EFFECT OF SPACING AND HARVESTING TIME ON THE SEED YIELD AND QUALITY OF FRENCH BEAN

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This is to certify that the thesis entitled **"Effect of Plant Spacing and Harvesting Time on the Seed Yield and Quality of French bean"** submitted to the Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **Master of Science in Horticulture**, embodies the result of a piece of *bona fide* research work carried out by **Md. Arafat Hossain** Registration No. **00747** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

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ABSTRACT

The experiment was conducted at the Seed Technology Division, BARI, Joydebpur, Gazipur during the period from October 2013 to May 2014 to find out optimum plant spacing, optimum harvesting time on the seed yield and quality of French bean. The experiment consisted of two factors such as four plant spacing, viz. S_1 (30 cm × 10 cm), S_2 (30 cm × 15 cm), S_3 (30 cm × 20 cm) and S_4 (30 cm × 25 cm) and four harvesting time, viz. H_1 (75 DAS), H_2 (80 DAS), H_3 (85 DAS) and H_4 (90 DAS). The two factors experiment was laid out in Randomized Complete Block Design with three replications. Plant spacing, harvesitng time and their combination showed significant effect on different parameters of French bean. Plant spacing of S_1 produces the highest yield (2.96 t/ha). Harvesting time H_1 showed the highest yield (3.12 t/ha). The combination of S_1H_1 gave the highest yield (3.04 t/ha) of French bean. So, the treatment combination of (30 cm × 10 cm) with (75 DAS) was found suitable for seed yield and quality of French bean.

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CHAPTER I

INTRODUCTION

French bean (*Phaseolus vulgaris* L.) is an important vegetable crop belonging to the family Leguminosae and sub-family Papiolionaceae which originated in the central and South America (Swaider *et al.*, 1992). It is also known as bush bean, kidney bean, snap bean, pinto bean, green bean, raj bean, common bean, baric bean, haricot bean, navy bean, pole bean, wax bean, string bean and bonchi (Duke, 1983; Salunkhe *et al.,* 1987; Tindall, 1988). In our country it is known as “Farashi Sheem” (Rashid, 1993). In Bangladesh, French beans mainly used as green vegetables.

The bush bean is the dwarf type of French bean whose green pods and dry seeds are used for consumption. French bean, though not familiar in Bangladesh, occupies the second position in the world in terms of production among the bean vegetables (Rashid, 1998) and as the main legume food in America, where it has great agricultural importance especially in Brazil, Mexico and U.S.A. In Asia, French bean has been extensively cultivated (34% of the cultivated area) in India (Lue *et a.,* 1990). In Bangladesh the time of its first cultivation is still unknown but it has been commercially introduced recently as winter vegetables. It is cultivated in Sylhet, Cox’s Bazar, Chittagong Hill Tracts and some other parts of the country on limited scale (FAO, 1998). *Phaseolus* beans are grown for both green vegetables and pulses. The most important species in *Phaseolus vulgaris*, it is used for canning and freezing as well as the fresh market. Pods of green beans are prepared whole, sliced or cut and the seeds may be harvested green as a vegetables or dry as a pulse. For whole beans, there is a trend particularly in Europe to develop varieties which produce a large proportion of very fine(6.6-8.0 mm diameter) or extra- fine (<6.5 mm) pods (Davis, 1997). The green pod is nutritionally rich which contains on an average of 1.7 % protein, 4.5 % carbohydrate, 1.8% fiber, calcium 50 mg, magnesium 29 mg, phosphorous 28 mg, and iron 1.7 mg per 100 gm of pod (Shanmugavelu, 1989)

The adoption of bush bean is increasing day by day due to its high nutritive value and export potentiality. Because of its high nutritive value, good taste and wide range of use, it has been considered as commodity for export in the ethnic and also in the extreme super market of European country. Hortex Foundation of Bangladesh already started to export vegetables French bean (Anonymous, 2001).

Bangladesh Rural Advancement Committee (BRAC) has been successful executing production, processing and export of bush bean through contact growers with technical assistance from Hortex Foundation (Kashem and Kamal, 2001). However, the productivity of bush bean at the farmers' field is rather low (700-800 kg/ha) due to lack of high yielding varieties, better production technology, including optimum time of sowing and spacing and harvesting stage for quality seed production.

Plant spacing is an important factor that influences the yields of any crop. There are several reports on spacing of French bean in Bangladesh and abroad. Pastucha (1992) reported that wider spacing increased the number of flower, pod sets, seed number and weight per plant than the narrower spacing. The plant spacing and spatial arrangement greatly affect the growth and yield of crop plants. Optimum plant spacing is essential for attaining desired yield because high planting density results in reduction in number of pods per plant and seeds per pod (Kueneman *et al*., 1979).

For this, Quality seed is essential for both vegetables and quality seed production of French bean. Immature green pods suitable for use as vegetable were harvested through hand picking and weighted to estimate the yield of fresh pod. At harvest, pods were mainly full-size with the seeds still small (about one- quarter developed) firm fresh (Swaider *et al*., 1992) and pods were soft and smooth. Early harvested seed results are poor quality that affects subsequent storability. Delayed harvested seed also result loss of yield due to shattering, damage etc. So it is important to harvest seed at an appropriate time for the quality seed. In view at this the present experiment is undertaken with following the objectives:-

a) To find out optimum plant spacing for maximizing the yield and quality seed of French bean.

b) To determine the optimum harvesting time to secure higher seed yield and quality of French bean.

CHAPTER II

REVIEW OF LITERATURE

French bean (*Phaseolus vulgaris*) is a popular vegetable crop of the world. It has recently been introduced in Bangladesh. Experiments regarding different aspects of French bean production have been conducting in various parts of the world. But research on the effects of plant spacing and harvesting time especially harvesting frequency on French bean production is sparse in scientific literature. In Bangladesh, available literature regarding plant spacing and harvesting time for French bean are insufficient. However, plant spacing and some of the literature with harvesting time on French bean production are reviewed in this chapter.

2.1 Review in relation to the effect of plant spacing

Ahlawat (1996) conducted a field experiment in New Delhi, India to study the comparative performance of French bean varieties and their response to plant density and observed that plant density significantly affects the seed yield and lower plant density (2,22,000 plants/ha) showed significant increase in pods/plants.

In an experiment on the growth and yield of French bean, it was found that plant height, LAI, TDM, CGR and dry matter accumulation increased with the decrease in spacing. However, the number of branches per plant, pod length, number of pods per plant, seed per pod and 1000 seed weight significantly increased with increase of spacing. Also maximum stem dry matter, leaf dry matter, pod dry matter, grain yields and pod yields were found in the narrowest spacing (Akhter, 1999).

An experiment was conducted to observe the effect of plant spacing on the yield of edible podded bean (Anon, 1995). It was found that at any specific line to line spacing, yield of vegetable bean decreased with the increase plant spacing. The maximum green pod yield was obtained with a plant spacing of 30 × 10 cm (11.84 t/ha). The results suggested that a closer spacing was better for a higher pod and seed yield. There was a report that the yield of pea could be as much as 241% higher with higher planting density under irrigation than that of lower density under dry farming (Stroker, 1975).

From an experimental result, the maximum total and early pod yield of pea was found at closer spacing. Closer spacing gave longer pods, number of seeds pod^{-1} and higher carbohydrate and nitrogen content in green seeds (EI-Habbasha *et al.*, 1996). Plant growth and pod quality were the highest with sowing on two sides of the ridge(28 plants m^{-1}) and the highest total pod yield was given by sowing three lines ridge^{-1} (42 plants m^{-2}). Another report was found that the highest planting density (40 plants m^{-2}) produced the highest green pod (9.26 t ha^{-1}) as well as grain yield (1.53 ton ha^{-1}) in edible podded pea (Rahman *et al.*, 2000).

Arf *et al.* (1996) carried out an experiment with six different row spacing and reported that decreasing plant spacing reduced dry weight/plant, pod number and seed number/plant but increased total pod length and seed yield/ha.

A field experiment in Albera, Canada with *Phaseolus vulgaris* cv. 'Centralia' and 'L. 9384' grown at row spacing of 23, 46 and 69 cm and densities of 24 or 48 plant m^{-2} and observed that reduction in row spacing increased yield in all years when grown at a density of 48 plants/m^2 but only increase yield in 1 of 3 years when grown at 24 plants/m^2. Narrow rows reduced plant biomass and increased bean yield (Blackshaw *et al*., 1999).

Bull (1977) stated that closely spaced plants yielded higher than that of wide spaced plants of *Phaseolus vulgaris* bean. An experiment was conducted with three pea varieties with 17 cm, 34 cm, 51 cm and 68 cm spacing between rows. They observed that decreasing row spacing and higher plant density generally increased yields of green peas (Guzal *et al*., 1976).

Chatterjee and Som (1984) conducted a field experiment in West Bengal, India with plant spacing of 40 × 10 cm, 40 × 15 cm or 40 × 20 cm and obtained seed yields of

2.88, 2.09 and 2.86 ton, respectively. They observed that seeds weight increased by increasing intra row spacing. Reducing the inter row spacing of *Phaseolus vulgaris* from 40 to 29 cm, yield was increased from 10.5 to 12.3 ton/ha (Bouriller, 1989).

Dwivedi *et al.* (1994) reported that wider spacing produced significantly higher number of branches plant^{-1}, length of leaves, pods plant^{-1}, green pod^{-1} and 1000 grain weight than other treatments of closer population in French bean. They also state that number of leaves per plant also positive correlation to the number of branches. Through plant growth was vigorous under wider row spacing, yield was the highest under closer spacing (4,00,000 plant ha^{-1}), which was due to higher plant population and the total number of pods plant^{-1} in this treatment. The highest grain yield was obtained under 3,33,333 plants ha^{-1} (Kenjale *et al.*, 1995).

