REVIEW OF LITERATURE
I. Variation in grain filling and grain density

Grain filling is one of the major constraints in rice productivity as it directly influences the grain yield by limiting the number of filled grains per unit area. A decrease in number of sterile grains is reflected in an increase in the percentage of ripened grains under luxurious growth conditions and is necessary for maximising the grain yields. Several factors have been reported to be responsible for filling of spikelets in rice. Any factor that affects spikelet fertility and grain filling may have a detrimental effect on grain yield. Hence, a detailed consideration of general factors influencing this trait is quite essential to understand the magnitude and mechanism of spikelet filling (grain filling). This review attempts to analyse the various factors that govern grain filling in rice with special reference to high density grain production.

a. Varietal variation

Under suitable environmental conditions the ripened grain (fertilised) percentage ranges among rice varieties from 75-90% (Murayama, 1971) indicating that the grain yield can be increased by 10-25% by improving grain filling (Yoshida et al., 1972). Considerable variation in the percentage of filled grains as well as high density grain among high yielding varieties has been reported earlier by Nagato
et al. (1976) and Murty and Murty (1981). A variation of 20-80% in high density grains was reported in the All India Coordinated Physiological Trials conducted by Directorate of Rice Research, Hyderabad (AICRIP, 1984). Among the early and late duration varieties large variation in the formation of potential grain was evident due to high susceptibility to environmental factors. The performance of primary tillers in regard to potential grain filling was uniformly better in early duration varieties at majority of the locations while the difference was negligible in late duration cultures (AICRIP, 1984). The proportion of potential grain (HDG) filling however varied from centre to centre and the grain grade index (HDG %) among the primary and tertiary tillers indicated that at majority of the centres primary tillers showed a better index than the tertiary in early varieties, while in late varieties tertiary tillers were on par with the primary (AICRIP, 1985). It is difficult to explain the possible reasons for such large variations in grain filling. One possibility lies in the assimilation capacity of plant itself followed by translocation to the developing grain. The other factor may be the failure in fertilisation which is considered to be insignificant. Therefore, the only possible reasons for the wide differences appears to be the influence of environmental factors on assimilation and translocation during the grain filling period (AICRIP, 1985).
Varietal differences in potential grain filling however indicate the type of variation existing and provide the amount of scope for improvement in maintaining potential yields (Rao and Venkateswarlu, 1986).

b. Grain filling pattern

Increase in spikelet number/panicle seems more dependent on the secondary than on the primary rachis branches (Matsushima, 1957). However, the relatively higher number on the secondary rachis branches would cause intensified reduction of the percentage of ripened grains (Matsushima, 1957; Yamada et al., 1957; Toriyama, 1962; Wada, 1969).

Tsunoda et al. (1965) reported that sterility per cent of the primary rachis branches was higher than that of secondary ones. The spikelets on the primary and secondary rachis branches differ in their rate of filling and final dry weight (Oota et al., 1958; Arai and Kono, 1978). Few variations in the average number of spikelets on the primary rachis branches exist in several japonica varieties (Manaka and Matsushima, 1971). Sivasubramanyam et al. (1969) reported that the middle portion of the panicle contained more chaff than top portion.

According to Vergara (1970) anthesis within a panicle starts from the top moving downwards and thus the top flowers are the earliest in fertilisation and grain filling. The
rest of the spikelets located in the middle and bottom portion of the panicle get filled subsequently in succession after the panicle exsertion. Thus, anthesis of all spikelets in a panicle may take about 7 days to be completed.

Nakayama (1974) observed that the development of each grain except the top one takes place in an ascending order and presumed that this may be a normal process during ripening. The lower portion of the panicle bear a high proportion of empty grains (Sikder and Dasgupta, 1976a,b; Arai and Kono, 1978).

Varietal variation in the structure of ear and the size of grain were examined on varieties of different eco-types by Sasahara et al. (1982). They classified five types of ear principally based on the difference in number of grains on the secondary rachis branch.

Varietal variation in the distribution of high density grain among primary and secondary rachis branches of the panicle was also observed by Rao et al. (1985a). In general, the occurrence of high density grain increased from the base of the panicle towards the top rather decreased from top to bottom. This pattern was very much similar to the nature of grain filling in rice (Vergara, 1970). Obviously the high density grain in all varieties were mostly localised in the
top portions of the panicle followed by middle and lower regions.

Based on specific gravity method, different grades of grain filling (average, good and very good) were identified in primary and tertiary tillers of the varieties (AICRIP, 1985). Late duration varieties exhibited better grain grade index than early ones. Primary tillers exhibited uniformly better filling in early varieties while in late duration varieties the differences among the primary and tertiary tillers were negligible. Observations on the grades of the grain in Mahsuri at different centres indicated that the proportion of very good grain varied from 51.1 to 83.6% in primary tillers and 55.1 to 81.3% in tertiary tillers, while in IET 5656 it ranged between 51.1 to 83.6% for primary and 61.8 to 91.0 for tertiary tillers.

Rao et al. (1985b) developed a screening technique for differentiating the degree of spikelet filling in rice varieties by specific gravity method. As specific gravity increased, the filled spikelets decreased while the test weight increased. The grain grade index denotes the proportion of fully filled spikelets recovered at 1.18 sp.gr. to the total number of spikelets formed. It was suggested that this index is useful as a screening tool in varietal improvement programme for identifying high yield potential plants.
Rao (1987a) reported that non-synchronous flowering in rice results in differential grain filling and yields a mixture of grain at harvest with varied kernel size. Despite the panicles being impressive with good size and number of spikelets, the yields are low indicating the influence of the pattern of grain filling in controlling yield potential. Studies made with different varieties on the nature of filled grain pattern in the panicle indicated that the per cent of filled grain (grain grade index) varied among different primary branches and was more at the top and lower at the bottom in a descending order irrespective of the variety and duration. It was suggested that based on the per cent of filled grain at the first primary branches (from the base) of the panicle the yield potential of the varieties could be identified as poor (when less than 10%), average (between 20-30%), moderate (30-40%) and high (more than 50%).

c. Number, test weight and percentages of different grades of grain

The study of assessment of potential grain filling with early, medium and late duration varieties at 9 centres under Coordinated trial was reported by AICRIP (1983). Variation in different grades of grain i.e. chaff, average, good and very good grains were also reported. Variation in test weight was also marked. The test weight of very good grain was found to be higher than the normal grains. This difference ranged
from 2-10 gm and the varieties showed differences at different centres. This variation among the two is an indication of the scope for filling under certain critical and stress conditions. Variations in number, test weight and percentages of different grades of grains were also reported by Venkateswarlu et al. (1986b).

