Improving the performance of system of rice intensification by seed priming

By

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2002-ag-1727
M.Sc. (Hons.) Agriculture

A thesis submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

AGRONOMY

Faculty of Agriculture,
University of Agriculture
Faisalabad, Pakistan
2015

DECLARATION

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DEDICATED

TO

MY PARENTS

MY TEACHERS

MY BROTHERS

&

MY SISTERS

SO MUCH OF WHAT I HAVE BECOME

IS BECAUSE OF YOU

AND I WANT TO TELL YOU

THAT I APPRECIATE YOU

THANK YOU AND LOVE YOU

ACKNOWLEDGEMENTS

I deem it utmost pleasure to avail the opportunity to express the heartiest gratitude and deep sense of devotion to my esteemed supervisor, ***Dr. Muhammad Azraf-Ul-Haq Ahmad****, Associate Professor, Department of Agronomy, University of Agriculture, Faisalabad for his incentive teaching, dynamic supervision, skillful guidance, valuable comments, scholastic and constructive suggestions throughout the course of studies, research endeavor and accomplishment of this manuscript.*

I feel scarcity of words to express my deep sense of devotion, emotions of appreciation and gratitude to ***Dr. Muhammad Farooq****, Associate Professor, Department of Agronomy, University of Agriculture, Faisalabad, for his inspiring guidance, keen interest and unstinted help during my study period and research endeavors.*

I offer my sincere thanks to ***Dr. Ghulam Murtaza****, Associate Professor, Institute of Soil and Environmental Sciences, member of supervisory committee, for his inspiring guidance and unstinted help during my study period and research endeavors.*

I feel my profound privilege to mention the help provided by my dear friends ***Naeem Fiaz****,* ***Hafeez-Ur-Rehman, M. Tauseef Sultan*** *and* ***Muhammad Amin*** *during my study period.*

I am also thankful to Higher Education Commission, Government of Pakistan, for awarding me the indigenous scholarship.

(Farhan Khalid)

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Abstract

Two field experiments to evaluate the performance of system of rice intensification (SRI) by seed priming were conducted during the 2nd week of June 2010 and 2011 at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan. Both the experiments were laid out into randomized complete block design with split split plot arrangement having three replications. The first experiment was conducted to assess the role of seed priming in evaluating the performance of rice nursery seedlings for SRI. The experiment was comprised of two rice varieties i.e. Basmati Super and Basmati Shaheen, three seedling age viz. 2, 3 and 4 weeks old and two seed priming treatments i.e. non-primed seeds (control) and primed with $CaCl_2$ (1.5 % soln.). The second experiment was conducted to evaluate the role of seed priming in improving the performance of direct seeding in SRI. Treatments was consist of two sowing systems i.e. conventional and SRI, two seeding techniques viz. direct seeding and transplanting and three seed priming treatments i.e. non-primed seeds, hydro primed seeds and primed seeds with $CaCl_2$ (1.5 % soln.). The results of first experiment showed that rice cultivars, seedling age and seed priming significantly affected the leaf area index, crop growth rate, leaf area duration and net assimilation rate during both the years. Two week old seedlings performed better than 3 and 4 weeks old seedlings especially when primed with $CaCl_2$ (1.5% soln.) by improving all the growth attributes which include tiller production, kernels per panicle, 1000 grain weight, kernel yield, straw yield and harvest index during both the years. Two weeks old seedlings whose seeds were osmoprimed with $CaCl_2$ improved the kernel length, kernel width, normal kernels, kernel protein contents and amylose contents and also improved leaf chlorophyll contents during both the years. In the second experiment rice production system, seeding technique and seed priming significantly affected the leaf area index, crop growth rate, leaf area duration and net assimilation rate during both the years. Transplanting of nursery seedlings which were osmoprimed with $CaCl_2$ under SRI significantly improved all the growth attributes which include tiller production, kernels per panicle, 1000 grain weight, kernel yield, straw yield and harvest index than that of direct seeding under both production systems as well as hydropriming and non primed seeds. Transplanting of younger seedling of two weeks old whose seeds were osmoprimed with $CaCl_2$ improved the kernel length, kernel width, normal kernels, kernel protein contents and amylose contents and also improved leaf chlorophyll contents under SRI than that of direct seeding under both conventional method and SRI during both the years.

Chapter 1

INTRODUCTION

Rice is the most important cereal crop and around 3 billion people, half of the world's population, depend on rice for survival (Khush, 2004). More than 90% of the rice in the world is grown in Asia (FAO, 2009) which accounts for 35-75% of total calorie intake (Khush, 2004). Rice ranks as second after wheat among the most staple food grain crops in Pakistan. The geographical area of Pakistan is 79.61 million hectares and its total cropped area is 22.51 million hectares. Rice sowing area is estimated as 2.31 million hectares with production of 5.54 million tonnes during the year 2012-13 in Pakistan. Rice accounts for 2.7% of the value added in agriculture and 0.6% of the gross domestic product (Govt. of Pakistan, 2013). The total quantity of rice (rice milled equivalent) exported was 3.41 million tonnes and the export value was 2.06 billion US dollars during the year 2011 (FAO, 2013).

Rice is an excellent food source as it has been found easy in digestion and has high nutritional contents. The energy needs obtained from rice accounts 80% for more than 2 billion peoples in Asia as it contains 80% starchy carbohydrate, 7 to 8 % protein contents, 3% fat, and 3% fiber (Juliano, 1985). In recent studies, rice was considered only a starchy food with abundant quantity of carbohydrates and some amount of protein. Though rice contains small amounts of protein even then it is of high nutritional value (Chaudhary and Tran, 2001). A campaign organized by FAO under the motto "Rice is Life" reveals the importance of rice as primary source of food and it focus on an understanding that rice based systems are necessary for food security, poverty alleviation and better livelihoods.

The system of rice intensification (SRI) originated from the uplands of Madagascar during 1980s and the originator was a French Priest Henri de Laulanie. Initially this system has faced many controversies ever since the effectiveness of its methods was confirmed in China and Indonesia seven years ago (Wang *et al.*, 2002; Gani *et al.*, 2002). It is not necessary that rice produces more under flooded conditions (Hatta, 1967). Other studies which have been conducted to evaluate the manipulation of depth and interval of irrigation has shown that rice does not necessarily need a continuously submerged conditions for high yields (Guerra *et al*., 1998).

SRI has been supported as a set of agronomic management practices for the cultivation of rice from more than a decade as that it offers high yield (Namara *et al*., 2008; Zhao *et al*., 2009), decreases the requirement of water (Satyanarayana *et al*., 2007), enhances the productivity of inputs (Sinha and Talati, 2007), is useful for smallholders (Stoop *et al*., 2002). In case of SRI intermittent irrigation is carried out to keep the soil just moist or saturated while organic matter application is carried out rather using inorganic fertilizers that reflects SRI is more favorable for the environment (Uphoff, 2003).

An increase of two billion will occur in world population over the next 40 years, especially in Asia where approximately half of the population is already under poor nourishment. To cope with this increasing demand for food due to increase in population, there will be a need to boost up rice yield and production. How such an increase will be accomplished is already contentious (Surridge, 2002; Denison *et al*., 2003). Recently, a new aspect was added to that conflict and it was suggested that the increase in production could be attained just by carrying out certain management practices in the rice crop along with SRI principles (Stoop *et al*., 2002; Uphoff *et al*., 2002). The inference is that conventional management systems for rice has been failed to exploit the true growth potential of the rice crop.

Major principles of SRI described by Stoop *et al*. (2002) are (1) Rice can survive under flooded conditions but doesn't thrive because rice is not an aquatic plant. (2) If nursery seedlings are transplanted more than 15 days old then their much of the potential is lost. (3) While transplanting is carried out, trauma or transplanting shock retrieved by the seedlings, especially roots should be reduced. (4) Using wider plant spacing boosts root tillering and growth. (5) Beneficial conditions are produced for root growth due to soil aeration and addition of organic matter.

Seed priming is a technique in which seeds are soaked partially in water or salt solution to initiate metabolic processes related its germination before radicle emergence (Bradford, 1986). Seed priming usually increases rate of germination, better germination uniformity and higher total germination percentage. During imbibitions these alterations in seed physiology greatly contribute towards the metabolic repair (Burgass and Powell, 1984; Bray *et al.,* 1989), a buildup of metabolites that promote germination (Farooq *et al.,* 2006a) and osmotic adjustment (Bradford, 1986). In addition seed priming has been reported to enhance germination, seedling establishment, allometry and yield under field sown rice (Farooq *et al*. 2006b).

Following are the objectives of the current study;

- ✓ To evaluate the performance of seed priming in different aged nursery seedlings of two fine rice cultivars and seeding techniques under SRI.
- ✓ To compare direct seeding and transplanting under SRI and conventional production systems.

Chapter 2

REVIEW OF LITERATURE

System of rice intensification (SRI) is a set of practices and insights initially developed by a priest Henri De Laulanie while working with farmers on the upland of Madagascar (Laulanie, 1993). This system offers many ways and insights by using certain crop management practices to obtain higher yields with reduced use of input resources. SRI principles with implementation of practices together give superior results over the conventional crop and water management practices used by the farmers (Uphoff, *et al.*, 2011).

2.1 Seedling age at transplanting

In rice crop during transplantation, seedlings' age mostly depends on the availability of water, labor, herbicides and certain other inputs used by farmers in fields. In case of tropical lowland rice, seedlings are transplanted at the age of 25-30 days old after germination by the farmers (De Datta, 1981; Wagh *et al.*, 1988; Singh and Singh, 1999).

However, the observations obtained from the work of many scientists showed a quite conflicting result but their work mostly supported transplantation of younger seedlings of 20 days old. In few studies it has been reported that transplantation of less than 25 days old seedlings have a beneficial impact on grain yield (Singh and Singh, 1998; Ashraf *et al.*, 1999; Nandini and Singh, 2000). On the other hand, some scientists have reported that no effect on yield has been recorded for the nursery seedlings transplanted at 30 and 60 days old (Chandra and Manna, 1988), while in few studies, transplantation of 45 days old seedlings have shown better results than those seedlings which were transplanted after 30, 60 and 75 days old (Khatun *et al.*, 2002).

Many studies have been carried out to make understanding of these differences. Few scientists accredited that younger seedlings of 25 days old have a significant superiority in case of 1000-grain weight and grain yield to the longer heading and maturity periods of 50 days old seedlings (NARC, 2004). However, few studies accredited it because of longer vegetative growth (Chandra and Manna, 1988). It has been reported that transplantation of younger seedlings of 14 days old can be the reason of low yield because of seedlings' mortality compared with 28 days old seedlings (Kewat *et al.*, 2002).

Further, Pasuquin *et al.* (2008) has reported that early aged seedlings of 7 days old produced consistently higher grain yield when compared with older aged seedlings of 14 and 21 day, respectively with elevated difference of 1 t ha^{-1} among the seedling age by keeping nursery and input practices same. Seedling age is one of the important factors that has its greater impact on growth and yield potential of rice genotypes (Slaton *et al.*, 2003; Yoshida, 1983 & Pattar *et al.*, 2001). The age of seedlings significantly affected the number of tillers per m^2 where greater number of tillers (405) was recorded in younger seedlings of 20 days old as compared to 35 days old seedlings (353) which ultimately enhance the yield potential of the rice plant (Nayak *et al.*, 2006).

In transplanted rice the most important determinants for seedling establishment is the age of nursery seedlings. Traditionally, in most parts of the world, transplantation of old nursery seedlings mainly results in poor and erratic growth. While, in case of system of rice intensification, transplantation of younger nursery seedlings of 8 to 15 days old is carried out as compared to the conventional transplanting system (Farooq *et al.,* 2006a). It has been reported that if the rice crop is being established by transplanting then best yield will be obtained if the seedlings are transplanted just 8 to 12 days old and not older than 15 days (Uphoff *et al.*, 2011). The farmer practice involves flooded nursery beds and seedlings receive much trauma under hypoxic conditions. Transplanting younger seedlings quickly within 15 to 30 minutes of gentle removal reduces trauma to the roots (Uphoff *et al.*, 2011).

In traditional rice cultivation system, plants are grown normally by using older nursery seedlings, close spacing, transplanting in clumps. Transplantation of seedlings in clumps under flooded conditions rarely acquire more than 7^{th} or 8^{th} phyllochron before the start of anthesis, that results in 8 to 13 tillers. Whereas, In case of system of rice intensification rice plant may reach up to the 12^{th} phyllochron and it can result in more than 80 tillers. If SRI practices are well managed then 13^{th} and even 14^{th} phyllochron may also be produced which may result in an increase of 150 to even 200 number of tillers. In SRI, the increased number of tillers is critical for the high yields as yield is in direct relation with the number of panicle bearing tillers, the number of grains per panicle and individual grain weight (Stoop *et al.,* 2002).

Pasuquin *et al.* (2008) reported that younger seedling transplantation is more advantageous for the early establishment of the crop and in reducing the trauma or transplanting shock to the seedlings resulting in higher grain yield. In results obtained from empirical trials, transplanting younger seedlings after the 1st but before the initiation of 4th phyllochron gives productivity benefits, and this effect has been found to be more prominent when combined with other SRI practices (Mishra and Salokhe, 2008).

If optimal growth and development conditions are maintained at early growth stage then it may be possible to get the full potential of individual plants for higher production whereas plants get minimum harmful effects from early set-backs. For this purpose certain practices has been proposed by Laulanie (1993) for growing nursery stock and transplanting them into the field to minimize such transplanting shock or trauma by transplanting younger nursery seedlings before the start of the tillering process during their 2nd or 3rd phyllochrons. Transplanting of younger seedlings with proper plant density (single seedling per hill in SRI) can help to achieve early crop canopy and to reduce the evaporation losses after crop establishment (Tuong *et al.*, 2000).

Rice seedlings are usually transplanted when they are about 30 days old. As one of the leading textbooks on rice, written by a former head of the agronomy department at IRRI, states: “It is fairly common to transplant seedlings that are 40-50 days old. However, 20-30 days is the best age for transplanting wet-bed seedlings (De Datta, 1981). Farmers believe that larger and more mature plants will survive and grow better. With SRI, however, seedlings are taken carefully from nurseries when they are still quite young, preferably only 8-12 days old and certainly not older than 15 days. As explained physiologically below, this increases their tillering potential, which is affected also by other SRI practices. While conventionally grown rice plants will have 5-20 tillers, with SRI the number per plant can be 50-80, and possibly over 100. Tillers are the grain bearing stalks that emerge as the plant grows. Not all tillers will flower and become fertile; those that do are called panicles.

Younger seedlings transplantation of 8-12 days old has the capacity to preserve its tillering and rooting potential while this potential is reduced if transplantation is carried out after the initiation of 4th phyllochron. Furthermore, in SRI combination of management practices such as plant, soil, water and nutrients promoted root growth, in addition with increased number of productive tillers, improved grain filling and higher grain weight which eventually resulted in maximum grain yield (Uphoff, 2001).

The SRI has been reported to increase yields from 2 to 5-10 t ha^{-1} at some locations (Uphoff, 2001). The increase in yield continuously year by year at the same location has also been reported by Rafaralahy (2002). There has been reported some explanations for observed yield responses i.e. root soil exploration is enhanced due to transplantation of very young seedlings, wide plant spacing and using single plant per hill and application of compost to improve the soil fertility (Uphoff, 2001).

Recent studies on SRI have focused the evaluation of SRI practices and impact of its sub components in wide range of environments. However, in a study conducted in temperate Japan where previously SRI was not being practiced, it has been reported that evaluation of several sub components of SRI revealed encouraging results. In this study no significance of the combined effect of younger seedlings and intermittent irrigation application with intervals of alternate wetting and drying until flowering stage were recorded as compared with the conventional practices (Chapagain and Yamaji, 2010).

2.2 Conventional method versus system of rice intensification

The conventional system, most of the farmers in the region of Pakistan, is being practiced with flood irrigation in plain irrigated areas which requires large amount of water and due to water scarcity which is increasing in many arid and semi-arid regions, farmers need water saving technologies and are shifting to crops which require less water (Thiyagarajan, 2001). In many recent studies it has been reported that SRI practices outperformed over the conventional management practices for rice cultivation (Katambara *et al.*, 2013; Ndiiri *et al.*, 2013; Sinha & Talati, 2007). The comparison for system of rice intensification to the conventional method of rice cultivation has shown improvement in yield and water saving over the conventional method. In a study conducted in West Bengal (India) 32% increase in yield and 67% higher net returns was recorded in fields where SRI practices were carried out compared with conventional method of rice cultivation (Sinha & Talati, 2007).

Higher growth and yield were recorded by planting younger seedling in SRI than planting older seedlings more densely under submergence, conventional method (Iranie *et al.*, 2009). SRI practices compared with conventional methods showed higher harvest index along with other plant attributes (Chapagain *et al.*, 2011).

SRI favorably affected all the yield attributes of rice like number of productive tillers, length of panicle and numbers of grains per panicle and made 17 % yield increment than conventional method of rice cultivation. Higher grain yield coupled with substantial water saving (24.1%) resulted in higher Water Use Efficiency of rice under SRI method and leaded to higher gross income, net profit and benefit cost ratio (Priya *et* *al.*, 2010). SRI methods has increased yield by 50%-100%, for most available cultivars used for trials over the conventional method of cultivation (Uphoff, 2006).

2.3 Direct seeding and transplanting

The common method of planting rice in Pakistan is through transplanting nursery seedlings in the prepared field, which is not only more laborious and time consuming but also expensive and inconvenient. This method can be replaced by direct seeding. However, different agronomic aspects of direct seeding although well tried at other places (Naklang *et al.*, 1996; Sharma and Ghosh, 1998) are still to be investigated in detail against the transplanting method in Pakistan.

Traditionally, rice is cultivated with the transplanting pattern, consisting of raising nurseries, picking seedlings up and transplanting, which cost a large number of manpower and financial resources. Direct seeding has replaced gradually and partially the planting pattern in the past two decades, in many developed countries (Naklang *et al.*, 1996; Pandey *et al.*, 2002; Dawe, 2005).

Direct seeding in rice particularly at the seedling stage provides growth environment that is completely different from transplanting. It has been reported that the direct seeding rice showed favorable changes for high yield formation in comparison with the transplanting rice, including earlier seedling emergence (Pandey *et al.*, 2002) while during early growth stage direct seeding results in stronger root activity, higher seed setting rate and greater biomass production (Naklang *et al.*, 1996).

It has been reported that higher leaf area production and rapid tillering was observed in direct seeded rice as compared to transplanting that resulted in higher biomass production even though grain yield was not higher in direct seeding when compared with transplanting regardless of overexpansion of foliage while reduction in leaf nitrogen contents and conversion of biomass into grain (Dingkuhn *et al.*, 1990a & b; San-oh *et al.*, 2004). The reduction in leaf total nitrogen contents in direct seeding conditions was assumed to be the result of enhanced tissue death and respiration losses at booting and ripening (Schnier *et al.*, 1990).

Rice cultivation under aerobic soil environment as in case of direct seeding results in higher water use efficiency as compared to conventional flooded system (Xiaoguang *et al.*, 2003). The lower yields recorded in direct seeded rice are mainly due to higher weed infestation. In a study, it has been reported that rice yield under aerobic conditions were lower (14-40%) than under flooded conditions. However, the water productivity was relatively more than the reduction in yield in direct seeded rice (20-40% and 80%) when compared with the conventional flooded rice (Castaneda *et al.*, 2003). Singh *et al.* (2003) reported 35-42% reduction in total water input during the crop growth in near saturated soil condition and 47% and 51% when the soil moisture was kept at 20 and 40 kPa in the rhizosphere.

Water saving in addition to other benefits of SRI management practices have been reported in many studies (Cabangon *et al.*, 2011; Bouman and Tuong, 2001). Rice production mainly depends on two most important inputs which are water and nitrogen. Rice can survive well in flooded condition and it needs heavy water application. Water is becoming a scarce commodity as demand for water is increasing due to increased population, urbanization, tourism, industry and ecosystem services (Guerra *et al.*, 1998; Bouman and Tuong, 2001). Managing rice with reduced water application is the need of time and many water saving techniques are being used among the most widely adopted is alternate wetting and drying termed as AWD (Li *et al.*, 2003; Lampayan *et al.*, 2004). Adopting AWD practices brings sequential nitrification and denitrification processes to be carried out in the rhizosphere due to periodic aerobic and anaerobic soil environment (Buresh and Haefele, 2010).

However, there are some disadvantages in direct seeding system. Firstly, seedling establishment is unstable and variable over varieties, sowing depths and water levels. Secondly, direct seeded rice plants have consistently shallower roots and greater biomass, thus being prone to lodge (Yamauchi and Chuong, 1995). Thirdly, the competition with weeds is considered as an inevitable barrier of high yield for direct seeded rice (Ito *et al.*, 1999). Singh *et al.* (1995) reported more uniform water extraction at various soil depths, and tolerance to drought consistently for a longer period in direct seeding as compared to transplanted crops. It has been observed that in direct seeding at early growth phase there is a rapid tillering and increased leaf area, in association with higher biomass production as compared to transplanting rice fields (Dingkuhn *et al.*, 1990b; San-oh *et al.*, 2004). In spite of luxury foliage growth and greater biomass production in direct seeded rice, in some cases the economic yield was not recorded higher (Dingkuhn *et al.*, 1990a; Schnier *et al.*, 1990) because of reduced leaf N concentration and biomass conversion into grain.

