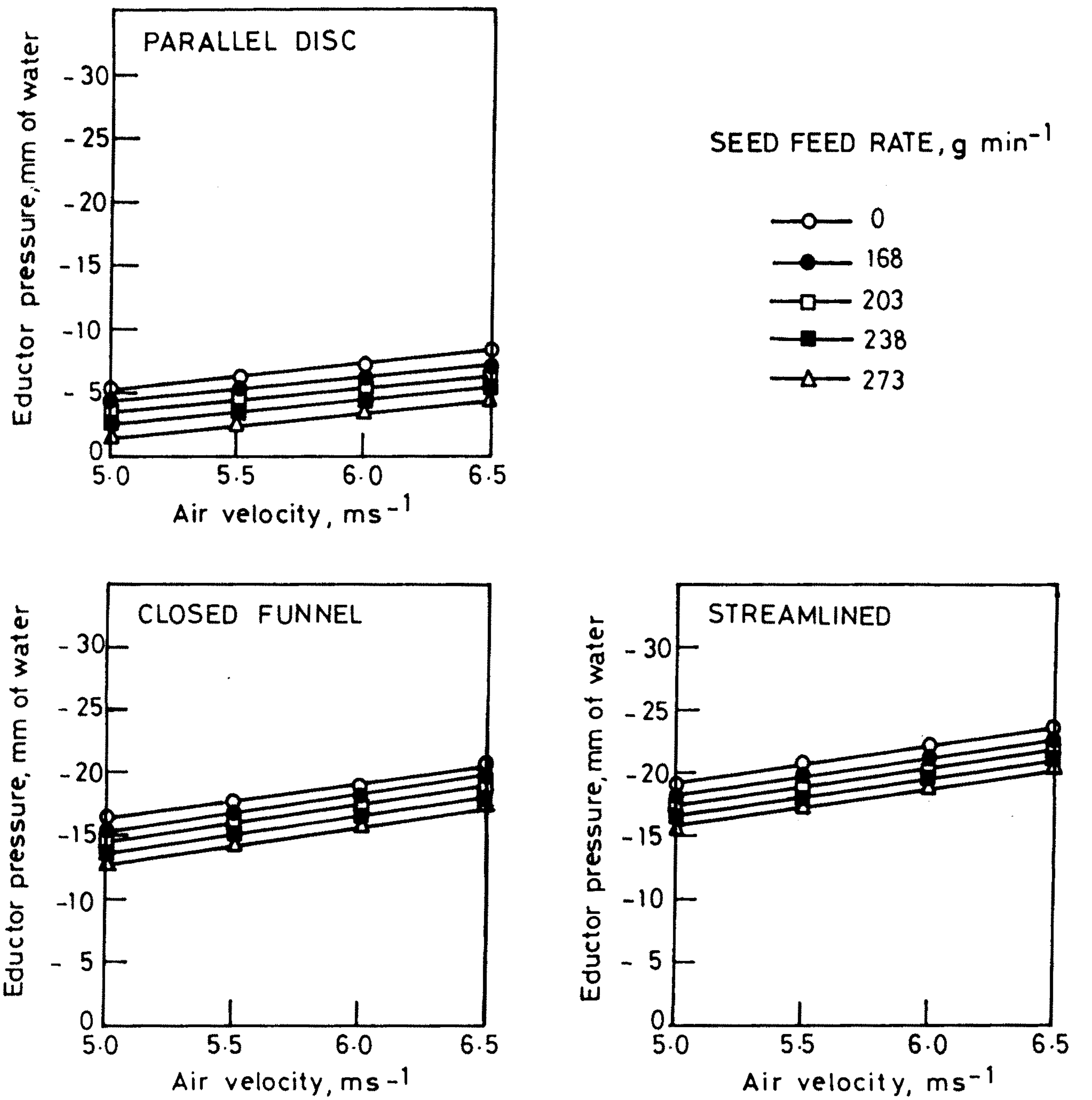


FIG. 4.19 EFFECT OF AIR VELOCITY AND PEARL MILLET FEED RATE ON EDUCTOR PRESSURE

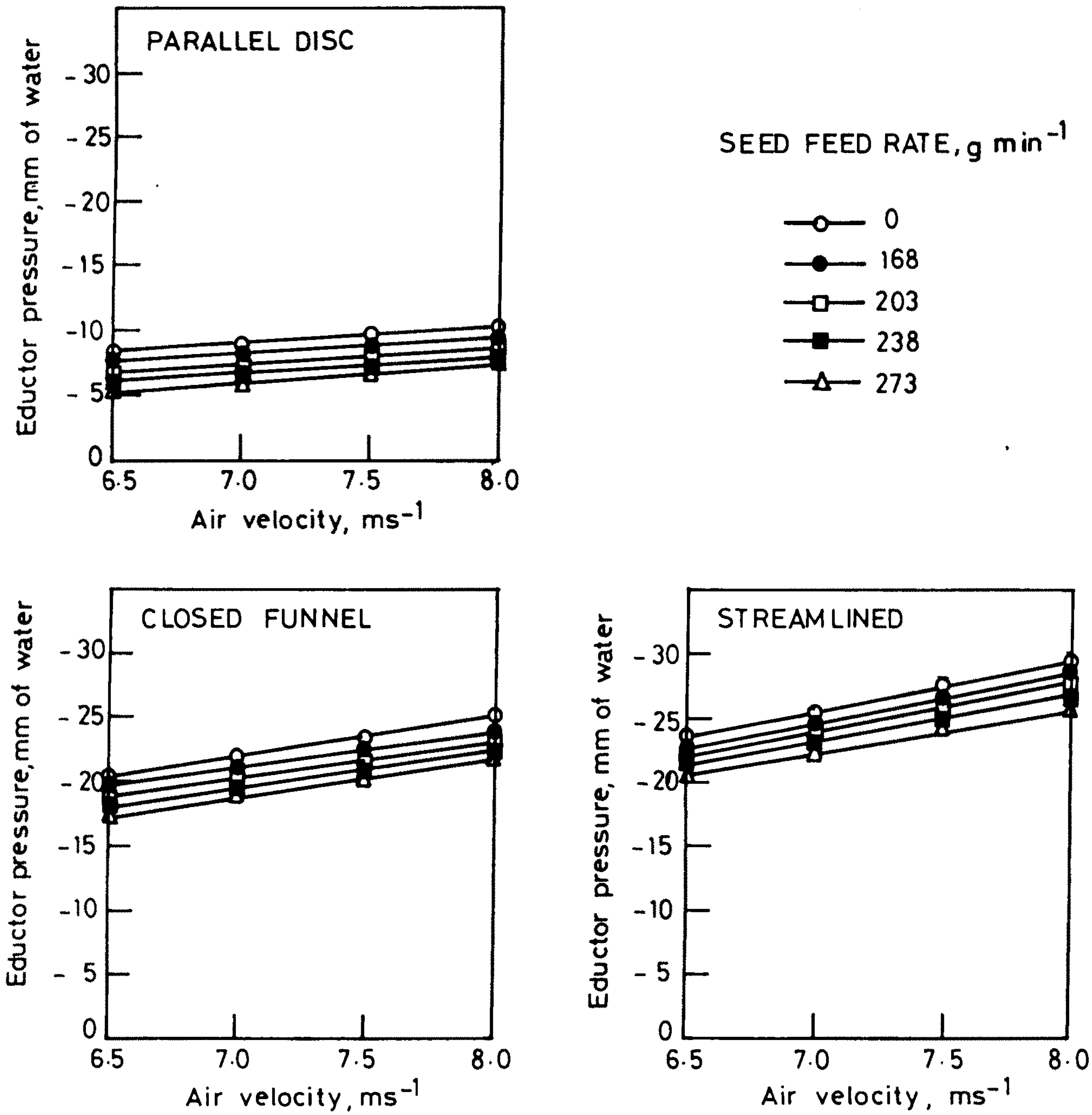


FIG. 4·20 EFFECT OF AIR VELOCITY AND SORGHUM FEED RATE ON EDUCTOR PRESSURE absolute pressure above the eductor due to increased seed flow rate. Comparing the effect of the eductor suction pressure for pearl millet and sorghum seeds at 6.5 ms^{-1} air velocity in streamlined flow head the eductor suction was -16 to -21 mm of water for pearl millet and -20 to -29 mm of water for sorghum in the seed feed rates tested. The same phenomena occured for the other heads also. This was due to the lower number of sorghum seeds fed per unit time than that of pearl millet. This led to comparatively lesser air flow resistance and hence increased suction pressure.

4.4.4. Trajectory of seed

a. Prediction of seed movement in vertical pipe

The relative velocity of sesame, pearl millet and sorghum seeds during vertical conveyance was calculated for different air velocities as explained in section 3.4.3a and shown in Fig.4.21. The curves explain how the seed introduced in the air stream at different air velocities gain speed as they travel along the vertical pipe until the terminal velocity was obtained. The difference in time taken by the individual seeds to reach terminal velocity was due to their weight and the velocity of air stream. It was observed that sesame attained terminal velocity after a time interval of 0.4167 second at the air velocities tested while the same for pearl millet and sorghum was 0.6667 and 0.7917 second respectively.

The predicted path traced by sesame and pearl millet seeds are shown in Fig.4.22. The predicted path along with the actual path traced by sorghum is shown in Fig.4.23-4.24. It was observed that the vertical height attained by the seed with respect to time appear to show curvilinear relationship initially and linear over certain height, thus attaining constant velocity. It was also observed that lighter seed like sesame attained constant relative velocity at a higher height than other seeds. This implied that longer vertical conveyance pipe was required for lighter seeds like sesame, if relative velocity of the seed at the entrance of the distributor head is to be maintained without change in air velocity. From the theoretical path traced, the height of vertical conveyance pipe was calculated taking into account the time