The plant geometry of 30 × 10 cm was ideal for maximum broadness of leaves, growth of the crop as well as proportionally translocating the photosynthesis into economic parts of French bean (Rahuri, 1989). He also found that the highest grain yield of French bean under 3,33,333 plants ha^{-1}. Plant population of 2,50,000 to 4,00,000 ha^{-1} gave the satisfactory results in French bean (Ali, 1989 ; Ali and Lal, 1992).

Different levels of plant population did not affect the rain and straw yield significantly. However, A spacing of 30 × 15 cm (2,22,000 plants ha^{-1}) showed numerically more yield than 30 × 20 cm (1,16,000 plants ha^{-1}) and 30 × 10 cm (3,33,000 plants ha^{-1}) (Jadhao, 1993). Similar results were also noted by Akola (1991). Wider spacing of 40 × 10 cm significantly increased seed yield by 18-8% over narrow spacing of 30 × 10 cm in rice bean (Mohapatra, 1998). This increase was due to favorable effect of wider spacing on branches plant^{-1} , seeds pod^{-1} , and 1000 seed weight.

Plant density showed strong, negative and significant correlation (r= -0.98) with number pods plant^{-1} and grain yield of black gram (Rahman *et al.*, 1994). They also said that increased plant density beyond optimum caused mutual shading which might be responsible for reduction in photosynthetic efficiency, resulting in flower drop, reduced number of pods plant^{-1} and finally reduction in yield. However, by increasing population density higher yields of grain legumes were obtained by a number of researchers (Nangiu, 1975; Mackenzie *et al.*, 1975; Babu *et al.*, 1988).

Dwivedi *et al.* (1994) studied the effect of plant population of French bean with 4,00,000 or 2,86,000 and 2,00,000 plants/ha using inter row spacing of 30, 45 and 60 cm, respectively with an intra row spacing of 8 cm and obtained the highest seed yield with the plant population of 4,00,000 plants/ha. A field experiment was conducted with spacing of 22.5 × 15 cm, 30 × 9 cm and 45 × 5 cm and obtained the mean seed yield of 1.30, 1.36 and 1.34 ton/ha, respectively (Bhosale *et al.,* 1994)

Dhanju *et al.* (1995) conducted a field experiment for 2 years (1991-92) to study the effect of barrier crops (maize, shorghum, okras, sunflowers and *Amaranthus caudatus*) and different spacing on the virus incidence and green pod yield of *Phaseolus vulgaris* cv. Jawala. Of the barrier crops, maize was the most effective as it reduced mosaic virus incidence by about 16% compared with controls with corresponding increase in yield of about 25%. Among the planting densities, the lowest and highest virus incidences were recorded at spacing of 30 × 10 cm and 45 × 30 cm, respectively. However, the highest green pod yield (77.06 q/ha in 1992) was obtained at a spacing of 30 × 10 cm.

Grafton *et al.* (1988) carried out a field experiment in the northern Great Plains, USA to investigate the effects of row spacing and plant population in *Phaseolus vulgaris*. Row spacing was decreased from 0.75 m to 0.25 m yield was increased in cv. 'UI-114' and 'Seafarer' by 52 and 42%, respectively. They also observed that row spacing × plant population had no interaction for yield in both cultivars. Closest spacing gave the higher pod yield (Argerich and Calvar, 1986).

Horn *et al*. (2000) conducted a field experiment, French bean cv. Pampa were grown at row spacings of 25, 50 or 75 cm and densities of 1,00,000, 2,00,000, 3,50,000 or 5,00,000 plants/ha. They observed that decrease in row spacing resulted in reduction of yield in French bean.

Jadhao (1993) observed from an experiment conducted in Maharashtra, India that 30 × 10 cm spacing (2, 20,000 plants/ha) showed better performance than plant spacing of 30 × 15 cm and 30 × 20 cm. another observation was found that the incidence of virus diseases of *Phaseolus vulgaris* increased by wider row to row and plant to plant spacing. The higher yield with lowest diseases incidence was obtained at a spacing of 30 × 10 cm (Azmi and Rathi, 1991).

Jadhao (1993) reported based on an investigation conducted in the plains of Maharashtra, India during winter, 1990-91 that among the three bush bean lines 'VL-63' was the highest grain yielder and 30 × 15 cm spacing (2,20,000 plant/ha) exhibited better performance to render numerically more yield than other plant spacings of 30 × 10 cm and 30 × 20 cm.

Koli *et al*. (1995) carried out an experiment on plant density of French bean (*phaseolus vulgaris*). Seeds were sown in rows 22.5 or 30 cm apart at plant densities of 2,22,222, 3,33,333 or 4,44,44 plant/ha. They observed the highest total dry matter at 20, 40 and 60 days after sowing and also the highest pod yield at harvest with crops sown at rows 30 cm apart and 2,22,222 plants/ha.

Latifi and Navabpoor (2000) conducted an experiment in Gorgan, Iran to evaluate the effect of 3 row spacing levels (40, 50 and 60 cm) and 3 plant densities (20, 30 and 40 plants/m^2) and observed that row spacing of 50 cm positively affected the different crop characters, particularly those of lines 11816.

Mangual *et al*. (1979) stated that different varieties needed different spacing for growth and yield of French bean. The widest plant distance gave highest pod weight and pod number per plant (Badilla-Feliceano *et al*., 1978).

Plant population is one of the most important inputs which can be manipulated to obtain higher yield (Jain and Chauhan, 1988). Grain yield generally increases with raising plant population, but this relationship is parabolic (Donald, 1968; Hamblin and Tennant, 1987). Similar trend was found by Hamid *et al*. (1991) in mungbean. Grain yield is function of yield of individual plant and population density. Per plant yield is governed by number of pods per plant, number of seeds per pod and seed size. Both yield and yield attributes were markedly influenced by population density (Rahman *et al.*, 1995).

Population density exerts marked effects on plant height. Increased density usually increases the plant height. In French bean, Kenjale *et al*. (1995) observed significantly taller plant in higher plant density than lower plant density. But Dwivedi *et al*. (1994) reported that in wider row spacing, plant height was significantly higher than other treatments of closer population in French bean.

Roy and Biswas (1991) observed a quadratic relationship with plant population and plant height in cowpea. Significantly taller plants with dense canopy than sparse ones were also recorded in soybean (Sharma and Sharma, 1993), in chickpea (Singh *et al*., 1993), in faba bean (Kumar and Singh, 1993) and (Rashid, 1998).

Shekhawat *et al*. (1967) observed that 45.7 cm row spacing gave the better yields than 30.5 cm, 61 cm or 91.4 cm rows and the inability of plant growth to compensate for the loss of yield may be due to reduced population at spacing above 45.7 cm with rows 30.5 cm apart.

Singh (2000) conducted an experiment in Bihwr, in India during 1991 and 1992 to study the response of French bean cv. Arka Komal to plant spacing of 40 × 40 cm, 40

× 15 cm, and 40 × 20 cm. with decreasing plant spacing from 40 × 20 cm to 40 × 10 cm improved the yield significantly without adversely affecting the pod quality. The highest net returns along with the higher rate of net profits were also observed for the closest spacing.

Singh and Behera (1998) carried out an experiment in India to study the response of French bean to spacing and found that closer spacing (35 × 25 cm) produced significantly the maximum green pod yield. Significant influence of row spacing on growth and pod yield of French bean. They observed that by increasing row spacing (45-75 cm), yield was decreased (Samontra *et al.,* 1998).

Singh *et al.* (1996) conducted an experiment an India to investigate the effects of spacing on the yield of French bean and observed that net return was the highest with 30 × 10 cm spacing.

Ozen and Ozdemir (1996) also conducted a field experiment in Turkey and observed an increase in seed yield per plant, pod number per plant and seed number per plant by increasing row spacing of French bean. Pod and seed number per unit area were more closely related to seed yield at higher plant densities.

The number of branches was associated with population density. Dwivedi *et al*. (1994) observed that population density of 20 plants m^{-2} produced significantly higher number of branches per plant than that of 30 or 40 plants m^{-2} in French bean. In case of sesame, first node was not affected due to plant density whereas, total number of branches increased with increase in plant population (Tomar *et al.,* 1992). However, branching was reduced significantly with each increment in seed rate in linear fashion because of low light intensity under plants at high seed rates in lentil (Tripathi and Singh, 1989).

Srinivas and Naik (1990) worked with different spacings in French bean. They found that wider spacing produced the highest number of leaves per plant compare to closer spacing.

The response of plants to total dry matter (TDM) due to increased densities has been well documented. In general total dry matter per unit area increased with the increase in population density but per plant basis it was decreased with increasing population density. Shinozaki and Kira (1956) found a linear relationship between the reciprocal of mean plant weight and density, plant to plant variation in weight and height generally increases with increased density. Roy and Biswas (1991) observed that dry matter production increases with increased plant population and the highest quantity of dry matter was achieved from 20 plants m^{-2} in cowpea. Similar results were observed in cowpea and soybean (Wein, 1975).

In edible podder pea, total dry matter, stem leaf and pod dry matter were maximum in the highest population density (Rahman, 2000). Dry matter production of black gram was higher under higher population density (50 plants M^2) but partitioning of dry matter to reproductive organ was better under intermediate population density of 33 plants m^{-2} (Biswas, 2001).

There are many but often conflicting reports about the effect of plant population density on growth parameters, viz. crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) in different crops. However, Pandey and Singh (1980) reported that CGR, RGR and NAR varied with the stage of development in genotypes and plant density in field pea.

Sharma and Sharma (1993) found a significant increasing trend of CGR and NAR with increasing population density in soybean. In contrasts, Rahman *et al*. (1994) recorded a higher CGR and NAR at the lowest population density and no significant RGR values due to different population densities in blackgram. Similarly, Rowden *et al*. (1981) recorded a maximum value of RGR, NAR and leaf area ratio (LAR) at the lower densities in pigeon pea. In mungbean CGR showed an initial lag phase in the crop growth, reached a peak between 46-60 days after sowing and then declined (Babu *et al.*, 1988). They also reported that CGR was significantly influenced by row spacing. The maximum CGR of 30.8 g m^{-2} day^{-1} decreased by 30% when the plant density decreased by 50%.