It had been recognized in previous studies that leaf area index enhanced quickly in direct seeded rice plants that results in production of large number of tillers in comparison with those plants which were transplanted (Dingkuhn *et al.*, 1990b; Dingkuhn *et al.*, 1991; Schnier *et al.*, 1990). However, in case of direct seeding the early vigorous leaf expansion results in over luxury growth which adversely affects the canopy CO_2 assimilation because of reduction in concentration of leaf N (Dingkuhn *et al.*, 1990a, b & 1991; Schnier *et al.*, 1990).

In direct seeded plants the potential sink size was sufficient or abundant as it has higher leaf area index and greater tillering activity (Dingkuhn, 1990a), but unfortunately direct seeded plants have poor ability for the conversion of higher biomass produced into grain yield when they are compared with the transplanted rice plants (Dingkuhn *et al.*, 1990a; Schnier *et al.*, 1990). Moreover, much reduction in grain yield is induced due to lodging at ripening stage (San-oh *et al.*, 2001). On the other hand, if direct seeded plants obtained optimum establishment of seedling and lodging doesn't occur, production of dry matter and grain yield were increased in the direct sowing than in transplanting (Dingkuhn *et al.*, 1990b; Heu and Kim, 1997; Sharma, 1995).

It has been observed that broadcasting of rice plants in a submerged paddy field or direct plantation by placing single plant per hill, always yielded more dry matter than the conventional transplanting method as in case of Takanari a lodging-resistant cultivar (San-oh *et al.*, 2001, 2002). In direct sown plants grain yield was found higher which was due to the result of higher crop growth rate from the stage of tillering to ripening. From these results it may be indicated that higher dry matter production and grain yield can be produced in direct seeded plants in comparison with transplanted rice under the conditions that luxuriant growth and lodging doesn't occur (San-oh *et al.*, 2004).

The direct seeded plants produced enhanced crown rooting that results in higher accumulation of nitrogen in the leaves during tillering to booting stage and also in ripening stage. In direct sown plants, after heading stage the lower leaves' color degradation was less extensive. These factors might also have contributed towards the greater production of dry matter in these plants (San-oh *et al.*, 2004).

2.4 Seed priming

Seed priming is a technique in which seeds are allowed to be partially hydrated to initiate germination process, without protrusion of the radicle (Bradford, 1986). Priming of seeds allows germination initiating metabolic processes without true germination. Basra *et al.* (2005) has reported that in case of primed seeds an increased rate of germination, higher germination uniformity as well as an increased total germination percentage has been recorded. Higher germination rate and uniformity have a significant contribution towards the metabolic repair during imbibition (Bray *et al.*, 1989), constitution of germination-enhancing metabolites (Basra *et al.*, 2005), osmotic adjustment (Bradford, 1986) and, for seeds, which are not redried after the treatment, a simple reduction in the imbibition lag time has been reported (Bradford, 1986).

Several seed invigoration techniques are being successfully used to achieve better seedling establishment in many horticultural and field crops by reducing the time of germination and improving germination rate (Bradford *et al.*, 1990; Dell'Aquilla and Tritto, 1991; Hussain *et al.*, 2006).

Osmopriming is a technique in which seeds are primed with salt solution rather using simple tap or distilled water. It has been reported that osmohardening in $CaCl_2$ with an osmotic potential of -1.5 MPa solution showed better results than by using other salts and simple hardening (Farooq *et al.*, 2005).

The growth and performance of rice nursery seedlings in case of transplanting can be enhanced by seed priming (Farooq *et al.*, 2006c, 2007a, b). It is also reported that seed priming increases the root proliferation that results in better nutrient and water uptake (Farooq *et al.*, 2006d), enhances tolerance to low temperature (Naidu and Williams, 2004; Sasaki *et al.*, 2005), salinity (Ruan *et al.*, 2003; Kim *et al.*, 2006) and drought (Du and Tuong, 2002) due to enhanced activities of antioxidants, which include superoxide dismutase, catalase (Fashui, 2002; Deshpande *et al.*, 2003), peroxidases, and glutathione reductase (Fashui, 2002).

Seeds as a sink symbolize a well-defined system, where seedlings are produced by the utilization of resources. The endosperm of rice seeds contains starch, proteins and a little amount of oils as stored reserves. Hydrolysis of these reserves is carried out by hydrolytic enzymes to convert it into readily available and useable form to provide energy for the growth of embryo. It has been observed that seed priming regulate carbohydrate metabolic enzymes to increase the availability of food for embryo growth (Kaur *et al.*, 2000, 2002).

2.5 Seed priming in SRI

Evidence is accumulating from recent research for different crop species and from different agro-ecological regions showing that fast germination, early emergence, and vigorous seedling growth may result in higher yielding crops (Harris *et al.*, 1999, 2000; Musa *et al.*, 1999). On-farm seed priming is another technique which is simple, low cost as well as low risk method of promoting rapid seedling establishment and early vigorous growth, in which seeds are soaked in water for some time and dried in shade before sowing. The duration of seed soaking is very important while doing priming. The duration for each crop should always be less than the safe limit which can be defined as the maximum length of time for which seeds can be primed before premature germination that could cause seedling damage (Harris *et al.,* 1999).

Proponents stress that SRI is not yet finished. The work for evolving and improving SRI is still in progress. This system is continuously being adapted for varied environments as such environments as well as SRI becomes better understood (Uphoff, 2008). It has been further reported by Uphoff (2008) that there are certain beneficial practices that can be recommended for use with SRI i.e. choice of most suitable varieties, selection of good quality seed, seed priming and use of raised beds or seedbed solarization (Culman *et al.,* 2005).

In system of rice intensification, nursery seedlings of younger age are transplanted as compared to conventional method where older nursery seedlings are transplanted (Farooq *et al.*, 2006e). Seed priming not only improve the growth of rice nursery seedlings but also their performance in transplanted culture. (Farooq *et al.*, 2006c, 2007a, b). It has been reported that seed priming enhances the root proliferation that increases nutrient and water uptake (Farooq *et al.*, 2006d). It also increases antioxidant activities which include superoxide dismutase, catalase (Fashui, 2002; Deshpande *et al.*, 2003), peroxidases, and glutathione reductase (Fashui, 2002) for improving the tolerance to low temperature (Naidu and Williams, 2004; Sasaki *et al.*, 2005), salinity (Ruan *et al.*, 2003; Kim *et al.*, 2006) and drought (Du and Tuong, 2002).

2.6 Seedling age and system of rice intensification

The time of transplanting and age of seedlings at transplantation are critical and non monetary inputs aside the other factors which are responsible for achieving higher rice yield potential. Similarly, seedling age plays a crucial role for attaining higher potential of rice as rice plants are highly sensitive to diverse soil conditions while duration of various cultivars behaves differently (Brar *et al.*, 2012). Current studies on SRI illustrated that higher crop performance has been recorded in nursery seedlings which are transplanted at the age of 14 days as compared to seedlings which were transplanted at the age of 21 to 23 days old (Makarim *et al.*, 2002; Thiyagarajan *et al.*, 2002). However, the study conducted in Madagascar by McHugh (2002) also reported highest yields in 8 to 15 days old seedlings transplanted at 25 hills m^{-2}, while in Sumatra even younger seedlings of about 10 days old produced the highest yields.

It has been indicated that longer the seedlings stay in the nursery more the growth pattern may affect due to high competition among seedlings (Mandal *et al.*, 1984). It also has been reported that the older seedling transplantation results in extension of the overall crop duration (Herrera and Zandstra, 1980).

Based on the assumption that performance of rice plants is adversely affected under submerged conditions due to aerenchyma formation, the SRI basically confronts the common perception that rice plants perform well under standing water conditions. However, in SRI the soil is just kept moist by intermittent irrigation application to reduce the drought stress. The intermittent irrigation saves water as compared to flood irrigation. Water saving techniques is being preferred in the field of rice research (Barker *et al.*, 2000) and scientists are trying to develop such water-saving irrigation techniques to avoid the loss of water. Rather than keeping fields under flooding conditions, in SRI soil is kept saturated by the application of intermittent irrigation to create alternate wetting and drying conditions (Bouman and Tuong, 2001; Tabbal *et al.*, 2002). However, Dobermann (2004) strongly criticized and reported that a review of cropping practices at known high yielding sites showed that the SRI practices are not necessary for growing rice near the yield potential. It has been reported that comparably no intensive system exists that could result in higher productivity for longer time with least input and indicate a remarkably efficient nutrient supply (Buresh *et al.*, 2001).

Though, the need is to differentiate between flooding and alternate wetting and drying condition having periodical aeration and to evaluate the most suitable condition for rice growth for enhancing the rice yields. The flooding conditions is most suitable to fertile lowland rice environments, whereas alternate wetting and drying is usually suitable for marginal soils that needs aeration to enhance oxygen supply towards the roots. Saturated conditions mainly results in buildup of reduced substances to a toxic level including ferrous iron (Fe^{2+}) and hydrogen sulfide (H_2S). Aerenchyma formation or root porosity (Armstrong, 1967) has direct relationship with the redox potential. However, those plants which have adapted themselves to wetland conditions attain the ability to grow best under slightly reduced conditions rather than strongly reducing or oxidizing soil conditions (Kludze and Delaune, 1995; Kludze and Delaune, 1996).

MATERIAL AND METHODS

3.1 Site selection

Two field experiments were conducted at Agronomic Research Area, University of Agriculture, Faisalabad (Pakistan), during the year 2010 and 2011, respectively. Faisalabad lies between 30.35-31.47° N latitude and 72.08-73.40° E longitude at an elevation of 184.4 m above sea level. The region is classified into hot desert climate with average yearly rainfall lies only at about 300 mm (12″) and is highly seasonal with approximately half of the yearly rainfall takes place in July and August.

3.2 Soil physico-chemical analysis

The site of the experimental area was analyzed for physico-chemical characteristics. The composite soil samples were taken up to a depth of 15 cm and 30 cm before sowing and just after the harvest of the crop during both the years. The physico-chemical analysis showed that the experimental soil was sandy loam having soil pH (8.3 & 8.6), electrical conductivity (0.37 & 0.33 dS m^{-1}) and organic matter (0.87 & 0.83%) before sowing during the year 2010 and 2011, respectively. However, after harvest the soil was having pH (8.1 & 8.5), electrical conductivity (0.36 & 0.31 dS m^{-1}) and organic matter (0.89 & 0.86%) during the year 2010 and 2011, respectively (Table 3.1).

3.3 Meteorological data

For both the years (2010 and 2011) the meteorological data were collected from the Department of Crop Physiology (agro meteorological cell) University of Agriculture, Faisalabad, Pakistan. In the year 2010, the average annual temperature was 25.8 ℃ and the average minimum and maximum air temperature during the entire crop season was 22.5 ℃ and 34.2 ℃, respectively. The total precipitation during the crop season was 591.9 mm, with most rain during July and August. However, in the year 2011, the average annual temperature was 23.3 ℃ and the average minimum and maximum air temperature during the entire crop season was 17.0 ℃ and 29.7 ℃, respectively. The total precipitation during the crop season was 507 mm, with most rain during the months of July, August and September (Figure 3.1 a & b).

Table 3.1: Physico chemical analysis of the experimental soil

		2010		2011	
Soil Characteristics	**Unit**	**Value before sowing**	**Value after harvesting**	**Value before sowing**	**Value after harvesting**
Texture		Sandy loam			
Soil pH		8.3	8.1	8.6	8.5
EC	dS m^{-1}	0.37	0.36	0.33	0.31
Exchangeable Na	mmole 100 g^{-1}	0.24	0.21	0.26	0.23
Organic matter	%	0.87	0.89	0.83	0.86
Nitrogen (N)	%	0.073	0.077	0.075	0.079
Phosphorus (P)	ppm	5.2	5.7	5.4	5.9
Potassium (K)	ppm	172	166	170	168
Zinc (Zn)	ppm	0.87	0.82	0.89	0.84
Iron (Fe)	ppm	6.83	6.76	6.88	6.81

Minerals were determined by spectrophotometric method

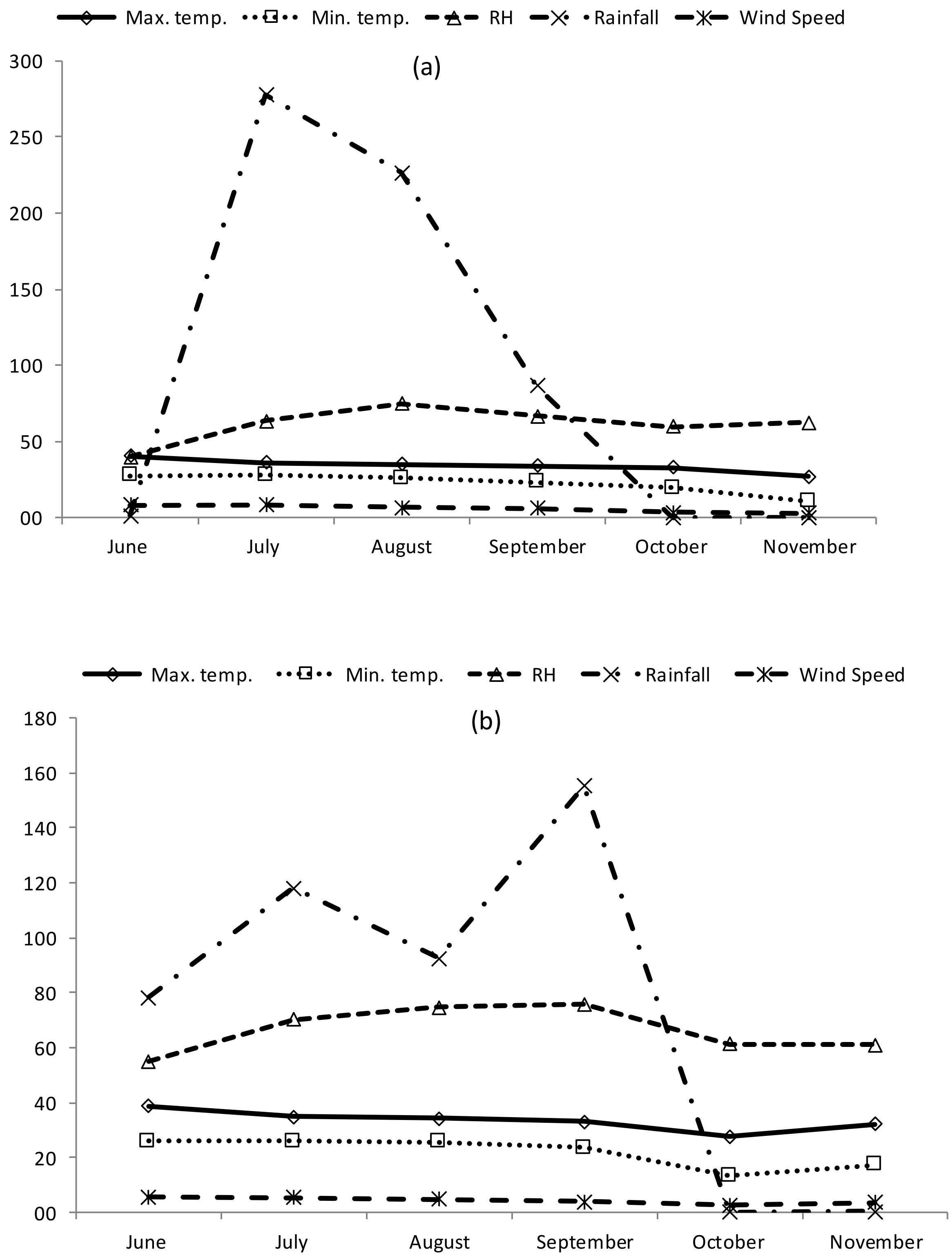


Figure 3.1: Meteorological data for the entire crop season during the year (a) 2010 (b) 2011
Temp. = Temperature (^{0}C), RH = Relative Humidity (%), Rainfall (mm), Wind speed= km/h

3.4 Experiment No. 1

3.4.1 Title of the experiment

Evaluating the role of seed priming in improving the performance of nursery seedlings for system of rice intensification

3.4.2 Experimental detail and treatments

The experiment was conducted for two seasons, 2010 and 2011, at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan (31.44º N and 73.07º E) to evaluate the role of seed priming in improving the performance of nursery seedlings for SRI. Two fine rice (*Oryza sativa* L.) seed varieties Super Basmati and Shaheen Basmati were used in this experiment. The seeds of Super Basmati and Shaheen basmati were obtained from Rice Research Institute, Kala Shah Kakoo, Sheikhupura and Soil Salinity Research Institute, Pindi Bhattian, Pakistan, respectively. The initial seed moisture contents of Super Basmati and Shaheen Basmati were 8.42% and 7.93%, respectively. The experiment was executed in randomized complete block design (RCBD) with split split plot arrangement and experimental units were repeated three times. Net plot size was 3 m × 6 m and seeds were sown on 2nd week of June, 2010 and 2011, respectively.
The treatments used are as under:

Factor A: (Varieties)

V_1= Basmati Super

V_2= Basmati Shaheen

Factor B: (Seedling age)

A_1= 2 weeks old seedlings

A_2= 3 weeks old seedlings

A_3= 4 weeks old seedlings

Factor C: (Priming)

P_1= Non primed

P_2= Primed with $CaCl_2$ (1.5 %)

3.4.3 Seed priming treatments

Seed priming treatments were: (a) non primed seeds as control treatment and (b) osmopriming with $CaCl_2$ (1.5 % soln.) for 46 hours and then primed seeds were subjected to drying with forced air before sowing. For seed priming the ratio of seed weight to solution volume was 1:5 (Farooq *et al.*, 2006f). Seeds were washed with distilled water three times and the seed moisture content was brought to their original moisture level by keeping under shade with forced air at room temperature (Farooq *et al.*, 2006d). The primed seeds were stored in refrigerator until use.

3.4.4 Nursery bed preparation

Sowing of the seeds was carried out during the 2nd week of June 2010 and 2011, respectively, on well prepared raised nursery beds. The beds were prepared by making a 5-7cm layer of soil and 2-3cm layer of farmyard manure above the soil layer. The soil and farmyard manure was then mixed to make a uniform bed. Nursery beds were not kept flooded (as in conventional practices), rather the beds were kept moist to reduce the hypoxic condition and trauma to the seedlings' roots (SRI practice). Nursery beds for the seedling age of 4 weeks old were prepared first followed by 3 and 2 weeks old with an interval of one week in each seedling age. In this way after one month all the nursery beds were having seedlings of 2, 3 and 4 weeks old ready to be transplanted at the same time in the field.

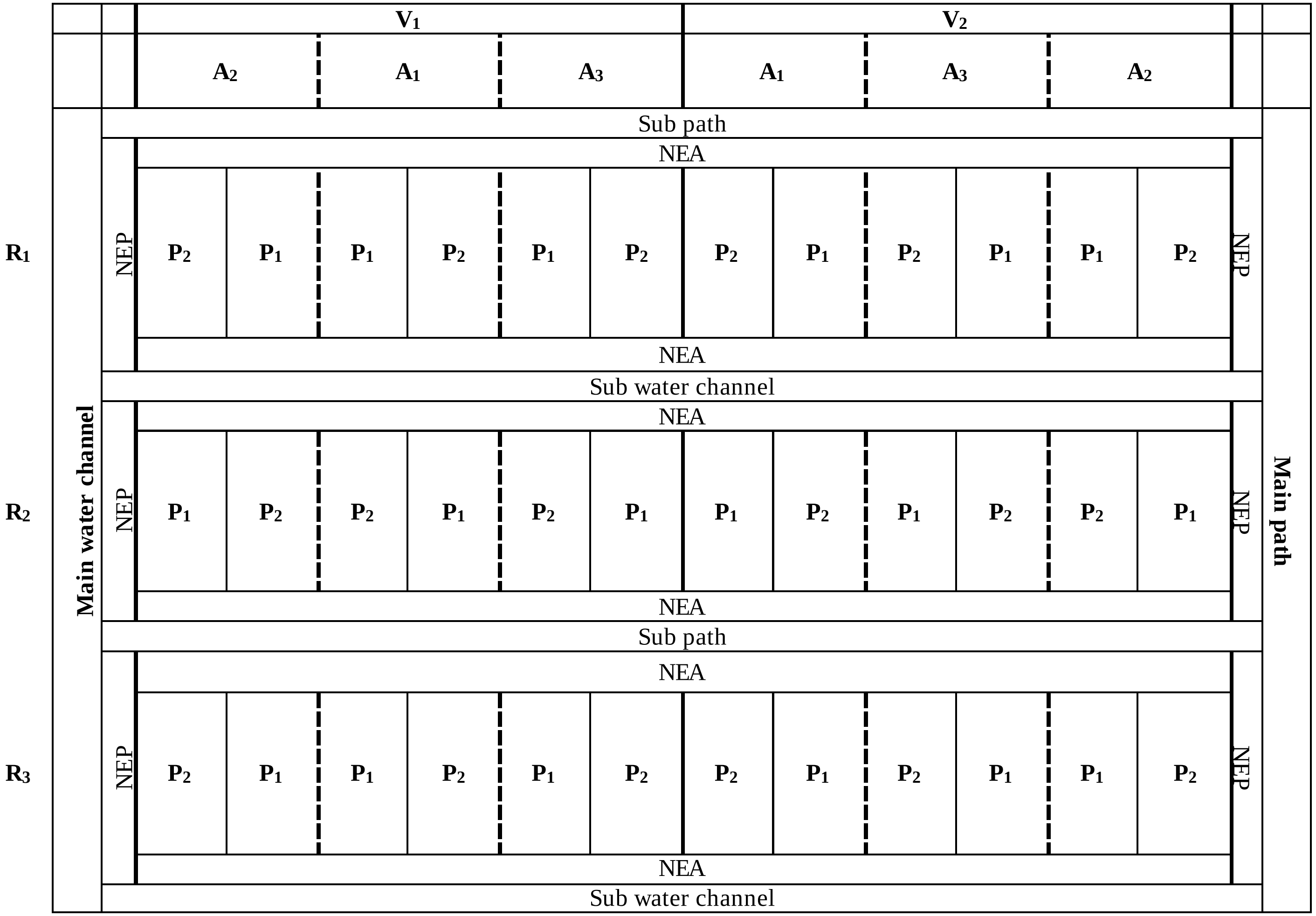
3.4.5 Land preparation and fertilizer application

Land preparation was carried out according to wetland preparation method for seedling transplantation. Three cultivations were carried out followed by two plankings to achieve the desirable soil structure. Fully decomposed farmyard manure (5 t ha^{-1}) was applied after completion of puddling, leveling and draining off excess water. Along with farmyard manure chemical fertilizer was applied to provide 75 kg N, 45 kg P and 35 kg K and 10 kg Zn ha^{-1} in the form of Urea (46%), single super phosphate (18% P_2O_5), sulphate of potash (50% K_20) and zinc sulphate (35% Zn). All the P, K, Zn and half of the N was applied at the final land preparation time as basal dose. The rest of the N was applied in two equal splits each at tillering and panicle initiation stage.