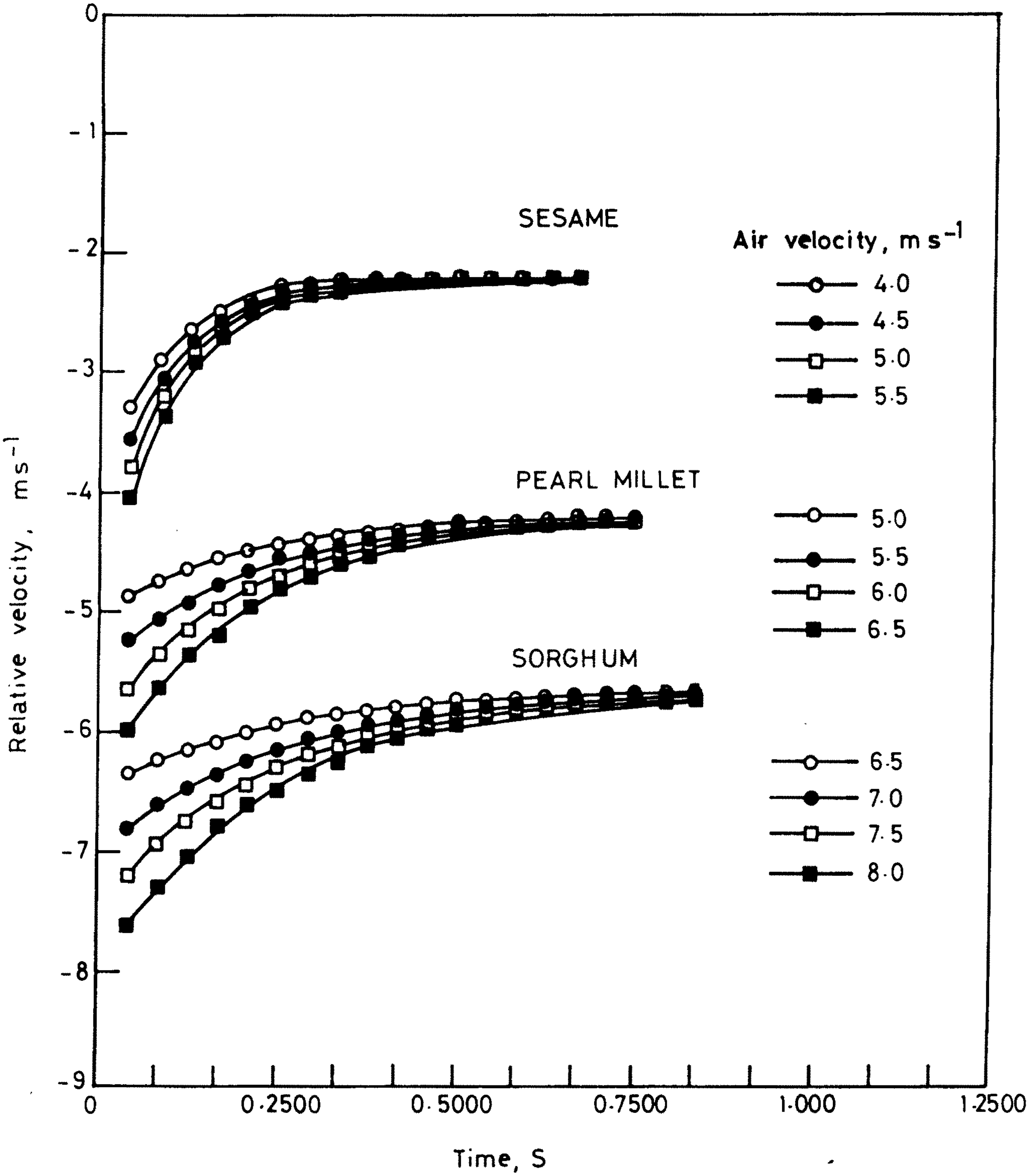


FIG.4·21 EFFECT OF AIR VELOCITY AND TIME ON RELATIVE VELOCITY

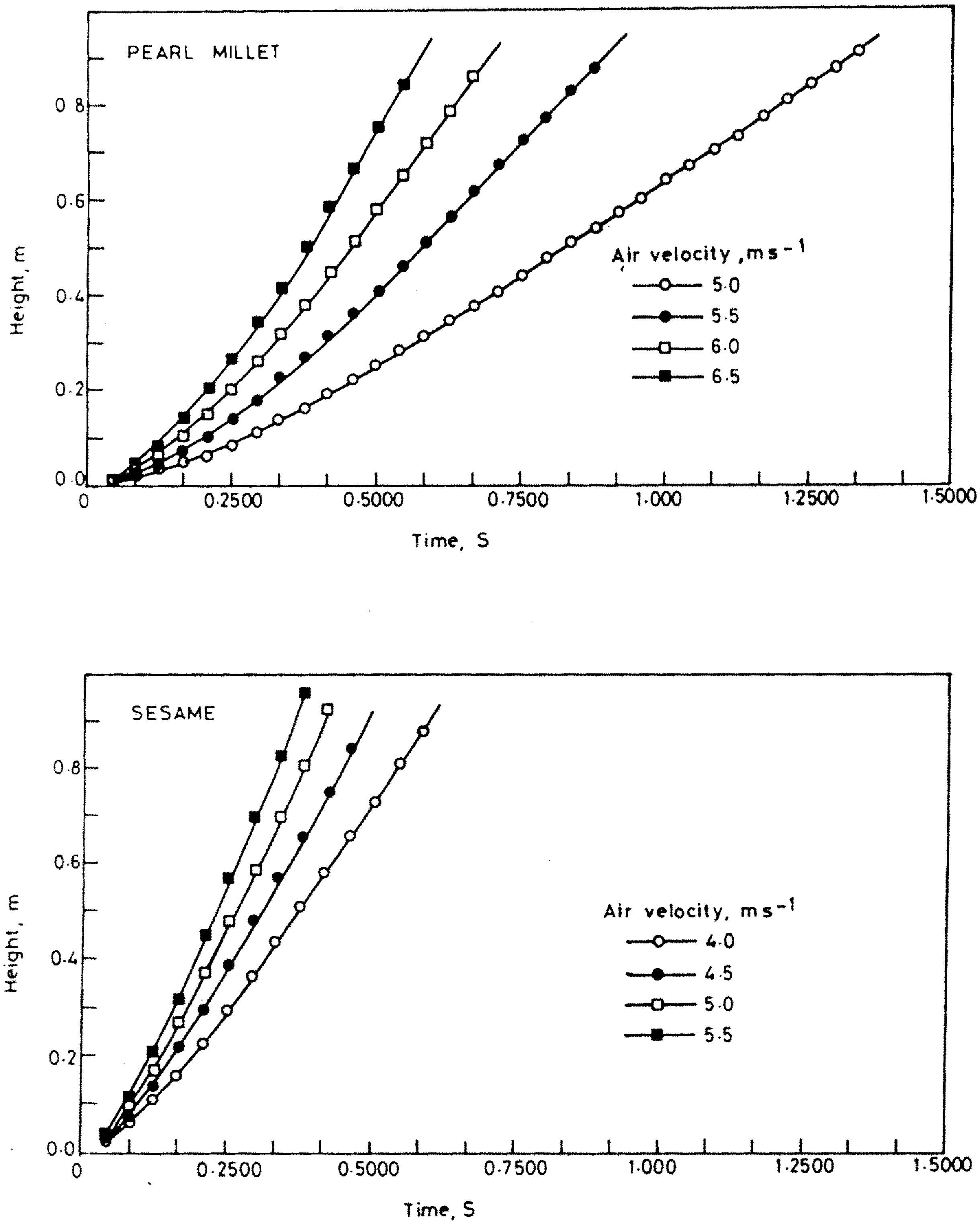


FIG. 4·22 PREDICTED PATH OF SEED IN VERTICAL PIPE

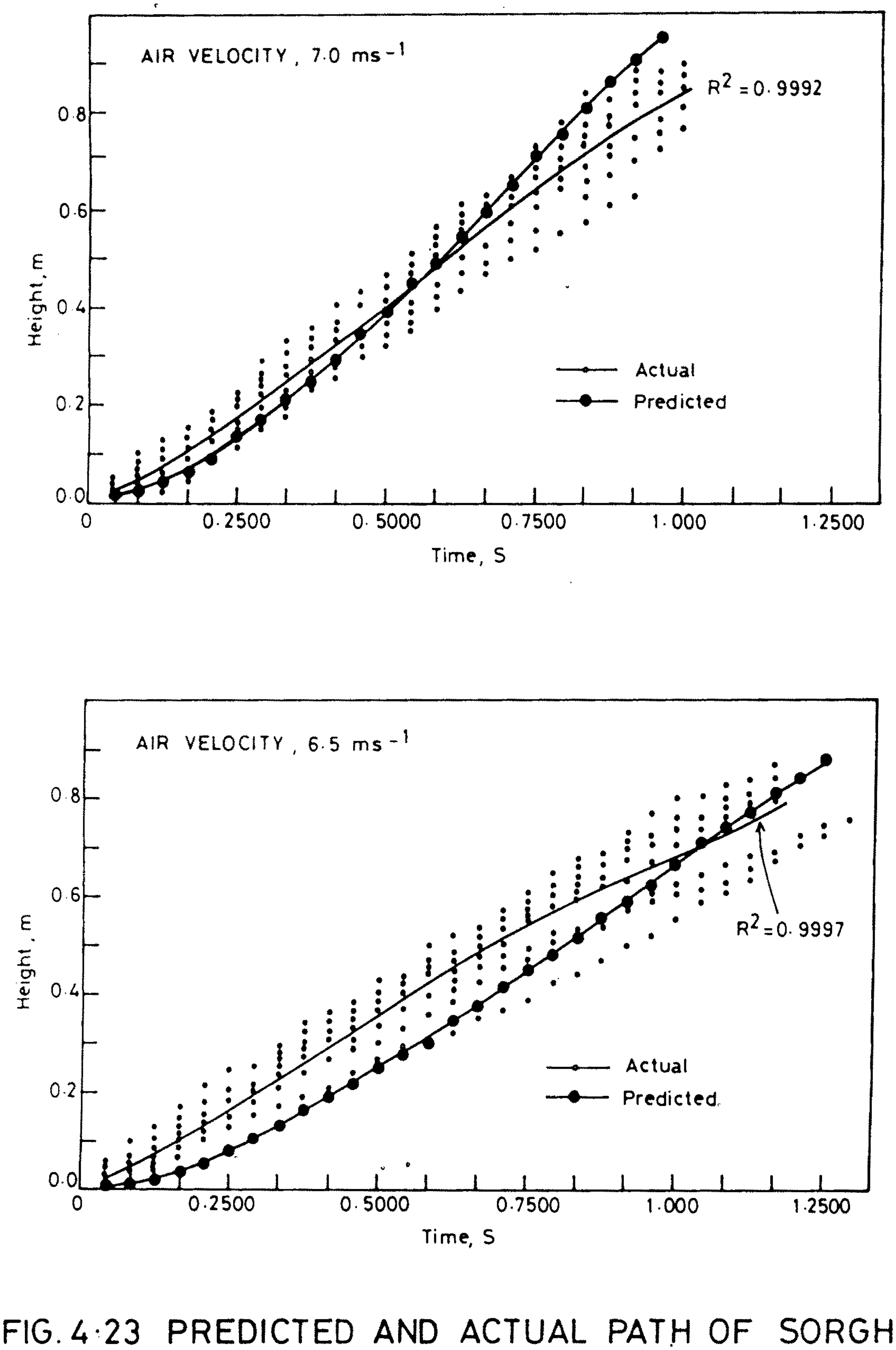
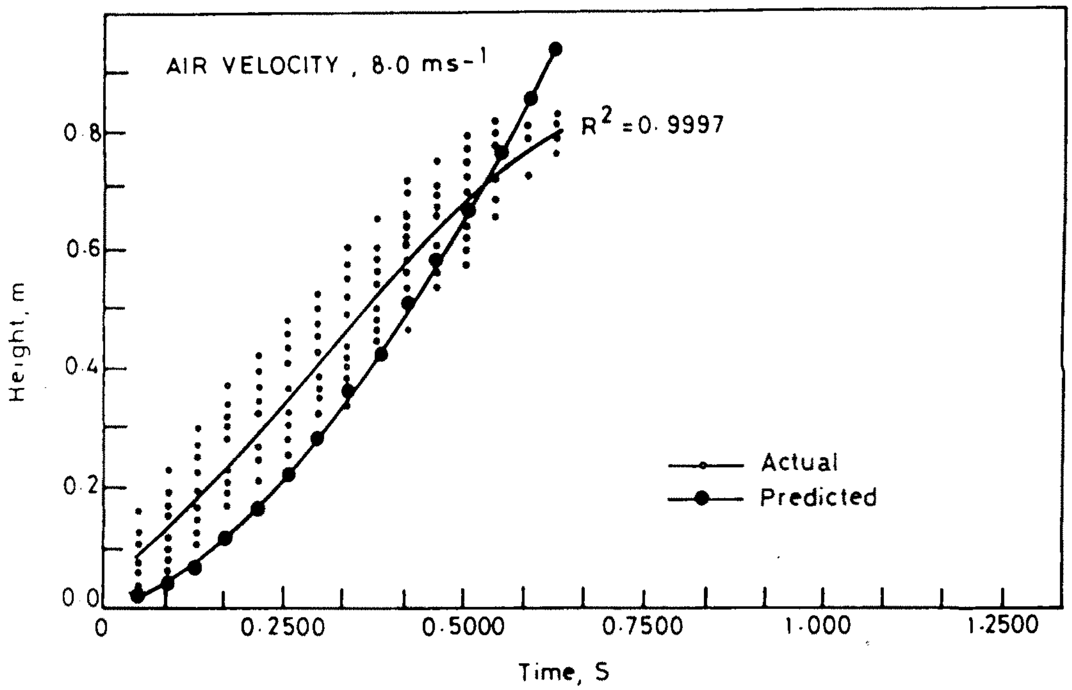


FIG. 4·23 PREDICTED AND ACTUAL PATH OF SORGHUM IN VERTICAL PIPE



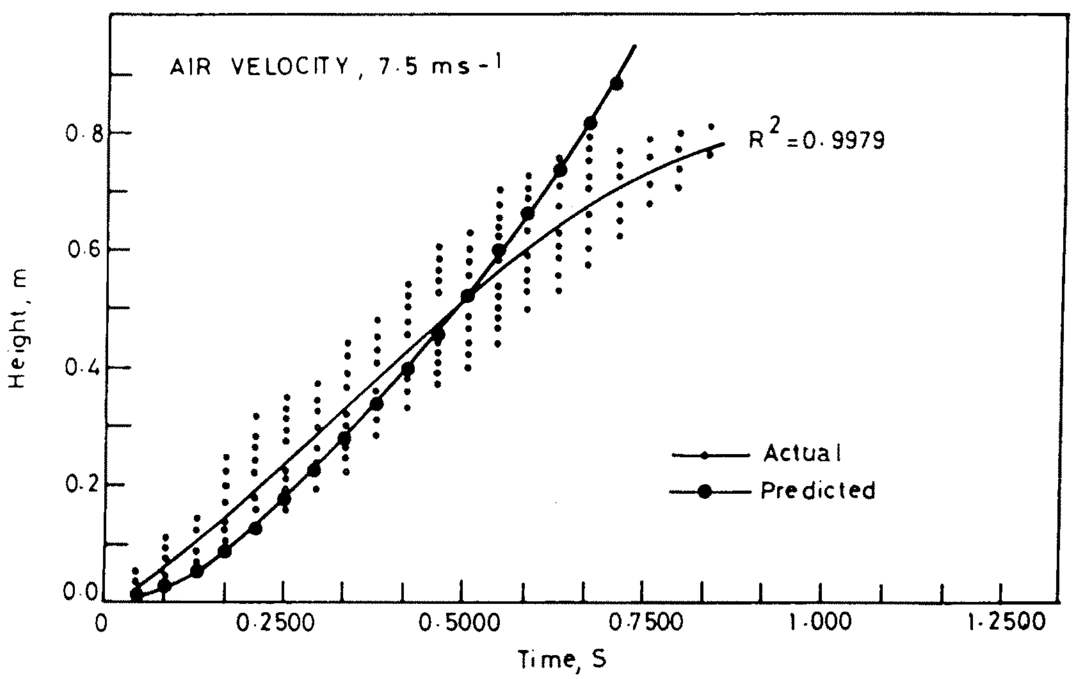


FIG. 4.24 PREDICTED AND ACTUAL PATH OF SORGHUM IN VERTICAL PIPE

taken by the seed to attain terminal velocity, Fig.4.21. Though the time taken by the sesame seed to reach constant relative velocity at different air velocities tested was same, the height travelled by the seed relative to the increased air velocity in the vertical conveyance pipe was higher. Hence the average of the height required to attain constant relative velocity at the four air velocities at which the experiment was conducted was fixed as the height of the vertical conveyance pipe. The average height at which sesame, pearl millet and sorghum seeds attained constant relative velocity was calculated as 0.84, 0.74 and 0.83 m. Hence the height of the vertical conveyance pipe was fixed at 0.85 m above the eductor level during experiments and in the prototype to accommodate the three types of seed in a single vertical pipe.

b. Tracing the actual path of seed in vertical pipe

The actual path traced by sorghum seed in the vertical conveyance pipe for different air velocities and distributor heads are shown in Fig.4.25-4.28. The actual path traced through videography showed more zig-zag paths at lower velocity of 6.5 ms^{-1} than the higher velocity of 8.0 ms^{-1}. At lower air velocities the streamlined flow distributor showed minimal whirling and curves compared to the other two distributors. As the air velocity increased, the velocity of seed also increased. The bouncing pattern of seed in the vertical conveyance pipe for all distributors was observed as 3 to 4. The horizontal movement of the seed during conveyance was almost negligible. There was not much difference in the seed path in the vertical conveyance pipe between the distributor heads.

The comparison of the actual and predicted path traced by the sorghum seed are shown in Fig.4.23-4.24. There was not much difference in the seed path inside the vertical conveyance pipe between the heads. Hence the actual path was plotted taking the average of the path traced by the three heads. The actual and predicted path showed minimum variation at all the air velocities tested. The seed initially travelled 0.07 $\pm$ 0.1 m, 0.03 m, 0.04 $\pm$ 0.01 m and 0.06 $\pm$ 0.02 m more height at 6.5, 7.0, 7.5 and 8.0 ms^{-1} air velocity respectively in