d. Filled spikelet distribution in panicle at different specific gravities

Variation in fully filled spikelets distribution in panicle determined by specific gravity method in some rice varieties was reported by Rao et al. (1985b). As the specific gravity increased the filled spikelets decreased while the test weight increased. The potential test weight was found to be more than the weight known for a variety. Different grades of grain were characterised as (i) average, (ii) good and (iii) very good based on the degree of spikelet filling. The grain grade index denotes the proportion of fully filled spikelets recovered at 1.18 sp.gr. to the total number of spikelets formed. It was suggested that this index is useful as a screening tool in varietal improvement programme for identifying high yield potential plants.

e. Grain filling and grain growth (mg grain\(^{-1}\)) at successive stages of ripening

Variation in grain filling and grain growth rate of different rice varieties were reported by Rao et al. (1986).
Studies made with grain filling pattern revealed that the partially filled grains appeared in declining order with the initiation of grain filling and the number of grains increased linearly with time. However, the absolute grain filling showed steadiness which gradually increased and tapered off. The study of grain growth rate was reported by Janardhan (1977), who suggested that the initial weight of each grain was mostly hull weight at flowering and the grain growth was almost complete at 2 weeks after flowering. According to him grain filling was rather a slow process. However, the per cent of filled grain continued till harvest, but at slower rate in all varieties.

Yoshida (1981) also stated that grain growth of a field crop is initially slow, enters a linear phase where the growth rate is fast and then slows down towards maturity. Under temperate climatic conditions, grain grew slowly for the first three weeks after flowering then rapidly and again slowly as they approached maximum grain weight (Fujita et al., 1984). They also reported that grain filling rate and duration varied depending upon the size of the grain as it was slow in small grain varieties and generally increased with increasing grain size.
II. Factors influencing grain filling and grain density

a. Climate

Solar radiation: Solar energy is the major factor governing grain filling and hence dry matter production and grain yield. A critical period in the life cycle of rice plant when solar radiation is mostly required i.e. 15 days before flowering to 25 days after flowering and lack of solar radiation at this stage decisively decreases grain yield. Especially the amount of solar radiation during the period of 25 days after heading has decisive effect on the percentage of ripened grain and the yield as well (Matsushima, 1980a). Chang (1985) also reported that during the reproductive and ripening phases, solar radiation is the major factor determining rice yield.

Matsushima et al. (1957) demonstrated that a combination of high temperature and low solar radiation seriously impaired ripening. Solar radiation during the reproductive stage also has a pronounced effect on spikelet number per square metre (Matsushima, 1957; Stansel et al., 1965). The percentage of filled grains may decrease when solar radiation during the ripening period is low or when adverse conditions such as nitrogen deficiency set in (Matsushima, 1957; Wada, 1969).
Murata (1964) found a close correlation between grain yield and solar radiation and daily mean temperature. Hanyu et al. (1966) also found a close correlation between grain yield and sunshine hours and daily mean temperature for 40 days of ripening period. Tanaka et al. (1966) demonstrated a close association between grain yield and dry weight increase after flowering. A high correlation between grain yield and solar radiation during the ripening period (Moomaw et al., 1967) or during 45 days from 15 days before flowering to harvest (De Datta and Zarate, 1970) was apparent. Murakami (1973) also demonstrated a close correlation between grain yield and daily mean temperature and sunshine hours for 40 days of ripening period. According to Yoshida and Parao (1976) yields were highly correlated (positively) with average daily solar radiation and negatively with daily mean temperature during reproductive stage i.e. the 25-day period before flowering.

Munakata et al. (1967) reported that relationship between light and ripening grade indicates that the effect of sunshine hours is positive under high temperature conditions irrespective of stage while negligible or even negative under low temperature conditions especially at 10 days after flowering. Munakata (1968) observed that ripening grade of rice plant was decreased by strong solar radiation (over 450 cal. cm$^{-2}$ day$^{-1}$ at high temperature above 27°C). Kiyosawa (1962) reported that the effect of light intensity on the ripening
grade (percentage of sterile grains) was negligible at 18°C during meiosis stage. The lower grain filling during the cloudy monsoon season has been attributed to the low solar radiation according to several investigators (Matsushima, 1957; Togari and Kashiwakura, 1958; Yamada, 1965; Wada, 1969; Osada et al., 1973; Murty et al., 1975; Sahu and Murty, 1976; Venkateswarlu, 1976; Yoshida and Parao, 1976).

**High temperature**: The detrimental effect of high temperature partly due to loss by increased respiration and decreased photosynthetic surface is evident (Murata, 1964). But contrary to this Yoshida (1972) observed that high temperature affect ripening by shortening the period of kernel growth. High temperature as a major factor impairing ripening has been reported by several workers (Osada et al., 1973; Reddy, 1977; Venkateswarlu et al., 1979; Fujiwara et al., 1980).

Rice is most sensitive to high temperature (26-35°C) at heading and the next most sensitive stage is about 9 days before heading. High temperature during reproductive stage mainly causes reduction in spikelet number per panicle (IRRI, 1975). The most sensitive stage of the rice plant to high temperature is considered to be the day of flowering and particularly the time of anthesis. High temperature (35°C) even for one hour at anthesis was found to be critical for fertilisation of the rice spikelet. A number
of workers reported a critical temperature range from approximately 18-30°C for panicle differentiation. Above 30°C adverse effects like delay or inhibition of panicle differentiation is observed resulting in reduction of spikelet number/panicle (Choudhuri and Ghildyal, 1970; Adachi and Inouye, 1972). Munakata (1976) reported that the number of spikelets/unit area was strongly influenced by temperature at 45 and 20 days before flowering.

However, little is known about high temperature injury at spikelet formation stage. Tsunoda (1964b) reported that ripening grade was scarcely influenced by water temperature up to 35°C but when water temperature was raised to 40°C the ripening grade decreased to about one half that at normal temperature. Sato et al. (1973) indicated that the ripening grade was hardly affected by day/night air temperature regime of 35/30°C.

Zheng and Mackill (1982) reported about the effect of high temperature on anther dehiscence and pollination of rice. The control plants were kept at 29/21°C and treated plants at 35/27°C for 10 days at flowering. Decrease in anther dehiscence was associated with a reduced number of pollen grains shed on to the stigma and reduced percentage of filled grains. Bhatti et al. (1983-1985) reported that temperature above 30 and 38°C at anthesis and flowering respectively induce sterility.
Sahu et al. (1983) reported about the influence of temperature and solar radiation on growth and yield of rice when planted at monthly intervals throughout the year. The crop planted in January-February (dry season) gave higher yield than that planted in June (wet season).