3.4.6 Seedling transplantation and irrigation

Seeds were sown in the nursery according to the seedling age with the interval of one week in each seedling age; 2 weeks, 3 weeks and 4 weeks old seedlings, respectively, in order to keep the transplanting time same for all the seedling age. Nursery seedlings were transplanted quickly, within 30 minutes of gentle removal from the nursery, at shallow depth with care. Transplanting was done in a wider square pattern of 30 cm × 30 cm in the field. A single seedling per hill was transplanted carefully in all plots. The field was irrigated by applying alternate wetting and drying (AWD) with the interval of 6-7 days for each. However, during the reproductive stage a 2-3 cm ponded layer of water was prevailed and irrigation application was withheld 12 days before harvesting.

3.4.7 Lay out experiment No. 1



NEP = Non experimental plots, NEA = Non experimental area

Design = RCBD split split
Plot size = 3 m × 6 m
Replications = 3

Factor A: Varieties (Main plots)

V_1 = Basmati Super
V_2 = Shaheen Basmati

Factor B: Seedling age (Sub plots)

A_1 = 2 weeks old seedlings
A_2 = 3 weeks old seedlings
A_3 = 4 weeks old seedlings

Factor C: Priming (Sub sub plots)

P_1 = Non primed
P_2 = Primed with $CaCl_2$

3.5 Experiment No. 2

3.5.1 Title of the experiment

Evaluating the role of seed priming in improving the performance of direct seeding in System of Rice Intensification

3.5.2 Experimental detail and treatments

The experiment was conducted at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan (31.44º N and 73.07º E) during the year 2010 and 2011 to evaluate the role of seed priming in improving the performance of direct seeding in SRI. The seeds of fine rice variety, Basmati Super, were obtained from Rice Research Institute, Kala Shah Kakoo, Sheikhupura, Pakistan. The initial seed moisture content was 8.42%. Randomized complete block design was used with split split plot arrangement and the experimental units were repeated thrice. The crop was sown during the 2nd week of June in both the years with a net plot size of 3 m × 6 m.

The treatments used in this experiment are as under:

Factor A: Sowing methods (Main plots)

M_1= Conventional method

M_2= SRI

Factor B: Seeding technique (Sub plots)

S_1= Direct seeded rice (DSR)

S_2= Transplanted rice (TPR)

Factor C: Seed priming (Sub sub plots)

P_1= Non primed

P_2= Hydropriming

P_3= Osmopriming with $CaCl_2$ (1.5%)

3.5.3 Seed priming treatments

Three priming treatments were used in this experiment. Seed priming treatments were: (a) non primed seeds as control treatment, (b) hydropriming in which seeds were soaked in aerated distilled water for 46 hours and (c) osmopriming in which seeds were primed with 1.5% solution of $CaCl_2$ for 46 hours. For seed priming the ratio of seed weight to solution volume was 1:5 (Farooq *et al.*, 2006f). Seeds were then washed with distilled water thrice and the seed moisture content was brought to their original moisture level by keeping under shade with forced air at room temperature (Farooq *et al.*, 2006d). The primed seeds were stored in refrigerator until use.

3.5.4 Nursery bed preparation

Sowing of the seeds was carried out during the 2nd week of June 2010 and 2011, respectively. The nursery beds were prepared according to the method described in Section 3.4.5. The difference in nursery beds of SRI and conventional methods was of raised beds which were used in SRI while in conventional method beds were not raised and were surrounded by bunds.

3.5.5 Land preparation and fertilizer application

In case of transplanting the land was prepared according to the method as described in 3.4.6. For direct seeding the land was prepared by 3 cultivations followed by 2 plankings to attain desirable soil structure. Direct seeding was carried out in wattar condition with the manual hand drill at the same time when nursery beds were being prepared. Fertilizer application for SRI was carried out in the same way as described in Section 3.4.6. However, for conventional method of cultivation fertilizer was applied to provide 150 kg N, 90 kg P, 75 kg K and 10 kg Zn ha^{-1} in the form of Urea (46%), single super phosphate (18% P_2O_5), sulphate of potash (50% K_2O) and zinc sulphate (35% Zn). All P, K, Zn and half of the N was applied at the final land preparation time as basal dose while the rest of the N was applied in two equal splits each at tillering and panicle initiation stage.

3.5.6 Direct seeding and seedlings' transplantation

Direct seeding and transplanting was carried out under conventional (aerated condition) and SRI (muddy condition) methods with the help of hand drill and manually by hands, respectively. However, direct seeding in SRI was carried out manually by hands and placing single seed per hill. Seeds were sown in 22.5 cm apart rows for transplanting and direct seeding in conventional method and 30 × 30 cm apart in squared pattern for both transplanting and direct seeding in SRI. Nursery seedlings of 2 and 4 weeks old were transplanted in field plots prepared by SRI and conventional methods, respectively.

3.5.7 Irrigation management under conventional and SRI method

The plots under conventional transplanting method were kept flooded during the vegetative phase with irrigation interval of 6-7 days. For conventional direct seeding plots, the irrigation application was carried out with an interval of almost same as in conventional flooding during the vegetative growth phase. When the crop reached to reproductive stage, the ponded water layer of 2-3 cm was maintained during this phase and irrigation was withheld 12 days before harvesting when the signs of physiological maturity appeared. For both conventional method of sowing and direct seeding under SRI, the field was kept moist during the vegetative growth phase with alternate wetting and drying irrigation application after an interval of 6-7 days of wetting and the same for drying. In this way the irrigation interval was of 12-14 days. However, during the reproductive stage a 2-3 cm ponded layer of water was prevailed and irrigation application was withheld 12 days before harvesting after appearance of signs of physiological maturity.

3.5.8 Crop water requirement under both production systems

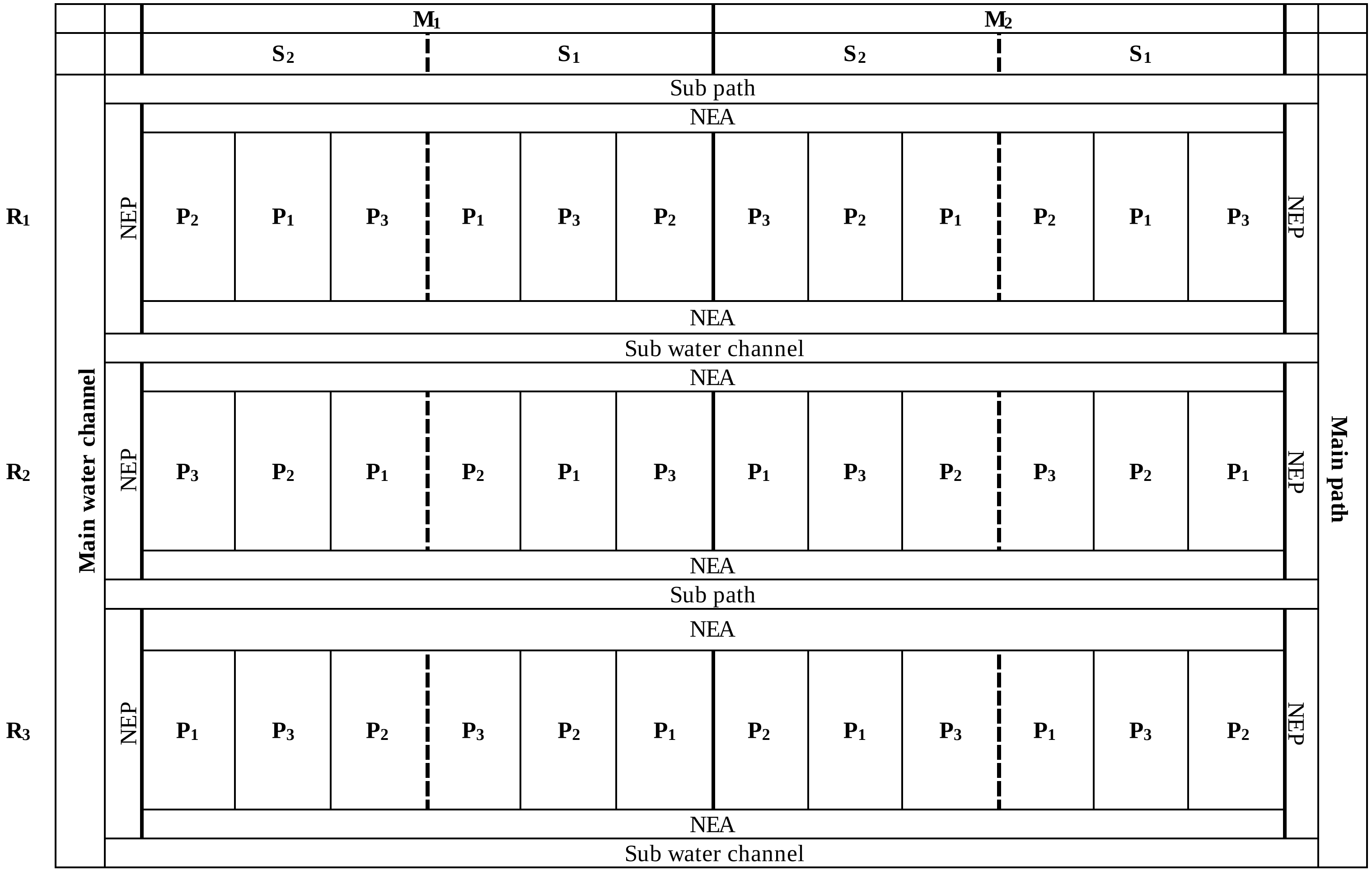
Rice crop water requirement (cm) of both direct seeding and transplanting under SRI is almost half than that of transplanting under conventional method (Table 3.2). Total number of irrigations required for transplanting under conventional method was 17 with irrigation depth of 8 cm while for same under SRI was 9 during the base period of crop (120 days). Similarly, total number of irrigations required for direct seeding under conventional method was 15 with irrigation depth of 6 cm and for same under SRI was 9 with same depth during the base period. Both seeding techniques under SRI required 58% less water than that of transplanting under conventional method. However, direct seeding under conventional method required 34% less than that of transplanting under conventional method.

Table 3.2: Crop water requirement (cm) of transplanted and direct seeded rice under conventional method and SRI

Seeding technique	CON	SRI
DSR	90	54
TPR	136	72

CON= conventional method, SRI = system of rice intensification, DSR = direct seeding, TPR= transplanting

3.5.9 Lay out experiment No. 2



NEP = Non experimental plots, NEA = Non experimental area

Design = RCBD split split
Plot size = 3 m × 6 m
Replications (R) = 3

Factor A: Sowing methods (Main plots)

M_1 = Conventional method

M_2 = SRI

Factor B: Seedling technique (Sub plots)

S_1 = Direct seeded rice (DSR)

S_2 = Transplanted rice (TPR)

Factor C: Priming (Sub sub plots)

P_1 = Non primed

P_2 = Hydro priming

P_3 = Osmoprimed with $CaCl_2$ (1.5% soln.)

3.6 Observations recorded in both the experiments

The following observations were recorded for the growth, yield and quality related attributes of rice in both the experiments during 2010 and 2011.

3.6.1 Allometry and crop growth

3.6.1.1 Leaf area index

Leaf area was measured with a leaf area meter (Licor, Model 3100) from each experimental unit with the interval of 15 days after transplanting at five different growth stages of rice. Leaf area index was calculated as the ratio of leaf area to land area (Watson, 1947).

3.6.1.2 Leaf area duration

Leaf area duration was determined by using the formula of Hunt (1978) at five different growth stages of rice with the interval of 15 days after transplanting.

$$LAD = \frac{LAI_1 + LAI_2}{2}(t_2 - t_1)$$

Where

LAD = Leaf area duration

LAI_1 = Leaf area index at first harvest

LAI_2 = Leaf area index at final harvest

t_1= Time of observation of first LAI

t_2= Time of observation of final LAI

3.6.1.3 Crop growth rate (g m^{-2} d^{-1})

Crop growth rate was measured with help of following formula given by Hunt (1978).

$$CGR = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{1}{G_a}$$

Where

CGR = Crop growth rate

W_1 = Total dry matter at first harvest

W_2 = Total dry matter at second harvest

t_1= Date of observation of W_1

t_2= Date of observation of W_2

G_a= Ground area

3.6.1.4 Net assimilation rate (g m^{-2} d^{-1})

Net assimilation rate was determined using the formula of Hunt (1978).

$$NAR = \frac{TDM}{LAD}$$

Where

NAR = Net assimilation rate

TDM = Final total dry matter at harvesting

LAD = Final leaf area duration at harvesting

3.6.2 Phenology

3.6.2.1 Days to heading

Three different sites were selected from each plot. Emergence to heading was recorded by counting the number of days taken from emergence to heading as time when 50% heading was completed and average was calculated.

3.6.2.2 Heading to maturity (days)

Three different sites were selected from each plot to calculate the time taken from heading to maturity. Heading to maturity was calculated as time taken from complete heading to maturity in each plot and the three values were averaged.

3.6.3 Agronomic and yield related attributes

3.6.3.1 Plant height at maturity (cm)

Plant height was measured from base to tip of leaf with the help of measuring rod. Twenty primary tillers were selected at random from each experimental unit for measuring plant height and average was carried out.

3.6.3.2 Productive and unproductive tillers (m^{-2})

Number of tillers was calculated from an area of 100 cm X 100 cm in each experimental unit at random from three different sites at maturity and the average was carried out thereafter. Panicle bearing tillers were counted from the same area by randomly selected and earmarked at three different points in each experimental unit at maturity and the average was worked out. Unproductive tillers were calculated by subtracting the productive tillers from total tillers in each experimental unit and average was calculated.

3.6.3.3 Panicle length (cm)

Ten panicles were selected from each experimental unit at random and panicle length was recorded by ruler. Thereafter the average was calculated.

3.6.3.4 Kernels per panicle

Twenty panicles of primary tillers were selected at random from each experimental unit at harvest. Kernels from each panicle were separated and after that average was worked out.

3.6.3.5 1000-kernel weight (g)

The 1000 kernel weight was measured form each experimental unit by using an electric balance in the laboratory.

3.6.3.6 Kernel yield (t ha^{-1})

From each experimental unit all the plants were harvested from total harvest area of 5 m^2 at physiological maturity. At this stage the grain is mature, fully developed, hard and free from green tint. This stage completes when 90-100% of the filled spikelets have turned yellow and senescence of upper leaves including the flag leaf is noticeable (De Datta, 1981). The grains were threshed, cleaned, dried and weighed (W). The moisture contents (M) of the grains were determined and grain weight was adjusted to 14% moisture, according to the following formula (Yoshida, *et al.*, 1976). The kernel weight was expressed in t ha^{-1}.

$$\boldsymbol{Adjusted\ weight = \frac{100 - M}{86} \times W}$$

3.6.3.7 Straw yield (t ha^{-1})

The straw yield from each experimental unit was determined after sun drying for one week and expressed in t ha^{-1}.

3.6.3.8 Harvest index (%)

Harvest index (HI) was calculated according to the following formula.

$$HI\ (\%) = \frac{Kernel\ yield}{Total\ yield} \times 100$$

3.6.4 Grain and grain quality attributes

A common electrical lamp fitted in box having glass sheet on top of it was to examine panicles under light. With the help of light passing through kernels, normal, abortive and chalky kernels were separated.

3.6.4.1 Opaque kernels (%)

Those kernels which have attained full size but they were not translucent due to lack of carbohydrates and also do not allow light to pass through them due to the dull chalky structure were classified as opaque kernels. However, these kernels were bigger than abortive kernels as their development stopped at later stage. Because of this these kernels were unable to acquire normal size due to retarded growth.

3.6.4.2 Abortive kernels (%)

The kernels which look dull and unable to pass light through them was classified as abortive kernels. Abortive kernels undergo fertilization but are unable to attain full size as they stop growing during early stages of kernel development.

3.6.4.3 Normal kernels (%)

Those kernels which were translucent, attain full size, show normal starch compaction and allow light to pass through them were classified as normal kernels. The normal kernels were calculated by subtracting all the abnormal kernels from total number of spikelets.

3.6.4.4 Chalky kernels (%)

The chalky kernels were calculated on the basis of chalky area present in different parts of the kernel by visual observation through high power magnifying glass. Chalky kernels were expressed in percentage after counting them.

3.6.4.5 Grain length (cm)

For measuring kernel length 100 seeds were selected from each experimental unit and length was recorded by using digital caliper.

3.6.4.6 Grain width (cm)

For measuring kernel width 100 seeds were selected from each experimental unit and width was recorded by using digital caliper.

3.6.4.7 Grain length and width ratio

Kernel length and width ratio was calculating by dividing the kernel length with kernel width.

3.6.4.8 Grain water absorption ratio

Grain water absorption ratio (WAR) was measured as a ratio of cooked rice to raw rice according to the formulae reported by Juliano *et al.* (1965).

$$WAR = \frac{Weight\ of\ cooked\ rice}{Weight\ of\ raw\ rice}$$

3.6.4.9 Kernel protein contents (%)

Protein contents were determined in rice grains first by carrying out Micro-Kjeldahl digestion and ammonia distillation. Then the digest was titrated to determine nitrogen concentration which was converted to protein by multiplying with the factor 5.95.

3.6.4.10 Kernel amylose contents (%)

The milled rice grains were ground on Restsch Mill equipped with 100 mesh sieve to determine the amylose contents by following the procedure reported by Juliano (1971). The intensity of blue color was measured at 620 nm in a spectrophotometer.

3.6.5 Chlorophyll contents determination

Chlorophyll contents were determined according to the methodology described by Yoshida *et al.* (1976) at panicle initiation stage. Fresh leaf tissues from the middle part of the main tiller were obtained and cut into small segments. From these segments, 2 g of the tissue was placed into a mortar and crushed thoroughly with a pestle. Acetone was added to make the final concentration of 80% (leaf blade contains approximately 80% H_2O) and the mixture was homogenized thoroughly. The mixture was passed through filter paper and the supernatant was poured into a 100-ml volumetric flask. The extraction procedure was repeated 2 to 3 times. Then, the volume of supernatant was brought to 100 ml with 80% acetone. Then, 5 ml of this solution was transferred into a 50 ml volumetric flask and make up to volume with 80% acetone. The absorbance of the leaf tissue extract was measured at 663 nm and 645 nm. Chlorophyll a and b contents were calculated according to the following formulae where D represents absorbance at given wavelength.

$$Ca = 0.0127 \times D663 - 0.00269 \times D645$$

$$Cb = 0.0229 \times D645 - 0.00468 \times D663$$

3.6.6 Economic and marginal analysis

Economic analysis was carried out by using the MSTATC ECON which utilizes the methodology suggested by CIMMYT (1988). The output obtained in this analysis was net benefit, measures of variability or risk and marginal returns for each treatment.

3.7 Statistical Analysis

Data collected were subjected to statistical analysis by using Fisher's analysis of variance technique and treatments' means were compared by using least significant difference (LSD) test at 5% probability level (Steel *et al.*, 1997).

Chapter 4

RESULT AND DISCUSSIONS

4.1 Experiment No. 1:

Evaluating the role of seed priming in improving the performance of nursery seedlings for system of rice intensification

4.1.1 Allometry and crop growth

4.1.1.1 Results

4.1.1.1.1 Leaf area index

Leaf area index increased consistently during the active growth period of plants and then started to decline during both years (Figure 4.1 a,b). The maximum leaf area index was recorded 65 days after transplanting in all the treatments of both the cultivars during the year 2010 (Figure 4.1 a) and the same trend was recorded during the year 2011 (Figure 4.1 b).

Among seedling age and osmopriming, maximum leaf area was recorded in 2 weeks old seedlings osmoprimed with $CaCl_2$ of both the cultivars in both years. However, the minimum leaf area index was recorded in non primed 4 weeks old seedlings of both the cultivars. Three weeks old seedlings resulted in higher leaf area index than that of 4 weeks old seedlings in both the cultivars during the year 2010 (Figure 4.1 a) and similar trend was also recorded during the year 2011 (Figure 4.1 b).