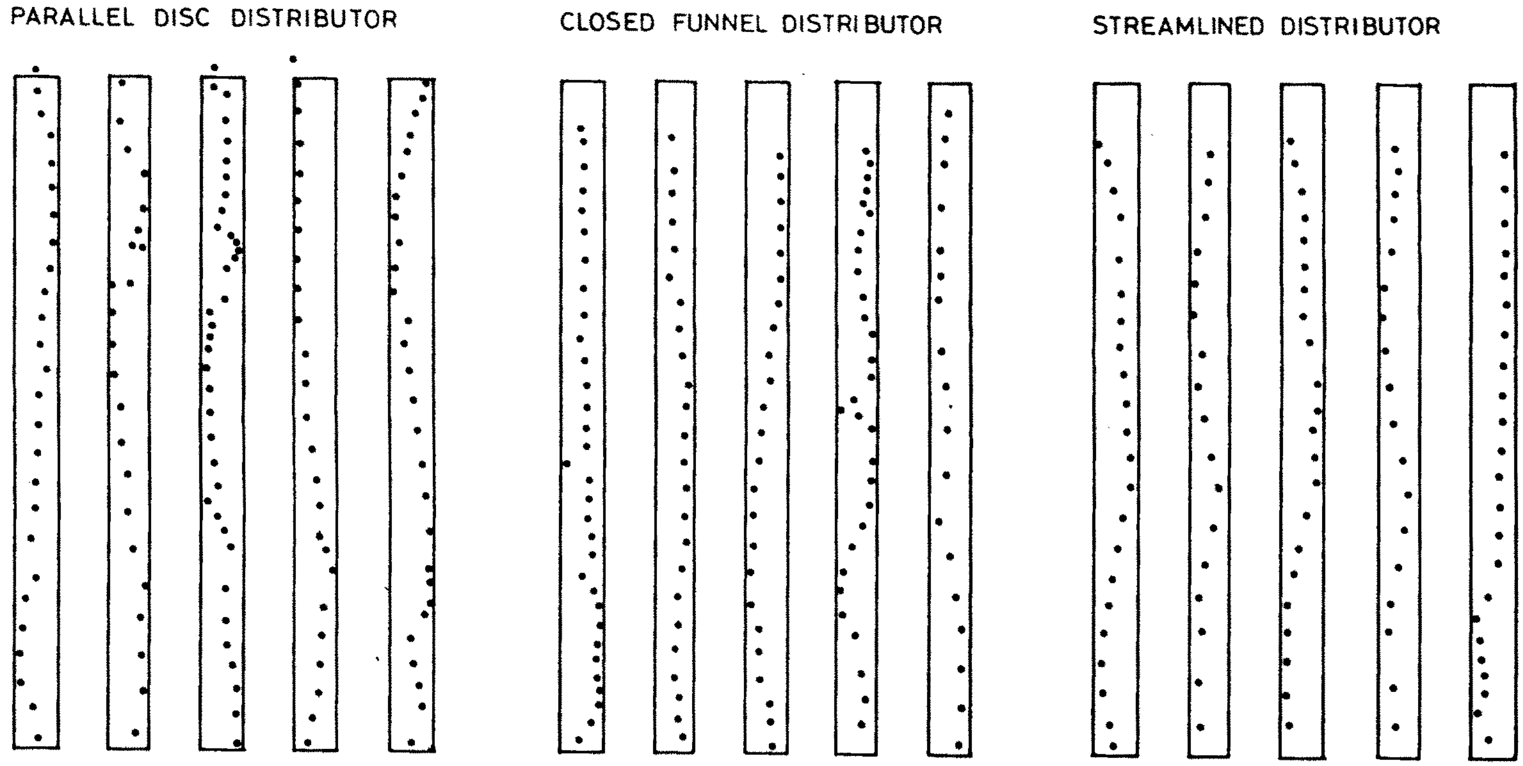


FIG. 4.25 ACTUAL SEED PATH IN VERTICAL PIPE AT 6.5 ms^{-1} AIR VELOCITY

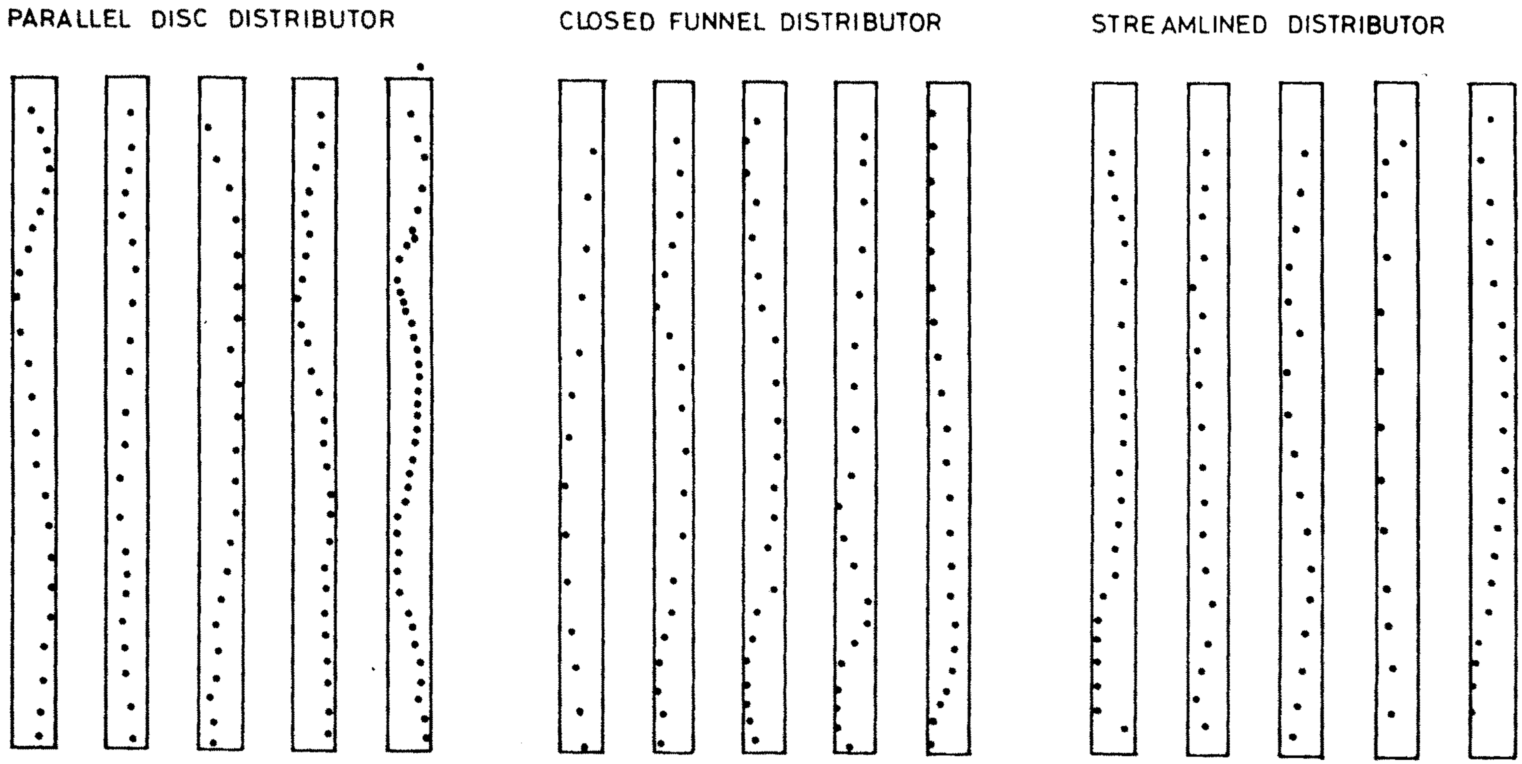


FIG. 4.26 ACTUAL SEED PATH IN VERTICAL PIPE AT 7.0 ms^{-1} AIR VELOCITY

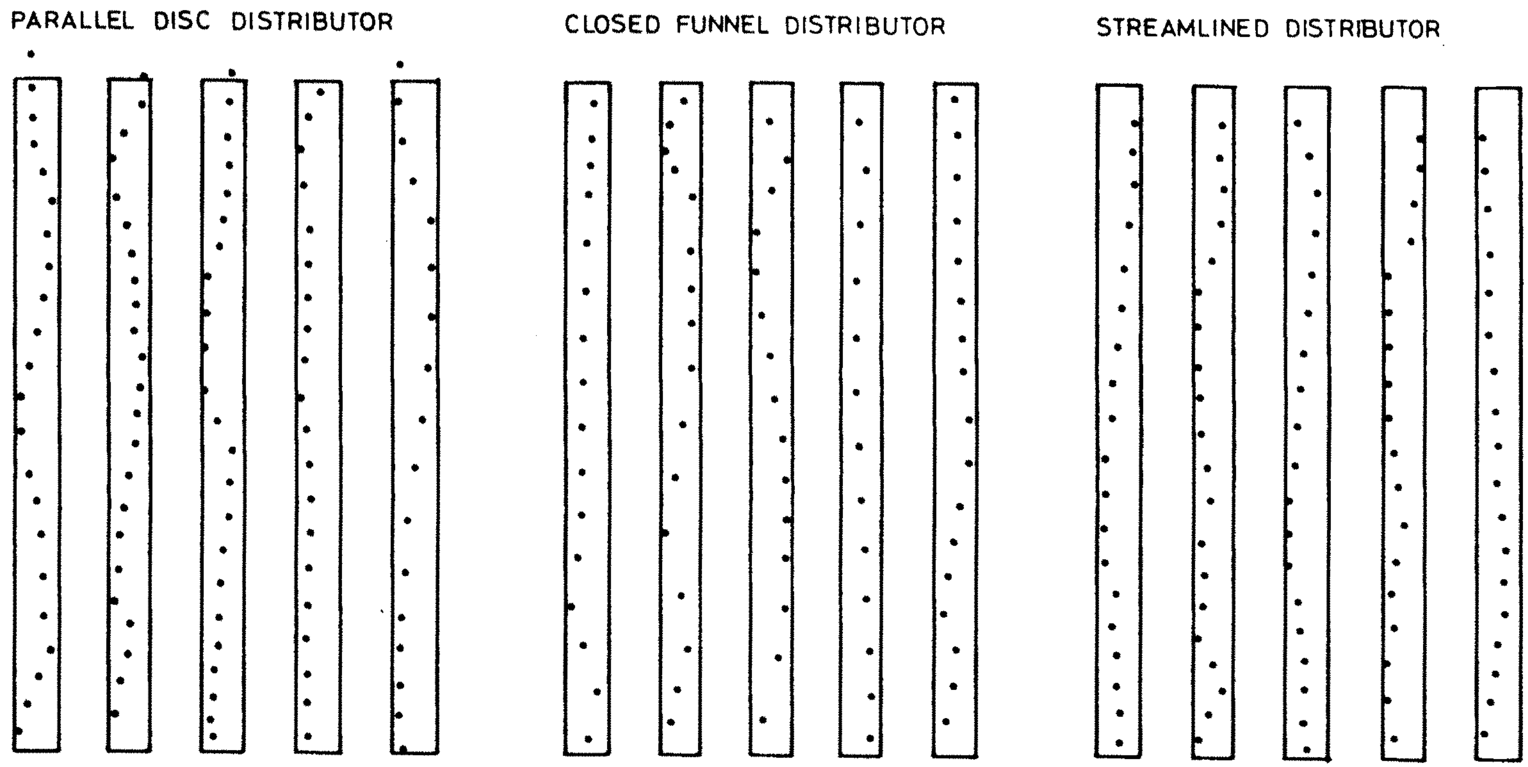


FIG. 4·27 ACTUAL SEED PATH IN VERTICAL PIPE AT 7·5 ms^{-1} AIR VELOCITY

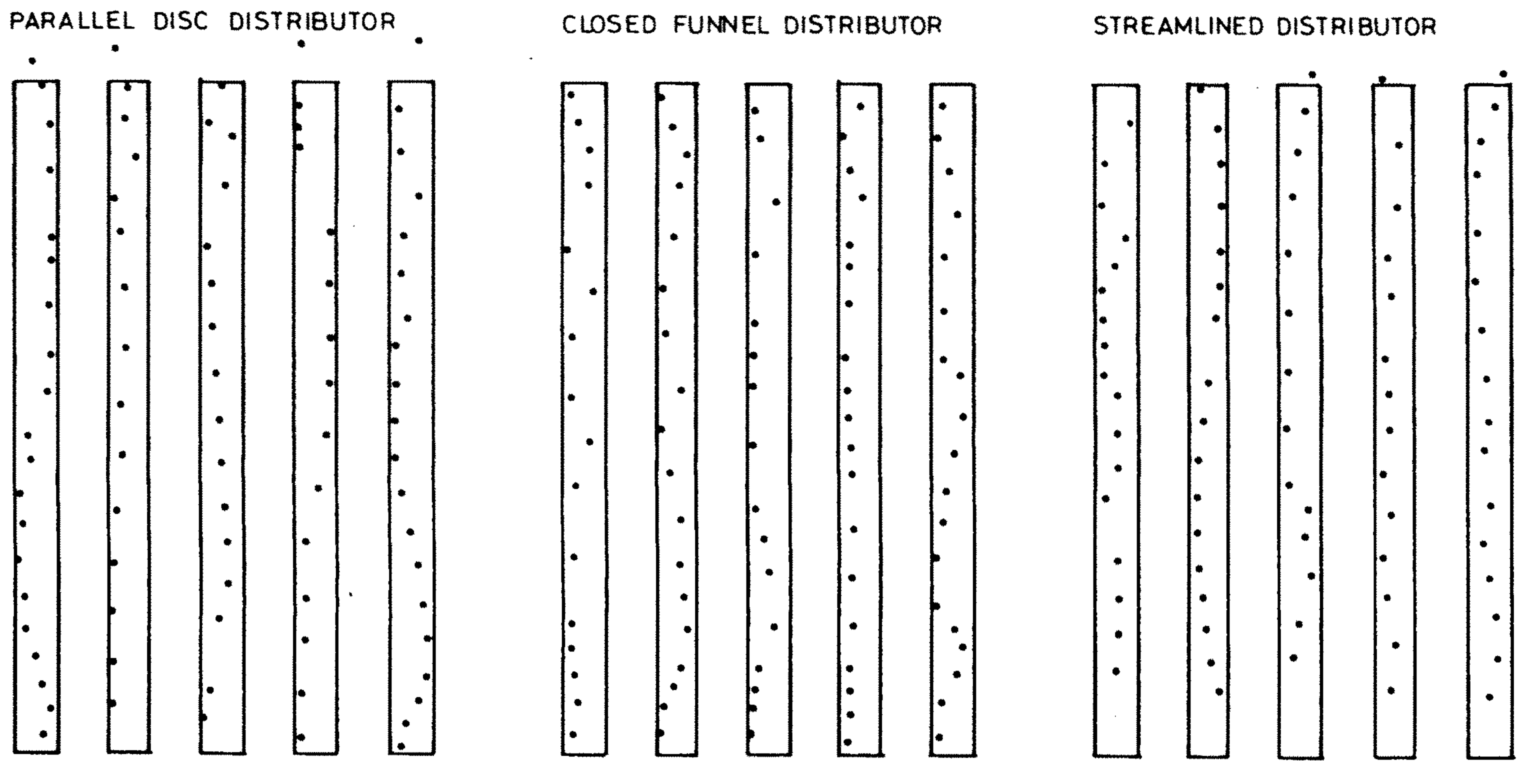


FIG. 4.28 ACTUAL SEED PATH IN VERTICAL PIPE AT 8.0 ms^{-1} AIR VELOCITY

actual path than predicted. As time progressed both paths joined together. Hence for design consideration predicted path of seed could be used. Thus the model developed by Chancellor (1960) coincided with the actual path traced by the seed during vertical conveyance.

c. Tracing the actual path of seed in the distributor

The path traced by the seed in the distributor head revealed the behaviour of individual seed during the travel from the head inlet to outlet. The path traced by the seed in the three distributors at different air velocities is illustrated in Fig.4.29 to 4.32. The path traced was viewed from single view point. The traced paths were projections of the three dimensional paths obtained on a plane perpendicular to the camera, Plate 4.1 to 4.3. The seeds followed different paths and exited through any one of the radial outlets. The paths shown in figures correspond to those traced by seeds exiting in outlets located on the plane perpendicular to the camera. The path of seed exiting on left and right outlets were shown on the same side for comparison in the figures.

In the parallel disc distributor, the seed paths show 90 degree deflection from axial direction to radial direction. The deflection of the seed path by the top disc of the distributor could be seen clearly at the highest air velocity of 8.0 ms^{-1}. At lesser air velocities of 6.5, 7.0 and 7.5 ms^{-1} the seed tend to turn along with the air stream and moved radially outward without much impact on the distributor walls. The flow path at 7.5 and 8.0 ms^{-1} showed highly consistent flow paths indicating the predominant effect of air flow in moving the seed through the distributor head.