**Low temperature**: Low temperature induces sterility at high altitude of the tropics (Vergara et al., 1970) and also at high latitudes in the temperate regions (Ishizuka et al., 1973). Low temperature also induced sterility in cool regions (Yoshida and Parao, 1976). The rice plant is most sensitive to low temperature at about 9 days before flowering and a daily mean temperature of less than 20°C is critical (Satake, 1976).

Sasaki and Wada (1973) and Satake (1976) reported that rice is most sensitive to low temperature (15-20°C) during the booting stage i.e. at about 14 to 7 days before flowering depending on the variety and weather condition. The second most sensitive stage is the flowering. Munakata (1976) reported about the reduction in spikelet number/panicle at temperature below optimum level. Yoshida (1981) also reported panicle tip degeneration due to low temperature which causes reduction in spikelet number/panicle.

Heeman (1984) reported that a temperature of 12°C for 4 days during microsporogenesis and anthesis caused
considerable sterility. Low temperature induced sterility was aggravated by high nitrogen supply.

Nishiyama (1984) stated that low temperature injury has been a source of rice yield reduction due to cool summer damage. Also low temperature imposed at booting stage induced sterility through effects on pollen mother cell meiosis. Elongation of palea and anther was reduced during cooling. Physiological effects arising from cooling at the young microspore stage and the resulting infertility include an increase in the anther, sucrose content and decrease in anther respiration and acid phosphatase activity.

According to Fujita et al. (1984) under controlled environmental conditions the plants grown in pots at day/night temperature of 32/24°C until 3 days after flowering and then subjected to 20/12°C during grain filling period showed a marked decrease in both filling rate and 1000 grain weight with increased duration of filling period.

The mechanism of low temperature damage has been investigated by Terao et al. (1942), Kondo (1943) and many others. Tsunoda (1964b) found that the per cent of sterile grain was the lowest at a day/night water temperature regimes of 25/20°C. Also Shibata et al. (1970) reported that the percent of sterile grain was the lowest at a day/night air temperature regime of 24/20°C. They also reported that occurrence of sterile paddy by low temperature treatment was more
serious at the spikelet differentiation stage than at heading.

**Light and temperature interaction**: Under reduced light and low temperature during heading the fertility of grains decreased (Wada et al., 1973). Low temperature (16–25°C) accompanied by high light intensity (above 300 gm cal. cm$^{-2}$ day$^{-1}$) during the ripening period are highly desirable for better grain filling (Yoshida and Hara, 1977).

Munakata (1976) reported that the number of spikelets per unit area was strongly influenced by temperature at (-45) and (-20) stage and by solar radiation at (-40) stage. The (-40) means the period of 20 days centering at 40 days before heading time. The combined effect of temperature and solar radiation on spikelet number was most prominent at (-40) stage. The ripening grade as expressed by the grain yield per spikelet number was mainly governed by the climatic factors at 2 stages of (-20) and (+20). The effect of solar radiation was positive through the reproductive stage while the effect of temperature was not same. The negative effect of low temperature on ripening grade was most severe at (-20) stage, followed by that at (+10) stage. Also a negative effect of high temperature was observed around the heading time. The optimum temperature for ripening grade was 26°C at heading, followed by 23°C at (-20) stage and 22°C at (+20) stage under
normal solar radiation.

b. Low light

Matsushima (1957) demonstrated that shading for one month before flowering reduced spikelet number/panicle. He found that cell division was the most sensitive stage to shading. Stansel et al. (1965) showed that shading from panicle differentiation to heading reduced grain yield by lowering the number of full florets per panicle. Thus high solar radiation combined with relatively low temperature during the reproductive stage tends to produce more spikelets. But the crop shaded during the ripening period had a low percentage of filled grains not because of increased sterility but because of increased partially filled grains. The percentage of filled grains may decrease when solar radiation during the ripening period is low or when adverse conditions such as nitrogen deficiency set in (Matsushima, 1957; Wada, 1969).

Matsushima (1957) reported that low light (15-20 klux) when imposed during the grain ripening period adversely affects yield and translocation of nitrogen and carbohydrate to panicle. Grain setting rather than grain filling was more sensitive to low light (Togari and Kashiwakura, 1958; Wang and Yan, 1964) due to limitation in assimilation supply. Post-flowering dry matter accumulation which is mainly in the form of grain
carbohydrates is closely associated with solar radiation under low light conditions during ripening phase (Tanaka et al., 1966). Matsushima (1970) reported the adverse effect of low light on percentage of ripened grain which is related to the reduction in the rate of carbon assimilation. Nagato and Choudhuri (1970) reported that shading one week earlier or later to heading decreased the ripened grain percentage. Similar results were reported by Stansel et al. (1965), Yoshida and Parao (1976) and Venkateswarlu (1976). Yoshida and Parao (1976) stated that low light during reproductive stage has a pronounced effect on spikelet number whereas at vegetative stage showed slight effect on yield and yield components. The impaired translocation of either already formed carbohydrate or those formed after flowering may also result in decreased filled grains under low light (Janardhan, 1977).

The grain yield was reduced under low light due to reduction in dry matter production, grain number per panicle (as a result of high spikelet sterility) and grain size (De Datta and Zarate, 1970; Murty et al., 1975; Venkateswarlu, 1977). However, recently it has been reported that source capacity is a limiting factor rather than grain setting for yield under low light (Venkateswarlu, 1977). Grain yield was reduced under low light due to low grain number/panicle and grain size (Janardhan et al., 1980).
Stansel et al. (1965) reported that the reduction of light up to 40% when imposed from tillering to primordial initiation reduced panicle number per unit area. Reduction in spikelet/panicle was observed by Matsushima (1966) when shade was applied either from 15 days after planting to harvest (26.4%) or primordial initiation to flowering (28.8%). Shading at ripening stage did not affect the spikelet/panicle. Similar results were reported by Yoshida and Parao (1976) and Nayak and Murty (1980). The reduction in grain number per panicle due to low light treatment has been reported earlier by Urs (1977) and Matsushima (1980b). Murty and Murty (1982) reported different types of shading application (50% of normal light). Shading ranging from 10 DBF to flowering and continuous shading from 10 DBF to maturity enhanced spikelet sterility more than shading at other stages. Sahu et al. (1984) suggested that plants grown in 55% shade for 14 days produced 50% less dry weight than those in full sunlight on the basis of leaf area per plant and reduction in dry matter with 55% shade. Inthavongsa et al. (1985) reported that shading with black cheese cloth from heading to maturity reduced plant dry weight. Shading initiated 10 days prior to heading also reduced dry matter accumulation. Patro and Sahu (1986) stated that the adverse effect of low light was less when plants were exposed to reduced light during vegetative stage than at reproductive stage, which drastically reduced
the spikelet number/panicle as most of the differential spikelets were degenerated. During ripening stage low light impaired grain filling thereby reducing grain number/panicle.