4.1.1.1.2 Leaf area duration

The trend in leaf area duration was similar to that of leaf area index as depicted from Figure 4.2 a,b. Higher leaf area duration in both the cultivars was recorded in 2 weeks old seedlings primed with $CaCl_2$ than that of primed and non primed 3 and 4 weeks old seedlings. Among seedling age higher leaf area duration was recorded in 2 weeks old seedlings than that of 3 and 4 weeks old seedlings in both the cultivars during the year 2010 (Figure 4.2 a) and similar trend was also recorded during the year 2011 (Figure 4.2 b). However, 3 weeks old seedlings performed better for leaf area duration than that of 4 weeks old seedlings during both years. For the cultivars leaf area duration was not differed significantly during both years (Figure 4.2 a,b).

4.1.1.1.3 Crop growth rate (g m^{-2} d^{-1})

Crop growth rate increased consistently during the active growth period and then declined suddenly during the maturity period for both cultivars during both years (Figure 4.3 a,b). For interaction of seedling age with osmopriming indicated that highest crop growth rate was recorded in 2 weeks old seedling osmoprimed with $CaCl_2$ in both cultivars during the year 2010 (Figure 4.3 a) and similar trend was also recorded during the year 2011 (Figure 4.3 b).

The least crop growth rate was recorded in untreated seeds of 4 weeks old seedlings in both cultivars during both years. Despite lower crop growth rate, osmoprimed and untreated seeds of 3 weeks old seedlings performed better than osmoprimed and untreated seeds of 4 weeks old seedlings in both cultivars during both years (Figure 4.3 a,b).

4.1.1.1.4 Net assimilation rate (g m^{-2} d^{-1})

The highest net assimilation rate was recorded in 2 weeks old seedlings which were primed with $CaCl_2$ in both the cultivars during both years (Figure 4.4 a,b). A decreasing trend was recorded with increase in seedling age in both cultivars for net assimilation rate during both years. The least net assimilation rate was recorded in untreated seeds of 4 weeks old seedlings in both cultivars during both years. For seed priming, primed seeds with $CaCl_2$ resulted in higher net assimilation rate than that of untreated seeds in both the years (Figure 4.4 a,b).

4.1.1.2 Discussion

All the growth relevant parameters were significantly influenced by the seedling age and osmopriming in both cultivars during both years. Among the three seedlings' age, 2 weeks old seedlings significantly improved the leaf area index (Figure 4.1 a,b), leaf area duration (Figure 4.2 a,b), crop growth rate (Figure 4.3 a,b) and net assimilation rate (Figure 4.4 a,b) during both years. The improvement in leaf area index due to age of seedling might be the result of improved strengthened seedlings growth as younger seedlings received less transplanting shock and recovered earlier than 3 and 4 weeks old seedlings.

Improvement in growth rate in younger seedlings seems to be the result of accelerated growth due to increased tillering and shortened phyllochron (Nemato *et al.*,

1995) than that of older seedlings of 3 and 4 weeks. The younger seedlings retrieved earlier and faced less effect of transplanting shock (Stoop *et al*., 2002) than that of older seedlings and this might have resulted in improved growth rate, leaf area index and net assimilation rate. Similarly, osmopriming with $CaCl_2$ tremendously improved crop growth rate, leaf area index, leaf area duration and net assimilation rate during both the years. This seems to be the result of earlier and uniform seedling stand establishment that gave a healthier start (Farooq *et al*., 2006a).

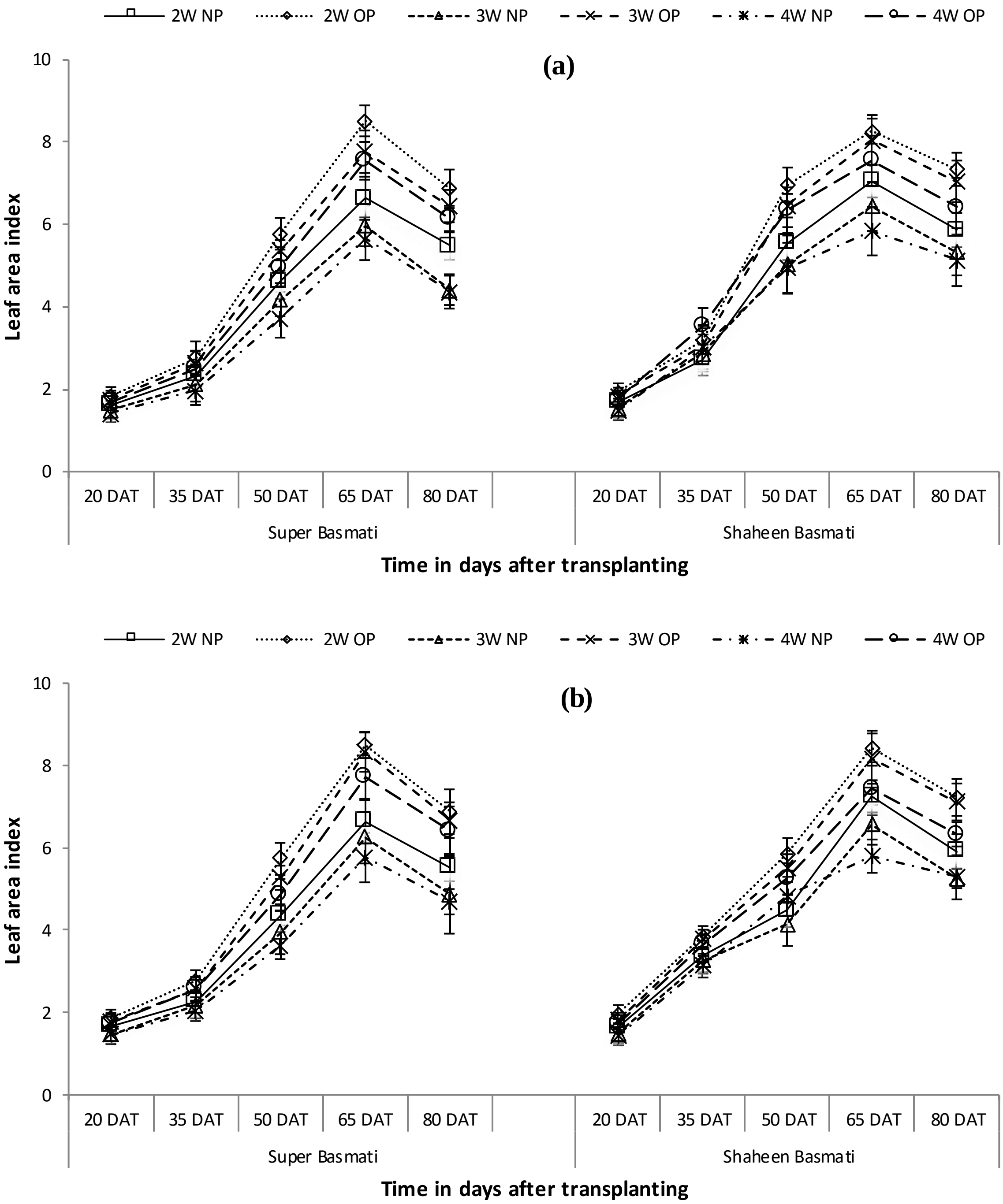


Figure 4.1: Influence of seedling age and osmopriming on leaf area index of fine rice cultivars during the year (a) 2010 (b) 2011
W = weeks old seedlings, NP = non primed, OP = osmoprimed with $CaCl_2$, Error bar = standard Error

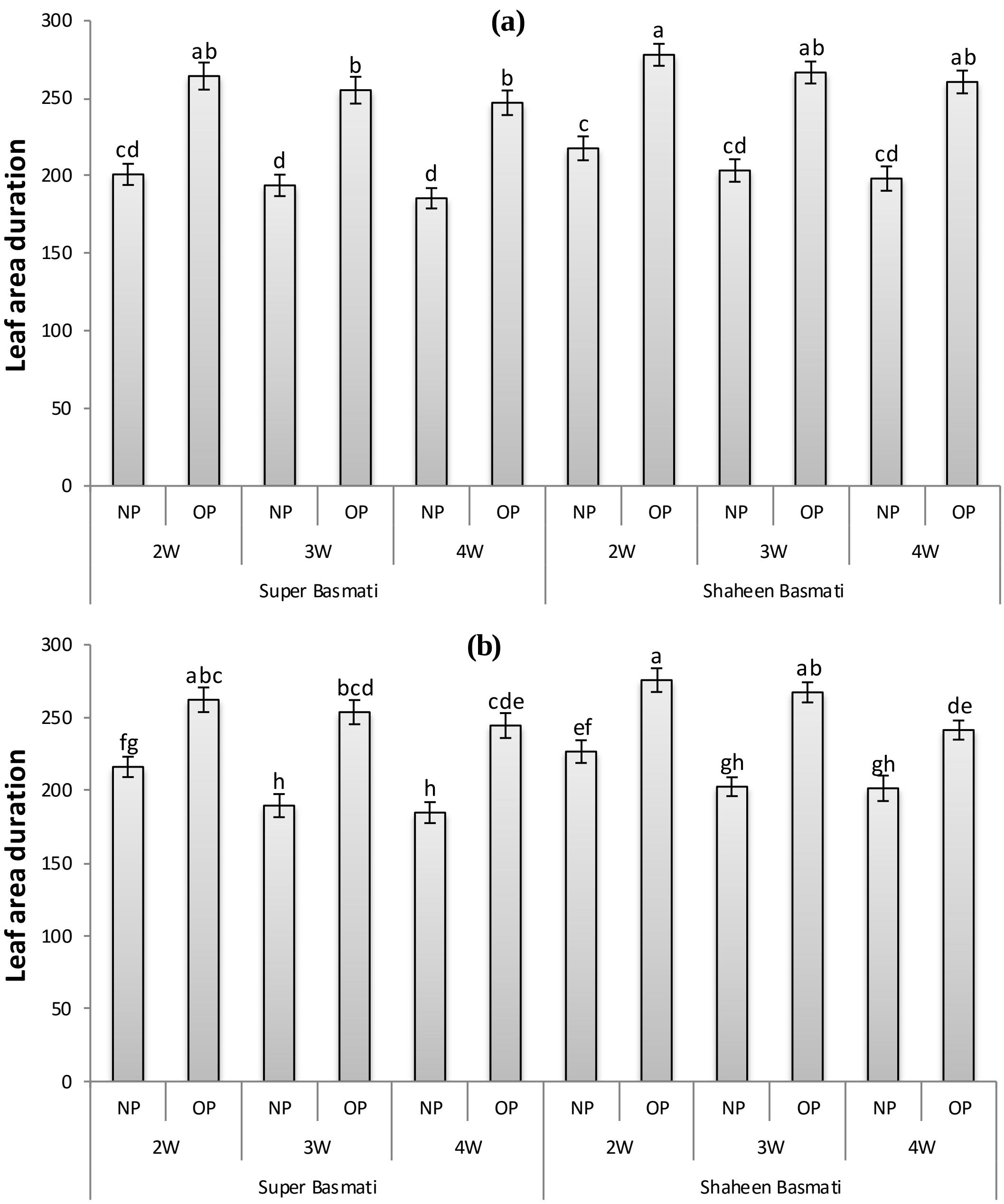
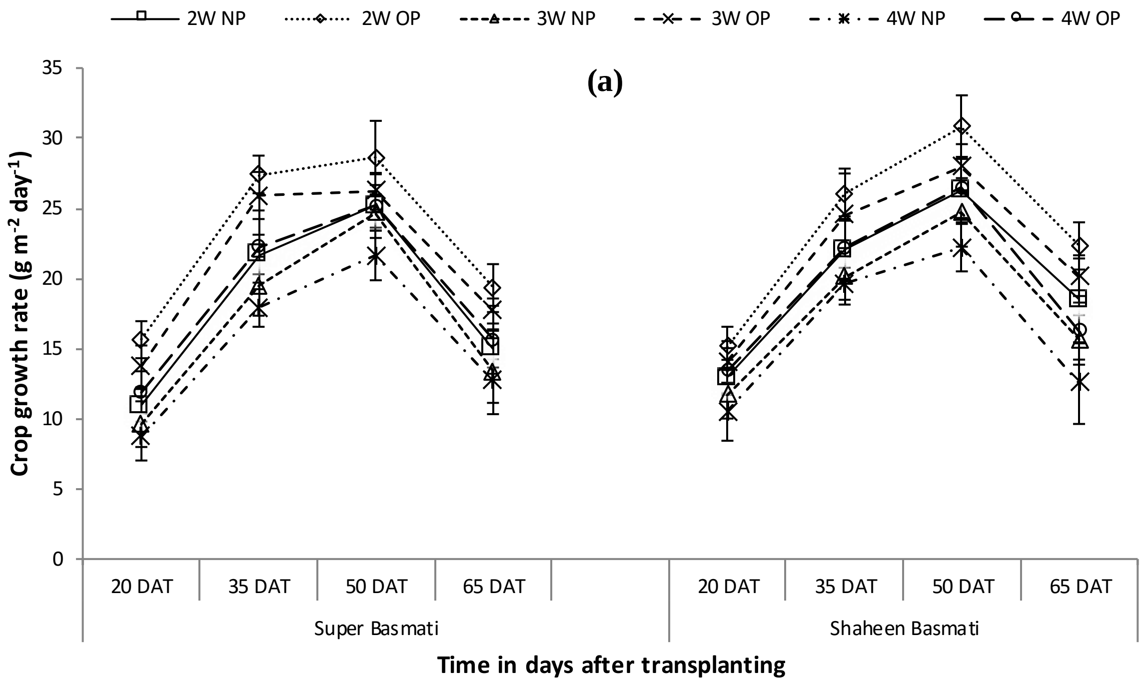


Figure 4.2: Influence of seedling age on leaf area duration of fine rice cultivars grown under system of rice intensification during the year (a) 2010 (b) 2011
W= weeks old seedlings, NP= non primed, OP= osmoprimed ($CaCl_2$), Error bar = standard Error



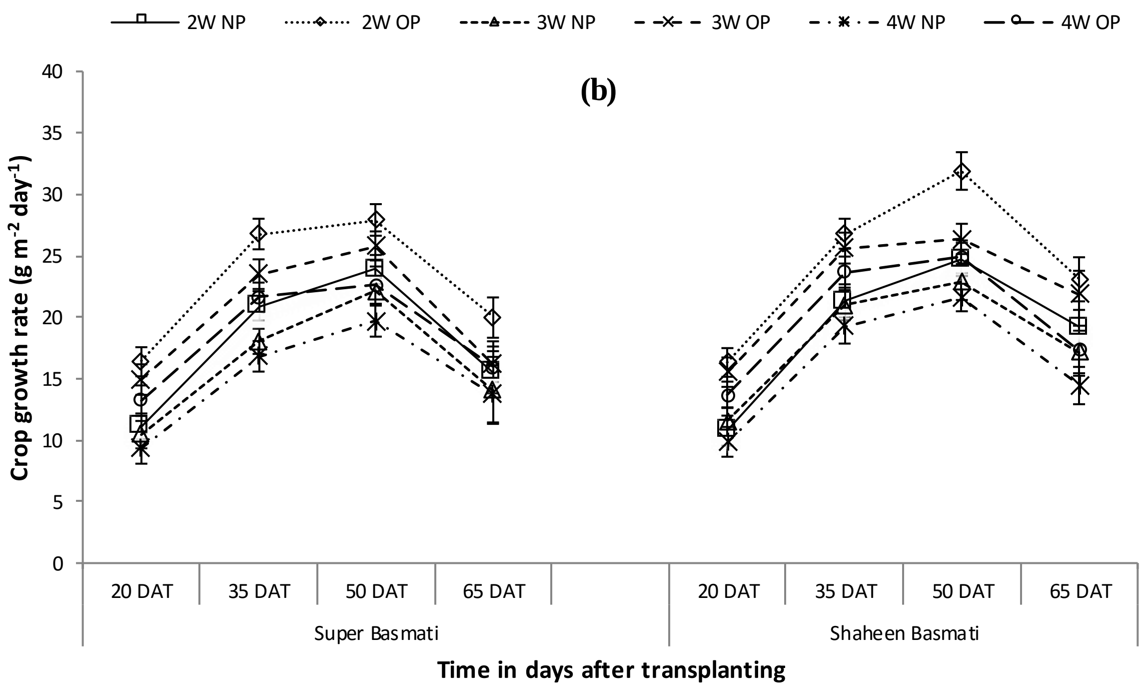
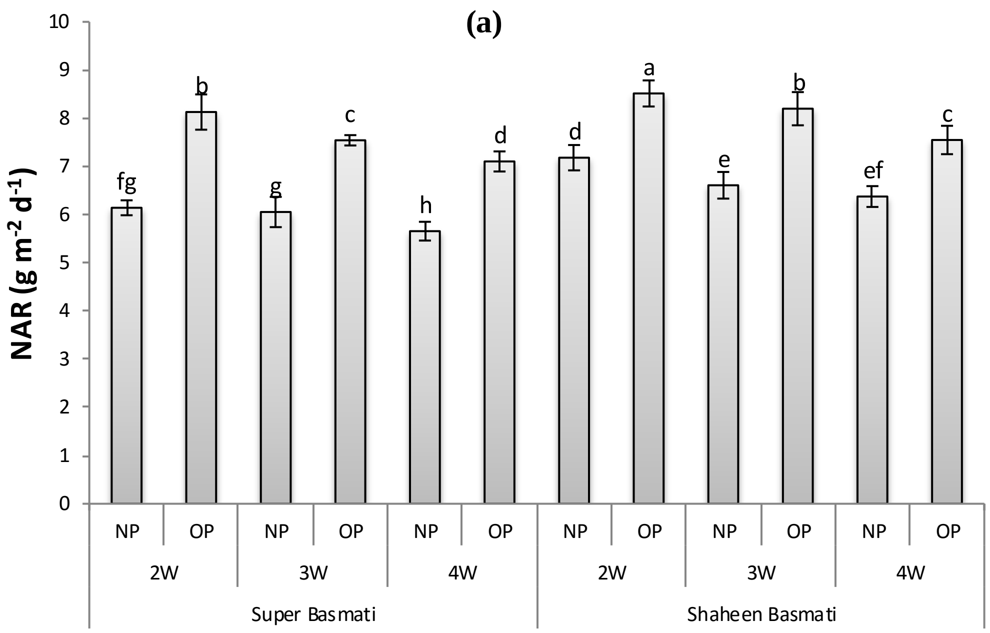


Figure 4.3: Influence of seedling age and osmopriming on crop growth rate of fine rice cultivars during the year (a) 2010 (b) 2011
W = weeks old seedlings, NP = non primed, OP = osmoprimed with $CaCl_2$, Error bar = standard Error



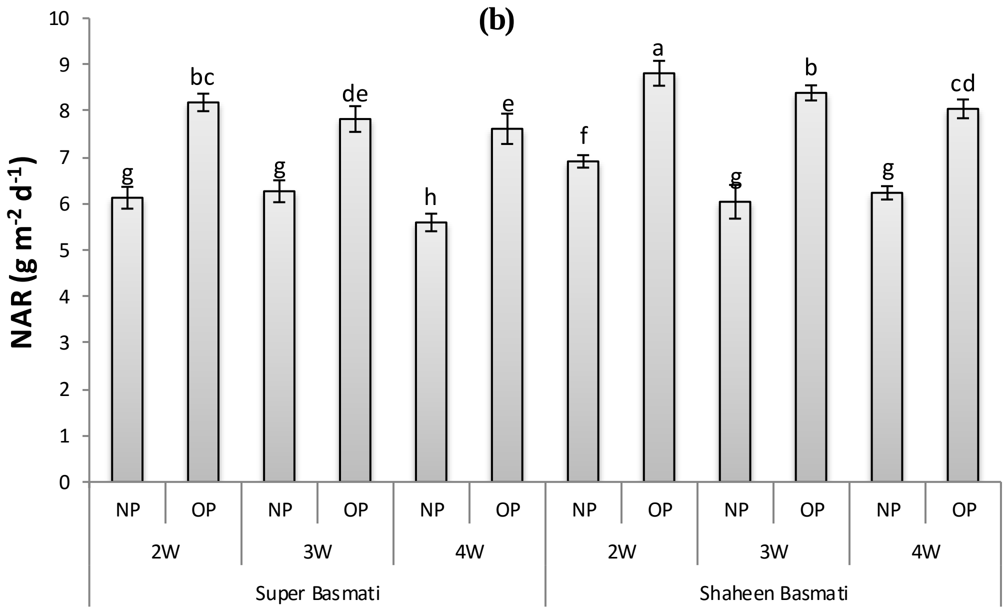


Figure 4.4: Influence of seedling age on net assimilation rate of fine rice cultivars grown under system of rice intensification during the year (a) 2010 (b) 2011

W= weeks old seedlings, NP= non primed, OP= osmoprimed with $CaCl_2$, Error bar = standard Error

4.1.2 Phenology

4.1.2.1 Results

4.1.2.1.1 Days to heading

Nursery seedling age and osmopriming significantly affected the days to heading (Table 4.1). Rice cultivars also differed significantly for days to heading whereas interaction of rice cultivars with osmopriming only significant during 2010 (Table 4.1). However, interaction of rice cultivars with seedling age and with both seedling age and osmopriming was not significant. Similarly, the interaction of seedling age with osmopriming was also non significant during both years (Table 4.1).

Rice cultivar, Shaheen Basmati took less time to heading than Super Basmati during both years of experimentation (Table 4.2). Two weeks old seedlings took less time to heading than 3 and 4 weeks old seedlings during both the years. Osmopriming in Shaheen Basmati significantly reduced the time taken to heading than that of Super Basmati and non primed treatment during the year 2010 (Table 4.3). Interaction among cultivars and osmopriming revealed that osmopriming in Shaheen Basmati significantly took less days to heading (64.3 d) than that of Super Basmati (85.1 d) and non primed seeds of both the cultivars (Table 4.3).