Three dwarf varieties of French bean were evaluated under three plant spacings with and without irrigation in 1978 and 1979. Guzhov *et al.* (1981) studied the variation in up to 11 characters, including many yield components and found that the lower the stand density, the lower was the phenotypic variation.

Three spacings (1.6 × 0.3 × 0.15 m, 1.6 × 0.3 × 0.1 m and 1.6 × 0.3 × .05 m) were compared by Argerich *et al.* (1986) with two bush bean cultivars. The results revealed that the yield of ‘providens’ was higher than ‘prevato’ at all spacings. Moreover, the closest spacing gave the higher pod yield of both ‘providens’ (9.4 t/ha) and ‘prevato’ (4.3 t/ha) varieties over other spacings.

To standardize the optimum spacing requirement between and within rows to increase seed production, Gill *et al*. (1972) conducted an experiment with ‘Contender’ variety in June, 1972 and July, 1973 at the vegetable research station of Katrain, IARI, India. The highest average pooled yield was obtained in 30 × 10 cm spacing followed by 30 × 5 cm and 40 × 5 cm.

Vulsteke (1985) conducted an experiment in Belgium with *Phaseolus vulgaris* cultivars ‘Belami’ and ‘Prifin’ and observed that 33 cm inter row-spacing gave an average of 37 plants/m^2 by planting 45 seed/m^2 and gave the most economic yields of green beans. Lima *et al*. (1983) reported that spacing had little effect on yield except during the wet season when yield was significantly higher at wider spacing.

Pastucha (1992) reported that wider spacing increased the number of flower, pod set, mature pods, and seed number weight per plant than narrow spacing.

2.2 Review in relation to the effect of harvesting time

Immature green pods suitable for use as vegetable were harvested through hand picking and weighed to estimate the yield of fresh pod. At harvest, pods were mainly full size; with the seeds still small (about one-quarter developed) firm flesh and pods were soft and smooth, (Swaider *et al.*, 1992).

Bush bean is ready for harvest from 40 days onwards after germination depending on cultivar. It takes about 7-12 days after flowering for the pods to be ready for picking. Ex-fine pod increases by hours and would be picked up within short time (Parthasarathy, 1993). It has been reported that pods are harvested at one or two day's interval for export purpose.

The pods were normally harvested at 9-12 days after flowering based on the crud method of fiber development (snapping technique) and 7-15 days after flowering owing to the purposes of experiment.

Inoue and Suzuki (1962) noted that germinability of bean seeds rose from nil for seeds harvested 15 days after anthesis to 100% when the seeds were harvested at 35 days. Although the seeds harvested at 15 days did not germinate at all in the fresh condition, they showed high germination with 20 days after-ripening (seeds allowed to dry on the harvested plants for 20 days). However, achievement of germinability in after-ripened samples cannot be attributed only to drying, as considerable increase in seed weight did occur during the after-ripening process. Long time ago, Sprague (1936) recognized that a beneficial, irreversible change takes place in corn seeds as a result of drying. He found that the germinability of immature, dried seed was much less variable than that of fresh seeds.

Perry (1972) noted that poorly matured pea seeds are subject to damage under wet seed-bed conditions due to the sudden inrush of water. They suggested that those seeds probably fail to achieve the sub-cellular coordination necessary for the successful resumption of the active state. Illustrated morphological deformities and structural irregularities of’ test as from early harvested pea seeds and noted that these were associated with increased permeability of the seed coat.

Bedford and Matthews (1976) have shown that undried pea seed set to germinate in the laboratory on the day of harvest was capable of’64% germination at an early stage (23 days after flowering); but seed which had been dried at 30°C failed to germinate at all when harvested earlier than 30 days after flowering. After this stage, germination of dried seed rose seed rose steeply to reach a maximum over 95% at 45 days. Similarly, Matthews (1973) showed that germinability of pea seeds that had been rapidity desiccated following harvesting improved with time after fertilization stressed that when seeds are harvested in the immature stage or have prematurely experienced fierce natural drying conditions, serious loss in vigor is likely to occur.

Germination is the emergence and development from the seed embryo of those essential structures, which indicate the ability to develop into a normal plant under favorable conditions in soil (ISTA, 1976). Seed germination and early seedling growth are considered critical for raising crop successfully as they indirectly determine the crop stand density and consequently the yield of crop (Gerlmond, 1978). Varietal differences in seed germination in response to environment variation determined cultivars adaptability (Takahashi 1984). Seed Vigor is this sum total of genetic properties (Perry, 1972), which determine the potential for rapid, uniform emergence and development of normal seedling under a wide range of field conditions (Mc Donald, 1980).

Goodwin *et al.* (1978) in one of their experiments observed lowered seed quality in Apollo bean which was cut one week later than the optimum and either dried slowly in heaps or dried rapidly at 45^0C. Beal (1978) while reporting a poor field germination of beans grown in Queens Land in 1973 and 1975 noted that the seed was harvested after lengthy delays in the field following rain. Hence it appears that choice of the optimum harvest stage for a seed crop is of critical importance.

Germination capacity is the main indicator of seed viability. Satisfactory crop establishment depends on some other associated factors like seed vigor and field condition. The seeds having lower vigor values cannot germinate well under field condition and do not help in better crop establishment. Khandakar and Bradbeer (1983) reported a wide gap between laboratory test and field germination. Low vigor in seed may be due to genetic, physiological, morphological, cytological, mechanical and microbial sectors (Heydecker, 1972). Mechanical damage during harvesting, processing and transportation is one of the real causes of low vigor in seeds (Roberts, 1972). Threshing, treating, bagging and planting processing may also cause in variations of seed viability (Copeland, 1976).

BIahovec and Patocka (1985) reported that Seed moisture Content (mc.) was reduced by low-temperature. Drying Seed strength fell with m.c. over almost the entire range (5-1 5%), irrespective of seed orientation. As seed m.c. fell a reduction in deformation was observed before rupture. This was explained by the reduced plasticity of compressed seeds associated with reduced moisture content.

Time of sowing of the pea has no effect on germination of the seeds produced, but affects seed vigor and electrical conductivity (Castillo *et al*., 1994). Seed quality is affected very much by environmental factors prevailing at the time of seed development. Even at the same location, seed nutrient content, viability and vigor is different at early, mid or late maturing pea crop is different because of varying environmental condition at the time of pod maturity.

Motshwari and Ronald (1996) determined that if' delaying harvest of soybeans having bean leaf beetle-injured pods would result in further reductions of seed quality. Beginning at harvest maturity, collection of soybean pods was done every 2 week, alter which seeds from bulk harvest, from injured and uninjured pods, and from underneath feeding lesions or locations without lesions, were tested tested seed germination. Seed from uninjured pods showed no significant loss in germination percentage, even when seeds were harvested 6 week following harvest maturity.

When pod injury is low, a delay in harvest would not be of great concern. However, germination decreased and the percentage of infection seed pathogens increased on seeds from injured pods and from underneath lesions when harvest was delayed.

Pokojska (1999) reported that changes in dry seed weight and seed moisture content during faba bean (*Vicia faba*) seed maturation were investigated in order to determine the date of seed physiological maturity. Also changes in seed germinability and vigor, and protein and tannin contents were studied to establish the relationship between seed maturity and its physiological quality. Seed dry weight and moisture content were determined, at two-day intervals, from 89 to 11 2 days after sowing. Maximum germination potential (95-100%) was recorded for seeds harvested 105-l08 days after Sowing and it was maintained until the last harvesting date. Maximum vigor was achieved at the same date 103—105 days after sowing). Loss of % vigor with time was shown by the seedling growth test but not confirmed by the conductivity test. The highest seed protein content (31%) was at physiological maturity. The highest amount of tannins was found in immature seeds (about 11 mg/g), while the lowest (about 7 mg/g) was found in seeds harvested 110 days after sowing.

Domingos *et al*. (2001) conducted an experiment to assess the effects of preharvest desiccation, harvest delay, windrowing and watering (by simulated rainfall) on dry bean (*Phaseolus vulgaris* cv carioca) seed yield and quality. The desiccants paraquat (400 g a.i. /ha) and paraquat (250 g a.i. /ha) ± diquat (150 g a.i. /ha) were applied at 31 days after flowering, when the seed moisture content was 35%. Harvests were conducted at 37, 41 and 45 days after flowering. Besides determining weight and yield, seed quality was evaluated by standard germination and vigour tests. Harvest delay reduced seed vigour. Windrowing was found to be harmful to seed quality, and its effects were enhanced when plants were subjected to watering.

Coste *et al*. (2002) indicated that at harvest, the quality a bean seed lot is the result of the Interactions between three factors: differences in the time of the end of seed filling throughout the seed population, seed desiccation rate and decrease rate in seed vigour during and after seed desiccation. This work was a first step towards the development of a decision-oriented model for optimizing the choice of threshing dates and pie-harvest techniques to obtain high quality seed lot. They identified the importance of each of the above factors in determining final seed quality and to test whether high yield and high seed lot quality arc compatible. To integrate the interactions of the three factors, they used experimental data from 1995 and 1 996 to build scenarios of differences in seed lot vigour during desiccation. Firstly, a high yield and a high seed lot quality were compatible. A high yield was associated with large differences in the time of the end of seed filling but a high desiccation rate and a slow rate of decline in seed vigour compensated for the negative impact on seed vigour of these large stage differences. Secondly, the rate of decrease in seed vigour was the most important factor in determining final seed lot quality. The differences in vigour losses between years and preharvest treatments were likely to be due to weather effects at the microclimatic level during desiccation. Finally, the results from the different scenarios supported the view that to explain and model variations in seed lot vigour the three factors influencing vigour have to be analyzed simultaneousiy.

Seed vigour as measured by electrical conductivity (EC) was maximum at physiological maturity (PM) and remained constant until harvest maturity (HM). Seeds in pods of different earliness and seeds of the whole crop all achieved maximum viability at the same moment beyond PM. The maximum viability achieved also as the same in all seed classes. Maximum seed vigour achieved at PM in individual seed classes and was achieved earlier in seeds from earlier pods than from later pods. The vigour of seeds from the individual earliness classes at their optimum moment of harvesting was higher than the vigour of seeds from all pods combined.