The seed traced random path between inlet to outlet in the closed funnel distributor. It was observed clearly that there was no movement of the seed in the lateral direction of the funnel. The seed tend to entangle to one side of the funnel alone. The zig-zag path traced by the seed reflect the turbulence created in the head. It was interesting to observe that at lower air velocities the seed travelled along the side walls and egressed through the outlet. At 7.5 ms^{-1} air velocity, the seed travelled upto the top of the funnel and deflected towards the

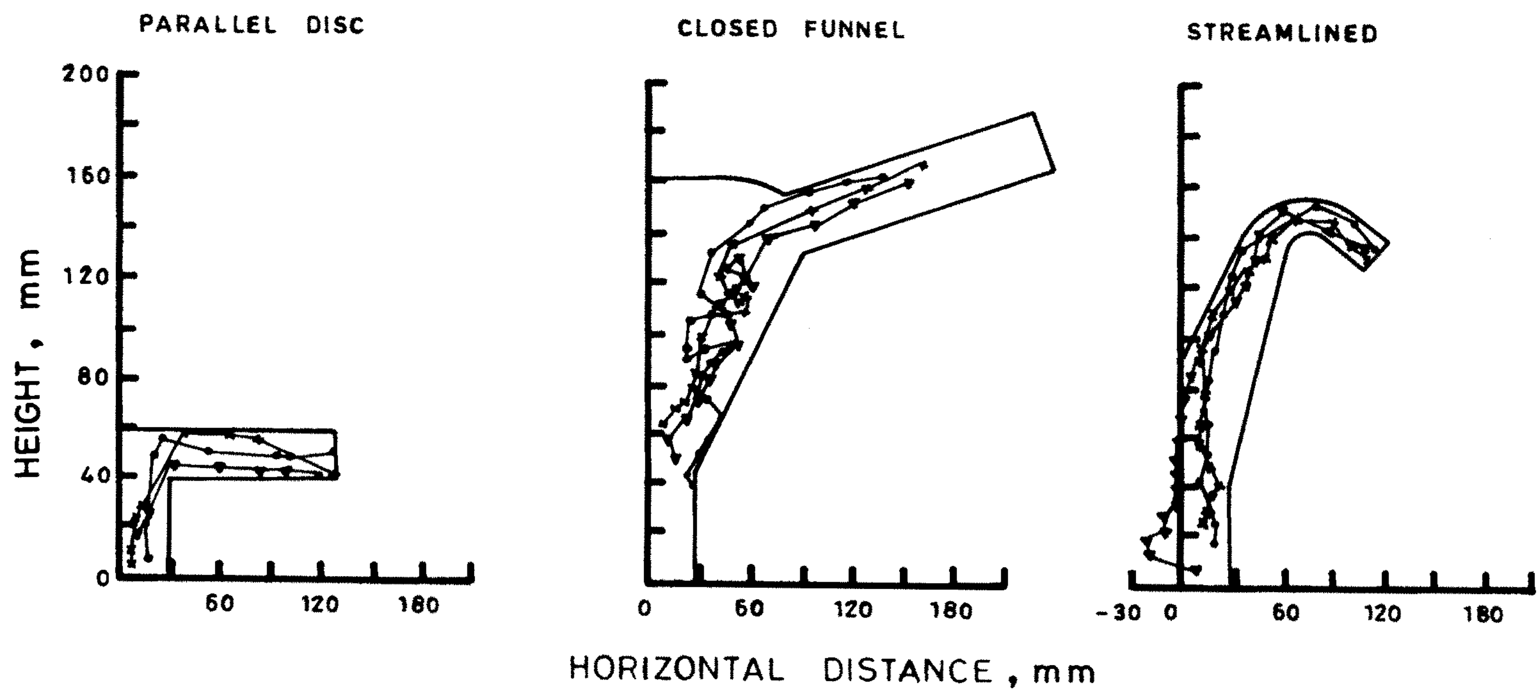


Fig. 4.29. TRAJECTORY OF SEED IN DISTRIBUTORS AT 6.5 ms^{-1} AIR VELOCITY

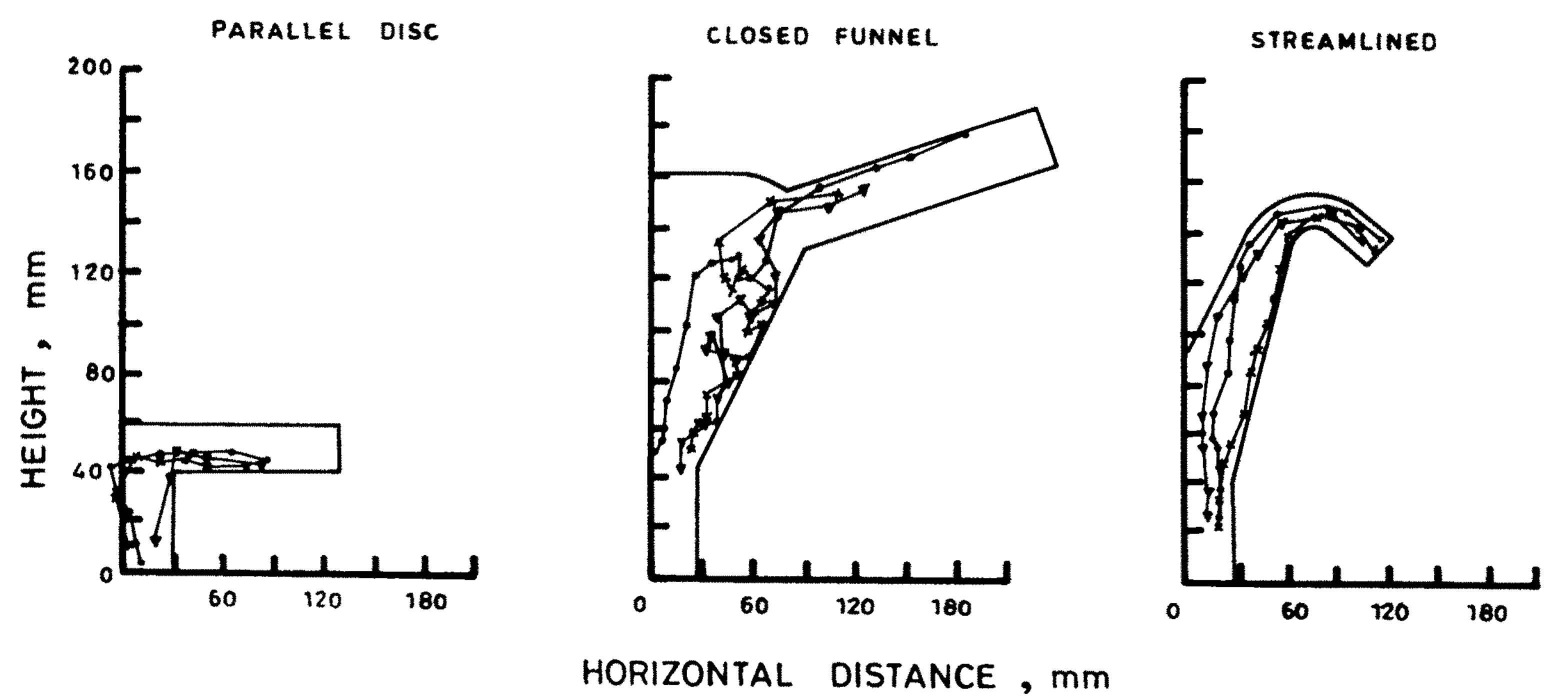


Fig. 4.30. TRAJECTORY OF SEED IN DISTRIBUTORS AT 7.0 ms^{-1} AIR VELOCITY

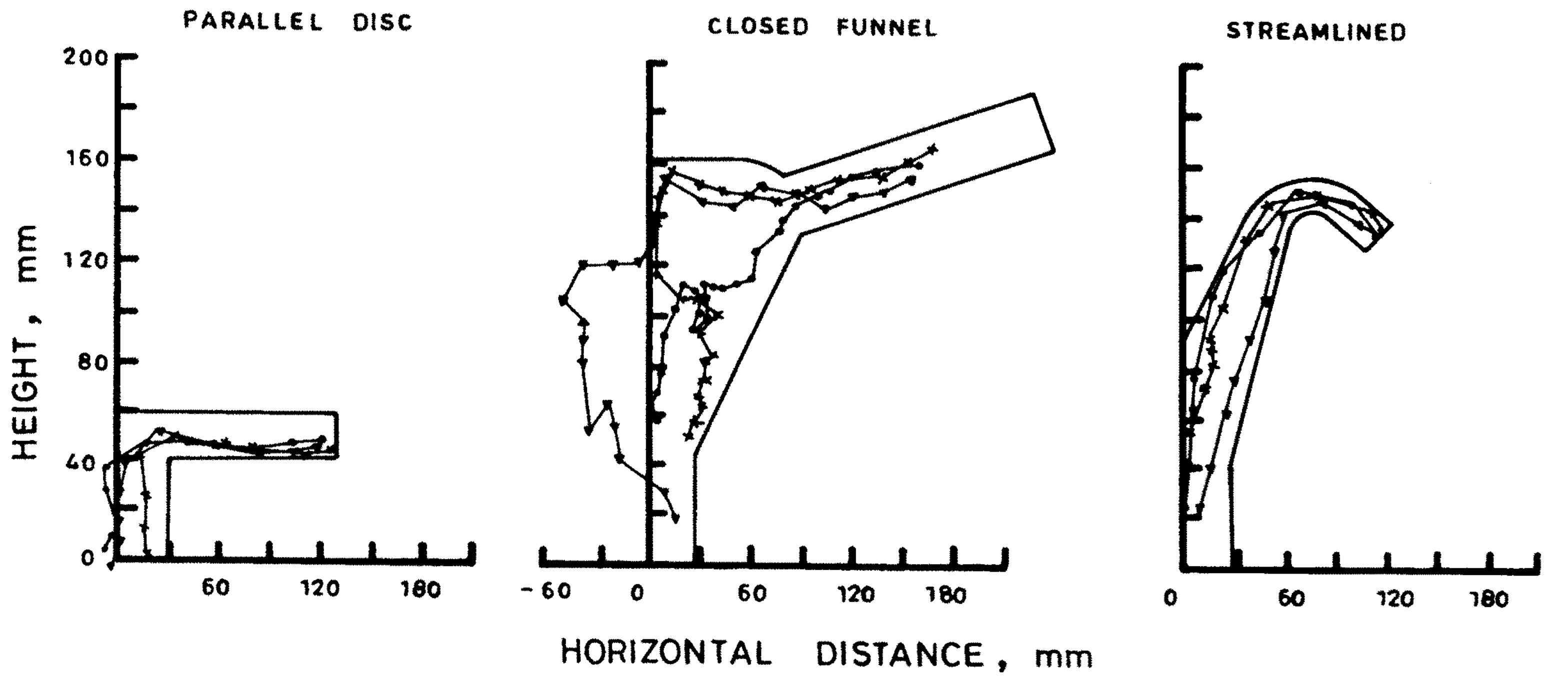


Fig. 4.31. TRAJECTORY OF SEED IN DISTRIBUTORS AT 7.5 ms^{-1} AIR VELOCITY

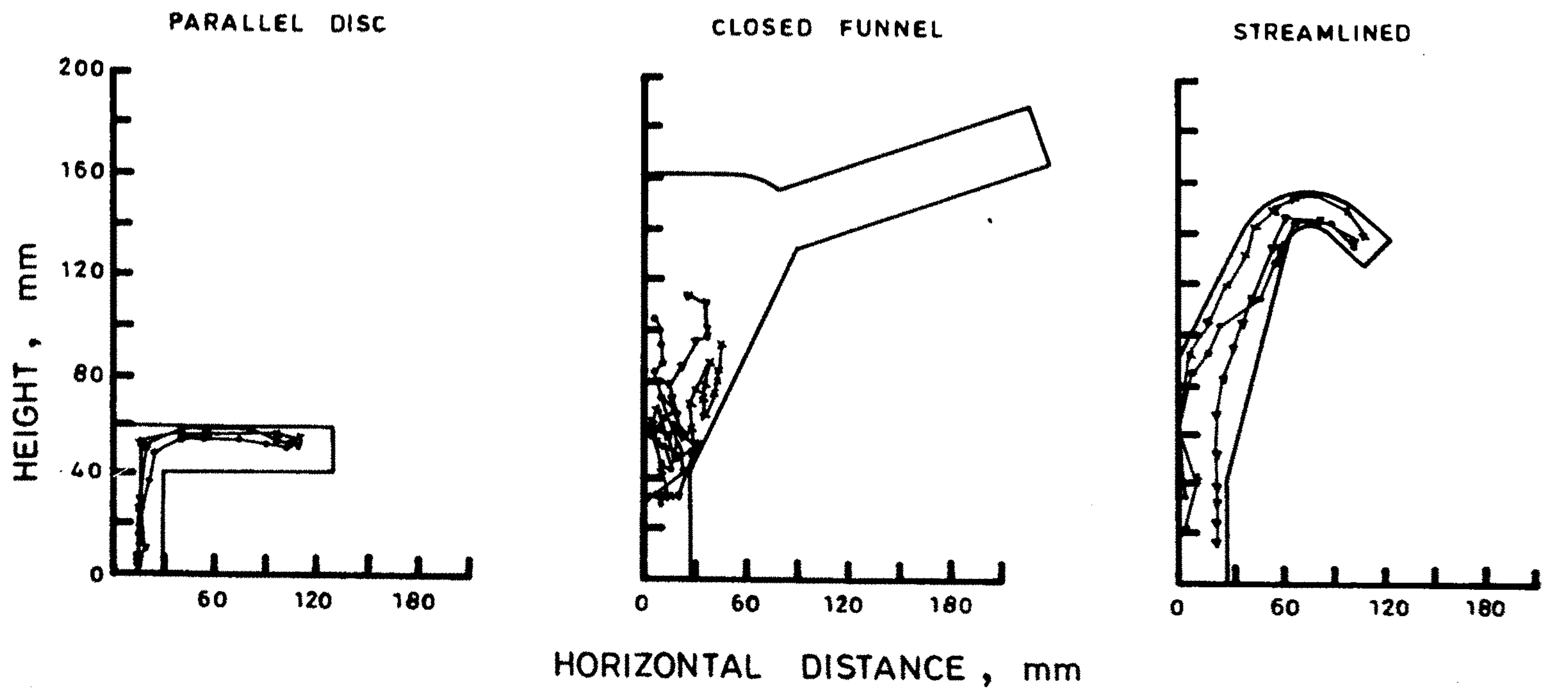


Fig. 4.32. TRAJECTORY OF SEED IN DISTRIBUTORS AT 8.0 ms^{-1} AIR VELOCITY

PLATE 4.1. SEED PATH IN PARALLEL DISC DISTRIBUTOR

PLATE 4.2. SEED PATH IN CLOSED FUNNEL DISTRIBUTOR

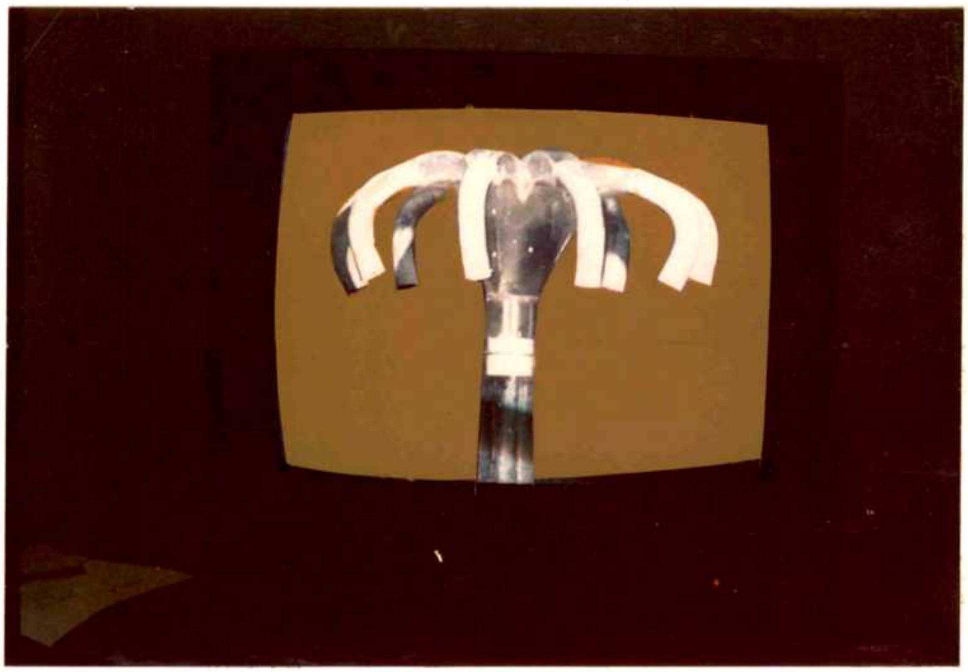


PLATE 4.3. SEED PATH IN STREAMLINED FLOW DISTRIBUTOR

outlet. It was observed that at 8.0 ms^{-1} air velocity, the seeds were drafted in the turbulence zone near the neck of the funnel and there was minimum flow of seed to the outlet.