4.1.2.1.2 Heading to maturity (Days)

Significant differences were recorded among rice cultivars regarding days from heading to maturity while seedling age and osmopriming were not significant as revealed from the analysis of variance (Table 4.1). Interaction of rice cultivars with seedling age and osmopriming were significant for days from heading to maturity during both the years while interaction among seedling age and osmopriming was only significant in 2010. However, overall interaction among cultivars, seedling age and osmopriming was not significant during both the years (Table 4.1).

Shaheen Basmati cultivar took less time from heading to maturity when 4 weeks old seedlings were transplanted as compared to 2 and 3 weeks old seedlings during both the years (Table 4.4). However, 2 weeks old seedlings of Super Basmati took less time from heading to maturity during both the years (Table 4.4). Osmopriming in Super Basmati and non primed Shaheen Basmati took less time from heading maturity during both the years (Table 4.5).

4.1.2.2 Discussion

The difference in days to heading and heading to maturity between the rice cultivars is due to the genetic characteristics of the varieties (Table 4.2, Table 4.4). In Shaheen Basmati fewer days to heading, and heading to maturity, might be due to short life cycle of the cultivar and it might accomplish all growth stages earlier as compared to long duration Super Basmati.

Different nursery seedlings' age significantly lowered the days taken to heading and heading to maturity in rice cultivars. Transplanting younger seedling significantly reduced the days taken to heading and heading to maturity (Table 4.2, Table 4.4). Reduction of time for phenological development due to seedling age is crucial. It seems due to more robust growth of rice cultivars when 2 weeks old seedlings were transplanted compared to 3 and 4 weeks old seedlings. The higher days taken to heading in lanky seedlings were perhaps due to more time for crop establishment and slower root and shoot growth because of poor utilization of resources (Brar *et al.*, 2012). The older aged seedling required more time to heading and heading to maturity due to slow establishment of these seedlings in the field than that of younger seedlings (Reddy & Reddy, 1992).

Osmopriming in both the cultivars significantly lowered the days taken to heading and heading to maturity (Table 4.3, Table 4.5) due to better crop establishment which results in vigorous crop growth and timely completion of all growth stages. Lowering of time taken to heading and heading to maturity might be the result of healthy and vigorous start of seedlings due to earlier and uniform germination (Farooq et al., 2006a; Basra *et al.*, 2004). It has been reported that seed priming enhance vigor levels due to rapid and regulated production of emergence metabolites (Basra *et al.*, 2005) which might resulted in healthy start of seedlings to accomplish growth stages earlier than untreated seeds.

4.1.3 Agronomic and yield related attributes

4.1.3.1 Results

4.1.3.1.1 Plant height at maturity (cm)

Rice cultivars differed significantly for plant height during both the years whereas osmopriming was only significant during the year 2010 as depicted from the analysis of variance (Table 4.1). Seedling age and interaction of rice cultivars with osmopriming was significant only during the year 2011. However, interaction among cultivars and seedling age, seedling age and osmopriming and overall interaction among rice cultivars, seedling age and osmopriming was not significant during both years (Table 4.1).

Higher plant height was recorded in Shaheen Basmati compared to Super Basmati during both years (Table 4.6). Among seedling age, 2 weeks old seedlings outperformed than 4 weeks old seedlings only during the year 2011 while 2 and 3 weeks old seedlings were found similar regarding plant height (Table 4.6). Osmopriming with $CaCl_2$ improved the plant height than that of untreated seeds during both the years (Table 4.7).

4.1.3.1.2 Productive tillers

Rice cultivars differed significantly for productive tillers, seedling age and osmopriming also affected the plant height during both the years (Table 4.1). Interaction between rice cultivars and seedling age was significant during both the years regarding productive tillers while interaction among cultivars and osmopriming was only significant during 2011. Similarly interaction among seedling age and priming and overall interaction among rice cultivars, seedling age and priming was also significant only during the year 2010 (Table 4.1).

Shaheen Basmati produced more productive tillers than Super Basmati during both years. While transplanting 2 weeks old seedlings outperformed than 3 and 4 weeks old seedlings regarding productive tillers during both the years (Table 4.8). Interaction of rice cultivars and seedling age revealed that 2 weeks old seedlings of Shaheen Basmati produced more number of productive tillers followed by Super Basmati with same seedling age during both the years. The fewest productive tillers were recorded in 4 weeks old seedlings of Super Basmati in both the years (Table 4.8).

Osmopriming resulted in higher numbers of productive tillers than the non primed seeds in both years (Table 4.10). Interaction of osmopriming with rice cultivars indicated that osmopriming in Shaheen Basmati resulted in greater number of productive tillers than non primed seeds of both the cultivars and osmopriming in Super Basmati during 2011 (Table 4.9). However, Super Basmati produced fewest productive tillers when the seeds were not primed.

From interaction table of seedling age and seed priming, a higher number of productive tillers was recorded in 2 weeks old seedlings primed with $CaCl_2$ than the osmoprimed and non primed 3 and 4 weeks old seedlings during the year 2010 (Table 4.10). The overall interaction of cultivars, seedling age and osmopriming indicated that 2 weeks old seedlings of Shaheen Basmati which were primed with $CaCl_2$ produced maximum productive tillers followed by 2 weeks old seedlings of the same cultivar which were not primed and 2 weeks old seedlings of Super Basmati which were primed with

$CaCl_2$. However, the least productive tillers were recorded in 4 weeks old seedlings of Super Basmati which were not primed (Table 4.11).

4.1.3.1.3 Unproductive tillers

Unproductive tillers were differed significantly when nursery of various age was sown during both the years. However, priming treatments were only significantly differed during 2011 (Table 4.12). However, interaction of fine rice cultivars with seedling age and osmopriming and overall interaction of cultivars with both seedlings age and osmopriming was not significant during both years. Similarly, interaction of seedling age with osmopriming was also not significant during both years (Table 4.12).

Among different seedling age, fewest unproductive tillers were recorded where 2 weeks old seedlings were transplanted than 3 and 4 weeks old seedlings during both years while 3 and 4 week old seedlings were statistically indistinguishable (Table 4.13). Osmopriming with $CaCl_2$ resulted in fewer unproductive tillers than non primed during 2011 (Table 4.13).

4.1.3.1.4 Panicle length (cm)

Seedling age significantly affected panicle length only during 2011 whereas osmopriming significantly affected the panicle length during both years (Table 4.12). While the interaction of cultivars with seedling age, osmopriming and with both seedling age and osmopriming was not significant for panicle length during both the years. Similarly, interaction among seedling age and osmopriming was also not significant during both the years (Table 4.12).

Mean comparison table (Table 4.14) indicated that panicle length was higher in 2 week old seedlings than 3 and 4 weeks old seedlings during 2011. Osmopriming with $CaCl_2$ increased the panicle length than non primed during both the years (Table 4.14).

4.1.3.1.5 Kernels per panicle

Fine rice cultivars, seedling age and osmopriming significantly affected kernels per panicle during both the years (Table 4.12). Similarly, interaction among fine rice cultivars and seedling age was also significant during both years. However, rice cultivar interaction with osmopriming and with both seedling age and osmopriming was not significant for kernels per panicle during both years. Similarly, interaction of seedling age with osmopriming was also not significant during both the years (Table 4.12).

Between rice cultivars, Shaheen Basmati produced more kernels per panicle than Super Basmati during both years (Table 4.15). Among different seedling age, 2 and 3 weeks old seedlings produced more kernels per panicle and were statistically at par than 4 weeks old seedlings in both years (Table 4.15).

Osmopriming with $CaCl_2$ produced significantly more kernels per panicle than that of untreated seeds in both years (Table 4.16). The interaction among seedling age and cultivars indicated that 3 week old seedlings of Shaheen Basmati produced more kernels per panicle during 2010 followed by 2 weeks old seedlings of the same cultivar whereas both the seedlings age were at par regarding kernels per panicle during 2011. The fewest kernels per panicle were recorded in 4 week old seedlings of Super Basmati during both years (Table 4.15).

4.1.3.1.6 1000-kernel weight (g)

Cultivars and seedling age significantly affected 1000 kernel weight during both years (Table 4.12) while osmopriming only affected during the year 2010. However, interaction among rice cultivars and osmopriming was also significant only during the year 2011 (Table 4.12). The interaction of rice cultivars with seedling age and both with seedling age and osmopriming did not affected 1000 kernel weight significantly during both the years. Likewise, seedling age interaction with osmopriming was also not significant only during 2010 (Table 4.12).

Higher 1000 grain weight was recorded in Shaheen Basmati than Super Basmati in both years (Table 4.17). Two weeks old seedling outperformed with respect to 1000 grain weight than 3 and 4 weeks old seedling in both years. However, 3 weeks old seedlings were statistically indistinguishable from 2 week old seedling only during year 2011 (Table 4.17). For seed priming, osmopriming with $CaCl_2$ produced greater 1000 grain weight compared to non primed seed during both the years (Table 4.18). The interaction of cultivars with osmopriming indicated that greater 1000 kernel weight was recorded in Shaheen Basmati which was primed with $CaCl_2$ followed by Super Basmati with same priming treatment during the year 2011. The least 1000 grain weight was recorded where non primed seeds of Super Basmati were used (Table 4.18).

Table 4.1 **Analysis of variance for the influence of seedling age and osmopriming on days to heading, heading to maturity, plant height and productive tillers of fine rice cultivars**

		Mean sum of squares							
		Days to heading		Heading to maturity (days)		Plant height (cm)		Productive tillers (m^{-2})	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Varieties (V)	1	2844**	3117**	434.03*	1236.7*	4993.8*	3541.36**	11757**	18432**
$Error_1$	2	7.19	8.44	11.19	18.11	99.53	5.05	23.84	105.18
Seedling age (A)	2	348.9**	304.8**	1.69	4.69	137.58	170.53*	19138**	21801**
V × A	2	0.36 ns	6.78	38.53**	47.19**	18.69	2.061	4956.8**	2255.8**
$Error_2$	8	8.40	15.57	3.61	1.57	43.39	21.46	193.96	201.91
Osmopriming (P)	1	676**	1100**	4.69	4.69	300.4*	318.56**	19465.6**	16517.2**
V × P	1	81*	38.03	90.25**	261.4**	1.00	0.51	74.41	428.78*
A × P	2	20.58	6.78	17.69*	10.36	3.69	1.22	477.48*	50.26
V × A × P	2	23.08	8.78	11.08	4.53	2.58	5.22	426.86*	137.09
$Error_3$	12	15.06	14.53	4.25	8.14	41.42	15.41	98.70	88.27

SOV = source of variation, df = degree of freedom, * = significant ($P<0.05$), ** = highly significant ($P<0.01$), ns = non significant
Year effect was not significant

Table 4.2: Influence of seedling age on days to heading of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	82.0	64.3	73.2 C	83.3	64.8	74.1 B
3 weeks old	89.3	71.2	80.3 B	91.0	70.8	80.9 A
4 weeks old	92.5	75.0	83.8 A	92.5	75.3	83.9 A
Means	87.9 A	70.2 B		88.9 A	70.3 B	

LSD_{2010} (V) = 3.9, LSD_{2010} (A) = 2.8, LSD_{2011} (V) = 4.2, LSD_{2011} (A) = 3.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.3: Influence of osmopriming on days to heading of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	90.8 a	76.0 c	83.4 A	93.4	76.9	85.2 A
Osmopriming	85.1 b	64.3 d	74.7 B	84.4	63.8	74.1 B

LSD_{2010} (P) = 2.9, LSD_{2010} (V × P) = 4.0, LSD_{2011} (P) = 2.8
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.4: Influence of seedling age on heading to maturity of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	32.2 b	28.8 c	30.5	34.0 c	25.8 d	29.9
3 weeks old	33.7 ab	26. 7 cd	30.2	36.5 b	25.5 d	31.0
4 weeks old	36.2 a	25.7 d	30.9	39.0 a	23.0 e	31.0
Means	34.0 A	27.1 B		36.5 A	24.8 B	

LSD_{2010} (V) = 3.9, LSD_{2010} (V × P) = 2.5, LSD_{2011} (V) = 4.2, LSD_{2011} (V × P) = 1.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.5: Influence of osmopriming on heading to maturity of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	35.2 a	25.1 d	30.2	39.6 a	22.4 d	31.0
Osmopriming	32.8 b	29.0 c	30.9	33.4 b	27.1 c	30.3
Means	34.0 A	27.1 B		36.5 A	24.8 B	

LSD_{2010} (V) = 3.9, LSD_{2010} (V × P) = 2.2, LSD_{2011} (V) = 4.2, LSD_{2010} (V × P) = 2.9
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.6: Influence of seedling age on plant height of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	123	150	136	127	148	137 A
3 weeks old	120	142	131	124	144	134 A
4 weeks old	119	141	130	120	139	130 B
Means	121 B	143 A		124 B	144 A	

LSD_{2010} (V) = 14.3, LSD_{2011} (V) = 3.2, LSD_{2011} (A) = 4.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.7: Influence of osmopriming on plant height of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	118	142	130 B	121	141	131 B
Osmopriming	124	147	135 A	127	147	137 A

LSD_{2010} (P) = 2.9, LSD_{2011} (P) = 2.9
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.8: Influence of seedling age on productive tillers of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	415 b	494 a	455 A	415 b	488 a	452 A
3 weeks old	387 cd	386 cd	386 B	372 d	390 cd	381 B
4 weeks old	369 d	400 bc	385 B	353 e	397 bc	375 B
Means	390 B	427 A		380 B	425 A	

LSD_{2010} (V) = 7.3, LSD_{2010} (A) = 13.0, LSD_{2010} (V × A) = 18.4, LSD_{2011} (V) = 14.4, LSD_{2011} (A) = 13.4, LSD_{2011} (V × A) = 18.9
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.9: Influence of osmopriming on productive tillers of fine rice cultivars grown under system of rice intensification

Osmopriming	2010		2011	
	Super Basmati	Shaheen Basmati	Super Basmati	Shaheen Basmati
Non primed	366	405	362 c	400 b
Osmopriming	415	448	398 b	450 a

LSD_{2011} (V × P) = 9.6
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.10: Influence of seedling age and osmopriming on productive tillers of fine rice cultivars grown under system of rice intensification

Seedling age	2010		2011	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	426 b	483 a	429	474
3 weeks old	370 d	403 c	362	400
4 weeks old	360 d	410 c	352	398
Means	385 B	432 A	381 B	424 A

LSD_{2010} (P) = 7.3, LSD_{2010} (A × P) = 12.5, LSD_{2011} (P) = 6.8
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.11: Influence of seedling age and osmopriming on productive tillers of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	389 ef	441 c	463 b	525 a	397	433	461	515
3 weeks old	363 gh	412 d	378 efg	393 e	359	384	365	415
4 weeks old	345 h	392 e	374 fg	427 cd	329	376	375	420

LSD_{2010} (V × A × P) = 17.7

Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.12: Analysis of variance for the influence of seedling age and osmopriming on unproductive tillers, panicle length, kernels per panicle and 1000-kernel weight of fine rice cultivars

		Mean sum of squares							
		Unproductive tillers (m^{-2})		Panicle length (cm)		Kernels per panicle		1000 kernel weight (g)	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Varieties (V)	1	1444	34.03	118.45	170.74	5215.3**	6950**	114.85*	106.43**
$Error_1$	2	86.33	323.36	18.94	50.29	22.39	3.89	3.61	0.45
Seedling age (A)	2	2793**	3072**	30.30	114.5**	191.5*	298.2**	9.51*	28.39*
V × A	2	32.25	141.44	11.23	4.88	185.3*	79. 57*	1.19	0.34
$Error_2$	8	247.81	286.99	11.92	10.61	25.96	17.33	1.53	5.16
Osmopriming (P)	1	576	4784**	95.71**	73.39*	331.9**	459.4**	47.8**	48.3
V × P	1	106.78	42.25	7.20	2.15	39.9	82.20	0.003	26.9**
A × P	2	188.58	14.11	2.61	0.46	8.67	25.46	0.52	3.58
V × A × P	2	45.03	104.33	0.19	4.69	32.94	9.239	2.49	1.51
$Error_3$	12	256.50	260.69	8.51	7.94	11.10	20.99	1.36	2.72

SOV = source of variation, df = degree of freedom, MS = mean sum of square, * = significant (P<0.05), ** = highly significant (P<0.01), ns = non significant
Year effect was not significant

Table 4.13: Influence of seedling age and osmopriming on unproductive tillers of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Non primed	Primed ($CaCl_2$)	Means	Non primed	Primed ($CaCl_2$)	Means
2 weeks old	99	89	94 B	110	85	98 B
3 weeks old	120	105	113 A	126	102	114 A
4 weeks old	124	125	124 A	140	119	130 A
Means	114	106		125 A	102 B	

LSD_{2010} (A) = 14.8, LSD_{2011} (A) = 16.0, LSD_{2011} (P) = 11.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.14: Influence of seedling age and seed priming on panicle length of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Non primed	Primed ($CaCl_2$)	Means	Non primed	Primed ($CaCl_2$)	Means
2 weeks old	26.4	30.6	28.5	28.5	31.8	30.2 A
3 weeks old	24.1	27.4	25.8	24.0	26.6	25.3 B
4 weeks old	24.5	26.8	25.6	23.1	25.8	24.4 B
Means	25.0 B	28.3 A		25.2 B	28.1 A	

LSD_{2010} (P) = 2.1, LSD_{2011} (P) = 2.1, LSD_{2011} (A) = 3.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.15: Influence of seedling age on kernels per panicle of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	86 c	104 b	95 A	86. c	115 a	101 A
3 weeks old	81 cd	113 a	97 A	82 cd	114 a	98 A
4 weeks old	79 d	100 b	89 B	80 d	102 b	91 B
Means	82 B	106 A		83 B	110 A	

LSD_{2010} (V) = 6.8, LSD_{2010} (A) = 4.8, LSD_{2010} (V × A) = 6.8, LSD_{2011} (V) = 2.9, LSD_{2011} (P) = 4.0, LSD_{2011} (V × A) = 5.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.16: Influence of seed priming on kernels per panicle of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	80	102	91 B	81	105	93 B
Osmopriming	84	110	97 A	85	116	100 A

LSD_{2010} (P) = 2.4, LSD_{2011} (P) = 3.3, LSD_{2011} (V × P) = 9.6
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.17: Influence of seedling age on 1000-krenel weight of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	17.7	20.5	19.1 A	17.0	20.8	18.9 A
3 weeks old	15.7	19.7	17.7 B	15.8	19.1	17.5 AB
4 weeks old	15.5	19.4	17.5 B	14.3	17.4	15.9 B
Means	16.3 B	19.9 A		15.7 B	19.9 A	

LSD_{2010} (V) = 2.7, LSD_{2010} (A) = 1.2, LSD_{2011} (V) = 1.0, LSD_{2011} (A) = 2.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.18: Influence of seed priming on 1000-kernel weight of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	15.1	18.7	16.9 B	15.4 c	17.1 b	16.3 B
Osmopriming	17.4	21.0	19.2 A	16.0 bc	21.2 a	18.6 A

LSD_{2010} (P) = 0.9, LSD_{2011} (P) = 1.2, LSD_{2011} (V × P) = 1.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

4.1.3.1.7 Kernel yield (t ha^{-1})

Kernel yield was significantly affected by rice cultivars, seedling age and seed priming during both the years (Table 4.19). Similarly, interaction of rice cultivars with seedling age was also found significant regarding kernel yield whereas cultivars interaction with osmopriming and with both seedling age and osmopriming, and among seedling age and osmopriming was not significant in both the years (Table 4.19).

Highest kernel yield was recorded in Shaheen Basmati than Super Basmati during both the years. In different seedling age, 2 weeks old seedlings resulted in maximum kernel yield than 3 and 4 weeks old seedling. However, transplanting seedlings of 3 weeks old resulted in better kernel yield than 4 weeks old (Table 4.20). The interaction among rice cultivars and seedling age showed that 2 weeks old seedling of Shaheen Basmati produced maximum kernel yield followed by 2 weeks old seedling of Super Basmati and these were superior from 3 and 4 weeks old seedling of both the cultivars in both the years (Table 4.20). Osmopriming with $CaCl_2$ resulted in higher kernel yield than non primed and this pattern was same during both the years (Table 4.21).

4.1.3.1.8 Straw yield (t ha^{-1})

The analysis of variance (Table 4.19) indicated that straw yield was significantly affected by different seedling age and osmopriming while no significant variation was recorded between the fine rice cultivars in both the years. The interaction of rice cultivars with seedling age was also found significant in both the years while cultivars interaction with osmopriming was only significant during 2010. Likewise interaction of seedling age with osmopriming and of rice cultivars with both seedling age and osmopriming was also not significant during both the years (Table 4.19).

4.1.3.1.9 Harvest index (%)

The data prevailing to harvest index indicated that significant variation was recorded in fine rice cultivars, seedling age and seed priming during both the years (Table 4.19). Rice cultivars interaction with seedling age, osmopriming and with both seedling age and osmopriming was only significant during the year 2010. However, interaction of different seedling age with osmopriming was not significant during both the years (Table 4.19).