CHAPTER III

MATERIALS AND METHODS

This chapter describes the materials used and methods of the experiment done in the field to find out the effect of plant spacing and harvesting time on the seed yield and quality of French bean. The materials and methods that were used and followed for conducting the experiment under the following headings:

3.1 Experimental site and duration

The experiment was conducted at the seed technology division of Bangladesh Agricultural Research Institute (BARI), Gazipur, under the agro-ecological zone of Modhupur Tract (AEZ 28) during the period from October 2013 to May 2014. The location of the site was about 35 km from Dhaka city with 24^0 $90^/$ N latitude and $90^0 26^/$ E longitude and elevation of 8.40 m from the sea level (Khan, 2009).

3.2 Climatic condition of the experimental site

The climate of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to February and the pre-monsoon or hot season from March to April and the monsoon period from May to October (Edris *et al.*, 1979). Details of the meteorological data during the period of the experiment were collected from Bangladesh Agricultural Research Institute, Gazipur and presented in Appendix I.

3.3 Characteristics of soil

The soil of the experimental area belongs to the Modhupur Tract under the AEZ 28 (UNDP, 1988). Soil of the experimental field was silty clay loam in texture acidic in nature. Soil sample of the experimental plot was collected from a depth of 30 cm before conducting the experiment and analyzed in the soil science division, Bangladesh Agricultural Research Institute, Gazipur (BARI) and have been presented in appendix II.

3.4 Design and Layout of experiment

The experiment was laid out in a RCBD (Factorial) with three replications. The unit plot size was 5 m × 1.5 m. The experimental plots were laid out in accordance with the experimental design.

3.5 Treatment of the experiment

There were two factors in the experiment. Factor A comprised of four plant spacing and Factor B had the four harvesting time.

Factor A: Spacing

S_1 : 30 cm × 10 cm

S_2 : 30 cm × 15 cm

S_3: 30 cm × 20 cm

S_4 : 30 cm × 25 cm

Factor B: Harvesting time

H_1 : 75 Days after sowing (DAS)

H_2 : 80 Days after sowing (DAS)

H_3 : 85 Days after sowing (DAS)

H_4 : 90 Days after sowing (DAS)

There were 16 treatment combinations in the present investigation, viz. S_1H_1, S_1H_2, S_1H_3, S_1H_4, S_2H_1, S_2H_2, S_2H_3, S_2H_4, S_3H_1, S_3H_2, S_3H_3, S_3H_4, S_4H_1, S_4H_2, S_4H_3 and S_4H_4

3.6 Land preparation

The selected land for the experiment was prepared thoroughly by a tractor driven disc plough and cross- harrowing and laddering by a power tiller until a good tilt was achieved. All weeds and stubbles were removed from the field. Drains were made around each plot and extraverted soil was used for raising the plots about 15 cm high from the field level.

3.7 Manure and fertilizer application

Cow dung @ 10 ton per hectare was applied during land preparation. TSP, MP and urea were applied as a source of P_2O_5, K_2O and N. Half of urea and full dose of TSP and half of MP were applied during final land preparation. The rest of Urea and MP were applied after 30 after days of sowing (BARI, 1997). The following doses of manures and fertilizers were applied to the experimental plot.

Manure/ Fertilizer	Dose/ha
Cowdung	10 ton
Urea	150 kg
TSP	160 kg
MP	160 kg

3.8 Planting materials

The experiment was conducted with the seeds of Bush bean variety BARI Jhar sheem-1 collected from Regional Agricultural Research Station (RARS), Hathazari, Chittagong, and BARI Jhar sheem-1 released from BARI in 1996. The plant character is erect and comparatively less sensitive to disease. The pods are of fewer fibers, light green in color.

3.9 Seed sowing

Seeds were subjected to germination test and were treated with vitavax -200@ 5 g/ kg seeds for an hour before sowing. Two seeds were sown per hill at a depth of 5 cm on 23 November in rows with following spacing of 30 cm × 25 cm, 30 cm× 20 cm, 30 cm × 15 cm, 30 cm × 10 cm. The seeds were covered with loose soil.

3.10 Intercultural operation

3.10.1 Gap filling

The seedlings were transplanted to fill up the gap. Seedlings about 15 cm in height were transplanted during evening and watering were done to protect the seedlings from wilting.

3.10.2 Thinning out

One seedling was kept in each hill and remaining was uprooted after 15 days of emergence.

3.10.3 Weeding and mulching

Weeding and mulching were done as when necessary during the crop growing season in order to ensure good establishment and proper plant growth. The crop was infested by Fusarium wilt at early stage of growth and controlled by applying Ridomil @ 2.58 g per liter at the base of the plant. Fungicide and insecticide were applied as and when necessary.

3.10.4 Irrigation

Irrigation was done whenever necessary. Watering was done frequently to bring the soil moisture control to the field capacity. Besides this, irrigation was given four times at an interval of 10 days depending on soil moisture content.

3.10.5 Plant protection

At the early stage of growth, some plants were attacked by insect pests (mainly aphids) and Malathion was sprayed to control them. Hairy caterpillar attacked the young plants. The infested leaves were removed and destroyed. Some plants were attacked by bean common mosaic virus (BCMV). The plants are removed from the plots and destroyed.

3.11 Harvesting

Harvesting with mature pods was started at 75 DAS (Day after Sowing) and continued up to 90 DAS (Days after Sowing) with an interval of 05 days. Harvesting was done usually by hand picking.

3.12 Data collection

The data pertaining to the following characters were recorded from ten plants randomly selected from each plot which was recorded plot wise.

3.12.1 Plant height

Plant height was measured from the base to the tip of the largest leaf of the plants at 75 DAS and continued up to 90 DAS with an interval of 05 days. A meter scale was used to measure plant height of the plant and expressed in centimeter (cm).

3.12.2 Number of leaves per plant

Number of leaves was recorded from 10 randomly selected plants at the time of 75 DAS, 80 DAS, 85 DAS and 90 DAS harvesting time from each plot and means were calculated.

3.12.3 Leaf length

Leaf length were measured by using measuring scale from 10 randomly selected plants of each unit plot at 75 DAS, 80 DAS, 85 DAS and 90 DAS and means were calculated.

3.12.4 Leaf breadth

Leaf breadth were measured by using measuring scale from 10 randomly selected plants of each unit plot at 75 DAS, 80 DAS, 85 DAS and 90 DAS and means were calculated.

3.12.5 Number of branches per plant

Only the primary branches in a plant were counted. Ten plants were randomly selected and counted the primary branches. The average of the branch number of ten plants gave the number of branch per plant.

3.12.6 Number of pods per plant

Total number of pods from 10 randomly selected plants from each unit plot was counted and then average value was calculated.

3.12.7 Pod length

Ten randomly harvested green pods from each unit plot was measured and mean was calculated.

3.12.8 Number of seeds /pod

Total number of seeds from 10 randomly selected pods from each unit plot was counted and means value was calculated.

3.12.9 Pod yield per plant

Fresh green pods of 10 randomly selected plants from each plot were weighed and their mean value was calculated.

3.12.10 Pod yield

Fresh pods at edible stage were harvested at regular interval from each unit plot and their weight was recorded. As harvesting was done at different interval and the total pod weights were recorded in each unit plot and expressed in kilogram (Kg). The green pod yields per plot were finally converted to yield per hectare and were expressed in tons.

3.12.11 Seed weight

Thousand dry seeds are taken from ten randomly selected plants of each unit plot. Then it was measured by electrical balance and expressed in gram (g).

3.12.12 Seed yield

The average seed yield per plant was first converted into seed yield per plot and then it was converted into seed yield per hectare and expressed in ton.

3.12.13 Moisture content

Moisture content was determined by using high constant temperature oven method following International Rules for Seed Testing (Anonymous, 1999). Four to five gram seeds from each container were taken in each replication. After grinding the seeds in grinding mill the weighed ground materials (the seeds) were poured in a small container with cover and kept in an oven maintained at a temperature of 130 - 133^{O}C for a period of 12 hours. The moisture content of seeds (wet basis) was determined by the following formula.

$$\text{Moisture content (\%)} = \frac{M_2 - M_1}{M_2 - M_3} \times 100$$

Where,

M_1= weight of the container in grams;

M_2= weight of seeds before drying in grams in the container;

M_3= weight of seeds after drying in grams in the container.

3.12.14 Germination test

Germination test was carried out in petridis at room temperature without any pretreatment of seeds. Sand was used as germination media. Adequate moisture level was maintained in the germination media. For this purpose, 400 seeds were randomly taken from the working sample from each storage container. The seeds were placed in 4 petridis, 100 seed in each replication. Data on germination, abnormal seedling, diseased seed, and fresh seeds were collected regularly up to final count (ISTA, 1993).

3.12.15 Vigor index

Seedling vigor index (SVI) was calculated according to Abdul-Baki and Anderson (1973) by using the following formula:

SVI = Seedling dry weight × Germination percentage

3.12.16 Seedling dry weight

For determining seedling dry weight, ten seedlings from each unit plot of fresh French bean were dried at 110^0 c for 17 hours and weighted in grams (g).

3.13 Statistical analysis

The recorded data on different parameters were statistically analyzed using MSTAT computer programmer. The analyses of variances for the characters under study were performed by F variance test. The differences between the pairs of treatment means were compared using the Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to investigate the effect of plant spacing and harvesting time on the seed yield and quality of French bean. The analyses of variances for different characters have been presented in appendices III to VI. Data on different parameters were analyzed statistically and the results have been presented in Tables 1 to 10. The results of the presented study have been presented and discussed in this chapter under the following headings.