c. Season and fertiliser level

Sahu and Murty (1975) while testing the productive efficiency of 6 early high yielding rice cultures during dry season at the rate of 80 kg and 160 kg N/ha showed that response to nitrogen varied from 5-14 kg of grain per additional kg of N and it was mostly due to an increase in panicle number. The dry matter production and N uptake were low upto panicle initiation stage and rapid thereafter in early varieties. Response of nitrogen in various components of yield is higher in dry than in wet season (Vergara et al., 1966; Sahu and Murty, 1976; Sahu and Murty, 1978a). Sahu and Murty (1978b) observed more accumulation of nitrogen in stem, leaf and panicle in wet than in dry. However, no difference was marked in total uptake of nitrogen. Rao (1987b) reported that production of high density grains differ with crop duration, season and nitrogen levels. High density grain index (% of fully filled grain at 1.18 sp.gr. divided by spikelet/panicle) is influenced positively by crop duration, season and negatively by nitrogen levels. High density grain had a negative relationship with higher N levels.
Patel et al. (1983) suggested that application of 60 kg N as granulated compost/ha was the most effective dose in increasing the number of panicles per unit area, fertile spikelets/panicle, 1000 grain weight and grain yield. Ram et al. (1984) stated fertiliser applied at the rate of 20, 40, 60 or 80 kg N/ha at sowing, tillering and panicle initiation to direct sown rice increased grain yield and the number of tillers/plant and decreased the number of filled spikelets. Garcia and Treto (1985) stated that nitrogen fertiliser applied at the rate of 0, 40, 80-200 kg N/ha showed that yield increased upto 120 kg N/ha. Total N uptake at harvest was 4.8-7.8 t/ha. Inthavongsa et al. (1985) stated that nitrogen application at the neck node initiation to spikelet initiation increased plant height, length of uppermost leaves and spikelet but reduced the percentage of ripened grains, grain weight and yield/hill. Takhro (1986) suggested significant differences in dry matter productions and grain yields occurred between different N treatments. Straw N accumulations increased with increasing N but grain N decreased at higher rates.

To increase the rice yields in the tropics by applying more nitrogen varietal responsiveness to N is necessary (Matsuo, 1952). Again grain production depends upon the substances which accumulate in the straw before flowering and the assimilation products produced after flowering. At low nitrogen application the starch accumulated in the straw
before flowering gets translocated to grain constituting as much as 40% of the total starch in the grain. On the other hand at high nitrogen level it is less than 10% (Murayama et al., 1955). The translocation of substances from the straw to the grains is slower in plants receiving a heavy nitrogen application than in plants receiving a low nitrogen application (Oshima, 1962).

Matsushima et al. (1956) gave a reliable evidence that the nitrogen supply during the ripening period had a good effect on the weight of the panicle and ripening. At the beginning of reproductive stage supplementary application of nitrogen may increase the number and size of florets per panicle (Matsuo, 1957). Wada and Matsushima (1962) confirmed on the basis of several years experiments, its favourable effect on percentage of ripened grain, 1000 grain weight and grain yield. Kamura and Takeda (1962) showed that under heavy (fertilisation) nitrogen supply a decrease in the fertilisation percentage occurs and becomes a factor in determining the percentage of ripened grains. Shimizu (1967) found a close relationship between the number of spikelets/unit area and the amount of nitrogen absorbed by the rice plant at heading.

Nitrogen contribute to sink size by only decreasing the number of degenerated spikelets and increasing the hull size. It also contributes to ripening by increasing specific
leaf weight, nitrogen content in leaves and by promoting carbohydrate accumulation (Wada, 1969). After heading, nitrogen contributes to carbohydrate production. In most cases, the amount of nitrogen which can be absorbed during the ripening period is very small compared to that of nitrogen requirement of grains. A large amount of nitrogen is translocated from leaves to grains with advance of ripening (Wada, 1969; Wada et al., 1973).

Murata (1969) and Murata and Matsushima (1975) suggested that nitrogen should be applied during ripening stage because a larger number of spikelets are formed relative to nitrogen absorbed at heading stage. The percentage of ripened grains is determined by the ratio of the amount of carbohydrate to the number of spikelets. In general, the percentage of ripened grains has a tendency to decrease with an increase in plant nitrogen content at the late stage of spikelet initiation or at heading stage (Wada et al., 1986).

Venkateswarlu et al. (1986b) stated that high density grains (grains > 1.20 sp.gr.) comprises a major yield component regardless of N level or variety tested. The proportion ranged from 37–88%. In all cases, the proportion of high density grains to total yield decreased with increase in N level. Increase in high density grains with increase in N level was evident in few varieties only. In contrast, in some other varieties no such tendency was observed. Again while
testing the influence of nitrogen on high density grains by the application of 0, 75, 150, 200 and 250 kg N/ha it was observed by Venkateswarlu et al. (1986b) that the high density grain did not increase after 75 kg of N level while in some other varieties there was increase with increased levels of N. The results also indicated that enhanced production of high density grain in a cultivar will have advantage even for low levels of N management as some of the varieties did not further increase with additional application of N.

d. Crop duration of grain filling

Duration of the grain filling period had a significant positive effect on both kernels per spike and kernel weight. Aksel and Johnson (1961) observed in barley plant that a long vegetative period partly contribute to higher grain yield. They further noted that grain yield was dependant on sink capacity, largely determined by initiation of floral structure during vegetative period and on photosynthetic capacity during grain filling period. However, Tsunoda (1964a) with rice and Stoy (1965) with spring wheat both showed positive correlation between grain yield and the duration of the grain filling period for several different cultivars. Gunn and Christensen (1965) found that late maturing hybrids of corn were characterised by a longer grain filling period
and larger kernels than those of early maturing groups. Gardener (1966) observed in barley long grain filling periods for high yielding cultivars than for low yielding cultivars in each of the two growing seasons.

Vergara et al. (1966) and Hanway and Russel (1969) reported a close correlation between grain yield and grain filling duration for several hybrids of corn. The length of the grain filling period is recognised as being important in determining grain yield (Bingham, 1969; Daynard et al., 1971; Spiertz et al., 1971; Daynard and Kannerberg, 1976). A significant linear relationship was found among several corn hybrids between grain yield and effective tillering period duration (Daynard et al., 1971).