Between rice cultivars, highest harvest index was recorded in Shaheen Basmati than Super Basmati in both the years (Table 4.24). Whereas, among different seedling age, greater harvest index was recorded in 2 weeks old seedling than 3 and 4 weeks old seedling during both years. Osmopriming with $CaCl_2$ recorded maximum harvest index than non primed in both the years (Table 4.25). The interaction of cultivars with seedling age revealed that maximum harvest index was recorded in Shaheen Basmati when transplanted with 2 weeks old seedling followed by Super Basmati with the same seedling age and these were superior from 3 and 4 weeks old seedling of both the cultivars during the year 2010 (Table 4.24). Similarly, osmopriming in Shaheen Basmati resulted in maximum harvest index compared to osmopriming in Super Basmati and non primed while the least harvest index was recorded in non primed Super Basmati during the year 2010 (Table 4.25).

The overall interaction of cultivars, seedling age and osmopriming revealed that osmopriming with $CaCl_2$ in 2 weeks old seedling of Shaheen Basmati yielded maximum harvest index followed by non primed 2 weeks old seedling of Shaheen Basmati and this was at par with osmopriming in 2 weeks old seedling of Super Basmati. The least harvest index was recorded in non primed 4 weeks old seedling of Super Basmati during the year 2010 (Table 4.26).

4.1.3.2 Discussion

The present study revealed that osmopriming with $CaCl_2$ and transplanting younger seedling of two different fine rice cultivars influenced the growth and yield related attributes which are discussed regarding plant height, productive and unproductive tillers, panicle length, kernels per panicle, 1000 kernel weight, kernel yield, straw yield and harvest index (Table 4.1, Table 4.12, Table 4.19). Among other factors that influenced the growth and yield of rice under SRI, the seedling age has an important role as it has tremendously affected the plant height, tiller production, kernels per panicle and other yield contributing attributes.

More tillers (Table 4.8) in young (2 weeks old) seedling indicate that younger seedling received shorter phyllochron duration which resulted in enhanced tiller production. It is evident that tiller production could be optimized by using younger seedling than direct seeding or using seedling of older age (Pasuquin *et al.*, 2008) due to the inverse relation between tiller production and length of phyllochron (Nemato *et al.*, 1995).

In the current study it is obvious that transplanting younger seedling has consistently improved the grain yield due to increased tiller production, kernels per panicle and 1000 kernel weight (Table 4.8, Table 4.15, Table 4.17) as younger seedling took longer growth period over 3 and 4 weeks old seedling. Similar trend was also recorded by Brar *et al.* (2012) who reported that transplanting younger seedling increased yield and yield contributing attributes. Improved kernel and straw yield and greater harvest index due to the age of seedling might be result of improved nutrient supply by promoting shorter phyllochron and greater tiller production (Nemato *et al.*, 1995). These results are in accordance with the findings of Nayak *et al.* (2006) who also reported greater number of tillers in younger seedling than that of older seedling which ultimately resulted in increased yield. SRI practices like wider spacing, soil aeration, transplanting single seedling improve nutrient supply and promote shorter phyllochron that resulted in increased tiller production and ultimately contributed towards higher yield (Ali *et al.*, 1995). Improved growth and yield characteristics due to the younger age seedling might be due to their ability to retrieve the transplanting shock as during transplanting minimal disturbance to smaller roots of younger seedling occur than that of larger roots of older seedling (Yamamoto *et al.*, 1998). The less transplanting shock received by the younger seedling is due to faster resumption of the rate of phyllochron development (Veeramani *et al.*, 2012).

Kernel yield improvement in SRI has also been reported in some recent research work in different countries (Namara *et al.*, 2008; Sato & Uphoff, 2007; Kabir & Uphoff, 2007). Similary, McHugh *et al.* (2002) also reported improvement in yield due to positive correlation between younger seedling age and grain yield. The increase in yield for younger seedling of 2 weeks old may be due to longer growth duration (14 days) than that of 3 and 4 weeks old seedling (Mandel *et al.*, 1984). However, 3 weeks old seedling (21 days), having adequate time for growth and development and took longer growth duration recorded comparatively less yield than 2 weeks old seedling as the seedling were thin at transplanting and received poor utilization of resources which resulted in tardy root and shoot growth (Brar *et al.*, 2012).

Osmopriming with $CaCl_2$ significantly improved plant height, tiller production, panicle length, kernels per panicle, 1000 kernel weight, kernel yield, straw yield and harvest index (Table 4.1, Table 4.12, Table 4.19). Improvement in plant height due to osmopriming seems to be the result of earlier, uniform and vigorous seedling that gave an energetic start (Farooq *et al.*, 2006b & 2007b; Basra *et al.*, 2004). The strong and vigorous seedling resulted in higher number of productive tillers per m^2 (Reddy, 2004). This increase in growth and yield components might be due to better crop establishment due to vigorous crop growth that resulted in timely completion of all growth stages. The

Ca^{2+} is an important essential element for growth (Taiz & Zeiger, 2006). Improvement in seedling emergence and seedling vigor due to osmopriming with $CaCl_2$ is also evident from the findings of Farooq *et al.* (2010).

Seedling improvement in tiller production due to osmopriming might be due to the result of higher germination percentage as reported by Farooq *et al.* (2006a) and also reported positive correlation between final emergence percentage and productive tillers. Further, it has been reported that priming with $CaCl_2$ improves Ca^{2+} contents of the seed which is helpful in seed metabolism. Improvement in plant growth and development might be attributed due to the crucial role of Ca^{2+} in maintenance of membrane integrity, transport processes across plasmalemma and enzyme activities (Taiz & Zeiger, 2006). In addition, Ca^{2+} also regulate the production of gibberellic acid in the scutellum and release hydrolases in the aleuronic layer and also transport them to the embryo for reserve mobilization (Srivastava, 2002).

The improvement in straw yield owing to osmopriming with $CaCl_2$ may be due to the earlier and uniform germination (Farooq *et al.*, 2006a) which might affected the plant height (Table 4.7), crop growth rate, net assimilation rate and finally resulted in increased straw yield (Table 4.23). Improvement in kernel yield as affected by osmopriming might be due to the improvement in yield contributing components which include productive tillers (Table 4.9), kernels per panicle (Table 4.16) and 1000 kernel weight (Table 4.18). Osmopriming with $CaCl_2$ improved the harvest index (Table 4.25) that seems to be the result of higher dry matter partitioning towards the panicle which also resulted in increased yield. Improved yield attributes with osmopriming is also evident from the findings of Farooq *et al.* (2006a & 2006b).

Table 4.19: Analysis of variance for the influence of seedling age and seed priming on kernel yield, straw yield and harvest index of fine rice cultivars

		Mean sum of squares					
		Kernel yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Varieties (V)	1	1.11*	0.69*	0.34	0.001	82.03*	38.42*
$Error_1$	2	0.05	0.01	0.13	0.05	1.388	0.87
Seedling age (A)	2	1.74**	1.77**	1.68**	1.98**	45.85**	47.17**
V × A	2	0.093**	0.08*	0.42*	0.44*	8.77**	2.53
$Error_2$	8	0.004	0.012	0.07	0.07	0.39	1.07
Osmopriming (P)	1	0.868**	0.67**	0.32*	1.58**	30.26**	11.27*
V × P	1	0.001	0.01	0.35*	0.05	2.42*	0.75
A × P	2	0.01	0.01	0.02	0.05	0.12	0.13
V × A × P	2	0.01	0.01	0.09	0.49	2.07**	4.50
$Error_3$	12	0.004	0.01	0.04	0.13	0.28	1.24

SOV = source of variation, df = degree of freedom, * = significant ($P<0.05$), ** = highly significant ($P<0.01$), ns = non significant
Year effect was not significant

Table 4.20: Influence of seedling age on kernel yield of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	4.30 b	4.63 a	4.47 A	4.30 b	4.59 a	4.44 A
3 weeks old	3.90 e	4.09 c	3.99 B	3.95 cd	4.06 c	4.00 B
4 weeks old	3.44 f	3.98 d	3.71 C	3.46 e	3.89 d	3.68 C
Means	3.88 B	4.23 A		3.90 B	4.18 A	

LSD_{2010} (V) = 0.3, LSD_{2010} (A) = 0.1, LSD_{2010} (V × A) = 0.08, LSD_{2011} (V) = 0.12, LSD_{2011} (A) = 0.1, LSD_{2011} (V × A) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.21: Influence of seed priming on kernel yield of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	3.72	4.08	3.90 B	3.78	4.03	3.90 B
Osmopriming ($CaCl_2$)	4.04	4.38	4.21 A	4.03	4.33	4.18 A

LSD_{2010} (P) = 0.1, LSD_{2011} (P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.22: Influence of seedling age on straw yield of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	13.7 ab	14.0 a	13.9 A	13.9 a	13.6 ab	13.8 A
3 weeks old	13.6 bc	13.2 de	13.4 B	13.5 bc	13.4 bc	13.4 B
4 weeks old	13.3 cd	12.9 e	13.1 C	12.7 d	13.2 c	12.9 C
Means	13.5	14.1		13.4	13.4	

LSD_{2011} (A) = 0.3, LSD_{2010} (V × A) = 0.4, LSD_{2011} (A) = 0.1, LSD_{2011} (V × A) = 0.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.23: Influence of seed priming on straw yield of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	13.6 a	13.2 b	13.4 B	13.1	13.2	13.2 B
Osmopriming ($CaCl_2$)	13.6 a	13.6 a	13.6 A	13.6	13.5	13.6 A

LSD_{2011} (P) = 0.1, LSD_{2010} (V × P) = 0.2, LSD_{2011} (P) = 0.3
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.24: Influence of seedling age on harvest index of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	31.3 b	33.1 a	32.2 A	30.9	33.7	32.3 A
3 weeks old	28.6 c	30.9 b	29.7 B	29.3	30.4	29.9 B
4 weeks old	25.8 d	30.8 b	28.3 C	27.2	29.6	28.4 C
Means	28.6 B	31.6 A		29.2 B	31.2 A	

LSD_{2010} (V) = 1.7, LSD_{2010} (A) = 0.6, LSD_{2010} (V × A) = 0.8, LSD_{2011} (V) = 1.3, LSD_{2011} (A) = 1.0
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.25: Influence of seed priming on harvest index of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	27.4 d	30.9 b	29.2 B	28.7	30.5	29.6 B
Osmopriming $CaCl_2$	29.8 c	32.3 a	31.0 A	29.6	31.9	30.7 A

LSD_{2010} (P) = 0.4, LSD_{2010} (V × P) = 0.5, LSD_{2010} (P) = 0.9
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.26: Influence of seedling age and seed priming on harvest index of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	30.4 de	32.3 b	32.0 b	34.1 a	30.4	31.4	33.3	34.2
3 weeks old	27.7 f	29.5 e	30.2 de	31.6 bc	28.4	30.3	30.2	30.6
4 weeks old	24.2 g	27.5 f	30.6 d	31.0 cd	27.4	27.1	28.1	31.0

LSD_{2010} (V × A × P) = 1.0
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

4.1.4 Grain and grain quality attributes

4.1.4.1 Results

4.1.4.1.1 Opaque grains (%)

In both the years, interaction of fine rice cultivars with seedling age and osmopriming significantly affected opaque grains (Table 4.27). Rice cultivars, seedling age and osmopriming did not differ significantly regarding opaque grains. Likewise, seedling age interaction with osmopriming and overall interaction of cultivars, seedling age and osmopriming was not significant during both the years (Table 4.27).

In interaction of cultivars with seedling age, maximum opaque grains were recorded in 4 weeks old seedling of Shaheen Basmati which was statistically at par with 2 weeks old seedling of Super Basmati and 3 weeks old seedling of Shaheen Basmati during the year 2010 (Table 4.28). During the year 2011, maximum opaque grains were recorded in 4 weeks old seedling of Shaheen Basmati followed by 2 weeks old seedling of Super Basmati while no significant difference was recorded in 3 weeks old seedlings of both cultivars, 4 weeks old seedling of Super Basmati and 2 weeks old seedling of Shaheen Basmati (Table 4.28). Interaction of rice cultivars with osmopriming revealed that osmopriming with $CaCl_2$ significantly reduced opaque grain than non primed during both the years (Table 4.29).

4.1.4.1.2 Abortive grains (%)

Seedling age affected abortive grains significantly in both the years whereas osmopriming was only significant during the year 2011 (Table 4.27). Rice cultivars were not differed significantly for abortive grains. Similarly, interaction of rice cultivars with seedling age and osmopriming and overall interaction among cultivars, seedling age and osmopriming was not significant for abortive grains during both years (Table 4.27).

Comparison of means revealed that transplanting of younger aged seedling of 2 weeks old reduced abortive grains as compared to 3 and 4 weeks old seedling in both years (Table 4.30). Osmopriming with $CaCl_2$ significantly reduced abortive grains than non primed during the year 2011 (Table 4.30).

4.1.4.1.3 Normal grains (%)

Nursery seedling age and osmopriming significantly affected normal grains in both years (Table 4.27). The overall interaction of cultivars, seedling age and osmopriming was also significant for normal grains only during the year 2011. Rice cultivars and interaction of cultivars with seedling age and osmopriming, and seedling age interaction with osmopriming were also not significant during both years (Table 4.27).

Two weeks old seedling produced maximum normal grains than 3 and 4 weeks old seedling whereas 3 weeks old seedling performed better than 4 weeks old seedling during both years (Table 4.31). Between the seed priming treatments, osmopriming with $CaCl_2$ produced maximum normal grains than non primed in both years (Table 4.31). Two weeks old seedling of Super Basmati and Shaheen Basmati when primed with $CaCl_2$ yielded maximum number of normal grains than non primed 2, 3 and 4 weeks old seedling of both the cultivars. The least normal grains were recorded in non primed 4 weeks old seedling of Super Basmati and non primed and primed with $CaCl_2$ of Shaheen Basmati only during the year 2011 (Table 4.32).

4.1.4.1.4 Chalky grains (%)

Seedling age and osmopriming affected chalky grains significantly in both the years. However, interaction of rice cultivars with seed age was only significant during 2010 and with osmopriming was only significant during 2011 (Table 4.27). Seedling age interaction with osmopriming and overall interaction among cultivars, seedling age and osmopriming was not significant for chalky grains during both years (Table 4.27).

Two weeks old seedling significantly reduced chalky grains than 3 and 4 weeks old seedling during both the years. The interaction among cultivar and seedling age indicated that the least chalky grain were obtained where transplanting 2 weeks old seedling of Super Basmati was carried out whereas 3 weeks old seedling of Super Basmati and 2,3 and 4 weeks old seedling of Shaheen Basmati performed equally and were statistically at par during the year 2010 (Table 4.33). Osmopriming with $CaCl_2$ significantly reduced chalky grains than non primed during both the years (Table 4.34). Interaction of cultivars with osmopriming indicated that maximum chalky grains were recorded in non primed Super Basmati followed by osmopriming in Super Basmati and Shaheen Basmati only during the year 2011 (Table 4.34).

4.1.4.1.5 Grain length (cm)

Data regarding grain length (Table 4.35) indicated that seedling age and osmopriming differed significantly during both the years. However, rice cultivars and interaction of rice cultivars with seedling age only differed during the year 2011. The interaction among cultivars and osmopriming, seedling age and osmopriming and overall interaction among cultivars, seedling age and osmopriming was not significant during both the years (Table 4.35).

Transplanting younger seedling of 2 weeks old produced maximum grain length than that of 3 and 4 weeks old seedling during both the years (Table 4.36). Among the rice cultivars, Shaheen Basmati remained superior regarding grain length than that of Super Basmati only during the year 2011. The interaction among cultivars and seedling age showed that 2 weeks old seedling of both the cultivars recorded greater grain length than that of 3 and 4 weeks old seedling while least grain length was recorded in 3 and 4 weeks old seedling of Super Basmati only during the year 2011 (Table 4.36). Osmopriming with $CaCl_2$ produced maximum grain length than that of not primed during both years (Table 4.37).

4.1.4.1.6 Grain width (cm)

The analysis of variance (Table 4.35) revealed that different seedling age and osmopriming significantly affected the grain width in both the years whereas cultivars differed only during 2010 and interaction among cultivars and seedling age was only significant during the year 2011 (Table 4.35).

The mean comparison (Table 4.38) revealed that greater grain width was recorded in 2 weeks old seedling than that of 3 and 4 weeks old during both the years. Three weeks old seedling performed better than 4 weeks old regarding grain width during the year 2011 while both were statistically at par during the year 2010. Interaction among cultivars and seedling age revealed that 2 weeks old seedling of Shaheen Basmati produced maximum grain width and was at par with 2 weeks old seedling of Super Basmati and 3 weeks old seedling of Shaheen Basmati while least grain width was recorded in 4 weeks old seedling of Super Basmati during the year 2011 (Table 4.38). Greater grain width was recorded in plants which were primed with $CaCl_2$ than that of non primed plants in both the years (

Table 4.39).

4.1.4.1.7 Grain length width ratio

Transplanting of different nursery seedling age affected the grain length width ratio significantly during both the years whereas rice cultivars differed only during the year 2010 whereas osmopriming and interaction of cultivars with seedling age only differed significantly during the year 2011 (Table 4.35). The interaction of cultivars with osmopriming, seedling age with osmopriming and interaction of cultivars with both seedling age and osmopriming was found not significant during both the years (Table 4.35).

Between the rice cultivars, greater length width ratio was recorded in Super Basmati than that of Shaheen Basmati during the year 2010 (Table 4.40). Among the different seedling age, less grain length width ratio was recorded in 2 weeks old seedling than that of 3 and 4 weeks old during both the years (Table 4.40). However, interaction among cultivars and seedling age revealed that the least grain length width ratio was recorded in 2, 3 and 4 weeks old seedling of Shaheen Basmati than that of Super Basmati with same seedling age during the year 2011 (Table 4.40). Osmopriming with $CaCl_2$ significantly reduced grain length width ratio than that of untreated seeds during the year 2011 (Table 4.41).

4.1.4.1.8 Grain water absorption ratio

Different nursery seedling age and osmopriming significantly affected the grain water absorption ratio in both the years whereas interaction of cultivars with seedling age differed only during the year 2011 and cultivars interaction with both seedling age and osmopriming only differed significantly during the year 2010 (Table 4.35). However, rice cultivars interaction with osmopriming and seedling age interaction with osmopriming remained non significant during both the years (Table 4.35).

Grain water absorption ratio was significantly affected by the seedling age where 2 weeks old seedling were superior to 3 and 4 weeks old seedling during both the years (Table 4.42). Cultivars interaction with seedling age revealed that maximum grain water absorption ratio was recorded in 2 weeks old seedling of Super Basmati which is at par with 2 weeks old seedling of Shaheen Basmati whereas the least grain water absorption ratio was recorded in 4 weeks old seedling of Super Basmati during the year 2011 (Table 4.42). Osmopriming was greater than non primed regarding grain water absorption ratio only during the year 2011 while no significant difference was recorded during the year

2010 (Table 4.41). Among different seedling age, maximum water absorption ratio was recorded in 2 weeks old seedling than that of 3 and 4 weeks old during both the years (Table 4.42). Interaction between cultivars and seedling age revealed that higher grain water absorption ratio was recorded in 2 weeks old seedling of Super Basmati which is at par with 2 weeks old seedling of Shaheen Basmati while the least grain water absorption ratio was recorded in 4 weeks old seedling of Super Basmati during the year 2011 (Table 4.42). Osmopriming with $CaCl_2$ recorded higher grain water absorption ratio than that of non primed during both the years (Table 4.43).

The overall interaction among cultivars, seedling age and osmopriming indicated that higher grain water absorption ratio was recorded in osmopriming with CaCl2 in 2 weeks old seedling of Super Basmati and non primed Shaheen Basmati with same seedling age followed by non primed Super Basmati and osmprimed Shaheen Basmati with same seedling age during the year 2010. The least grain water absorption ratio was recorded in non primed 4 weeks old seedling of Super Basmati and Shaheen Basmati during the same year (Table 4.44).