4.1 Effect of plant spacing and harvesting time on different seed yield and quality of French bean

4.1.1 Plant height

Plant height showed significant differences due to the effect of spacing in French bean plant (Appendix III). However the longest plant (43.38 cm) was found from S_1 (30 × 10 cm) which was statistically similar (41.92 cm) to S_2 (30 × 15 cm) and the shortest plant (36.33 cm) was performed by S_4 (30 × 25 cm) (Table 1). The plant became more longer because of the highest plant population in the plot as well as the effect of closer spacing. Kenjale *et al*. (1995) stated that taller plant was found in higher density compare to lower density. The present finding also agreed to the results in their study. Kumar and Singh (1993) also found similar trends of the results in their trail.

4.1.2 Number of branches per plant

There was no significant variation on number of branches per plant due to the effect of different plant spacing (Appendix III). However, the maximum number of branches (7.01) was obtained from the broadest spacing S_4 (30 × 25 cm) whereas the closest spacing S_1 (30 × 10 cm) gave the minimum number of branches (5.00) (Table 1). Due to the broadest spacing of the plant occupied to chance for more spreading and produced the more branches. Dwivedi *et al*. (1994) showed that wider spacing produced significantly higher number of branches per plant which is support to the present study.

4.1.3 Number of leaves per plant

The number of leaves per plant significantly influenced by the different plant spacing in the present study (Appendix III). The highest number of leaves per plant (49.09) was counted from S_4 (30 × 25 cm) which was statistically identical (48.02) to S_3 (30 × 20 cm) and the lowest number of leaves per plant (43.07) was performed by S_1 (30 × 10 cm) (Table 1). Wider spacing S_4 (30 × 25 cm) took more space for producing abundant branches with more leaves. On the other hand, minimum population got chance to uptake optimum nutrients, moisture and more space as a result the plant produced the maximum number of leaves. The present findings also agreed to the results of Srimivas and Naik (1990).

4.1.4 Leaf length per plant

Significant variation was observed on leaf length per plant due to the effect of different plant spacing (Appendix III). The longest leaf (10.12 cm) was obtained from S_4 (30 × 25 cm) treatment which was statistically similar (10.05 cm and 9.75 cm) to S_3 (30 × 20 cm) and S_2 (30 × 15 cm), respectively. The shortest leaf length (9.42 cm) was recorded from S_1 (30 × 10 cm) (Table 1). The widest spacing got maximum opportunity to uptake more nutrient compare to other closer spaced plant population which enhanced to produce the maximum leaves in the plant. Dwidevi *et al.* (1994) reported that wider spacing of the plant produced the longest leaf which was positive co-relation to the number of branches.

4.1.5 Leaf breath per plant

Different plant spacing showed significant variation on leaf breadth per plant (Appendix III). The maximum leaf breadth (6.98 cm) was observed in S_4 (30 × 25) which was similar (6.70 cm) to S_3 (30 × 20 cm) and the closest spacing S_1 (30 × 10 cm) gave the minimum leaf breadth (6.58 cm) (Table 1). Wider spacing produced the minimum breadth of leaves in the plant which encouraged broadness to the leaves due to sufficient air, light and availability of other favorable conditions. The results of present study also agreed to the findings of Rahuri (1989).

Table 1. Main effects of plant spacing on different yield attribute and yield of French bean

Treatment	Plant height(cm)	Number of branches/plant	Number of leaves / plant	Leaf length (cm)	Leaf breath (cm)
S_1	43.38 a	5.00	43.07 c	9.42 b	6.58 b
S_2	41.92 a	5.03	46.05 b	9.75 ab	6.62 b
S_3	38.12 b	6.12	48.02 ab	10.05 a	6.70 ab
S_4	36.33 b	7.01	49.09 a	10.12 a	6.98 a
$LSD_{(0.05)}$	3.41	2.84	3.302	0.503	0.18
CV (%)	9.36	8.48	7.97	10.21	8.23

In a column, values with same letter(s) do not differ significantly at 5% level of probability

Where,

S_1 = 30 x 10 cm, S_2 = 30 x 15 cm, S_3 = 30 x 20 cm, and S_4 = 30 x 25 cm

4.1.6 Pod length

Pod length significantly influenced by different plant spacing (Appendix IV). The longest pod (14.39 cm) was observed in S_1 (30 × 10 cm) plant spacing which was statistically similar to S_2 (14.03 cm) and S_3 (13.58 cm) while the shortest pod (13.38 cm) was obtained from the wider spacing S_4 (30 × 25 cm) (Table 2). Increasing the length of pod related with the age up to the limit. Yield was highly correlated with the pod length. Ozen and Ozdemir (1996) stated that length of pod is closely related to the plant densities. Arf *et al*. (1996) reported that decreasing plant spacing up to a certain limit increasing the pod length. The present trail also gave the longest pod at closer spacings.

There was no significant variation on pod length due to the effect of different harvesting time in French bean (Appendix IV). However, the longest pod (13.87 cm) was obtained from H_1 (75 DAS) and the shortest pod (13.06 cm) was noted from H_4 (90 DAS) (Table 3).

Combined effect of plant spacing and harvesting time on pod length was statistically significant (Appendix IV). The longest pod length (14.13 cm) was found from the treatment combination of plant spacing S_1 (30 × 10 cm) with harvesting time H_1 (75 DAS) and the shortest pod length (11.95 cm) was found from the treatment combination of plant spacing S_3 (30 × 20 cm) with harvesting time H_2 (80 DAS) (Table 4).

4.1.7 Number of seeds per pod

There was no significant variation on number of seeds per pod due to the effect of different plant spacing in French bean (Appendix IV). The maximum number of seeds per pod (5.13) was counted from S_1 (30 × 10 cm) whereas the minimum number of seeds per pod (5.00) was obtained from S_4 (30 × 25 cm) (Table 2). Ozen and Ozdemir (1996) reported that closer density with higher population ensured the maximum number of seeds per pod. Their findings also agreed to the present study.

The number of seeds per pod did not significantly differ due to the effect of different harvesting time (Appendix IV). The maximum number of seeds per pod (5.10) was found from H_1 (75 DAS) and the minimum number of seed per pod (4.97) was counted from H_4 (90 DAS) (Table 3).

Combined effect of plant spacing and harvesting time did not show the significant variation on number of seeds per plant (Appendix IV). However, the maximum number of seeds per pod (5.60) was found from the treatment combination of plant spacing S_1 (30 × 10 cm) with harvesting time H_1 (75 DAS) and the lowest number of seeds per pod (4.82) was found from the treatment combination of plant spacing S_4 (30×25 cm) with harvesting time H_4 (90 DAS) (Table 4).

4.1.8 Pod yield per plant

Significant variation was found on pod yield per plant due to the effect of different plant spacing (Appendix IV). The highest weight of fresh pod was found (86.85 g) from S_1 (30 × 10 cm) plant spacing and the lowest fresh weight of pod per plant was found (82.99 g) in S_4 (30 × 25 cm) plant spacing. S_1 (30 × 10 cm) treatment might be provided favorable space for better vegetative growth of plant which led to the formation of higher photosynthesis which ultimately resulted in higher weight of fresh pod per plant (Table 2). Singh and Behera (1998) reported that at closer plant spacing performed the maximum green pod yield. The present study also supported by their findings.

The weight of pod yield per plant significantly varied due to the effect of different harvesting time in French bean (Appendix IV). The maximum weight of pod per plant (85.75 g) was recorded from H_1 (75 DAS) harvesting time whereas the minimum weight of pod per plant (81.89 g) was obtained from H_4 (90 DAS) harvesting time (Table 3). Harvesting at 75 DAS, the pod of plant became more green and succulent as a result the fresh weight of pod per plant was increased compare to other late harvesting.

Combined effect of plant spacing and harvesting time on pod yield per plant showed statistically significant (Appendix IV). The maximum pod yield per plant (108.59 g) was found from the treatment combination of plant spacing S_1 (30 × 10 cm) with harvesting time H_1 (75 DAS) and the lowest pod yield per plant (64.33 g) was found from the treatment combination of plant spacing S_4 (30 × 25 cm) with harvesting time H_4 (90 DAS) (Table 4).

Table 2. Main effects of plant spacing on different yield attribute and yield of French bean

Treatment	**Pod length (cm)**	**Number of seeds / pod**	**Pod yield/plant (gm)**
S_1	14.39 a	5.13 a	86.85 a

S_2	14.03 ab	5.09 a	84.93 b
S_3	13.58 ab	5.05 a	83.58 bc
S_4	13.38 b	5.00 a	82.99 c
$LSD_{(0.05)}$	0.962	0.729	1.322
CV (%)	10.16	8.97	8.81

In a column, values with same letter (s) do not differ significantly at 5% level of probability

Where,

S_1 = 30 x 10 cm, S_2 = 30 x 15 cm, S_3 = 30 x 20 cm, and S_4 = 30 x 25 cm

Table 3. Main effects of harvesting time on different yield attributes and yield of French bean

Treatment	Pod length (cm)	Number of seeds / pod	Pod yield/plant (g)
H_1	13.87	5.10	85.75 a
H_2	13.72	5.06	83.83 b
H_3	13.62	5.04	82.48 bc
H_4	13.06	4.97	81.89 c
$LSD_{(0.05)}$	1.063	0.801	1.613
CV (%)	10.16	8.97	8.81

In a column, values with same letter (s) do not differ significantly at 5% level of probability

Where, H_1 = 75 DAS, H_2 = 80 DAS, H_3 = 85 DAS and H_4 = 90 DAS

Table 4. Combined effects of plant spacing and harvesting time on different yield attributes and yield of French bean

Treatment	Pod length (cm)	Number of seeds / pod	Pod yield/plant (g)
S_1H_1	14.13 a	5.60	108.59 a
S_1H_2	13.35 ab	5.57	90.28 c
S_1H_3	13.11 ab	5.45	79.42 d
S_1H_4	12.71 ab	5.41	68.99 e

S_2H_1	13.31 ab	5.56	100.36 b
S_2H_2	12.82 ab	5.46	88.45 c
S_2H_3	12.85 ab	5.38	78.21 d
S_2H_4	12.80 ab	5.35	67.25 ef
S_3H_1	13.21 ab	5.53	101.03 b
S_3H_2	11.95 b	5.36	91.35 c
S_3H_3	12.33 b	5.30	79.35 d
S_3H_4	12.35 b	5.25	68.11 e
S_4H_1	13.26 ab	5.48	99.25 b
S_4H_2	12.15 b	5.32	90.09 c
S_4H_3	12.69 b	5.25	78.31 d
S_4H_4	12.13 b	4.82	64.33 f
$LSD_{(0.05)}$	1.705	2.263	3.158
CV (%)	10.16	8.97	8.81

In a column, values with same letter (s) do not differ significantly at 5% level of probability

Where, S_1 = 30 x 10 cm, S_2 = 30 x 15 cm, S_3 = 30 x 20 cm and S_4 = 30 x 25 cm

H_1 = 75 DAS, H_2 = 80 DAS, H_3 = 85 DAS and H_4 = 90 DAS

4.1.9 Seed weight

Thousand seed weight had significantly influenced on different plant spacing in French bean (Appendix V). The maximum 1000 seed weight (146.10 g) was found in plant spacing S_1 (30 × 10 cm) and the minimum 1000 seed weight (132.60 g) was found in spacing of S_4 (30 × 25 cm) (Table 5). Due to closer spacing the plant produced the longest pod which gave the maximum number and large sized seed, as a result possibly seed weight was increased.