However, plant breeders have turned to studies of grain filling rates and duration as possible measures of physiological efficiency in corn (Daynard et al., 1971; Johnson and Tanner, 1972; Carter and Poneleit, 1973; Cross, 1975). In general their results indicated that genetic differences exist for both rate and duration of grain filling and in most cases duration was more closely related to yield than filling rate. Evans and Wardlaw (1976) indicated that variation in the duration of the vegetative period accounted for 5 to 10% of the variation in grain yield in cereals.
Long duration varieties had greater high density grain percentages than short and medium duration varieties. Short and medium duration varieties performed better in the dry season (65% H.D. grain) than in the wet season (45-55%). Late duration varieties exhibited better grain grade index than the early ones (AICRIP, 1985). Rao (1987b) reported that production of high density grain differs with crop duration, season and N levels. They also found that high density grain index (fully filled grain percentage at 1.18 sp.gr.) was influenced positively by crop duration and season.

e. Growth regulators

Many reports regarding the foliar application of growth regulators during the grain development of cereals are available. Chatterjee et al. (1976) stated that GA$_3$ produced more dry matter/unit area of land but reduced grain yield by decreasing grain straw ratio considerably. Dey (1980) reported that pre- and post-flowering foliar application of auxin H-61 increased the yield, number of panicles/m$^2$ and number of spikelets/panicle, the increase being highest with post-flowering application of auxin H-61. IAA slightly increased but GA$_3$ decreased yield. Quddus and Pendleton (1983) stated that foliar spray of growth regulators, IAA, NAA, GA$_3$ and 2,4-D at 1, 10 and 100 ppm during late milk ripe stage or at flowering had no significant effect on yield. Debata and
Murty (1984) reported that foliar spray of 10 ppm kinetin or triacontinol (senescence retardant) at 10 DAF delayed leaf senescence in rice with greater retention of leaf area and enhanced photosynthesis. Singh et al. (1984) reported that spray of IAA and kinetin at 5 and 10 ppm respectively during anthesis and again one week later showed increased number of grains/panicle, percentage of filled spikelets, 1000 grain weight and yield while GA$_3$ (5 ppm) and ethrel (25 ppm) had little effect on these parameters. Rao (1985) reported 0.5 ppm triacontinol treatment at booting stage increased the photosynthetic rate of leaves, leaf protein and non-protein nitrogen contents. Biswas and Mandal (1986) suggested that application of kinetin to flag leaf of Ratna delayed leaf senescence and increased grain yield and yield components while application to panicles increased sink capacity and growth rate of grain mostly at the early stage of development.

Many of the studies emphasised the fact that cytokinin seems to be of particular importance during early stages of grain development but during later phase (active filling period) auxins and gibberellins might play a major role (Wheeler, 1972; Michael and Kelbitch, 1972). The higher fertility per cent may be due to high level of auxinic substances which enhances the accumulation of photosynthates in the grains. Again endogenous gibberellins play an important regulatory role in the growth and development of rice kernel
during the grain filling period (Osada et al., 1973). Kinetin application at post-flowering stage prolonged the longevity of leaves and other tissues which contribute to grain filling and enhance the process of export of assimilates to ear. Kinetin produced a pronounced effect on grain filling and increased the yield possibly by increasing leaf longevity (Ray and Choudhuri, 1981). GA\textsubscript{3} and IAA also increased the grain filling significantly over the controls but the effects were less marked than those of kinetin. Saha et al. (1986) reported that hormonal activity in the grain was higher during the first week after anthesis in the tissues during seed setting and cell division.

Obviously the leaves are the main source of photosynthates and other metabolites for the grains. Evidently the treatment with hormones might defer leaf senescence and thus influence yield (Yoshida, 1972). Nevertheless, very little attempts have been made to evaluate the effects of spraying growth hormones on yield of intact crop plants, particularly during grain filling. The concept of mobilization of nutrients was reported by Biswas and Choudhuri (1981). Their concept indicated that there is possibility of augmenting yield by prolonging the period of mobilization of metabolites from leaves to grains as a result of hormonal treatments. Regulation of starch and sugar level in relation to grain development by the application of growth regulators
was studied by Singh and Singh (1982). Total soluble sugars decreased during the course of grain development while starch accumulation increased. Kinetin caused maximum accumulation of starch in the grain. Kinetin and IAA significantly increased the grain weight/plant and 1000 grain weight and number of grains/panicle.

f. Defoliation

Murayama et al. (1955) found that when photosynthesis during ripening is restricted by defoliation the stored carbohydrate appears to be able to support grain growth of rice at a normal rate for some time. However, the loss of a photosynthetic organ stimulates the photosynthetic activity of other organs in rice plant and thus compensate for the loss. But the exact mechanism which initiates the process is not known (Wardlaw, 1968; Neales and Incoll, 1968).

King et al. (1967) showed that during grain filling in wheat most of the assimilates from the flag leaf are translocated to the ear but removal of the ear leads to an accumulation of assimilates in the flag leaf and fall in its photosynthetic rate to about half the initial rate within hours. Also a feed back interaction between sink and source has been reported by Evans (1972), Palit et al. (1976) and Mandal et al. (1977), whereas sink (panicle) depends on the source for carbohydrate and the efficiency of the source to synthesize
carbohydrates is triggered by sink activity (Murty and Venkateswarlu, 1978).

Nakayama (1974) reported that an improvement in the translocation of substances takes place by cut leaf or cut panicle treatments. The grain filling thus depends on the availability of carbohydrates in the source (leaf) and translocation of carbohydrates to panicle (sink) from vegetative parts (Murty and Venkateswarlu, 1978). Venkateswarlu (1976) stated that at present evolution level leaf is not efficient enough to cater to the demand of all the spikelets in a panicle. But compensation is one of the important factors to be considered in defoliation (Yoshida, 1972).

A decrease in the ripening percentage (by 36% of the control) by complete defoliation was reported by Matsushima (1957). Nagato and Choudhury (1970) observed that leaf cutting and shading treatments resulted in a decrease in the carbohydrate allocation per spikelet. Their conclusion was the degree of ripening in these treatments is dependant on the extent of competition for nutrients among the spikelets.

Rao (1962) reported that excision of the flag leaf at ear emergence resulted in higher sterility and lower grain number per panicle. Removal of any one or two leaves or all leaves impair grain filling in rice plants and the sterility was highest when all the leaves were removed and lowest when
the third top leaf was removed (Urs et al., 1975).