It was observed in the streamlined distributor that the seed travelled along the surfaces of the funnel towards the outlet without much zig-zaging in the entire range of air velocity. Though the number of contacts with the inner walls of the distributor was more than parallel disc distributor there was no head on impact with the walls as in the case of the parallel disc distributor. It was also observed that the seed travelled at a very slow speed in this head compared to the parallel disc distributor. This might be due to the lower air velocity in the head. Hence the impact experienced by the seed was reduced in this design. In addition to distributing the seed, this distributor deflected the seeds moving up in the vertical conveyance pipe towards the seed tubes. Thus streamlined flow head partially changes the direction of seed in the head itself. Hence the overall construction of the streamlined flow head along with seed tubes made was more compact as compared to the other two heads.

The uniformity of seed flow between the outlet tubes was considered to be influenced by the variations in air distribution between the individual tubes due to non-symmetric construction of the head. These experiments showed that in parallel disc distributor, the movement of the seed was due to both by impact deflecion and air suspension. In the closed funnel distributor, due to the restricted outlets provided, the seed tend to get accumulated inside the funnel and entrapped in the turbulence created. When sufficient quantity of seed accumulated, this exhibited a plug flow phenomenon and the seeds were discharged only in periodic pulsations.

4.5. Development of pneumatic seed drill

4.5.1. Fabrication of prototype

A prototype pneumatic seed drill to sow small seeds like sesame, pearl millet and sorghum has been fabricated using the optimised variables of distributor head, air velocity and seed feed rate, Plate 4.4. The unit consisted of major components like main frame, air blower and drive, seed hopper and feeding device, seed distributor and seed tube and furrow opener and closer as shown in Fig. 4.33.

a. Main frame

The standard spring tyned cultivator frame was used for the fabrication of air seeder. The small seeds selected for the study are mostly sown in drylands, where high speed drilling is required to cover large area within a short time to conserve the moisture. The high speed operation is possible with the spring tyned cultivator. Moreover the pneumatic seed drill can be easily converted as cultivator for preparatory tillage by removing the seeding attachment. The hitching arrangement of the cultivator is convenient to take central drive to the blower from PTO shaft of the tractor. The row width of the selected crops for rainfed agriculture is 30 cm. Hence cultivator frame of 2640 mm width was selected to accommodate nine rows. The overall size of the frame was 2640 mm x 765 mm. The frame was made of 40 x 75 x 40 mm mild steel channels.

b. Air blower and drive

A commercially available blower of the following specifications was fitted on the frame of the cultivator.

Fan diameter	:	495 mm
Air inlet diameter	:	190 mm
Air outlet diameter	:	50 mm
Speed	:	2860 rpm
Power required	:	1.5 kW
Air flow rate	:	0 to 0.039 $m^3\ s^{-1}$

The blower was powered from the PTO shaft of the tractor through a drive shaft by 'V' belt pulleys. The shaft was driven from the tractor PTO using the standard PTO extension shaft. During field operation of the tractor, the PTO rpm obtained was measured as 500-520.

PLATE 4.4. PNEUMATIC SEED DRILL

Through 'V' pulleys and belt power transmission, the rpm of the blower drive shaft was increased to 1900-1950. To supply the air upto 8.0 ms^{-1} velocity to the vertical conveyance pipe, a forward curved fan blower generating 20 ms^{-1} air velocity at 2860 rpm was selected and mounted on the right hand side of the cultivator frame. A butterfly valve was provided in the blower to regulate the air flow rate at the inlet so as to have required air velocity at the outlet.

c. Seed hopper and feeding device

A seed hopper of 25 kg capacity to cater about 1.5 ha was mounted at the centre of the cultivator. At the bottom of the hopper, internal double run seed feeding mechanism with seed flow rate adjustment was attached. The sesame seed could be regulated from 3.5 to 8 g per revolution of the rotor, while 4.0 to 8.5 g and 4.0 to 7.5 g was kept for pearl millet and sorghum respectively. The seed dropped was conveyed to an eductor fixed in the vertical pipe through a transparent hose of 25 mm diameter. It drew the seeds inside. The eductor fixed in the experimental set up, Fig.3.5, created suction in the range of -15 to -29 mm of water over the entire velocity range and seed feed rate of all the three types of seed for the streamlined flow distributor. This suction force was sufficient to draw the seeds in the prototype and hence the same design was adopted. The drive to the seed feeding mechanism was taken from the ground wheel fixed at the rear side of the frame. The drive ratio of the ground wheel and seed feeding mechanism has been fixed as 1:1.1 based on the seed rate, slip encountered in the field and the range of seed rate adjustment in the feeding mechanism. The slip encountered in the drive mechanism was 5.3 per cent. It was due to the fact that there was only one seed feeding wheel in this machine unlike in the conventional seed drills. The vertical conveyance pipe height was kept as 0.85 m above eductor based on the studies of relative velocity of seed, actual and predicted path of seed in the vertical pipe.

d. Seed distributor and seed tubes

The studies on the performance of the distributor heads through the uniformity of seed distribution, seed conveying system pressure and seed path traced in the distributor showed that the streamlined flow distributor was the best to sow sesame, pearl millet and sorghum. Hence it was selected for use in the prototype. The seed distributed by the head was conveyed to the furrow openers by a 25 mm transparent tube varying in length from 1.9 to 2.25 m depending on the position of the furrow opener.

e. Furrow opener and closer

The hoe type furrow opener used in the cup feed seed planter was used as furrow opener. A plank type furrow closer provided at the rear side of the seed drill closed the furrows.

4.5.2. Performance characteristics of the pneumatic seed drill under static condition of the power unit

The performance of the pneumatic drill was evaluated to determine the uniformity of seed distributed in the nine furrow openers. The variation in the seed distribution was 2.3, 2.1 and 1.8 per cent for sesame, pearl millet and sorghum respectively.

4.5.3. Performance characteristics of the pneumatic seed drill under dynamic condition of the power unit

The performance of distributor head under dynamic condition of the power unit was evaluated. The velocity of the tractor was not constant and was subjected to accelerations and decelerations. Feeding mechanism might be influenced by the variations under field conditions like slip of ground wheel and vibration of the implement frame. Hence the performance of distributor under static and dynamic conditions were compared for the three types of seed using the head and operational parameters optimised by experiments.

a. Performance for sesame

The analysis of variance of the mean quantity of seed distributed to the furrow openers is shown in Table 4.25.

Table 4.25 Analysis of variance of mean - sesame

SV	DF	SS	MS	F
Treatment	35	203.3419	5.8098	125.58**
Tube (T)	8	0.3497	0.0437	<1
Forward speed (V) [Seed feed rate]	3	201.9563	67.3188	1455.10**
T X V	24	1.0359	0.0432	<1
Error	72	3.3310	0.0463	
Total	107	206.6729		

C.V = 2.6%, ** - Significant at 1% level

The insignificant variation in the main effect of the tube indicated uniform distribution of seed between furrow openers. The seed feed rate was related to the tractor speed hence resulting significant variation in the main effect of seed feed rate. In the absence of any interaction effects between the furrow openers and the feed rate, it was definitely confirmed that the travel speed did not affect the uniformity of seed distribution between the furrow openers. To arrive at the seed feed rate which yielded the least mean deviation between the furrow openers, the technique explained in section 3.4.1 was used. The best treatment causing the least mean deviation (0.1349) of seed distributed between the furrow openers among the statistically on par treatments was 79 g min^{-1} seed feed rate which correspond to 3.5 kph of forward speed, Table 4.26. The optimised levels were same as that obtained from the static experiments.

Table 4.26 Operational parameters - sesame

Head : Streamlined flow, Air velocity : 5.5 ms^{-1}

Speed of travel kph	Seed feed rate $gmin^{-1}$	Mean deviation within furrow openers	Variation per cent
3.5	79	0.1349	-
2.5	57	0.1382	2.45
3.0	68	0.1412	4.67
4.0	90	0.1471	9.04

b. Performance for pearl millet

The analysis of variance on the mean quantity of seed distributed to the furrow openers is shown in Table 4.27. The insignificant variation in the main effect of the tube indicated uniform distribution of seed between furrow openers. The seed feed rate was related to the tractor speed hence resulting significant variation in the main effect of seed feed rate. But a weak interaction was present between the seed feed rate (speed of operation) and the quantity of seed distributed to individual furrow openers. The interaction was explained by the fact that the tube mean on paired comparison showed very slight significance between certain furrow openers. But this effect could be neglected for practical convenience without sacrificing the quality of work appreciably.

Table 4.27 Analysis of variance of mean - Pearl millet

SV	DF	SS	MS	F
Treatment	35	2070.0740	59.1450	158.92**
Tube (T)	8	3.3902	0.4238	1.14NS
Forward speed (V) [Seed feed rate]	3	2047.3240	682.4413	1833.70**
T X V	24	19.3598	0.8067	2.17**
Error	72	26.7959	0.3722	
Total	107	2096.8700		

C.V = 2.5%, **-Significant at 1% level, NS-Not significant

The seed feed rate which yielded the highest uniformity between seed tubes among the statistically on par treatments is presented in Table 4.28. The results revealed that the seed feed rate of 273 $gmin^{-1}$ corresponding to an operating speed of 4 kph resulted least mean deviation of 0.3149 in distributing the seed between the furrow openers. This was different from the results of the static test wherein the seed feed rate optimised as 168 $gmin^{-1}$ was followed by 273 $gmin^{-1}$

Table 4.28 Operational parameters - Pearl millet

Head : Streamlined flow

Air velocity : 6 ms^{-1}

Speed of travel kph	Seed feed rate $gmin^{-1}$	Mean deviation within furrow opener	Variation per cent
4.0	273	0.3149	-
2.5	168	0.3324	5.56

c. Performance for sorghum

The analysis of variance on the mean quantity of seed distributed to the outlet tubes is presented in Table 4.29.

Table 4.29 Analysis of variance of mean - Sorghum

SV	DF	SS	MS	F
Treatment	35	2042.1645	58.347	209.31**
Tube (T)	8	1.4240	0.1780	<1
Forward speed (V) [Seed feed rate]	3	2035.2388	678.4129	2433.70**
T X V	24	5.5017	0.2292	<1
Error	72	20.0705	0.2788	
Total	107	2062.2351		

C.V = 2.2%, **-Significant at 1% level

The insignificant variation in the main effect of the tube indicated uniform distribution of seed between furrow openers. The seed feed rate was related to the tractor speed hence resulting significant variation in the main effect of seed feed rate. The absence of any interaction effects between the tube and the seed feed rate definitely confirmed that the travel speed did not affect the uniformity of seed distribution between the individual furrow openers.

The seed feed rate which yielded the least mean deviation between the furrow openers among the statistically on par treatments is presented in Table 4.30.

Table 4.30 Operational parameters - Sorghum

Head : Streamlined flow

Air velocity : 8.0 ms^{-1}

Speed of travel kph	Seed feed rate $gmin^{-1}$	Mean deviation within furrow opener	Variation per cent
3.5	238	0.1777	-
2.5	168	0.2202	23.92
3.0	203	0.3731	109.96

The result inferred that the seed feed rate of 238 $gmin^{-1}$ corresponding to operating speed of 3.5 kph yielded least mean deviation (0.1777) of seed distributed between the furrow openers. This level was in agreement with the results of the experiments conducted under static condition.

4.6. Field performance evaluation

The pneumatic seed drill was used to sow sesame, pearl millet and sorghum. The plant stand of sesame and pearl millet is shown in Plate 4.5 and 4.6. The analysis of variance for the number of plants per metre length of row for the three types of seed is shown in Table 4.31. This analysis reflected the uniformity of seed flow from a single seed tube.

PLATE 4.5. SESAME CROP SOWN BY PNEUMATIC DRILL

PLATE 4.6. PEARL MILLET CROP SOWN BY PNEUMATIC DRILL

Table 4.31 Analysis of variance for number of plants per metre

a. Sesame

SV	DF	SS	MS	F
Replication	2	79.6000	39.8000	3.47NS
Rows	4	89.0667	22.2666	1.94NS
Error	8	91.7333	11.4666	
Total	14	260.4000		

C.V = 7.8%, NS- Non Significant

b. Pearl millet

SV	DF	SS	MS	F
Replication	2	2.5333	1.2666	<1
Rows	4	64.2666	16.0666	2.29NS
Error	8	56.1333	7.0166	
Total	14	122.9333		

C.V = 6.3%, NS- Non Significant

c. Sorghum

SV	DF	SS	MS	F
Replication	2	14.8000	7.4000	1.35NS
Rows	4	17.3333	4.3333	<1
Error	8	43.8667	5.4833	
Total	14	76.0000		

C.V = 6.5%, NS- Non Significant

The plant stand should be uniform along the row. The treatment and the replications showed insignificance for all the three types of seed inferring that no significant variation in number of plants in a row. In the same plot, the plant population per square metre was recorded from nine random locations for the three types of seed. The mean plant population per square metre was 87, 78 and 32 for sesame, pearl millet and sorghum respectively. The coefficient of variation between the nine replications was in the range of 7 to 10 per cent indicating that there was no significant variation between different locations.

The frequency distribution for plant spacing for the three crops is shown in Fig 4.34 to Fig. 4.36. The results of fifteen replicatory tests were superimposed on one another for each crop. In all the cases, it represented normal distribution (Rohrbach *et al*, 1971) with the peak aligned at the mean value. The figure showed the mean spacings for sesame and pearl millet as 40 mm, whereas the same for sorghum was 70 mm. There was minimum multiples in sorghum crop because of its larger size and lesser number of seed metered per unit time. Sesame and pearl millet recorded more multiples in hills than sorghum.