Thousand seed weight had also significant variation on different harvesting time in French bean (Appendix V). The maximum 1000 seed weight (159.40 g) was found in harvesting time of H_1 (75 DAS) and the minimum 1000 seed weight (119.50 g) was found in H_4 (90 DAS) (Table 6). At 75 DAS, grown plant bears more fresh pod and maximum turgid condition possibly that's why the seed in pods became more weightable compare to late harvesting.

Thousand seed weight was significantly influenced by the combined effect of different plant spacing and harvesting time (Appendix V). The maximum 1000 seed weight (165.57g) was observed in the treatment combination of S_1H_1 (30 × 10 cm spacing with 75 DAS and the minimum (114.90 g) weight was found the treatment combination of S_4H_4 (Table 7).

4.1.10 Pod yield

Significant variation was observed due to different plant spacing in respect of fresh pod yield per hectare (Appendix V). The highest fresh pod yield (18.12 t/ha) was observed from S_1 (30 × 10 cm) plant spacing which was similar to S_2 (30 × 15 cm) and S_3 (30 × 20 cm) plant spacing (18.09 t/ha and 18.01 t/ha) respectively. On the other hand, the lowest fresh pod yield (17.36 t/ha) was found in S_4 (30 ×25 cm) plant spacing. The results of the present experiment agreed with the findings of Anonymous, (1995) (Table 5). Due to the closer spacing, the plant population was higher rather than other spacing in the plot and develop higher number of pods compare to other spacing treatment. As a result performed the maximum yield in closer spacing plots which ultimately increased total yield. Singh *et al*. (1996) showed that closer spacing at 30 × 10 cm performed the highest yield which agreed to the present study.

Significant variation was observed among the different harvesting time in respect of fresh pod yield per hectare (Appendix V). The highest yield (23.91 t/ha) was exhibited by H_1 (75 DAS) treatment and the lowest yield (13.18 t/ha) was obtained from H_4 (90 DAS) (Table 6).

Combined effect of plant spacing and harvesting time on pod yield (t/ha) was found statistically significant. The maximum pod yield (24.73 t/ha) was found from the treatment combination of plant spacing S_1H_1 and the lowest pod yield (12.23 t/ha) was found from the treatment combination of plant spacing S_4 (30 × 25 cm) with harvesting time H_4 (90 DAS) (Table 7).

4.1.11 Seed yield

Significant variation was observed among the different plant spacing in respect of seed yield (t/ha) (Appendix V). The highest seed yield (2.96 t/ha) was obtained from S_1 (30 × 10 cm) plant spacing and the lowest seed yield (t/ha) (2.31 t/ha) were recorded from S_4 (30 × 25 cm) at wider spacing (Table 5). The highest seed yield was obtained from S_1 (30 × 10 cm) plant spacing probably due to the better vegetative growth of plants which ultimately led to the better flowering, fruit set and ultimately increase seed yield.

Harvesting time had significantly influenced on seed yield of French bean (Appendix V). Significant variation was observed among the harvesting time. The highest seed yield (3.12 t/ha) was found in H_1 (75 DAS) harvesting time and the lowest seed yield (1.92 t/ha) was found in H_4 (90 DAS) harvesting time. (Table 6). Due to late harvest at (90 DAS), the plant was going to be a senescence stage which reduced the weight of seed and yield was lower.

Combined effect of plant spacing and harvesting time on seed yield was statistically significant (Appendix V). The maximum seed yield (3.04 t/ha) was found from the treatment combination of plant spacing S_1 (30 × 10 cm) with harvesting time H_1 (75 DAS) and the lowest seed yield (1.90 t/ha) was found from the treatment combination of plant spacing S_4 (30 × 25 cm) with harvesting time H_4 (90 DAS) (Table 7).

Table 5. Main effects of plant spacing on different yield attribute and yield of French bean

Treatment	1000 seed weight (g)	Pod yield (t/ha)	Seed yield (t/ha)
S_1	146.10 a	18.12 a	2.96 a
S_2	142.50 ab	18.09 ab	2.35 b
S_3	134.10 b	18.01 ab	2.33 b
S_4	132.60 b	17.36 b	2.31 b
$LSD_{(0.05)}$	1.081	0.761	0.396
CV (%)	10.24	9.67	7.02

In a column, values with same letter (s) do not differ significantly at 5% level of probability

Where, S_1 = 30 x 10 cm, S_2 = 30 x 15 cm, S_3 = 30 x 20 cm, and S_4 = 30 x 25 cm

Table 6. Main effects of harvesting time on different yield attributes and yield of French bean

Treatment	1000 seed weight (g)	Pod yield (t/ha)	Seed yield (t/ha)
H_1	159.4o a	23.91 a	3.12 a
H_2	141.20 b	19.41 b	2.41 b
H_3	135.30 b	15.38 c	2.08 c
H_4	119.50 c	13.18 d	1.92 d
$LSD_{(0.05)}$	6.076	0.665	0.398
CV (%)	10.24	9.67	7.02

In a column, values with same letter (s) do not differ significantly at 5% level of probability,

Where,H_1 = 75 DAS, H_2 = 80 DAS, H_3 = 85 DAS and H_4 = 90 DAS

Table 7. Combined effects of plant spacing and harvesting time on different yield attributes and yield of French bean

Treatment	1000 seed weight	Pod yield (t/ha)	Seed yield (t/ha)
S_1H_1	165.57 a	24.73 a	3.04 a
S_1H_2	160.90 b	19.95 c	2.98 ab
S_1H_3	134.10 f	15.05 de	2.97 ab

S_1H_4	120.30 i	14.21 ef	2.91 b
S_2H_1	156.50 c	24.49 ab	2.52 c
S_2H_2	154.50 c	18.55 c	2.38 d
S_2H_3	151.70 d	15.44 de	2.21 e
S_2H_4	131.60 g	13.22 fg	2.11 e
S_3H_1	154.43 c	23.20 b	2.40 d
S_3H_2	144.51 c	19.74 c	2.34 d
S_3H_3	131.60 g	15.77 d	2.06 e
S_3H_4	134.20 f	13.00 fg	2.04 e
S_4H_1	130.40 g	23.21 b	1.94 f
S_4H_2	124.90 h	19.41 c	1.93 f
S_4H_3	122.60 hi	15.25 de	1.92 f
S_4H_4	114.90 j	12.23 g	1.90 f
$LSD_{(0.05)}$	2.32	1.468	0.797
CV (%)	10.24	9.67	7.02

In a column, values with same letter (s) do not differ significantly at 5% level of probability

Where,

S_1 = 30 x 10 cm, S_2 = 30 x 15 cm, S_3 = 30 x 20 cm and S_4 = 30 x 25 cm

H_1 = 75 DAS, H_2 = 80 DAS, H_3 = 85 DAS and H_4 = 90 DAS

4.1.12 Germination percentage

Seed germination percentage significantly varied due to the effect of spacing (Appendix VI). The highest seed germination percentage (87.01%) was observed in plant spacing S_1 (30 × 10 cm) which was statistically similar to (86.68% and 85.02%) the plant spacing S_2 (30 × 15 cm) and S_3 (30 × 20 cm), respectively. The lowest seed germination (82.03%) percentage was noted from plant spacing of S_4 (Table 8). EI-Habbasha *et al*. (1996) reported that at closer spacing grown plant contain higher carbohydrate which enhance to germination at higher percentage. The results also supported to above study.

There was a significant variation on germination percentage due to the effect of different harvesting time in French bean (Appendix VI). The highest seed germination (94.10%) percentage was recorded from the harvesting time of H_1 (75 DAS) which was followed by H_2 (80 DAS) harvesting time. The lowest seed germination (75.49%) percentage was found in the harvesting time of H_4 (90 DAS) (Table 9).

Seed germination percentage varied significantly due to the combined effect of plant spacing and harvesting time (Appendix VI). The highest seed germination (96.05%) percentage was observed in treatment combination of (S_1H_1). The lowest seed germination (73.33%) percentage was observed in treatment combination of (S_4H_4) (Table 10).

4.1.13 Seedling dry weight

Significant variation was found on seedling dry weight due to the effect of different plant spacing (Appendix VI). The maximum dry weight of seedling (0.154 g) was obtained from S_1 (30 × 10 cm) and the minimum (0.124 g) was found from S_4 (30 × 25 cm) plant spacing (Table 8). Rahman (2000) reported that the maximum dry matter was recorded at closer spacing. Roy and Biswas (1991) stated that dry matter production increases with the increasing plant population. The present results also agreed to their findings.