Kim et al. (1982) stated about the effect of defoliation and panicle removal at heading stage on grain weight in rice. More the tillers were defoliated at heading lower the mature grain ratio and grain weight/panicle. Partial defoliation gave higher mature grain ratio and grain weight/panicle than complete defoliation.

Chikov et al. (1984) reported the influence of partial removal of an ear or leaves on assimilate transport and photosynthetic productivity in spring wheat. According to them partial removal of an ear decreased the assimilate translocation from the leaves and increased assimilate entry into roots. Also a partial removal of leaves decreased the assimilate transport from the remaining leaves and assimilate import into the root decreased considerably when only a small fraction of the ear was removed and the grain yield even increased by 30%.

Removing any of the top three leaves at flowering decreased the number of heavy grain (high density grain). Removing only the fourth leaf however increased their number indicating that it is a liability and that assimilates are diverted for its maintenance (IRRI, 1985).

Inthavongsa et al. (1985) reported that thinning at heading (removal of top 10 cm) improved the ripened percentage
by 27-32% by allowing more light to lower panicles but removal of top 20 cm produced only 0.5-5% of the improvement. Removal of the flag leaf and subsequent leaves increased empty spikelets and poor grains but removing the 4th leaf increased heavy grains and decreased light grains. Removal of the leaf below the 2nd leaf showed a pattern of grain weights similar to that of intact plants (IRRI, 1986).

g. Translocation

One of the essential and characteristic phenomenon of ripening stage of rice is the translocation and accumulation of substances in ripening panicle. Dynamic aspects of consumption, accumulation and distribution of photosynthates assimilated at various growth stages was studied by Lian and Tanaka (1967) using $^{14}$C tracer. During the study of senescence in rice grain, Nakayama (1969) opined that neither the photosynthetic capacity nor the sink size but the translocation may limit grain filling. However, translocation is a process to transport and accumulate the substance which had been absorbed and assimilated by plants into grain in a very short period (Kasai, 1973). The reduction in the number of filled grains under low light conditions was related to the decrease in translocation of carbohydrates (Janardhan, 1977; Janardhan and Murty, 1978). Nayak et al. (1979) reported a reduction in photosynthesis and translocation rates under
very low light intensity (below 30% of normal light). According to them since translocation is a process of active loading of carbohydrates into the conducting vessels (Shiroya, 1968), it may consume ATP for this purpose (Kursanov and Brovchenko, 1961) and light intensity below 70% of normal may probably be critical for the energy supply resulting in decrease translocation rate.

The period of 10 days before heading to 20 days after heading is the most critical period when most of the carbohydrates for translocation to the ear are produced (Togari et al., 1954). Translocation to panicle was higher from boot leaf than from other leaves (Rao, 1970). Evans (1972) reported that the grain receives about 90% of the net assimilates during the grain filling period. Leaf N₂ beyond 2.4% at flowering showed depressing effect on translocation (Rao, 1972). In early varieties, translocation was found to be quicker even during first week after anthesis whereas in medium types maximum translocation was observed 2 weeks after flowering (Murty et al., 1974). At flowering the rate of translocation differed among varieties. Some accumulate the photosynthates temporarily in stem while in others a direct translocation to panicle occurred (Murty et al., 1974).

King and Evans (1967) observed that the translocation of assimilates is dependant upon the proximity of sink (panicle) to source (leaf). During the study of senescence in rice
grain Nakayama (1969) opined that the translocation may limit grain filling but not the photosynthetic capacity or the sink size. However, translocation rate is considered to be controlled by hormones released from sink to source (Sweet and Wareing, 1966; Bidwell and Turner, 1966; Rai, 1974). Sasahara (1981) reported that when ear or shoot of rice were fed with $^{14}$CO$_2$ at 10-14 days after ear emergence, $^{14}$C translocation rate was not rapid in the first hour after feeding. During one week the grain acted as a sink and the rachis branches, the abortive grains and in some cases the hull functioned as sources of carbohydrates.

Deore and Jadhav (1985) observed in wheat the drifts of alternate increase and decrease in 1000 grain weight in the spikelets from the bottom to top of the ears and attributed the differences to variations in assimilate supply and the presence of some regulatory mechanism in translocation. Wang and Honada (1982) observed that 24 hours later the movement of $^{14}$C exposure was the greater in upper than in lower tillers. The main stem supplied more assimilates to primary than to secondary tillers and more to upper than to lower tillers. Seo and Ota (1982) reported that in incompletely sterile panicles $^{14}$C was translocated from lower to higher branches and from lower to higher grains on these branches implying that the translocation is dependant on sugar gradient.
Heyland and Werner (1983) in wheat reported that apical spikelets had the highest assimilation rate and transport from spikelets was mainly to neighbouring spikelets especially those on the same side as the $^{14}$C treated spikelet and mainly upward. Roeb et al. (1986) reported that the labelled assimilates reached the ear after about one hour depending upon the physiological age of the plant. In the main ear filling period most assimilates were translocated to the ear but at the end of the period more were translocated to the roots.

III. **Biochemical aspects**

a. **Phosphorylase activity during grain filling**

As rice seed is a typical storage organ, starch being the reserve polysaccharides in endosperm so the seed at the mid-milky stage is suitable for studying enzymes involved in carbohydrate metabolism. Naturally these enzymes (in synthesis and break down of starch) have received much attention by several workers.

The distribution of phosphorylase within the rice plant was first observed in the tissue where starch is formed, from which it has been confirmed that phosphorylase participates in the starch synthesis in rice plants (Aimi and Murakami, 1955). Research work further indicated that
(a) optimum pH for starch synthesis by phosphorylase is about 6.2 and the optimum temperature is about 38°C, (b) the pH value of endosperm cells in ripening rice grains is about 5.4 until about 4 days after flowering and suddenly rises upto 6 or more subsequently, and (c) inorganic phosphate in the endosperm decreased as the seed ripened and starch got accumulated. According to Akazawa et al. (1964) phosphorylase is involved in the synthesis of starch which constitutes 70-80% of mature rice grain. Aimi and Murakami (1964) found during ripening process a parallel relationship exists between starch synthesis and phosphorylase activity in rice. However, high ratio of inorganic phosphate to sugar phosphate in plants which is unfavourable to starch formation raises doubt about the role of phosphorylase in polysaccharide synthesis. Physiology of ripening of rice plant relating to starch accumulation in the endosperm by the enzyme phosphorylase was presumed by the reaction GI-1-PO₄ + Primer $\rightarrow$ Starch + iP (Reizo Aimi, 1967). As glucose-1-P occupies a crucial position in sucrose starch conversion and is a substrate for phosphorylase, it is therefore rapidly utilised during the development.