4.6.1. Cost economics

The field capacity of the pneumatic seed drill was 0.65 hah^{-1}. The cost of operation was Rs.146 per ha. The cost of conventional method of sowing was Rs.325 per ha., with saving in cost and time of 55 and 92 per cent respectively, compared to conventional method of sowing. The cost of the pneumatic seed drill including cultivator frame worked out to Rs.20,000.

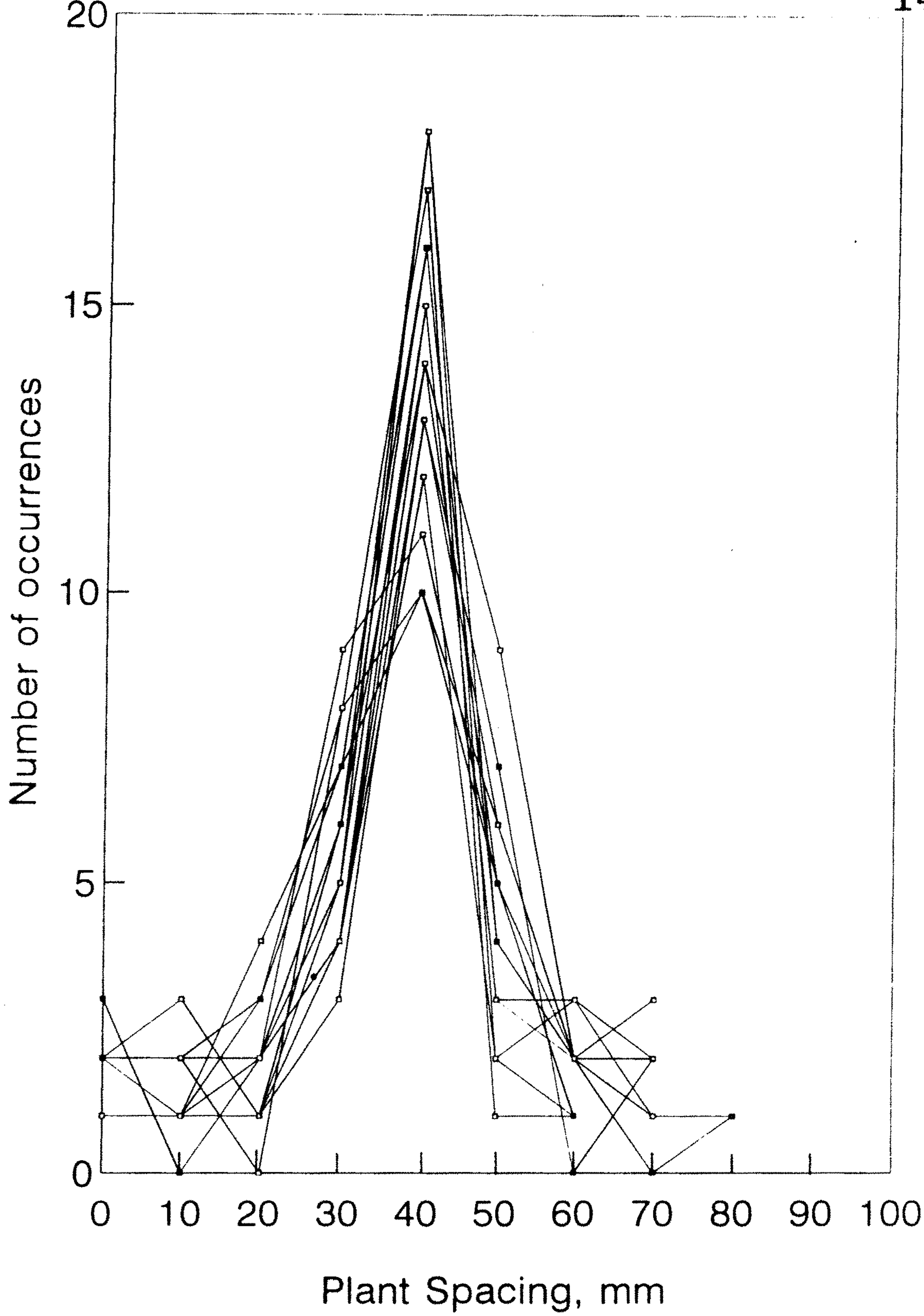


Fig. 4.34. FREQUENCY DISTRIBUTION OF PLANT SPACING FOR SESAME

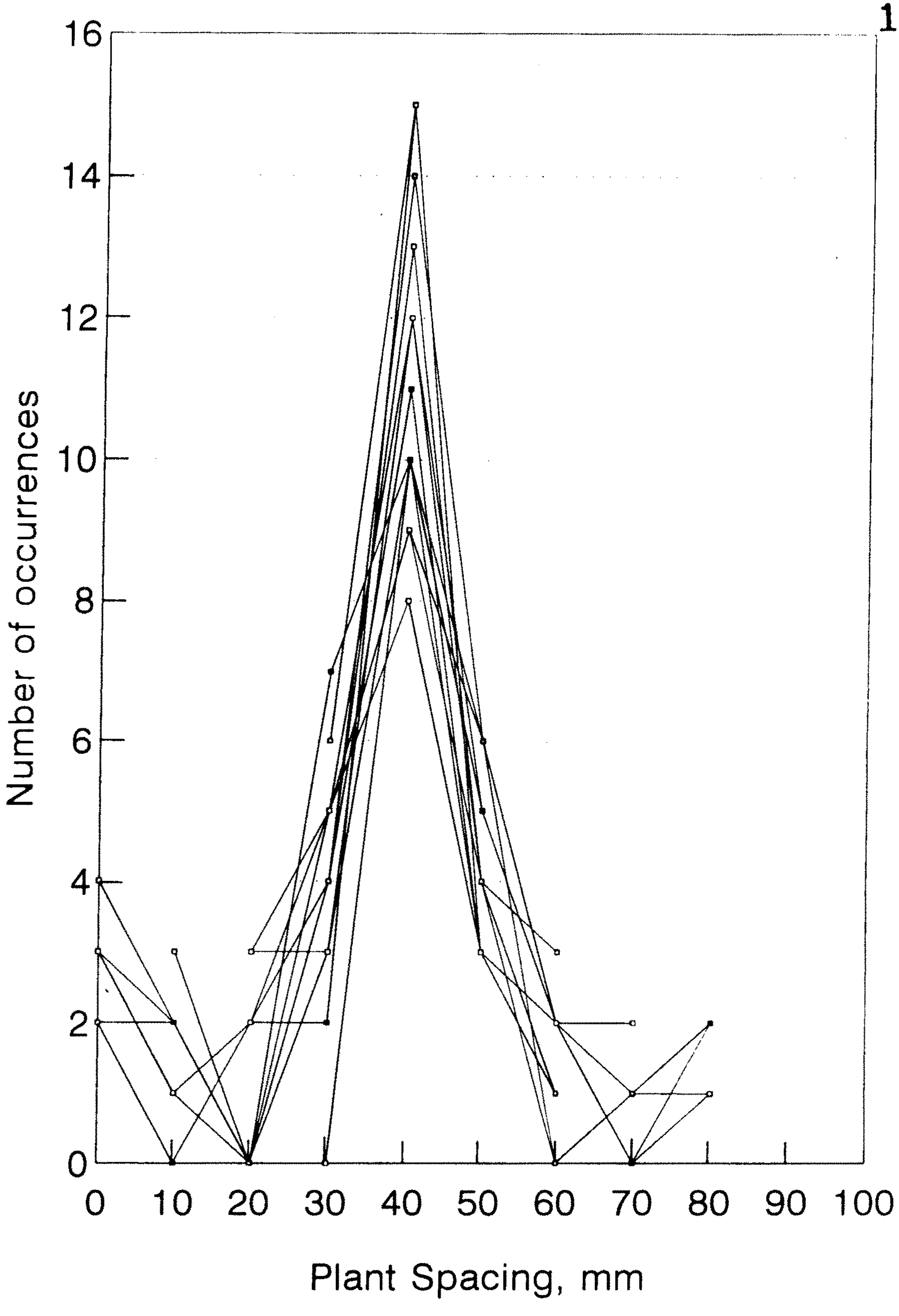


Fig. 4.35. FREQUENCY DISTRIBUTION OF PLANT SPACING FOR PEARL MILLET

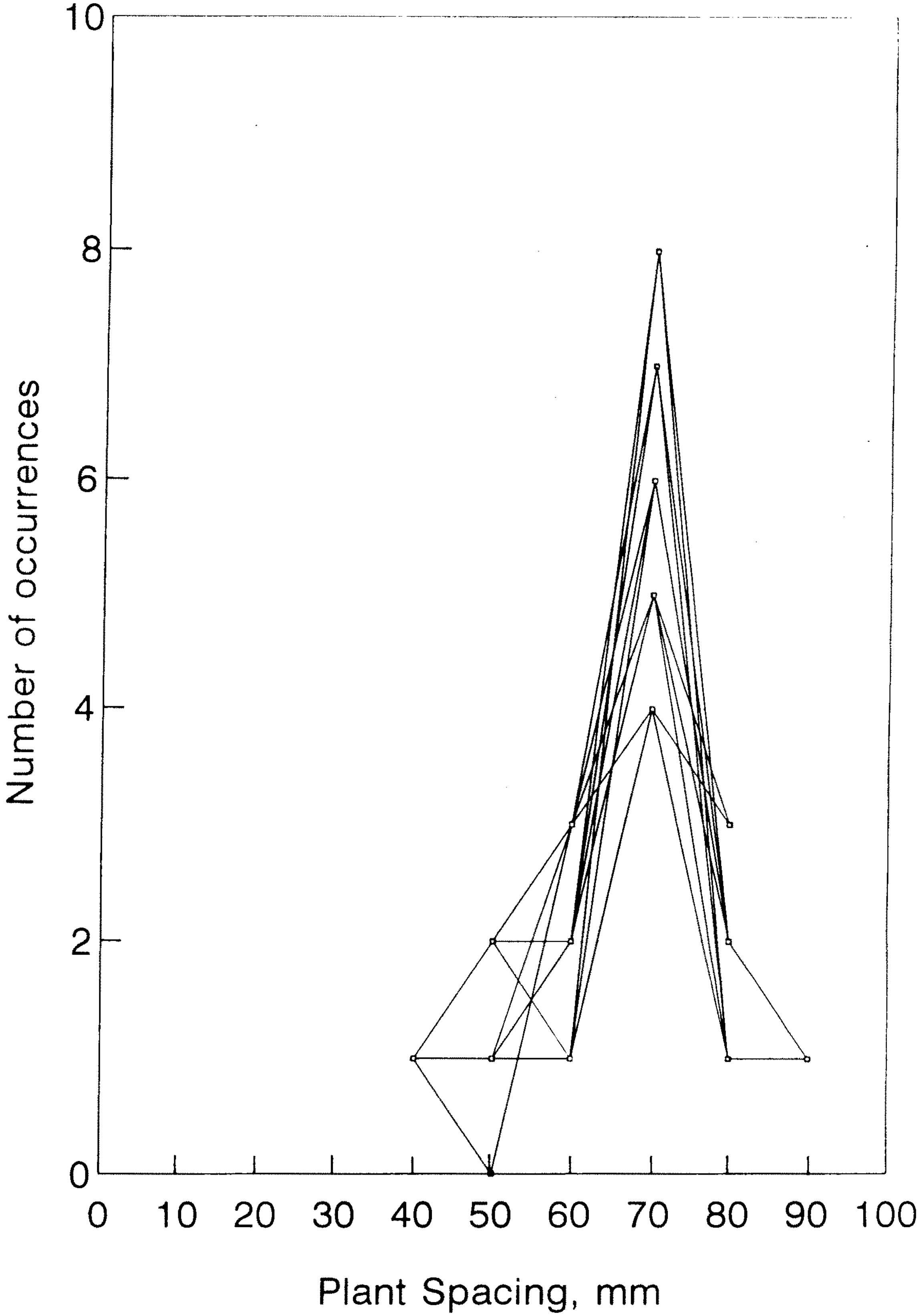


Fig. 4.36. FREQUENCY DISTRIBUTION OF PLANT SPACING FOR SORGHUM

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

Maintaining uniform crop stand in the field begins with an appropriate seed metering system that gives proper placement of seeds at proper density. In recent years, developed countries are adopting seed drills capable of operating at high speeds and thereby covering more area. But in our country, this evolution has not taken place fully though there is demand for labour saving planting equipment. Hence an attempt was made to develop a high speed pneumatic seed drill for small seeds like sesame, pearl millet and sorghum.

Suitable instrumentations, methodologies were developed for the study. Experiments were conducted in the following aspects.

a. The physical and aerodynamic properties of sesame, pearl millet and sorghum were determined using standard procedures.

b. Three seed distributors namely parallel disc, closed funnel and streamlined flow were developed.

c. The performance of the distributors was evaluated using a test rig specially developed.

d. Measurement of air velocity was made using a pitot tube micromanometer combination.

e. The actual path of seed traced in vertical conveyance pipe and distributor was recorded using videographic technique.

f. A pneumatic seed drill was developed and its field performance was evaluated for drilling three types of seed.

The following conclusions were drawn from the analysis of results obtained from the study.

1. Pearl millet and sorghum were spherical in shape while sesame was elliptical.

2. The average length and width of sesame was 2.76 ± 0.21 and 1.53 ± 0.18mm respectively, while the average diameter of pearl millet and sorghum was 2.55 ± 0.14 and 3.18 ± 0.22 mm respectively.
3. The mean frontal area of sesame, pearl millet and sorghum was 3.34 ± 0.54, 5.14 ± 0.56 and 8.02 ± 1.05 sq.mm respectively.
4. The average thousand seed weight of sesame, pearl millet and sorghum was 2.26 ± 0.08, 8.2 ± 0.11 and 26.0 ± 0.14 g respectively.
5. The mean true density of sesame was 961 ± 6.28 kg m^{-3}, while that of pearl millet and sorghum was 1266.8 ± 8.09 and 1350.2 ± 6.31 kg m^{-3} respectively.
6. The mean angle of repose of sesame, pearl millet and sorghum was 26.25, 21.80 and 24.38 ° respectively.
7. The average coefficient of restitution of sesame, pearl millet and sorghum was 0.14, 0.22 and 0.20 for acrylic and 0.22, 0.36 and 0.40 for mild steel respectively.
8. The mean terminal velocity of sesame was 2.2 ± 0.13 ms^{-1}, while for pearl millet and sorghum it was 4.2 ± 0.08 and 5.6 ± 0.11 ms^{-1} respectively.
9. The mean drag coefficient of sesame was 2.36 ± 0.59, while the same for pearl millet and sorghum was 1.42 ± 0.21 and 1.65 ± 0.33 respectively.
10. The mean air velocity distribution was statistically uniform in all the outlet tubes of the three distributors for the air velocity varying from 3 to 8 ms^{-1}.
11. When air-sesame mixture was introduced in the distributor, the mean air velocity distribution was uniform in all the outlet tubes for a given head. However, there was variation in the above value among the different distributors.
12. There was no variation in the air velocity distribution pattern when sesame was fed at the rate of 57 and 79 g min^{-1} either through the streamlined flow or parallel disc head.

13. It was observed that the uniformity of the distribution of sesame gradually increased as the seed feed rate was decreased irrespective of the type of head. The more and more the air velocity, the higher and higher was the uniformity of distribution of sesame.