Table 4.27: Analysis of variance for the influence of seedling age and seed priming on opaque, abortive, normal and chalky kernels of fine rice cultivars

		Mean sum of squares							
		Opaque grains (%)		Abortive grains (%)		Normal grains (%)		Chalky grains (%)	
SOV	df	2010	2011	2010	2011	2010	2011	2010	2011
Varieties (V)	1	1.93	4.94	1.38	0.58	0.12	16.81	0.11	0.75
$Error_1$	2	4.16	2.15	0.08	0.10	51.18	2.40	9.81	9.51
Seedling age (A)	2	0.42	10.39*	1.65*	1.43**	323.98**	160.75**	132.03**	83.26**
V × A	2	36.38**	47.39**	0.26	0.11	5.27	5.37	47. 98**	29.30
$Error_2$	8	2.0	1.75	0.36	0.06	4.26	2.06	4.38	6.90
Osmopriming (P)	1	52.39**	87.83**	1.16	2.40**	192.75**	281.12**	176.89**	174.24**
V × P	1	5.47	0.91	0.06	0.51	7.02	3.87	6.25	69. 44**
A × P	2	2.63	0.25	0.06	0.32	2.92	6.70	4.57	15.04
V × A × P	2	0.40	0.76	0.02	0.39	0.75	17.11**	0.02	0.34
$Error_3$	12	2.39	2.52	0.28	0.11	4.06	2.22	6.35	4.54

SOV = source of variation, df = degree of freedom, * = significant ($P<0.05$), ** = highly significant ($P<0.01$), ns = non significant
Year effect was only significant for abortive grains

Table 4.28: Influence of seedling age on opaque grains of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	16.9 a	13.7 bc	15.3	16.1 b	13.4 c	14.8 AB
3 weeks old	14.6 bc	15.5 ab	15.1	14.0 c	13.8 c	13.9 B
4 weeks old	13.6 c	17.3 a	15.4	13.2 c	18.3 a	15.7 A
Means	15.1	15.5		14.4	15.2	

LSD_{2010} (V × A) = 1.9, LSD_{2011} (A) = 1.3, LSD_{2011} (V × A) = 1.8
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.29: Influence of seed priming on opaque grains of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	15.9	17.1	16.5 A	15.8	16.9	16.4 A
Osmopriming $CaCl_2$	14.2	13.9	14.1 B	13.0	13.4	13.2 B

LSD_{2010} (P) = 1.1, LSD_{2011} (P) = 1.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.30: Influence of seedling age on abortive grains of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Non primed	Primed ($CaCl_2$)	Means	Non primed	Primed ($CaCl_2$)	Means
2 weeks old	1.72	1.36	1.54 B	2.15	1.48	1.81 B
3 weeks old	2.26	2.05	2.15 A	2.77	2.04	2.41 A
4 weeks old	2.46	1.96	2.21 A	2.49	2.35	2.42 A
Means	2.15	1.79		2.47 A	1.96 B	
	1.97 B			2.21 A		

LSD_{2010} (A) = 0.6, LSD_{2011} (A) = 0.2, LSD_{2011} (P) = 0.3, LSD (Year) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.31: Influence of seedling age on normal grains of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Non primed	Primed ($CaCl_2$)	Means	Non primed	Primed ($CaCl_2$)	Means
2 weeks old	63.1	68.2	65.7 A	61.5	67.1	64.3 A
3 weeks old	57.7	63.1	60.4 B	57.8	64.8	61.3 B
4 weeks old	53.5	57.0	55.3 C	55.0	59.0	57.0 C
Means	58.1 B	62.8 A		58.1 B	63.7 A	

LSD_{2010} (A) = 1.9, LSD_{2011} (A) = 1.4, LSD_{2010} (P) = 1.5, LSD_{2011} (P) = 1.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.32: Influence of seed priming on normal grains of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	63.4	69.3	62.8	67.0	62.9 bc	67.2 a	60.0 de	67.0 a
3 weeks old	56.9	62.7	58.5	63.4	57.7 ef	64.8 ab	57.8 ef	64.8 ab
4 weeks old	52.9	57.8	54.2	56.3	54.6 g	62.0 cd	55.3 fg	56.1 fg

LSD_{2011} (V × A × P) = 2.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.33: Influence of seedling age on chalky grains of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	18.3 c	22.6 b	20.5 C	18.6	22.2	20.4 B
3 weeks old	24.0 b	23.7 b	23.9 B	24.2	24.1	24.1 A
4 weeks old	28.9 a	25.3 b	27.1 A	26.8	24.2	25.5 A
Means	23.7	23.9		23.2	23.5	

LSD_{2010} (A) = 2.0, LSD_{2010} (V × A) = 2.8, LSD_{2011} (A) = 2.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.34: Influence of seedling age and seed priming on chalky grains of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	26.4	25.7	26.0 A	26.8 a	24.3 b	25.5 A
Osmopriming	21.1	22.1	21.6 B	19.6 c	22.7 b	21.1 B

LSD_{2010} (P) = 1.8, LSD_{2011} (P) = 1.6, LSD_{2011} (V × P) = 2.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.35: Analysis of variance for influence of different seedling age and seed priming on grain amylose contents, grain length, grain width and grain length width ratio of fine rice cultivars

		Mean sum of squares							
		Grain length (cm)		Grain width (cm)		Grain length width ratio		Grain water absorption ratio	
SOV	df	2010	2011	2010	2011	2010	2011	2010	2011
Varieties (V)	1	0.26	0.47**	0.56*	0.39	3.78*	2.17	0.18	0.14
$Error_1$	2	0.12	0.00	0.02	0.03	0.15	0.25	0.07	0.02
Seedling age (A)	2	1.78**	1.24**	0.89**	0.20**	3.09**	0.36*	0.86**	0.71**
V × A	2	0.05	0.13*	0.02	0.05**	0.49	0.30*	0.04	0.17**
$Error_2$	8	0.02	0.02	0.02	0.01	0.15	0.06	0.02	0.02
Osmopriming (P)	1	1.25**	0.83**	0.60**	0.31**	2.41	0.93*	0.48**	0.52**
V × P	1	0.02	0.00	0.002	0.05	0.12	0.46	0.03	0.01
A × P	2	0.02	0.06	0.004	0.01	0.04	0.01	0.14	0.01
V × A × P	2	0.00	0.00	0.000	0.002	0.02	0.004	0.18*	0.002
$Error_3$	12	0.02	0.04	0.064	0.01	0.74	0.18	0.04	0.01

SOV = source of variation, df = degree of freedom, * = significant (P<0.05), ** = highly significant (P<0.01), ns = non significant
Year effect was only significant for grain length width ratio

Table 4.36: Influence of seedling age on grain length of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	7.30	7.34	7.32 A	7.27 a	7.25 a	7.26 A
3 weeks old	6.64	6.94	6.79 B	6.59 c	6.96 b	6.77 B
4 weeks old	6.48	6.65	6.56 C	6.49 c	6.82 b	6.65 B
Means	6.80	6.97		6.78 B	7.01 A	

LSD_{2010} (A) = 0.1, LSD_{2011} (A) = 0.2, LSD_{2011} (V) = 0.03, LSD_{2011} (V × A) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.37: Influence of seedling age and seed priming on grain length of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	6.60	6.81	6.70 B	6.62	6.87	6.74 B
Primed ($CaCl_2$)	7.01	7.14	7.08 A	6.94	7.15	7.05 A

LSD_{2010} (P) = 0.1, LSD_{2011} (P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.38: Influence of seedling age on grain width of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	1.82	2.01	1.91 A	1.73 ab	1.79 a	1.76 A
3 weeks old	1.38	1.59	1.49 B	1.47 c	1.70 ab	1.59 B
4 weeks old	1.24	1.58	1.41 B	1.34 d	1.67 b	1.50 C
Means	1.48 B	1.73 A		1.51	1.72	

LSD_{2010} (V) = 0.2, LSD_{2010} (A) = 0.1, LSD_{2011} (V × A) = 0.1, LSD_{2011} (A) = 0.1, LSD_{2011} (V × A) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.39: Influence of seedling age and seed priming on grain width of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	1.34	1.60	1.47 B	1.38	1.66	1.52 B
Primed ($CaCl_2$)	1.61	1.85	1.73 A	1.64	1.77	1.71 A

LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.40: Influence of seedling age on grain length width ratio of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	4.07	3.69	3.88 B	4.26 bc	4.06 c	4.16 B
3 weeks old	4.90	4.45	4.67 A	4.54 b	4.10 c	4.32 AB
4 weeks old	5.38	4.27	4.83 A	4.92 a	4.09 c	4.50 A
Means	4.79 A	4.14 B		4.57	4.08	

LSD_{2010} (V) = 0.6, LSD_{2010} (A) = 0.4, LSD_{2011} (A) = 0.2, LSD_{2011} (V × A) = 0.3
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.41: Influence of seedling age and seed priming on grain length width ratio of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	5.10	4.34	4.72	4.85	4.13	4.49 A
Primed ($CaCl_2$)	4.47	3.94	4.20	4.30	4.03	4.17 B
Means (Year)	4.46 A			4.33 B		

LSD_{2011} (P) = 0.3, LSD (Year) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.42: Influence of seedling age on grain water absorption ratio of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	4.38	4.39	4.38 A	4.39 a	4.24 ab	4.32 A
3 weeks old	3.96	4.19	4.08 B	3.86 de	4.10 bc	3.98 B
4 weeks old	3.76	3.95	3.85 C	3.70 e	3.98 cd	3.84 C
Means	4.03	4.17		3.98	4.11	

LSD_{2010} (V) = 0.6, LSD_{2010} (A) = 0.1, LSD_{2011} (A) = 0.1, LSD_{2011} (V × A) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.43: Influence of seedling age and seed priming on grain water absorption ratio of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	3.89	4.09	3.99 B	3.88	3.97	3.93 B
Primed ($CaCl_2$)	4.17	4.26	4.22 A	4.08	4.25	4.17 A

LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.44: Influence of seed priming on grains water absorption ratio of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	4.21 abc	4.54 a	4.56 a	4.21 abc	4.32	4.46	4.13	4.35
3 weeks old	3.81 de	4.12 bcd	3.94 cde	4.44 ab	3.76	3.96	3.93	4.27
4 weeks old	3.65 e	3.86 cde	3.76 e	4.14 bcd	3.57	3.83	3.84	4.12

LSD_{2010} (V × A × P) = 0.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

4.1.4.1.9 Grain protein contents (%)

The analysis of variance table indicated that rice cultivars, seedling age and osmopriming differed significantly regarding grain protein contents during both the years (Table 4.45). Similarly, the interaction among cultivars and seedling age was also significant for grain protein contents during both the years. Cultivars interaction with osmopriming, seedling age with osmopriming and overall interaction among cultivars, seedling age and osmopriming was not significant during both the years (Table 4.45).

Between rice cultivars, Shaheen Basmati produced more grain protein contents than that of Super Basmati during both the years (Table 4.46). Among different seedling age, 2 weeks old seedling yielded maximum protein contents than that of 3 and 4 weeks old seedling during both the years (Table 4.46). The interaction between cultivars and seedling age revealed that 2 weeks old seedling of both Shaheen Basmati and Super Basmati produced maximum grain protein contents followed by 3 weeks old seedling of Shaheen Basmati while the least grain protein contents were recorded in 4 weeks old seedling of Super Basmati during both the years (Table 4.46). Three weeks old seedling of Super Basmati were statistically at par with 4 weeks old seedling of Shaheen Basmati regarding grain protein contents during both the years (Table 4.46).

Osmopriming with $CaCl_2$ increased grain protein contents significantly more than that of non primed during both the years (Table 4.47). However, no variation was recorded for cultivars interaction with osmopriming regarding grain protein contents during both the years (Table 4.47).

4.1.4.1.10 Grain amylose contents (%)

Rice cultivars differed significantly regarding amylose contents only during the year 2011 whereas seedling age and osmopriming affected grain amylose contents significantly during both the years (Table 4.45). The interaction between cultivars and osmopriming and overall interaction of cultivars, seedling age and osmopriming affected grain amylose contents significantly only during the year 2010 (Table 4.45). Cultivars interaction with seedling age and seedling age interaction with osmopriming was not significant for grain amylose contents during both the years. The interaction of cultivars with osmopriming and overall interaction among cultivars, seedling age and osmopriming was only significant during the year 2011 (Table 4.45).

In Shaheen Basmati more grain amylose contents were recorded than that of Super Basmati only during the year 2011 (Table 4.48). Among different seedling age, significantly lowered amylase contents were recorded in 2 weeks old seedling than that of 3 and 4 weeks old seedling during both the years (Table 4.48). Interaction of cultivars with seedling age could not affect grain amylose contents during both the years (Table 4.48). Lower amylose contents were recorded during the year 2011 than that of 2010.

Lower amylose contents were recorded where seeds were primed with $CaCl_2$ than that of non primed during both the years (Table 4.49). The interaction among cultivars and osmopriming revealed that maximum grain amylose contents were recorded in Shaheen Basmati and Super Basmati whose seeds were not primed and least amylose contents were recorded in Super Basmati whose seeds were primed with $CaCl_2$ during the year 2010 (Table 4.49).

The interaction among cultivars, seedling age and osmopriming revealed that maximum amylose contents were recorded in 4 weeks old seedling of both Shaheen Basmati and Super Basmati whose seeds were primed with $CaCl_2$ followed by 4 weeks old seedling of both the cultivars whose seeds were not primed during the year 2010 (Table 4.50). Two weeks old seedling of Super Basmati primed with $CaCl_2$ and 3 weeks old seedling of Shaheen Basmati whose seeds were not primed were also lower in amylose contents during the year 2010. However, the least amylose contents were recorded in non primed 2 and 3 weeks old seedling of Super Basmati which were statistically at par with each other during the same year (Table 4.50).

4.1.5 Leaf chlorophyll contents

4.1.5.1.1 Chlorophyll a contents

The chlorophyll a contents were affected significantly by cultivars, seedling age and osmopriming during both the years whereas seedling age interaction with osmopriming and interaction among cultivars, seedling age and osmopriming was only significant during the year 2010 and 2011, respectively (Table 4.45). Cultivars interaction with seedling age and osmopriming was not significant during both the years (Table 4.45).

Between rice cultivars, Shaheen Basmati significantly improved chlorophyll a contents than Super Basmati during both the years (Table 4.51). Different seedling age revealed that 2 weeks old seedling performed better regarding chlorophyll a contents than that of 3 and 4 weeks old seedling in both the years while no variation was recorded for cultivars interaction with seedling age (Table 4.51).

Osmopriming with $CaCl_2$ produced maximum chlorophyll a contents as compared to non primed during both the years (Table 4.52). Seedling age interaction with osmopriming revealed that higher chlorophyll a contents were recorded in 2 weeks old seedling which were primed with $CaCl_2$ followed by 3 weeks old seedling with same priming treatment while the least chlorophyll a contents were recorded in non primed 4 weeks old seedlings only during the year 2010 (Table 4.52). Three weeks old seedlings primed with $CaCl_2$ performed equally as non primed 2 weeks old seedlings during the year 2010 (Table 4.52).

Interaction among cultivars, seedling age and osmopriming revealed that osmopriming with $CaCl_2$ in 2 weeks old seedlings of Shaheen Basmati recorded higher chlorophyll a contents and is at par with 3 weeks old seedlings of the same cultivar and same priming treatment during the year 2011 (Table 4.53). Three weeks old seedling of Shaheen Basmati primed with $CaCl_2$ recorded statistically similar chlorophyll a contents that that of 2 weeks old seedling of Super Basmati with same priming treatment. Similarly, 3 weeks old seedling of Super Basmati were at par with 4 weeks old seedling of non primed Shaheen Basmati and Super Basmati primed with $CaCl_2$ during the year 2011 (Table 4.53).

4.1.5.1.2 Chlorophyll b contents

Rice cultivars and interaction of cultivars with seedling age differed significantly for chlorophyll b contents only during the year 2010 while seedling age and osmopriming affected chlorophyll b contents significantly during both the years (Table 4.45). However, cultivar interaction with osmopriming and interaction of seedling age with osmopriming significantly affected the chlorophyll b contents only during the year 2011. Likewise, overall interaction among cultivars, seedling age and osmopriming was only significant for chlorophyll b contents during the year 2010 (Table 4.45).

Between rice cultivars, Shaheen Basmati produced maximum chlorophyll b contents than Super Basmati only during the year 2010 (Table 4.54). Different seedling age showed that 2 weeks old seedling performed better regarding chlorophyll b contents that that of 3 and 4 weeks old seedling during both the years (Table 4.54). The interaction of cultivars with seedling age revealed that 2 weeks old seedling of Shaheen Basmati produced maximum chlorophyll b contents and was statistically similar to 2 weeks old seedling of Super Basmati and 3 weeks old seedling of Shaheen Basmati during the year 2010 (Table 4.54). The least chlorophyll b contents were recorded in 4 weeks old seedling of Shaheen Basmati which was at par with 4 weeks old seedling of Super Basmati during the year 2010 (Table 4.54).

Osmopriming with $CaCl_2$ recorded more chlorophyll b contents than non primed during both years (Table 4.55). Interaction of cultivars with osmopriming indicated that maximum chlorophyll b contents were recorded in Super Basmati primed with $CaCl_2$ followed by Shaheen Basmati with same priming treatment during the year 2011 (Table 4.55). The least chlorophyll b contents were recorded in non primed Shaheen Basmati which is at par with non primed Super Basmati during the same year (Table 4.55).

Interaction of seedling age with osmopriming revealed that higher chlorophyll b contents were recorded in 2 weeks old seedling primed with $CaCl_2$ which is followed by 3 and 4 weeks old seedling with same priming treatment during the year 2011 (Table 4.56). However, similar chlorophyll b contents were found in non primed 2 and 3 weeks old seedling while the least chlorophyll b contents were recorded in non primed 4 weeks old seedling during the same year (Table 4.56).

Interaction among cultivars, seedling age and osmopriming indicated that greater chlorophyll b contents were recorded in 2 weeks old seedling of Shaheen Basmati primed with $CaCl_2$ followed by 2 weeks old seedling of Super Basmati primed with $CaCl_2$ which is at par with 3 weeks old seedling of Shaheen Basmati with same priming treatment during the year 2010 (Table 4.57). Similarly, 3 weeks old seedling of Shaheen Basmati primed with $CaCl_2$ were similar to non primed Shaheen Basmati with same seedling age during the same year (Table 4.57). The minimum chlorophyll b contents were recorded in non primed 4 weeks old seedling of Shaheen Basmati in the same year (Table 4.57).

4.1.5.1.3 Chlorophyll a/b

Different seedling age affected chlorophyll a/b significantly only during the year 2010 while osmopriming affected during both the years (Table 4.45). However, interaction of cultivars with seedling age and overall interaction among cultivars, seedling age and osmopriming also differed significantly only during the year 2010 (Table 4.45). Seedling age interaction with osmopriming regarding chlorophyll a/b was only significant during the year 2011 (Table 4.45).

No variation was recorded between the rice cultivars regarding chlorophyll a/b during both the years (Table 4.58). Different seedling age significantly affected chlorophyll a/b and reduced chlorophyll a/b was found where 2 weeks old seedling were transplanted which is at par with 3 weeks old seedling while higher ratio was recorded in 4 weeks old seedling during the year 2010 (Table 4.58). Cultivars interaction with seedling age revealed that least chlorophyll a/b was recorded in 2 weeks old seedling of Super

Basmati which is at par with 2 and 3 weeks old seedling of Shaheen Basmati while the higher ratio was recorded in 4 weeks old seedling of Shaheen Basmati during the year 2010 (Table 4.58).

Osmopriming with $CaCl_2$ significantly reduced chlorophyll a/b compared to non primed during both years (Table 4.59). However, interaction of seedling age with osmopriming revealed that 2 weeks old seedling primed with $CaCl_2$ significantly reduced the chlorophyll a/b and is statistically at par with 3 weeks old seedling with same priming treatment during the year 2011 (Table 4.59). Non primed 4 weeks old seedling recorded higher chlorophyll a/b during the same year (Table 4.59).

Interaction among cultivars, seedling age and osmopriming revealed that 2 weeks old seedling of Super Basmati primed with $CaCl_2$ recorded minimum chlorophyll a/b ratio and is at par with 2 and 3 weeks old seedling of Shaheen Basmati primed with $CaCl_2$ and 3 weeks old seedling of non primed Shaheen Basmati and primed with $CaCl_2$ of Super Basmati during the year 2010 (Table 4.60). The maximum chlorophyll a/b was recorded in non primed 4 weeks old seedling of during the same year (Table 4.60).

4.1.5.1.4 Total Chlorophyll contents

It is evident from the analysis of variance (Table 4.45) that cultivars, seedling age and osmopriming significantly differed for total chlorophyll contents during both the years. Cultivars interaction with seedling age and seedling age interaction with osmopriming was only significant during the year 2010 (Table 4.45). The overall interaction among cultivars, seedling age and osmopriming affected total chlorophyll contents significantly during both the years (Table 4.45).

Between rice cultivars, higher total chlorophyll contents were recorded in Shaheen Basmati than that of Super Basmati during both the years (Table 4.61). Different seedling age revealed that 2 weeks old seedling produced maximum total chlorophyll contents followed by 3 weeks old seedling and minimum total chlorophyll contents were recorded in 4 weeks old seedling during both the years (Table 4.61).

Cultivars interaction with seedling age revealed that higher total chlorophyll contents were recorded where 2 weeks old seedling of Shaheen Basmati were transplanted followed by 3 weeks old seedling of the same cultivar and of Super Basmati during the year 2010 (Table 4.61). Three weeks old seedling of Shaheen Basmati is statistically at par with 2 weeks old seedling of Super Basmati while the least total chlorophyll contents were recorded in 4 weeks old seedling Super Basmati and Shaheen Basmati during the same year (Table 4.61).

Osmopriming with $CaCl_2$ was superior to non primed treatment regarding total chlorophyll contents during the year 2010 (Table 4.62). Seedling age interaction with osmopriming revealed that maximum total chlorophyll contents were found where 2 weeks old seedling primed with $CaCl_2$ were grown followed by 3 weeks old seedling with same priming treatment and non primed 2 weeks old seedling during the same year (Table 4.62). However, the least total chlorophyll contents were recorded in non primed 4 weeks old seedling during the same year (Table 4.62).

Interaction among cultivars, seedling age and osmopriming revealed that higher total chlorophyll contents were recorded in 2 weeks old seedling of Shaheen Basmati primed with $CaCl_2$ during the year 2010 and of both cultivars during the year 2011 (Table 4.63). Three weeks old seedling primed with $CaCl_2$ of Shaheen Basmati and 3 weeks old seedling of Super Basmati with same priming treatment were found statistically similar to 2 weeks old seedling of Super Basmati primed with $CaCl_2$ and non primed 3 weeks old seedling of Shaheen Basmati, respectively during the year 2010 (Table 4.63). However, 3 weeks old seedling of Super Basmati primed with $CaCl_2$ were found statistically similar for total chlorophyll contents to non primed 2 weeks old seedling and 4 weeks old seedling of Shaheen Basmati primed with $CaCl_2$ during the year 2011 (Table 4.63). The least total chlorophyll contents were recorded in non primed 4 weeks old seedling of Super Basmati during both the years (Table 4.63).