Aimi et al. (1956) observed little synthesis of starch in seed upto 4th day after flowering and a very rapid synthesis between 7th and 20th day. The content of reducing sugar increased until around 15th day after flowering and decreased
rapidly thereafter. They also noticed an increase in amount of phosphorylase in endosperm until the 18th day after flowering followed by a decrease continuously with complete loss of activity by 30th day. Aimi and Murakami (1958) studied the activity duration of phosphorylase within the ripening kernel when plants were kept under cool temperature. They found that the active duration of starch phosphorylase which were placed in cool temperature considerably prolonged further than the control without any lowering in the enzyme activity of the corresponding age of the kernel. Aimi and Fujimaki (1960) studied the localisation and quality of inorganic phosphorus in rice kernel during ripening. The amount of this phosphorus was largest at the stage of yellow ripening in which the highest accumulation of starch was formed. They predicted a hypothesis basing on the above result that when starch is synthesised by phosphorylase the liberated inorganic phosphorus is trapped temporarily in the phosphorus body and accumulated in the aleurone layer as a form of phosphorylase.

Yoshida and Takahashi (1962) observed the activity was in the order leaf blade > leaf sheath > root. However, it was noticed that the activity of this enzyme in leaf sheath and leaf blade showed a remarkable peak at elongation stage. Participation of phosphorylase in starch synthesis in rice plant was again confirmed by Aimi and Murakami (1964). Murata
(1974) reported that in rice plant sucrose is synthesised in the leaves and stems and is translocated to grains where it eventually transformed to starch.

Akazawa et al. (1964) reported the changes in starch sugar content of grain during ripening. A sharp increase of both reducing and non-reducing sugars occurred immediately after the onset of flowering reaching a maximum at about 9 days. Thereafter a steady decrease occurred towards the full maturation period. Starch synthesis at first increased in parallel with low mol weight sugars, continued steadily even after the decline of the latter and the accumulation reached a maximum level at about 30 days. However, starch synthesis in rice grain was most rapid during the first two weeks after flowering particularly at mid-milky stage. Based on the starch content the calculated weighed mean rate of starch accumulation was highest 8-9 days after flowering but the biggest increase was between 8-9 days and 11-12 days after flowering. Baun et al. (1970) reported that in developing rice grains phosphorylase Q-enzyme and R-enzyme had peak activities at 10 days after flowering, whereas α- and β-amylases had maximal activities at 14 days after flowering. Although both starch synthetase and phosphorylase have been mentioned as enzyme involved in starch synthesis the former enzyme is thermodynamically favoured for synthesising starch from sucrose. The pathway is almost irreversible
whereas phosphorylase system is reversible since phosphorylase activity is high when starch synthesis is rapid and its function may be to produce the primer molecules needed by starch synthetase to synthesise starch. In the ripening grain with a pH of 5 to 6 phosphorylase activity is high. Perez et al. (1975) reported that the level of non-reducing sugars and the rate of starch accumulation were maximum at 11 to 12 days after flowering when the level of soluble protein was also the highest. Singh and Juliano (1977) reported that starch started to accumulate 3 days after flowering and the rate of accumulation was almost linear from 5 to 9 days after flowering. The starch content of the grain becomes constant at 18-21 days after flowering. The total amount of sugars in the developing grain was maximum at 9 days after flowering in rice varieties. The level of non-reducing sugars was also decreased and reached a maximum at 9 days after flowering. Singh et al. (1978) reported that starch is the major constituent of rice endosperm and starts accumulating from four days after flowering. Maximum rate of starch accumulation has been observed at the mid-milky stage at 7-9 days after flowering and a linear increase in starch content and dry matter per grain occurs during the milky stage from 5-9 days after flowering.

It has long been believed that phosphorylase is engaged in the biosynthesis of starch and glycogen (Akazawa, 1972). Under suitable experimental conditions it was also speculated
that plant phosphorylase is engaged in the break down of starch molecule instead of their synthesis, although there is no evidence available supporting this work. Aimi and Murakami (1958) and Baun et al. (1970) reported that the activity of phosphorylase is high when starch synthesis in developing rice seed is rapid.

b. Carbohydrates, nitrogen and chlorophyll contents during grain filling

Carbohydrates: Fujiwara et al. (1951) reported that the initial growth stage of plant is the protein phase dominated by protein synthesis whereas the later stage is carbohydrate phase characterised by low synthesis of protein and more accumulation of starch.

Starch in the rice grain is derived from the two sources (a) the accumulated starch in straw before heading, and (b) assimilated products during ripening (Ishizuka and Tanaka, 1953; Murayama et al., 1955). The active period of carbohydrate formation for translocation to the ear appear to correspond to the period of 10 days before heading to 20 days after heading (Togari et al., 1954). When photosynthesis during ripening is restricted by 90% shading the accumulated carbohydrate supports grain growth at almost a normal rate for about 2 weeks after flowering (Murayama et al., 1955). This indicates that when the current supply
of assimilate is insufficient for rapid grain growth the accumulated carbohydrate can be easily translocated into grain. This translocation may prevent the occurrence of the unfilled spikelets (spikelets that are fertilised but fail to grow at early stages of grain filling).

Murayama et al. (1955) also observed that grain filling largely depends on the carbohydrate present during the ripening period. Number of filled grains is basically determined by the ratio of total carbohydrates to the total number of spikelets to be filled (Kumura, 1956; Matsushima, 1957; Yamada et al., 1957).

The reduced solar radiation during the crucial period (10 days before heading to 20 days after heading) considerably impairs the carbohydrate production (Yamada et al., 1957). Grain carbohydrate depends more on accumulated carbohydrate when light intensity after heading is low because photosynthesis during ripening is reduced (Soga and Nozaki, 1957).

Carbohydrate content is relatively low at early stages of growth since it is used for growth and N uptake (Tanaka, 1964a). But after ear initiation stage there was a significant accumulation of carbohydrates in the straw. Ripening of grain depends upon the nitrogen stored in the straw until flowering and also to a great extent upon the carbohydrates
stored in the straw up to flowering.

Carbohydrates such as sugars and starch begin to accumulate sharply about two weeks before heading and reach a maximum concentration in plant's vegetative parts mainly in the leaf sheath and culm at around heading. The concentration begins to decrease as ripening proceeds and may rise again slightly near maturity. Direct qualitative evidence that the accumulated carbohydrates are translocated into grains was obtained with a $^{14}$C technique (Murayama et al., 1961; Oshima, 1966).