14. The highest uniformity of 98.4 and 96.8 per cent was obtained with streamlined flow and parallel disc distributor at an air velocity of 5.5 ms^{-1} for all feed rates.

15. The best performance for sesame distribution was obtained with streamlined flow distributor at an air velocity of 5.5 ms^{-1} and seed feed rate of 79 g min^{-1} as the least mean deviation of seed distribution was 0.1349 between the outlet tubes.

16. When air-pearl millet mixture was introduced in the distributor, the mean air velocity distribution between the outlet tubes varied statistically among the heads.

17. The mean air velocity distribution decreased as the feed rate increased for the three heads. The streamlined flow head gave 14.82 and 5.5 per cent higher mean air velocity than closed funnel and parallel disc distributors respectively.

18. There was statistical variation in uniformity of seed distribution between the three distributors. The streamlined flow gave 31 per cent higher mean seed distribution than the other heads.

19. The highest uniformity of 98.0 and 98.10 per cent was obtained with streamlined flow and parallel disc distributor at 6 and 6.5 ms^{-1} air velocity respectively at all feed rates.

20. The best performance for pearl millet was obtained with streamlined flow distributor, at an air velocity of 6.0 ms^{-1} and seed feed rate of 273 g min^{-1} as the least mean deviation of seed distribution was 0.3149 between the outlet tubes.

21. When air-sorghum mixture was introduced in the distributor, the air velocity distribution between the outlet tubes varied statistically among the heads.

22. The mean air velocity distribution decreased as the feed rate increased for all the heads. The streamlined flow distributor gave 10.24 and 4 per cent higher air distribution than the closed funnel and parallel disc distributors.

23. There was statistical variation between the three heads in uniformity of seed distribution. The streamlined flow and parallel disc distributors yielded 23.94 per cent higher seed distribution.

24. The highest uniformity of 98.95 and 98.43 was obtained with streamlined flow and parallel disc distributors at an air velocity of 8.0 ms^{-1} for all feed rates.

25. The uniformity of distribution was independent of seed feed rate and the effect of air velocity was negligible, when the velocity exceeded 7.5 ms^{-1} both for parallel disc and streamlined flow distributors.

26. The best performance was obtained for sorghum with streamlined flow distributor at an air velocity of 8.0 ms^{-1} and seed feed rate of 238 g min^{-1}, as the mean deviation of seed disribution was 0.1777 between the outlet tubes.

27. It was found that a very low pressure of 2.5 mm of water was developed in the streamlined flow distributor head inlet for all the three types of seed, when the seed was introduced into the air stream.

28. The streamlined flow distributor offered the least resistance to seed flow since the blower outlet pressure was in the order of 15.5, 25.6 and 30.2 mm of water for sesame, pearl millet and sorghum respectively as compared to the other heads.

29. Highest suction pressure of -16 to -21 mm of water was developed at the eductor for the streamlined flow distributor for all levels of air velocity and feed rates.

30. The sesame, pearl millet and sorghum seeds attained constant relative velocity at mean height of 0.84, 0.74 and 0.83m respectively with air-seed column.

31. In the vertical column, the path traced by the seed was not influenced by the type of head.

32. There was no variation between the actual and predicted path of the seed in the vertical column.
33. In the parallel disc distributor, the seed was deflected by the top disc at an air velocity of 8.0 ms^{-1}. However at lower velocities there was no appreciable impact.
34. The flow of seed in the closed funnel distributor was turbulent in nature and it was observed that the seeds were drawn towards zone of turbulence and the distribution was not uniform.
35. In the streamlined flow distributor, the flow pattern of the seed was quite uniform without much impact.
36. The uniformity of distribution of seed in streamlined flow distributor remained unaltered even at different forward speed of the power unit.
37. The highest uniformity of seed distribution obtained during dynamic test was 97.9, 98.39 and 98.50 per cent at the forward speeds of 3.5, 4.0 and 3.5 kph at the air velocity of 5.5, 6.0 and 8.0 ms^{-1} with streamlined flow distributor for sesame, pearl millet and sorghum respectively.

The design parameters adopted for the development of pneumatic seed drill were as given below :

Sesame

Distributor	:	Streamlined flow
Air velocity	:	5.5 ms^{-1}
Seed feed rate	:	79 $gmin^{-1}$

Pearl millet

Distributor	:	Streamlined flow
Air velocity	:	6.0 ms^{-1}
Seed feed rate	:	273 $gmin^{-1}$

Sorghum

Distributor	:	Streamlined flow
Air velocity	:	8.0 ms^{-1}
Seed feed rate	:	238 $gmin^{-1}$

The performance of the pneumatic seed drill was evaluated in the field for drilling sesame, pearl millet and sorghum. The field capacity of the unit was 0.65 hah^{-1}. There was no variation in the number of plants germinated in the individual row. The mean population observed was 87, 78 and 32 per sq. metre for sesame, pearl millet and sorghum respectively. The frequency distribution of plant spacing showed normal distribution with peak aligned along the mean spacing. The mean spacing obtained for sesame and was 40 mm, while for sorghum it was 70 mm. The cost of operation of the unit works out to Rs.150 per ha. The saving in cost and time are 55 and 92 per cent respectively compared to conventional method. The cost of the unit is Rs.20,000.

Suggestions for future work

Further studies in the following aspects can be taken up.

i. The principle of pneumatic metering may be tried for pulses like greengram and blackgram.

ii. The principle of seed divider working on concentric cones arranged successively, can be evaluated for uniform distribution of the seed by gravity flow.

iii. The pneumatic seed drill has to be evaluated in larger area for its utility and effectiveness and to collect feed back information.

REFERENCES

REFERENCES

Anonymous, 1971. IH develops air force planter. *Agricultural Engineering*, **52**(4) : 182.

Anonymous, 1988. Advanced drill by Accord *Farm Equipment International*, **9**(1) : 8.

Anonymous, 1989. Combined seed drill and cultivator. *Farm Equipment International*, **10**(2) : 22.

Anonymous, 1990. Drilling and cultivating, Royal show preview. *Power Farming*, **70**(7) : 17.

Anonymous, 1992. Air drill with power harrow. *Farm Equipment International*, **13**(1) : 7.

Anonymous, 1992. Rau - Rotosem seeding aggregate for exact metering. *Accord seed drill catalogue* : 6.

Bainer, R. 1947. Precision planting equipment. *Agricultural Engineering*, **28**(2) : 49-54.

Bakker - Arkema, F.W., J.R. Rosenau and W.H. Clifford. 1971. The effect of grain surface area on the heat and mass transfer rates in fixed and moving beds of biological products. *Transactions of the ASAE*, **14**(5) : 864-867.

Barmington, R.D. 1968. Precision planting of sugar beets. *Agricultural Engineering*, **49**(10) : 588.

Bilanski, W.K., S.H. Collins and P. Chu. 1962. Aerodynamic properties of seed grains. *Agricultural Engineering*, **43**(4) : 216-219.

Bilanski, W.K., and R. Lal. 1965. Behaviour of threshed materials in a vertical wind tunnel. *Transactions of the ASAE*, **8**(3) : 411-413 and 416.

Bjerkan, A.J. 1947. Precision Planting. *Agricultural Engineering*, **28**(2) : 55 and 57.

Brandt, R.G., and Z. Fabian. 1964. Developing a high speed precision planter. *Agricultural Engineering*, **45**(3) : 254-255.

Brundrett, E., and P.T. Vermes. 1987. Evaluation of tube diameter and fan induced swirl in polyethylene ventilation tubes. *Transactions of the ASAE*, **30**(4) : 1131-1134.

Chancellor, W.J. 1960. Relations between air and solid particles moving upward in a vertical pipe. *Agricultural Engineering*, **41**(3) : 168-171 and 176.

Chand, P., and D.P. Ghosh. 1968. Dynamics of particles under pneumatic conveyance. *J. Agric. Engng. Res.*, **13**(1) : 27-35.

Chen, C., M.F. Kocher and D.D. Jones. 1994. Granular particle linear flow velocity measurement using an electronic linear image sensor. *Computers and Electronics in Agriculture*, **11**(2 & 3) : 117-129.

Chhinnan, M.S., J.H. Young and R.P. Rohrbach. 1975. Accuracy of seed spacing in peanut planting. *Transactions of the ASAE*, **18**(5) : 828-831.

Chittey, E.T., and D.J. Perkins. 1967. A method of recording and evaluating seedling distributions, *J. Agric. Engng. Res.*, **12**(2) : 133-141.

Clarke, B., M. Salyani and T.Nithianandan. 1990. Flow properties of fluidized seeds and grains. *J. Agric. Engng. Res.*, **47**(2) : 123-132.

Coulson, J.M., and J.F. Richardson. 1970. Chemical Engineering, Vol. I. Fluid flow, heat transfer and mass transfer 2nd edn. Pergamon press oxford, London.

Crop Production Guide. 1991. Directorate of Agriculture and Tamil Nadu Agric. Univ. : 51-214.

Curray, J.K. 1951. Analysis of sphericity and roundness of quartz grains. M.S. Thesis in mineralogy. The Phensylvania State University, University Park, pa. As quoted by Mohsenin, N.N. 1980. Physical properties of plant and animal materials. Gordon and Breach Science Engineers, NewYork.

Das, R.S., and M.M. Kashyap. 1975. Particle trajectories horizontal wind tunnel and their application to pneumatic separation. *J. Agrl. Engg.*, **12**(1) : 19-23.

Datta, R.K. 1974. Development of some seeders with particular reference to pneumatic seed drills. *The Harvester*, **16** : 26-29.

Day, C.L. 1964. A device for measuring voids in porous materials. *Agricultural Engineering*, **45**(1) : 36-37.

Dutta , S.K., V.K. Nema and R.K. Bhardwaj. 1988. Physical properties of gram. *J. Agric. Engng. Res.*, **39** : 259-268.

FAO year-book production, 1990. Rome, **44**(99) : 114.

Fertilizer Statistics, 1992-93. *The Fertilizer Association of India,* New Delhi.

Garrett, R.E., and D.B. Brooker. 1965. Aerodynamic drag of farm grains. *Transactions of the ASAE*, **8**(1) : 49-52.

Ghate, S.R., S.C. Phatak and C.A.Jaworski. 1981. Seeding pre-germinated vegetable seeds in plots. *Transactions of the ASAE*, **24**(5) : 1099-1107.

Giannini, G.R., W.J. Chancellor and R.E.Garrett. 1967. Precision planter using vacuum for seed pick up. *Transactions of the ASAE*, **10**(5) : 607-610 and 614.

Gorial, B.Y., and J.R.O'Callaghan. 1990. Aerodynamic properties of grain/straw materials. *J. Agric. Engng. Res.*, **46(4)** : 275-290.

Harwood, F.W., and C.N. Hinkle. 1973. Micro air flow determination. *Transactions of the ASAE*, **16**(5) : 963-964.

Hassan, A.E. 1981. Precision drum seeder for uniform spacing. *Transactions of the ASAE*, **24**(4) : 879-883.

Hawk, A.L., D.B.Brooker and J.J.Cassidy. 1966. Aerodynamic characteristics of selected farm grains. *Transactions of the ASAE*, **9**(1) : 48-51.

Houston, R.K. 1957. New criterion of size for agricultural products. *Agricultural Engineering*, **39**(12) : 856-858.

Howard, P. 1991. Till drill carriage. *Power Farming*, **72**(1) : 5-6.

Howard, P. 1991. Agromek show. *Power Farming*, **71**(3) : 16.

Hudspeth Jr.E.B., and D.F.Wanjura. 1970. A planter for precision depth and placement of cotton seed. *Transactions of the ASAE*, **13**(2) : 153-154.

Hunt, D.R. 1986. Engineering models for Agricultural Production, AVI Publishing Co. Inc., West Port, connecticut.

Inman, J.W. 1968. Precision planting - a reality for vegetables. *Agricultural Engineering*, **49**(6) : 344-345.

IS : 6316-1971. Test code for seed cum fertilizer drill. Bureau of Indian Standards, New Delhi.

IS : 9164-1979. Guide for estimating cost of farm machinery operations. Bureau of Indian Standards, New Delhi.

Ishikawa, K. 1985. Flow characteristics of seeds and air within the transport pipe. *Bulletin of the Faculty of Agric.*, Miyazaki University, Japan. **32**(1) : 113-122.

Ishikawa, K. 1985. Floating distribution of seeds within the rising pipe. *Bulletin of the faculty of Agric.*, Miyazaki University, Japan. **32**(1) : 123-130.

Ishikawa, K. 1985. Theoretical studies on floating motion of seeds within the rising pipe. *Bulletin of the faculty of Agric.*, Miyazaki University, Japan. **32**(1) : 131-140.

Ishikawa, K. 1985. A study on the prediction of characteristics of multiple rows distribution. *Bulletin of the faculty of Agric.*, Miyazaki University, Japan, **32**(1) : 141-147.

Jindal, V.K., N.N. Mohesin and J.V. Husted. 1974. Surface area of selected agricultural seeds and grains. *Transactions of the ASAE*, **17**(4) : 720-725.

Kallen, P.H. 1961. Handbook of Instrumentation and controls. 1st edn. McGraw Hill Book Company, London.

Keck, H., and J.R. Goss. 1965. Determining aerodynamic drag and terminal velocities of agronomic seeds in free fall. *Transactions of the ASAE*, **8**(4) : 553-554 and 557.

Khairwal, I.S., C. Ram and K.C. Ashok. 1990. Pearl millet seed production technology, Manohar Publications, New Delhi.

Maheswari, M.U., N. Vaideki, N. Vasudevan, C. Venkatraman and P.S. Vidhya. 1990. Design and development of a pneumatic broadcaster attachment to power sprayer. Unpublished B.E.(Ag.) Project work, T.N.A.U., Coimbatore.

Marshall, I. 1991. Drills. *Power Farming*, **72**(5) : 16-18.

Menzies, D., and W.K.Bilanski, 1968. Aerodynamic properties of alfalfa particles. *Transactions of the ASAE*, **11**(6) : 829-831.

Mizrach, A., A. Zaltzman, G.Manor and Z.Nir. 1984. Gravitational motion of spheres in a fluidized bed. *Transactions of the ASAE*, **27**(6) : 1674 - 1678.

Mohsenin, N.N. 1980. Physical properties of plant and animal materials. Gorden and Breach Science, Engineers, NewYork.

Morrison Jr., J.E., R.R. Allen, D.E. Wilkins, G.M.Powell, R.D. Grisso, D.C.Erbach, L.P. Herndon, D.L.Murray, G.E. Formanck, D.L.Pfost, M.M. Herron and D.J. Baumert. 1988. Conservation planter, drill and air type seeder selection guideline. *Applied Engineering in Agriculture*, **4**(4) : 300-309.

Oje, K., and E.C. Ugbor. 1991. Some physical properties of oil bean seed. *J. Agric. Engng. Res.*, **50**(4) : 305-313.

Prince, R.P., and J.W. Bartok Jr. 1966. A recording air flow planimeter. *Agricultural Engineering*, **47**(9) : 487.

Purser, R.M.J., and D.J.Greig. 1967. Pressure variations in lateral air ducts. *J. Agric. Engng. Res.*, **12**(3) : 184-193.