Due to the effect of different harvesting time, significant variation was found on seedling dry weight in French bean. (Appendix VI). The highest seedling dry weight (0.145 g) was observed in H_1 (75 DAS) which was statistically similar to (0.135 g and 0.123 g) H_2 (80 DAS) and H_3 (85 DAS) respectively. The lowest seedling dry weight (0.110 g) was found in H_4 (90 DAS) (Table 9).

Combined effect of different plant spacing and harvesting time showed significant variation on seedling dry weight (Appendix VI). The highest seedling dry weight (0.152 g) was found from the treatment combination of S_1H_1 while The lowest seedling dry weight (0.84 g) was noted in treatment combination of S_4H_4 (Table 10).

4.1.14 Vigor index

There was no significant variation observed in vigor index of French bean seed harvested from different plant spacing (Appendix VI). However, the maximum vigor index (58.60) was obtained from S_1 (30 × 10 cm) and the minimum (52.70) was found from S_4 (30 × 25 cm) (Table 8).

Vigor index had significant difference due to the effect of harvesting time in French bean (Appendix VI).The highest vigor index (60.50) was found in H_1 (75 DAS) which was statistically similar to H_2 (80 DAS) and H_3 (85 DAS). The lowest vigor index (44.31) was recorded from H_4 (90 DAS) (Table 9).

Due to the combined effect of different plant spacing and harvesting time varied significantly on vigor index (Appendix VI).The highest vigor index (68.48) was found in treatment combination of S_1H_1 and the lowest vigor index (40.88) was noted in treatment combination of S_4H_4 (Table 10).

Table 8. Effect of plant spacing on seed quality parameters of French bean

Treatment	Germination (%)	Seedling dry weight (g)	Vigor index
S_1	87.01 a	0.154 a	58.60
S_2	86.68 a	0.137 b	55.19
S_3	85.02 a	0.125 bc	53.59
S_4	82.03 b	0.124 c	52.70
$LSD_{(0.05)}$	2.777	0.113	7.85
CV (%)	9.90	8.84	10.19

In a column, values with same letter(s) do not differ significantly at 5% level of probability

Where, S_1 = 30 x 10 cm, S_2 = 30 x 15 cm, S_3 = 30 x 20 cm and S_4 = 30 x 25 cm

Table 9. Effect of harvesting time on seed quality parameters of French bean

Treatment	Germination (%)	Seedling dry weight (g)	Vigor index
H_1	94.10 a	0.145 a	60.50 a
H_2	87.43 b	0.135 a	55.87 a
H_3	81.47 c	0.123 ab	53.78 a
H_4	75.49 d	0.110 b	44.31 b
$LSD_{(0.05)}$	3.790	0.209	7.820
CV (%)	9.90	8.87	10.19

In a column, values with same letter (s) do not differ significantly at 5% level of probability

Where, H_1 = 75 DAS, H_2 = 80 DAS, H_3 = 85 DAS and H_4 = 90 DAS

Table 10. Combined effect of plant spacing and harvesting time on seed quality parameters of French bean

Treatment	Germination (%)	Seedling dry weight (g)	Vigor index
S_1H_1	96.05 a	0.152 a	68.48 a
S_1H_2	89.38 bc	0.147 ab	63.81 ab
S_1H_3	84.05 cd	0.132 abc	60.74 abc
S_1H_4	76.05 ef	0.130 abc	48.84 bcd
S_2H_1	92.05 ab	0.127 abc	57.27 abcd
S_2H_2	88.05 bc	0.126 abc	56.41 abcd
S_2H_3	81.38 de	0.124 abcd	59.21 abc
S_2H_4	76.05 ef	0.113 abcd	53.74 abcd
S_3H_1	92.05 ab	0.129 abc	54.73 abcd
S_3H_2	84.05 cd	0.117 abcd	52.55 abcd
S_3H_3	76.07 ef	0.115 abcd	50.55 bcd

S_3H_4	76.02 f	0.107 bcd	49.70 bcd
S_4H_1	95.32 a	0.116 abcd	56.11 abcd
S_4H_2	88.05 bc	0.105 cd	45.85 cd
S_4H_3	84.06 cd	0.103 cd	41.43 de
S_4H_4	73.33 f	0.84 d	40.88 d
$LSD_{(0.05)}$	5.662	0.416	16.683
CV (%)	9.90	8.87	10.19

In a column, values with same letter (s) do not differ significantly at 5% level of probability

Where,

S_1 = 30 x 10 cm, S_2 = 30 x 15 cm, S_3 = 30 x 20 cm S_4 = 30 x 25 cm

H_1 = 75 DAS, H_2 = 80 DAS, H_3 = 85 DAS and H_4 = 90 DAS

CHAPTER V

SUMMARY AND CONCLUSION

A Field experiment was conducted at the Seed Technology Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur during the period from October 2013 to May 2014 to find out optimum plant spacing, optimum harvesting time on the seed yield and quality of French bean. The experiment was involved two factors such as (i) four plant spacing viz. S_1 (30 cm × 10 cm), S_2 (30 cm × 15 cm), S_3 (30 cm × 20 cm) and S_4 (30 cm × 25 cm), and (ii) four harvesting time, viz. H_1 (75 DA), H_2 (80 DAS), H_3 (85 DAS) and H_4 (90 DAS). The experiment consisting of 16 treatment combinations was laid out in Randomized Complete Block Design (RCBD) with three replications. The size of each unit plot was 5m × 1.5m. The seeds of French bean were sown in each plot on 23 November, 2013. The plants were randomly selected from each plot to record data on the growth and yield contributing characters of plants. The collected data were statistically analyzed and the differences among the means were evaluated by Duncan's Multiple Range Test (DMRT). The results of this experiment have been summarized as follows:

From the results of the experiment it was found that the main effect of plant spacing had significant effect on the pod length, pod yield per plant, pod yield (t/ha) and seed yield (t/ha). The highest weight of fresh pod yield per plant was found (86.85 g) from S_1 (30 × 10 cm) plant spacing. The highest fresh pod yield (18.12 t/ha) was observed from S_1 (30 × 10 cm) plant spacing. The highest seed yield (2.96 t/ha) was found in S_1 (30 × 10 cm) plant spacing.

Statistical analysis showed that the effect of harvesting time had significant on the 1000 seed weight, pod yield per plant, pod yield (t/ha) and seed yield (t/ha). The maximum weight of pod yield per plant (85.75) was recorded from H_1 (75 DAS). The highest fresh pod yield (23.91 t/ha) was observed in H_1 (75 DAS) harvesting time. The highest seed yield (3.12 t/ha) was found in H_1 (75 DAS) harvesting time.

Combined effect of plant spacing and harvesting time showed significant variation, pod length, number of seeds per pod, 1000 seed weight, pod yield per plant, pod yield (t/ha) and seed yield (t/ha). The maximum pod yield (24.73 t/ha) was found from the treatment combination of plant spacing S_1 (30 ×10 cm) with harvesting time H_1 (75 DAS). The highest seed yield (3.04 t/ha) was found from the treatment combination of plant spacing S_1 (30 × 10 cm) with harvesting time H_1 (75 DAS).

It was found that the main effect of plant spacing had significant effect on the seed quality. The highest seed germination (87.01%) percentage was observed in plant spacing S_1 (30 × 10 cm). The lowest seed germination (82.03%) percentage was noted from plant spacing S_4 (30 × 25 cm). The maximum dry weight of seedling (0.154 g) and vigor index (58.60) was found from S_1 (30 × 10 cm). The highest seed germination (94.10%) percentage was recorded from the harvesting time of H_1 (75 DAS). The lowest seed germination (75.49%) percentage was found in the harvesting of H_4 (90 DAS). The maximum dry weight of seedling (0.145 g) and vigor index (60.50) was observed in H_1 (75 DAS). Seed germination percentage, seedling dry weight and vigor index significantly varied due to the effect of the different treatment combination. The highest seed germination (96.05%) percentage was observed in treatment combination of S_1 (30 × 10 cm) and H_1 (75 DAS). The lowest seed germination (73.33%) was observed in treatment combination of S_4 (30 × 25 cm) and H_4 (90 DAS). The maximum dry weight of seedling (0.152 g) and vigor index (68.48) was obtained from the treatment combination of S_1H_1.

Conclusions:

The following conclusion may be drawn from the results of the present study:

- The seed yield and quality parameters of French bean were positively influenced by plant spacing and harvesting time.

- Use of 30 ×10 cm plant spacing and pod harvested at 75 DAS gave the highest yield and also showed the best performance in case of germination and other seed quality parameters.

- The possibility of successful production of French bean using different plant spacings and harvesting times may be investigated further at different locations of Bangladesh.

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APPENDICES

Appendix I. Monthly mean temperature , rainfall and relative humidily during the crop period.

Year	Month	Temperature (^{o}C)		Relative Humidity (%)	Rainfall (mm)
		Maximum	Minimum		
2013	November	27.90	20.75	81.50	00.00
	December	32.60	25.79	59.05	00.00
2014	January	32.50	25.60	90.17	00.00
	February	32.27	25.67	84.60	00.00

Source: Bangladesh Agricultural Research Institute, (BARI), Gazipur

Appendix II. Analytical data of initial soil of the STD experimental field at BARI, (Gazipur)

Component	Amount	Critical level
P^{H}	6.67	-
OM (%)	1.08	-
Ca (meq $100g^{-1}$)	10.2	2.0
Mg (meq $100g^{-1}$)	1.48	0.8
K (meq $100g^{-1}$)	0.65	0.02
Total N (%)	0.03	-
P (µg g^{-1})	21	14
S (µg g^{-1})	12	14
B (µg g^{-1})	0.50	0.20
Mn (µg g^{-1})	19	5.0
Zn (µg g^{-1})	0.58	0.6

Source: Soil Science Division, Bangladesh Agricultural Research Institute, (BARI), Gazipur

Appendix Ill. Analysis of variance of plant height, number of branches per plant, number of leaves per plant, leaf length and leaf breath as influenced by plant spacing.