Yoshida and Ahn (1968) reported the role of pre-flowering carbohydrate for assimilation of grain carbohydrate during post-flowering period. They also reported that carbohydrate content of grain is dependant largely on the amount of photosynthesis after flowering. So far as carbohydrate balance is concerned between flowering and harvest sugar is more important than starch in both dry and wet seasons. However, starch is predominant before flowering and especially during dry season.

Cock and Yoshida (1972) observed that 68% of the accumulated carbohydrate was translocated into grain, 20% was respired during ripening period and 12% remained in the vegetative parts. The amount of carbohydrate translocated was equal to about 26% of the grain carbohydrate or equivalent of about 2 ton grains/ha when the yield was 7.8 ton/ha.
Prior to flowering the carbohydrate accumulation was low and increased considerably as the plants approaches towards heading (Yoshida, 1972). Cock and Yoshida (1972) stated that pre-flowering carbohydrate account for only 26% of the total grain yield.

The insufficiency of carbohydrates results in degeneration (Murata, 1969) and non-filling of spikelets relative to the total demand (Sikder and Dasgupta, 1976a; Venkateswarlu et al., 1976).

Singh and Juliano (1977) reported about the changes in sugars (water soluble sugars) in the developing grain of rice in relation to the role of these sugars as precursors of ADP glucose in starch accumulation. The level of total sugars, total reducing sugars and other non-reducing sugars showed the peak value at 9 days after flowering.

Yoshida (1981) reported that the accumulated carbohydrate has three possible functions in grain production, (a) to supply a portion of the grain carbohydrate, (b) to support sustained grain growth under variable weather conditions and (c) to stabilise grain yield under unfavourable weather conditions.

Jones (1982) reported the effect of shading which reduced solar radiation by 46% on grain filling. Starch levels were lowered particularly in the internodes. Starch levels in the
vegetative plant parts increased rapidly after flowering but declined during rapid grain filling.

Applied nitrogen levels affect the carbohydrate status of the plant. Thus an increase in N uptake causes a decrease in carbohydrate content while a limited uptake causes an accumulation of carbohydrates (Fujiwara et al., 1951; Takahashi et al., 1955). Carbohydrate content in the plant is also associated with nitrogen responsiveness. Low N responsive varieties generally contain less starch at vegetative stage than high N responsive varieties. Accumulation of starch in the straw decreases with the increase in N supply and this decrease is more apparent in low responsive varieties because they absorb more nitrogen and have a greater increase in growth rate (Tanaka, 1964b).

The reduction in C:N ratio was observed at high level of nitrogen (100 kg N/ha) and during wet season which gave an indication of less synthesis of carbohydrates compared to nitrogen. This might be one of the reasons for poor grain filling at high level of nitrogen and for reduction in grains/panicle (Matsushima, 1966).

At low nitrogen level large amount of carbohydrate accumulate in the vegetative parts before heading and contribute substantially to the grain carbohydrate later (Murayama et al., 1955; Yoshida and Ahn, 1968; Wada, 1969).
Nitrogen: Nitrogen absorbed during reproductive phase determines the number of spikelets/panicle and that at full heading influences the percentage of ripened grains (Matsushima, 1964). However, nitrogen metabolism seems to have a pivotal role in determining the fertility of spikelets (Khan, 1973). Nitrogen absorbed at panicle initiation stage may increase the spikelet number/panicle (De Datta, 1981). The percentage of ripened grains is determined by the ratio of the amount of carbohydrate to the number of spikelets. In general the percentage of ripened grains has a tendency to decrease with an increase in plant nitrogen content at the late stage of spikelet initiation or at heading stage. In order to increase the percentage of ripened grains it is necessary to increase carbohydrate production (Wada et al., 1986). Wada (1969) concluded that dry matter production during ripening period is closely related with the total N in leaves at heading stage, amount of N absorbed during the ripening period and average daily solar radiation during ripening period. However, it was notable that percentage of ripened grains shows a tendency to increase progressively with an increase of the amount of carbohydrate stored in shoots by the heading stage.

Murayama (1969) reported that the nitrogen and spikelet number relationship varies in different areas of production. There is a positive correlation between the ratio of the
number of degenerated spikelets to that of differentiated ones and the life span of plants. Low nitrogen content in leaves during the period from the late stage of spikelet initiation to the heading stage increases the number of degenerated spikelets (Wada, 1985). The number of spikelets is composed of two components i.e. the number of panicles and the number of spikelets per panicle. The number of panicles is correlated with the amount of nitrogen in plants at the neck node initiation stage because in most cases the neck node initiation stage coincides with the maximum number of tillers stage (Wada, 1969; Takahashi, 1975). On the other hand the number of spikelets per panicle is determined by the ratio of the amount of nitrogen in plants at the late stage of spikelet initiation to the amount of plant nitrogen at the neck node initiation stage (Wada, 1969). Further more, Takahashi et al. (1976) reported that there is a high correlation coefficient between the number of spikelets and the maximum rate of nitrogen absorption at the time before the neck node initiation stage. Thus the number of spikelets is influenced by the nitrogen nutrition of plants. The more the amount of nitrogen absorbed up to the neck node initiation stage, the more the number of panicles. The more the amount of nitrogen absorbed during the period from neck node initiation stage to the late stage of spikelet initiation, the more the number of spikelets per panicle.
Chlorophyll: According to Liu (1980) chlorophyll content was found positively correlated to net photosynthetic rate and hence it is reasonable to attribute that chlorophyll plays a major role in controlling grain growth rate and grain filling processes. However, the intensity of chlorophyll is considered to be an indication of the degree of senescence and maturity in plant tissue. Particularly chlorophyll content was found to be more in leaves followed by stems with a marginal difference in panicle (Dunand and Dilly, 1982) during grain filling period. The organs like leaves, stems and panicle showed senescence differently. Among these organs chlorophyll in leaves decreased rapidly from active/mid-tillering to panicle initiation stage. Highest and lowest values of chlorophyll content were associated with faster and slower grain filling pattern respectively (Rao et al., 1986). The role and contribution of chlorophyll directly or indirectly towards the developing grain (as the chlorophyll content is associated with net photosynthetic rate) were further studied by Rao et al. (1986).

Evidently inspite of considerable work on grain filling mostly by Japanese workers, the investigations on quality grain or high density grain (HDG) are very meagre. The factors associated with HDG have not yet been well understood.
Recently attempts are being made at Directorate of Rice Research, India and International Rice Research Institute, Philippines to utilise this potential factor for enhancing grain yield. The present work is aimed to understand the variation in HDG among rice varieties and the factors associated with the production of high density grains in tropical rice.