Rohrbach, R.P., R.D. Brazee and H.J. Barre. 1969. On spacing statistics of plant populations produced by uniform seed placement devices. *J. Agric. Engng. Res.*, **14**(3) : 210-225.

Rohrbach, R.P., R.D. Brazee and H.J. Barre. 1971. Evaluating precision planting based on a Monte Carlo planter model. *Transactions of the ASAE*, **14**(6) : 1146-1149.

Rohrbach, R.P., and K.H. Kim. 1972. A fluidic seed meter. *Transactions of the ASAE*, **15**(6) : 1003-1004 and 1009.

Roth, L.O., and J.G. porterfield. 1960. Some basic performance characteristics of a horizontal plate seed metering device. *Transactions of the ASAE*, **3**(2) : 105-107.

Saini, K.S., R.B. Ram, V.K.Sharma and P.C.Grover 1984. Similitude studies on pneumatic separation of some agricultural materials. *J. Agrl. Engg.*, **21**(3) : 51-60.

Sajikumar, G., M.Arulanantham, R.Sethumadhavan and R.Vasudevan. 1990. Inclined U-tube manometer to measure low pressures. *Invention Intelligence*, **25**(10) : 464-465.

Scheidegger, A.E. 1957. The physics of flow through porous media. The MacMillan Co., NewYork : 8-9.

Shafii, S., and R.G. Holmes. 1990. Air jet seed metering, - a theoretical and experimental study. *Transactions of the ASAE*, **33**(5) : 1432-1438.

Shafii, S., A. Sasao and S.K. Upadhyaya. 1991. Air jet seed singulation. *Transactions of the ASAE*, **34**(5) : 1973-1977.

Shearer, S.A., and R.G. Holmes. 1991. Precision seed metering with a submerged turbulent air jet. *Transactions of the ASAE*, **34**(3) : 781-786.

Shedd, C.K. 1953. A micromanometer. *Agricultural Engineering*, **34**(3) : 178.

Shellard, J.E., and R.H. MacMillan. 1978. Aerodynamic properties of threshed wheat materials. *J. Agric. Engng. Res.*, **23** : 273-281.

Sirohi, R.S., and H.C. Radhakrishna. 1983. Mechanical measurements, Wiley Eastern Limited, Bombay.

Smith, R.D. and R.L. Stroshine. 1985. Aerodynamic separation of cobs from corn harvest residues. *Transactions of the ASAE*, **28**(3) : 893-897 and 902.

Smith, D.W., R.R. Yoerger. 1975. Variations in the forward motion of farm tractors. *Transactions of the ASAE*, **18**(3) : 401-403 and 408.

Snyder, K.A., and J.W. Hummel. 1985. Low pressure air jet seed selection for planters. *Transactions of the ASAE*, **28**(1) : 6-10.

Speelman, L. 1975. The seed distribution in band sowing of cereals. *J. Agric. Engng. Res.*, **20**(1) : 25-37.

Sreenarayanan, V.V., R. Visvanathan and V.Subramaniyam. 1988. Physical and thermal properties of soyabean. *J. Agrl. Engg.*, **25**(4) : 76-82.

Srivastava, N.S.L. 1975. A manually operated sugarbeet seed drill. J. Agrl. Engg., **13**(3-4) : 26.

Statistical Hand Book of Tamil Nadu, 1993. Commissioner of statistics, Dept. of statistics, Madras.

Thompson, R.A., and G.W.Isaacs. 1967. Porosity determinations of grains and seeds with an air-comparison pycnometer. *Transactions of the ASAE*, **10**(5) : 693-696.

Wanjura, D.F., and E.B. Hudspeth Jr. 1968. Metering and seed-pattern characteristics of a horizontal edge drop plate planter. *Transactions of the ASAE*, **11**(4) : 468-469 and 473.

Wanjura, D.F., and E.B. Hudspeth Jr. 1969. Performance of vacuum wheels metering individual cotton seeds. *Transactions of the ASAE*, **12**(6) : 775 - 777.

Waziri, A.N., and J.P. Mittal. 1983. Design related physical properties of selected agricultural products. Agrl. Mech. Asia, Africa and Lat. America, **14**(1) : 59-62.

Whitney, R.W., and J.G. Porterfield. 1968. Particle separation in pneumatic conveying system. *Transactions of the ASAE*, **11**(4) : 477-479.

Wilkins, D.E., and D.H. Lenker. 1981. A microprocessor controlled planter. *Transactions of the ASAE*, **27**(1) : 2-4 and 8.

Wratten, F.T., W.D. Poole, J.L. Chesness, S. Bal and V. Ramarao. 1969. Physical and thermal properties of rough rice. *Transactions of the ASAE*, **12**(60) : 801-803.

Yadav, B.G. 1976. Design, development and testing of a pneumatic paddy planter. *J. Agrl. Engg.*, **13**(3) : 134-135.

Zulin, Z., S.K. Upadhyaya, S.Shafii and R.E. Garrett. 1991. A hydropneumatic seeder for primed seed. *Transactions of the ASAE*, **34**(1) : 21-26.

ANNEXURE

ANNEXURE I

Seed feed rate for sesame at 2.5 kph.

Speed of tractor	=	2.5 kph
	=	41.67 m min^{-1}
Sesame spacing	=	300 x 150 mm
Width of coverage	=	0.3 x 9 = 2.7m
Therefore, Area covered per minute	=	41.67 x 2.7
	=	112.50 m^2
Seed rate	=	5000 g ha^{-1}
	=	0.5 g m^{-2}
Therfore, Seed rate for 112.50 m^2	=	112.50 x 0.5
	=	56.25 g
	=	57 g

ANNEXURE II

Mean deviation :

```
      CLS
      INPUT "OUTPUT FILE NAME PL.  "; FIL$
      OPEN FIL$ FOR OUTPUT AS #1
1000  INPUT "TREATMENT NAME  "; N$
      PRINT "FEED THE NINE VALUES ,PL. "
      FOR I = 1 TO 9
      INPUT A(I)
      NEXT I
      FOR N = 1 TO 9
      MAX = 0!
      FOR I = 1 TO 9
      IF A(I) > MAX THEN MAX = A(I): IND = I
      NEXT I
      B(N) = MAX
      A(IND) = 0!
      NEXT N
      FOR I = 1 TO 9
      PRINT B(I);
      NEXT I
      PRINT
      DEV = 0!
      FOR I = 1 TO 8
      FOR J = (I + 1) TO 9
      DEV = DEV + B(I) - B(J)
      NEXT J, I
      DEV = DEV / 36!
      PRINT N$, DEV
      PRINT #1, N$, DEV
      INPUT "WANT TO CONTINUE  "; YN$
      CLS
      IF YN$ = "Y" OR YN$ = "y" THEN 1000
      CLOSE #1
      END
```

ANNEXURE III

Forces on a unit mass seed are

$$dV_r/dt = g\{(V_r^2/V_s^2)-1\}$$

where,

V_r = Relative velocity of seed, ms^{-1}
t = Time, s
g = Acceleration due to gravity, ms^{-2}
V_s = Suspension velocity of seed, ms^{-1}

$$V_s\, d(V_r/V_s) / \{(V_r/V_s)^2 - 1\} = gdt$$

$$-V_s \coth^{-1}(V_r/V_s) = g\,t + c$$

When $t = 0$, $V_r = V_{r0}$

Therefore,

$$-V_s \coth^{-1}(V_{r0}/V_s) = c$$

$$t = (V_s/g)\{\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)\}$$

$$H_x = \int t\, dV_r$$

where,

H_x = Height relative to original position in air stream

$$H_x = (V_s/g)\int\{\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)\}dV_r$$

$$H_x = (V_s/g)\{\coth^{-1}(V_{r0}/V_s)V_r-V_s\int \coth^{-1}(V_r/V_s)d(V_r/V_s)\}+c$$

$$= (V_s/g)\{V_r\coth^{-1}(V_{r0}/V_s)-V_s[(V_r/V_s)\coth^{-1}(V_r/V_s)$$
$$-\int((V_r/V_s)d(V_r/V_s)/(1-(V_r/V_s)^2))]\}+c$$

$$H_x = (V_s/g)\left\{V_r[\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)] + \int (V_r d(V_r/V_s)/(1-(V_r/V_s)^2))]\right\}+c$$

$$= (V_s/g)\left\{V_r[\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)] + V_s \int ((V_r/V_s)d(V_r/V_s)/(1-(V_r/V_s)^2))]\right\}+ c$$

$$= (V_s/g)\left\{V_r[\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)] - (V_s/2)\ln(1-(V_r/V_s)^2)\right\}+ c$$

At $t = 0$, $Vr = Vr0$, $hx = 0$

$$0 = -(V_s^2/2g)\ln\left\{1-(V_{r0}/V_s)^2\right\}+ c$$

Therefore,

$$H_x = (V_s/g)\left\{V_r[\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)] +(V_s/2)\ln[(1-(V_{r0}/V_s)^2)/(1-(V_r/V_s)^2]\right\}$$

$$H_x = (V_s/g)\left\{V_r[\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)] +(V_s/2)\ln[(V_s^2-V_{r0}^2)/(V_s^2-V_r^2)]\right\}$$

$$H_x = (V_s/g)\left\{V_r[\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)] +(V_s/2)\ln[(V_{r0}^2-V_s^2)/(V_r^2-V_s^2)]\right\}$$

$$H_t = (V_a+V_r)\, t - H_x$$

$$Ht = V_a t + V_r(V_s/g)\left\{\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)\right\} -(V_s/g)\left\{V_r[\coth^{-1}(V_{r0}/V_s)-\coth^{-1}(V_r/V_s)] +(V_s/2)\ln[(V_{r0}^2-V_s^2)/(V_r^2-V_s^2)]\right\}$$

Therefore,

$$H_t = V_a t-(V_s^2/2g)\ln[(V_{r0}^2-V_s^2)/(V_r^2-V_s^2)]$$

ANNEXURE IV

Relative velocity and height-sesame

```
      PROGRAM HEIGHT
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      OPEN(1,FILE='HEGIN.DAT',STATUS='NEW')
      VSUS=-2.2
      G=9.81
      DO 510 IVAIR=40,55,5
      DO 500 IT=1,40
      VAIR=IVAIR/10.
      T=IT/24.
      VREL0=(-1.)*VAIR
      Y1=(VREL0/VSUS)
      COHI=0.5*(LOG((Y1+1.)/(Y1-1.)))
      Y2=COHI-(T*G/VSUS)
      COH=(EXP(2*Y2)+1.)/(EXP(2*Y2)-1.)
      VREL=COH*VSUS
      Y3=LOG((VREL0**2.-VSUS**2.)/(VREL**2.-VSUS**2.))
      HIGHT=VAIR*T-(VSUS**2)/(2*G)*Y3
      WRITE(*,*)VAIR,T,VREL,HIGHT
      WRITE(1,300)VAIR,T,VREL,HIGHT
300   FORMAT(2X,F3.1,2X,F6.4,2X,F5.2,2X,F6.4)
500   CONTINUE
510   CONTINUE
      STOP
      END
```

ANNEXURE V

a. Size and Shape of sesame

Sl. No.	Natural rest position D_c mm	Natural rest position D_i mm	Vertical position D_c mm	Vertical position D_i mm	Sphericity NRP	Sphericity VP	Sphericity Average	Length L_1 mm	Width L_2^1 $(L_2+L_3)/2$ mm
1	5.5	3.0	14.0	3.0	0.55	0.21	0.38	2.56	1.10
2	6.0	4.0	16.0	4.0	0.67	0.25	0.46	3.11	1.46
3	6.5	4.5	15.0	4.0	0.69	0.27	0.48	2.74	1.65
4	7.0	4.5	17.0	3.5	0.64	0.21	0.43	3.11	1.65
5	6.5	5.0	17.0	5.0	0.77	0.29	0.53	2.93	1.83
6	6.5	4.0	16.0	4.0	0.62	0.25	0.44	2.74	1.37
7	6.0	3.0	15.0	5.0	0.50	0.33	0.42	2.74	1.28
8	5.5	3.5	12.0	2.0	0.64	0.17	0.41	2.20	1.28
9	7.5	5.0	17.0	4.5	0.67	0.26	0.47	3.11	1.83
10	6.0	5.5	13.0	4.0	0.92	0.31	0.62	2.38	1.83

NRP - Natural rest position
VP - Vertical position

b. Size and Shape of pearl millet

Sl. No.	NRP		VP		Sphericity			Diameter			Average* Diameter
	D_c mm	D_i mm	D_c mm	D_i mm	NRP	VP	Average	L_1 mm	L_2 mm	L_3 mm	mm
1	7.5	7.0	7.0	6.3	0.93	0.89	0.91	2.65	3.29	2.38	2.77
2	6.5	5.85	6.5	5.5	0.89	0.85	0.87	2.20	2.74	1.83	2.26
3	7.5	6.5	6.5	5.5	0.87	0.85	0.86	2.38	3.11	2.38	2.62
4	7.5	7.0	7.5	7.0	0.93	0.93	0.93	3.29	2.74	2.56	2.86
5	8.0	7.5	6.5	5.0	0.94	0.77	0.86	2.74	3.01	1.83	2.53
6	7.5	7.0	7.5	6.5	0.93	0.87	0.90	2.56	3.11	2.20	2.62
7	8.0	7.5	6.5	6.0	0.94	0.92	0.93	2.92	2.92	2.01	2.62
8	7.5	7.0	7.0	6.0	0.93	0.86	0.90	2.74	2.74	2.29	2.59
9	7.5	7.0	7.5	6.0	0.93	0.80	0.87	2.56	2.56	2.29	2.47
10	7.0	6.5	6.0	5.0	0.93	0.83	0.88	2.38	2.38	1.74	2.17

* Average diameter = $L_1 + L_2 + L_3 / 3$

NRP - Natural rest position

VP - Vertical position

c. Size and Shape of sorghum

Sl. No.	NRP		VP		Sphericity			Diameter			Average* Diameter mm
	D_c mm	D_i mm	D_c mm	D_i mm	NRP	VP	Average	L_1 mm	L_2 mm	L_3 mm	
1	11.0	10.0	7.5	7.0	0.91	0.93	0.92	3.84	4.03	3.02	3.63
2	11.0	10.0	7.5	7.0	0.91	0.93	0.92	3.84	3.84	2.65	3.44
3	10.5	10	7.5	6.5	0.95	0.87	0.91	4.03	3.84	2.38	3.42
4	7.5	7.0	5.5	4.5	0.93	0.82	0.88	2.74	2.93	1.83	2.50
5	9.5	9.0	8.0	7.0	0.95	0.88	0.92	3.57	3.29	2.38	3.08
6	9.5	9.0	7.0	6.0	0.95	0.86	0.91	3.48	3.57	2.20	3.08
7	10.0	9.5	8.0	6.5	0.95	0.81	0.88	3.48	3.29	2.38	3.03
8	11.0	10.0	8.5	7.5	0.91	0.88	0.90	3.84	3.93	2.56	3.44
9	9.5	9.0	7.0	6.5	0.95	0.93	0.94	3.29	3.48	2.29	3.02
10	10.0	9.5	7.5	6.5	0.95	0.87	0.91	3.66	3.66	2.20	3.17

* Average diameter = $L_1 + L_2 + L_3 / 3$

NRP - Natural rest position

VP - Vertical position