Source of variation	Degrees of freedom	Mean square				
		Plant height at harvest	Number of branches per plant	Number of leaves/ plant	Leaf length	Leaf breath
Replication	2	123.23	0.5833	62.4	0.717	0.1021
Plant Spacing (A)	3	20.25*	0.354^{NS}	86.2*	1.256*	0.354*
Error	30	1.262	2.261	5.520	1.172	1.639

*: Significant at 0.05 level of probability

NS: non significant

Appendix IV. Analysis of variance of pod length, number of seeds per pod, pod yield per plant as influenced by plant spacing and harvesting time.

Source of variation	Degrees of freedom	Mean square		
		Pod length	Number of seeds/pod	pod yield per plant
Replication	2	0.526	0.447	2.206
Plant Spacing(A)	3	3.778**	0.898^{NS}	27.35**
Harvesting Time(B)	3	2.349^{NS}	1.653^{NS}	100.25**
Interaction (A × B)	9	0.797	2.352^{NS}	9.212**
Error	30	1.827	1.356	4.962

*: Significant at 0.05 level of probability

* *: Significant at 0.01 level of probability

NS: no significant

Appendix V. Analysis of variance of 1000 seed weight, pod yield and seed yield as influenced by plant spacing and harvesting.

Source of variation	Degrees of freedom	Mean square		
		1000 seed weight	Pod yield (t/ha)	Seed yield(t/ha)
Replication		26.890	5.516	0.439
Plant Spacing(A)	3	8.836**	6.515**	3.338*
Harvesting Time(B)	3	14.146*	102.361**	4.674*
Interaction (A × B)	9	7.765**	2.269**	1.651**
Error	30	1.978	1.701	1.445

*: Significant at 0.05 level of probability

* *: Significant at 0.01 level of probability

NS: non significant

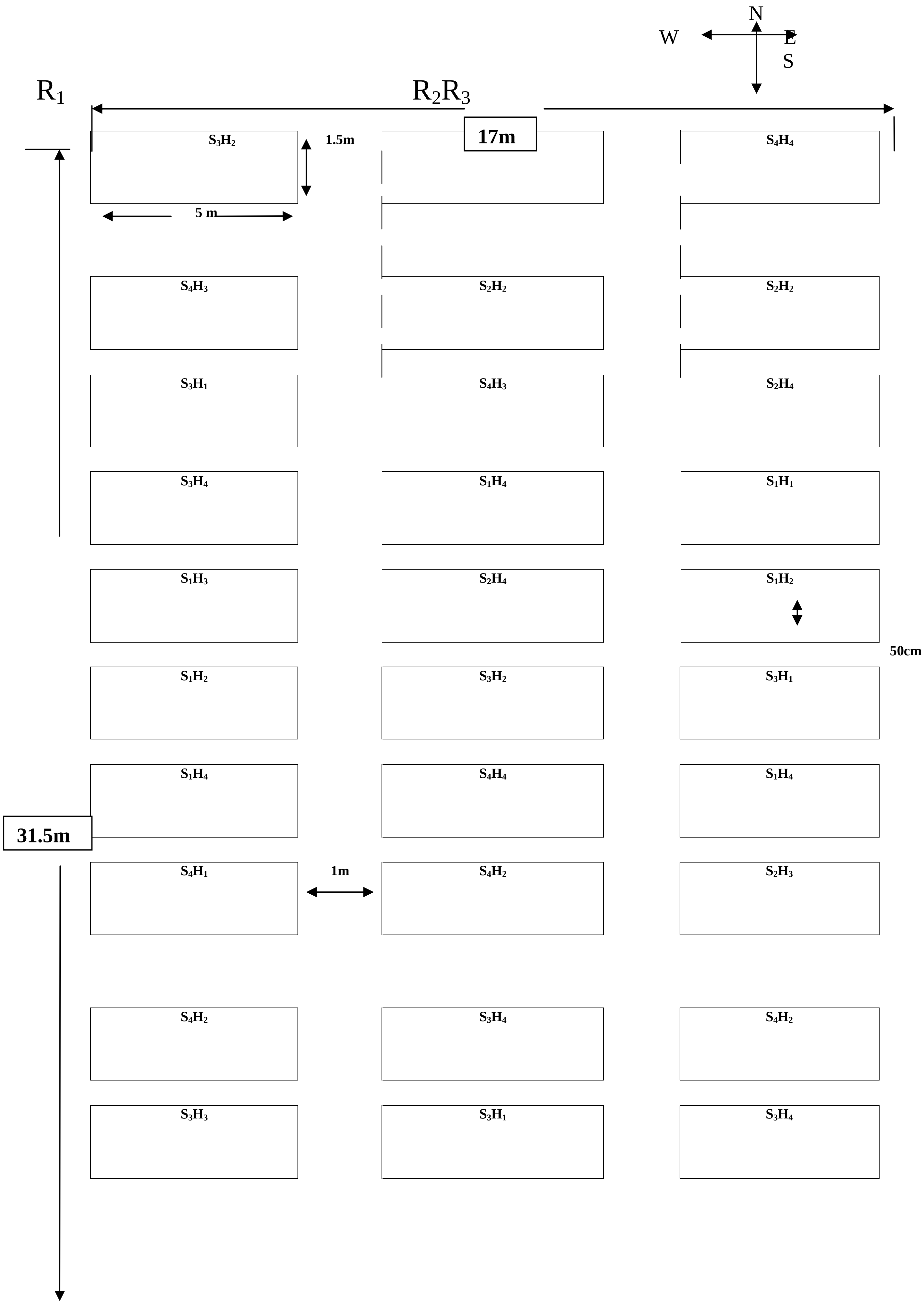
Appendix VI. Analysis of variance of germination percentage, seedling dry weight and vigor index as influenced by plant spacing and harvesting time.

Source of variation	Degrees of freedom	Mean square		
		Germination (%)	Seedling dry weight	Vigor index
Replication	2	23.306	21.214	18.264
Plant Spacing(A)	3	48.480*	18.76**	74.081^{NS}
Harvesting Time(B)	3	612.952*	56.564*	434.626*
Interaction (A × B)	9	8.643*	1.472**	63.104*
Error	30	7.777	1.854	2.489

* : Significant at 0.05 level of probability

* * : Significant at 0.01 level of probability

NS : no significant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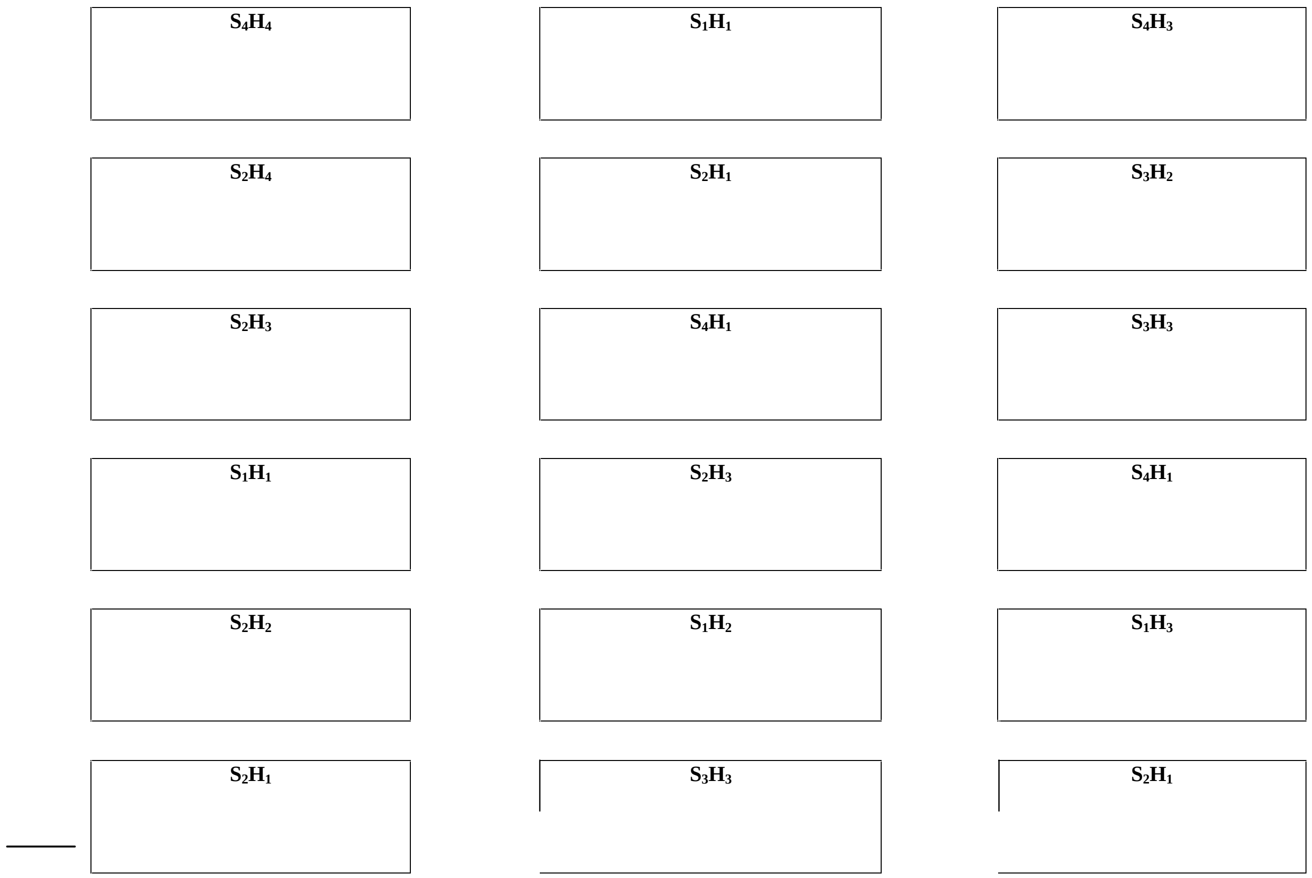

Fig. Lay out of the Experimental Field.