Table 4.45: Analysis of variance for influence of different seedling age and seed priming on grain amylose contents, grain length, grain width and grain length width ratio of fine rice cultivars

		Mean sum of squares											
		Grain protein contents (%)		Grain amylose contents (%)		Ch. a contents (mg g^{-1} FW)		Ch. b contents (mg g^{-1} FW)		Ch. a/b ratio		Total ch. contents (mg g^{-1} FW)	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Varieties (V)	1	0.48*	0.43*	3.42	9.10*	0.88**	1.09**	0.18*	0.03	0.05	1.09	1.83**	0.74**
$Error_1$	2	0.01	0.02	0.34	0.11	0.00	0.01	0.01	0.02	0.04	0.09	0.01	0.002
Seedling age (A)	2	1.55**	1.12*	43.5**	22.3**	2.26**	1.23**	1.22**	0.52**	0.63**	0.13	6.81**	3.35**
V × A	2	0.15*	0.07*	2.12	1.50	0.001	0.02	0.17**	0.003	0.80**	0.03	0.15*	0.04
$Error_2$	8	0.03	0.01	0.66	1.07	0.01	0.02	0.01	0.01	0.04	0.05	0.03	0.04
Osmopriming (P)	1	1.58**	0.71*	43.8**	46.5**	1.03**	1.40**	1.98**	1.97**	2.82**	1.70**	5.87**	6.69**
V × P	1	0.01	0.01	1.10*	0.47	0.001	0.03	0.01	0.02*	0.01	0.01	0.004	0.00
A × P	2	0.03	0	0.48	0.03	0.02*	0.01	0.01	0.03**	0.10	0.07*	0.03*	0.01
V × A × P	2	0.01	0.02	1.29**	1.79	0.001	0.05*	0.04*	0.01	0.31*	0.03	0.05**	0.09*
$Error_3$	12	0.07	0.01	0.17	1.10	0.004	0.01	0.01	0.004	0.06	0.02	0.01	0.02

SOV = source of variation, df = degree of freedom, * = significant ($P<0.05$), ** = highly significant ($P<0.01$), ns = non significant
Ch. = Chlorophyll, FW = fresh weight
Year effect was only significant for grain amylase contents

Table 4.46: Influence of seedling age on grain protein contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	8.29 a	8.27 a	8.28 A	8.15 a	8.21 a	8.18 A
3 weeks old	7.59 cd	8.02 b	7.80 B	7.62 c	7.99 b	7.81 B
4 weeks old	7.44 d	7.71 c	7.58 C	7.46 d	7.69 c	7.57 C
Means	7.77 B	8.00 A		7.74 B	7.96 A	

LSD_{2010} (A) = 0.2, LSD_{2010} (V × A) = 0.2, LSD_{2011} (A) = 0.1, LSD_{2011} (V × A) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.47: Influence of seedling age and seed priming on grain protein contents of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	7.57	7.77	7.68 B	7.58	7.84	7.71 B
Osmopriming	7.96	8.22	8.09 A	7.90	8.08	7.99 A

LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.48: Influence of seedling age on grain amylose contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	23.6	24.8	24.2 B	24.0	25.6	24.8 C
3 weeks old	24.1	25.1	24.6 B	25.3	26.4	25.8 B
4 weeks old	27.8	27.5	27.7 A	27.4	27.6	27.5 A
Means	25.2	25.8		25.5 B	26.5 A	
Means (Year)	25.5 B			26.0 A		

LSD_{2010} (A) = 0.8, LSD_{2011} (V) = 0.5, LSD_{2011} (A) = 1.0, LSD (Year) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.49: Influence of seedling age and seed priming on grain amylose contents of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	26.44 a	26.71 a	26.4 A	26.6	27.8	27.2 A
Primed ($CaCl_2$)	23.89 c	24.86 b	24.4 B	24.5	25.3	24.9 B

LSD_{2010} (P) = 1.0, LSD_{2010} (V × P) = 0.4, LSD_{2011} (P) = 0.8
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.50: Influence of seed priming and seedling age on grain amylose contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	22.6 f	24.5 d	23.5 e	26.0 bc	22.9	25	24.5	26.8
3 weeks old	22.7 f	25.5 c	24.7 d	25.5 c	23.8	26.7	25.4	27.3
4 weeks old	26.4 b	29.3 a	26.3 b	28.7 a	26.8	28	26	29.3

LSD_{2010} (V × A × P) = 0.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.51: Influence of seedling age on chlorophyll a contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	3.06	3.4	3.23 A	3.05	3.31	3.18 A
3 weeks old	2.82	3.11	2.97 B	2.69	3.06	2.88 B
4 weeks old	2.23	2.54	2.39 C	2.33	2.74	2.54 C
Means	2.71 B	3.02 A		2.69 B	3.04 A	

LSD_{2010} (V) = 0.01, LSD_{2010} (A) = 0.1, LSD_{2010} (V × P) = 2.5, LSD_{2011} (V) = 0.1, LSD_{2011} (A) = 0.1, LSD_{2011} (V × P) = 1.7, FW = fresh weight
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.52: Influence of seedling age and seed priming on chlorophyll a contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010		2011	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	3.11 b	3.36 a	3.00	3.36
3 weeks old	2.81 c	3.14 b	2.66	3.10
4 weeks old	2.17 e	2.60 d	2.35	2.73
Means	2.69 B	3.03 A	2.67 B	3.07 A

LSD_{2010} (P) = 2.8, LSD_{2010} (A × P) = 0.1, LSD_{2011} (P) = 2.8, FW = fresh weight
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.53: Influence of seedling age and osmopriming on chlorophyll a contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non prime d	Primed ($CaCl_2$)
2 weeks old	2.95	3.17	3.25	3.54	2.83 e	3.27 bc	3.18 c	3.45 a
3 weeks old	2.66	2.98	2.94	3.28	2.53 f	2.86 de	2.79 e	3.35 ab
4 weeks old	2.01	2.45	2.33	2.75	2.21 g	2.46 f	2.49 f	3.00 d

LSD_{2011} (V × A × P) = 0.2, FW = fresh weight
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.54: Influence of seedling age on chlorophyll b contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	1.59 a	1.71 a	1.65 A	1.62	1.53	1.58 A
3 weeks old	1.27 b	1.66 a	1.46 B	1.43	1.39	1.41 B
4 weeks old	1.07 c	0.99 c	1.03 C	1.18	1.14	1.16 C
Means	1.31 B	1.45 A		1.41	1.35	

LSD_{2010} (V) = 0.1, LSD_{2010} (A) = 0.1, LSD_{2010} (V × A) = 0.2, LSD_{2011} (A) = 0.1, FW = fresh weight
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.55: Influence of seed priming on chlorophyll b contents of fine rice cultivars grown under system of rice intensification

Osmopriming	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
Non primed	1.06	1.23	1.14 B	1.16 c	1.15 c	1.15 B
Primed ($CaCl_2$)	1.56	1.67	1.61 A	1.67 a	1.57 b	1.63 A

LSD_{2010} (P) = 0.02, LSD_{2011} (P) = 0.02, LSD_{2011} (V × P) = 0.1, FW = fresh weight
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.56: Influence of seedling age and seed priming on chlorophyll b contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010		2011	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	1.40	1.90	1.29 d	1.87 a
3 weeks old	1.25	1.67	1.22 d	1.61 b
4 weeks old	0.78	1.27	0.95 e	1.38 c

LSD_{2011} (A × P) = 0.1, FW = fresh weight
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.57: Influence of seed priming on chlorophyll b contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	1.36 de	1.82 b	1.44 cd	1.98 a	1.29	1.96	1.29	1.77
3 weeks old	0.98 f	1.56 c	1.53 c	1.78 b	1.20	1.66	1.23	1.55
4 weeks old	0.84 fg	1.30 de	0.73 g	1.25 e	0.98	1.39	0.91	1.37

LSD_{2010} (V × A × P) = 0.2, FW = fresh weight
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.58: Influence of seedling age on chlorophyll a/b of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	1.97 c	2.03 c	1.99 B	1.93	2.21	2.07
3 weeks old	2.33 b	1.89 c	2.11 B	1.91	2.21	2.06
4 weeks old	2.15 bc	2.74 a	2.44 A	2.01	2.48	2.25
Means	2.14	2.21		1.95	2.30	

LSD_{2010} (A) = 0.2, LSD_{2010} (V × A) = 0.3
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.59: Influence of seedling age and seed priming on chlorophyll a/b ratio of fine rice cultivars grown under system of rice intensification

Seedling age	2010		2011	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	2.22	1.77	2.33 b	1.81 d
3 weeks old	2.34	1.88	2.20 b	1.94 cd
4 weeks old	2.82	2.05	2.51 a	1.99 c
Means	2.46 A	1.90 B	2.35 A	1.91 B

LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.1, LSD_{2011} (A × P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.60: Influence of seed priming and seedling age on chlorophyll a/b of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	2.18 cdef	1.75 f	2.27 cd	1.79 ef	2.19	1.67	2.47	1.95
3 weeks old	2.75 b	1.92 def	1.93 def	1.85 def	2.12	1.71	2.27	2.15
4 weeks old	2.40 bc	1.89 def	3.25 a	2.22 cde	2.26	1.77	2.76	2.20

LSD_{2010} (V × A × P) = 0.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.61: Influence of seedling age on total chlorophyll contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010			2011		
	Super Basmati	Shaheen Basmati	Means	Super Basmati	Shaheen Basmati	Means
2 weeks old	4.66 b	5.11 a	4.89 A	4.68	4.84	4.76 A
3 weeks old	4.09 c	4.77 b	4.43 B	4.12	4.46	4.30 B
4 weeks old	3.30 d	3.53 d	3.41 C	3.52	3.88	3.71 C
Means	4.02 B	4.47 A		4.11 B	4.40 A	

LSD_{2010} (V) = 0.1, LSD_{2010} (A) = 0.2, LSD_{2010} (V × A) = 0.2, LSD_{2011} (V) = 0.1, LSD_{2011} (A) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.62: Influence of seedling age and seed priming on total chlorophyll contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010		2011	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	4.51 c	5.26 a	4.29	5.22
3 weeks old	4.06 d	4.81 b	3.87	4.71
4 weeks old	2.96 f	3.87 e	3.29	4.11
Means	3.84 B	4.65 A	3.82 B	4.69 A

LSD_{2010} (P) = 0.1, LSD_{2011} (P) = 0.1, LSD_{2011} (A × P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

Table 4.63: Influence of seed priming and seedling age on total chlorophyll contents of fine rice cultivars grown under system of rice intensification

Seedling age	2010				2011			
	Super Basmati		Shaheen Basmati		Super Basmati		Shaheen Basmati	
	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)	Non primed	Primed ($CaCl_2$)
2 weeks old	4.32 e	5.00 b	4.69 c	5.53 a	4.12 d	5.24 a	4.47 c	5.22 a
3 weeks old	3.64 g	4.55 d	4.48 d	5.07 b	3.73 f	4.52 c	4.02 de	4.90 b
4 weeks old	2.85 i	3.75 g	3.06 h	3.99 f	3.19 g	3.86 ef	3.40 g	4.37 c

LSD_{2010} (V × A × P) = 0.1, LSD_{2011} (V × A × P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference.

4.1.6 Economic and marginal analysis

4.1.6.1 Net field benefits

Economic analysis of two fine rice cultivars transplanted with different old nursery seedling either untreated or primed with $CaCl_2$ during the year 2010 and 2011 is given in Table 4.64 & Table 4.66, respectively. It is clear from both the tables that osmopriming with $CaCl_2$ in 2, 3 and 4 weeks old seedling of both cultivars increased the net benefits than that of non primed seeds during both the years. However, maximum net returns or field benefits were obtained from 2 weeks old seedling of Shaheen Basmati whose seeds were osmoprimed with $CaCl_2$ followed by Super Basmati of same seedling age and same seed priming treatment during both the years (Table 4.64 & Table 4.66) and then untreated 2 weeks old seedling of Shaheen Basmati during both the years. In comparison with seedling age, higher net returns were obtained in 2 weeks old seedling than that of 3 and 4 weeks old seedling of both the cultivars during both years (Table 4.64 & Table 4.66). However, the least net field benefits were recorded in 4 weeks old seedling of Super Basmati whose seeds were not primed with $CaCl_2$ during both the years.

4.1.6.2 Marginal rate of return

It is clear from the Table 4.65 that higher marginal rate of return was obtained where 2 weeks old seedling of Shaheen Basmati whose seeds were primed with $CaCl_2$ during both years (Table 4.65 & Table 4.67) followed by 4 weeks old seedling of Super Basmati with same priming treatment during the year 2010 (Table 4.65) and 2 weeks old seedling of Super Basmati which were primed with $CaCl_2$ during the year 2011 (Table 4.67). Among seedling age, in both the cultivars 2 weeks old seedling gave higher marginal rate of return than that of 3 and 4 weeks old seedling during both the years. Osmopriming with $CaCl_2$ gave higher marginal rate of return than that of non primed seeds in both the cultivars during both the years (Table 4.65 & Table 4.67).

4.1.6.3 Discussion

It is apparent from the current study that seedling age and osmopriming with $CaCl_2$ significantly affected the grain attributes which include opaque, abortive, normal and chalky grains, grain dimensions and grain quality during both years (Table 4.27, Table 4.35, Table 4.45). Improvement in grain attributes due to age of seedling and osmopriming might be the result of improved nutrients and moisture supply which consequently resulted in reduced sterile spikelets due to enhanced fertilization (Thakuria and Choudhary, 1995). This might have resulted in increased number of normal grains (Table 4.31, Table 4.32) and reduced opaque (Table 4.28, Table 4.29), abortive (Table 4.30) and chalky grains (Table 4.33) due to greater partitioning and assimilation of photosynthates towards the panicle.

Seedling age and osmopriming significantly improved grain length, grain width, grain length width ratio and grain water absorption ratio (Table 4.35). Improvement in grain dimension due to younger seedling and osmopriming seems to be the result of improved net assimilation rate (Figure 4.7, Figure 4.4) that resulted in better translocation of photo assimilates towards the grains. Improvement in grain water absorption ratio seems to be the result of improved grain dimension and protein contents. Improvement in grain quality due to osmopriming is also supported by the findings of Thakuria & Choudhary (1995) and Zheng *et al.* (2002) who reported improved grain quality due to osmopriming under direct seeding and flooded conditions, respectively.

The results of current study are also supported by the findings of Farooq *et al.* (2006 a&b) and Rehman *et al.* (2011) and they reported improvement in grain quality of rice with osmopriming. The improvement in plant height, kernel yield and chlorophyll contents was also reported by Kadiri and Hussaini (1999) when seeds were primed with $CaCl_2$ or KNO_3 in a solution of 100 mg per liter than that of untreated seeds. In another study a significant improvement in total chlorophyll contents, chlorophyll a, b and chlorophyll a:b ratio was recorded in wheat seeds when osmoprimed with different salts of NaCl, $CaCl_2$ and Na_2SO_4 (Roy and Srivastava, 2000).

4.1.7 Conclusion

Among rice cultivars, Shaheen Basmati remained superior to Super Basmati in growth and grain yield. Two weeks old seedling whose seeds were osmoprimed with $CaCl_2$ (1.5% soln.) remained best and significantly improved the growth and yield of rice by increasing kernel yield of 12% and 7% during the year 2010 and, 11% and 8.7% during the year 2011, repectively, than that of 2 and 3 weeks old seedling. Two weeks old seedling primed with $CaCl_2$ also gave higher net benefits (Rs. 146654 & 143110) and marginal rate of return (12498 & 13814) during the year 2010 and 2011, respectively.

Table 4.64: Economic analysis of rice cultivars as affected by seedling age and osmopriming during the year 2010

	Super Basmati						Shaheen Basmati						Remarks
	2 weeks old		3 weeks old		4 weeks old		2 weeks old		3 weeks old		4 weeks old		
	NP	OP	NP	OP	NP	OP	NP	OP	NP	OP	NP	OP	
Kernel yield	4.15	4.46	3.76	4.03	3.25	3.63	4.42	4.84	3.96	4.22	3.87	4.09	t ha^{-1}
Adjusted yield	3.74	4.01	3.39	3.63	2.93	3.27	3.98	4.35	3.56	3.80	3.48	3.68	10% less than actual
Value	126056	135371	114311	122513	98719	110307	134156	146914	120184	128183	117551	124234	Rs. 1350/40 kg
Gross benefits	126056	135371	114311	122513	98719	110307	134156	146914	120184	128183	117551	124234	Rs. ha^{-1}
Cost of $CaCl_2$	-	60	-	60	-	60	-	60	-	60	-	60	Rs. 100 kg^{-1}
Cost of priming	-	200	-	200	-	200	-	200	-	200	-	200	Aeration pump & container rent Rs. 50/ day each
Cost that vary	-	260	-	260	-	260	-	260	-	260	-	260	Rs. ha^{-1}
Net benefits	126056	135111	114311	122253	98719	110047	134156	146654	120184	127923	117551	123974	Rs. ha^{-1}

NP = non primed, OP = osmoprimed with $CaCl_2$ (1.5% soln.)

Table 4.65: Marginal analysis of rice cultivars as affected by seedling age and osmopriming during the year 2010

Cultivars	Seedling age	Seed priming	Costs that vary (Rs. ha^{-1})	Marginal cost (Rs. ha^{-1})	Net benefits (Rs. ha^{-1})	Marginal net (Rs. ha^{-1})	Marginal rate of return (%)
Super Basmati	2 weeks old	NP	0	-	126056	-	-
		OP	260	260	135111	9055	9055
	3 weeks old	NP	0	0	114311	0	D
		OP	260	260	122253	7941	7941
	4 weeks old	NP	0	0	98719	0	D
		OP	260	260	110047	11329	11329
Shaheen Basmati	2 weeks old	NP	0	0	134156	-	-
		OP	260	260	146654	12498	12498
	3 weeks old	NP	0	0	120184	0	D
		OP	260	260	127923	7739	7739
	4 weeks old	NP	0	0	117551	0	D
		OP	260	260	123974	6423	6423

NP = non primed, OP = osmoprimed with $CaCl_2$ (1.5% soln.)

Table 4.66: Economic analysis of rice cultivars as affected by seedling age and osmopriming during the year 2011

	Super Basmati						Shaheen Basmati						Remarks
	2 weeks old		3 weeks old		4 weeks old		2 weeks old		3 weeks old		4 weeks old		
	NP	OP	NP	OP	NP	OP	NP	OP	NP	OP	NP	OP	
Kernel yield	4.01	4.38	3.77	4.03	3.35	3.57	4.26	4.72	3.92	4.19	3.81	4.07	t ha^{-1}
Adjusted yield	3.61	3.94	3.39	3.63	3.02	3.21	3.83	4.25	3.53	3.77	3.43	3.66	10% less than actual
Value	121797	133082	114413	122411	101858	108439	129296	143370	119070	127373	115830	123525	Rs. 1350/40 kg
Gross benefits	121797	133082	114413	122411	101858	108439	129296	143370	119070	127373	115830	123525	Rs. ha^{-1}
Cost of $CaCl_2$	-	60	-	60	-	60	-	60	-	60	-	60	Rs. 100 kg^{-1}
Cost of priming	-	200	-	200	-	200	-	200	-	200	-	200	Aeration pump & container rent Rs. 50/ day each
Cost that vary	-	260	-	260	-	260	-	260	-	260	-	260	Rs. ha^{-1}
Net benefits	121797	132822	114413	122151	101858	108179	129296	143110	119070	127113	115830	123265	Rs. ha^{-1}

NP = non primed, OP = osmoprimed with $CaCl_2$ (1.5% soln.)

Table 4.67: Marginal analysis of rice cultivars as affected by seedling age and osmopriming during the year 2011

Cultivars	Seedling age	Seed priming	Costs that vary (Rs. ha^{-1})	Marginal cost (Rs. ha^{-1})	Net benefits (Rs. ha^{-1})	Marginal net (Rs. ha^{-1})	Marginal rate of return (%)
Super Basmati	2 weeks old	NP	0	-	121797	-	-
		OP	260	260	132822	11026	11026
	3 weeks old	NP	0	0	114413	0	D
		OP	260	260	122151	7739	7739
	4 weeks old	NP	0	0	101858	0	D
		OP	260	260	108179	6321	6321
Shaheen Basmati	2 weeks old	NP	0	0	129296	-	-
		OP	260	260	143110	13814	13814
	3 weeks old	NP	0	0	119070	0	D
		OP	260	260	127113	8043	8043
	4 weeks old	NP	0	0	115830	0	D
		OP	260	260	123265	7435	7435

NP = non primed, OP = osmoprimed with $CaCl_2$ (1.5% soln.)

4.2 Experiment No. 2:

Evaluating the role of osmopriming in improving the performance of direct seeding in system of rice intensification

4.2.1 Allometry and crop growth

4.2.1.1 Results

4.2.1.1.1 Leaf area index

Leaf area index was affected by seeding technique and osmopriming under both conventional method and SRI during both years (Figure 4.5 a,b). Leaf area index was consistently increased during the active growth period, reached maximum 80 days after transplantation and then started to decline at physiological maturity. Transplanting of seedling whose seeds were primed with $CaCl_2$ resulted in higher leaf area index under both conventional method and SRI during the year 2010 (Figure 4.5 a) and similar trend was also recorded during the year 2011 (Figure 4.5 b). Transplanting of seedling whose seeds were hydroprimed, however lower in leaf area index than transplanting of osmoprimed but remained higher than direct seeding with osmoprimed seeds under conventional method and lower under SRI (Figure 4.5 a) during the year 2010. However, opposite trend was recorded during the year 2011 (Figure 4.5 b). The least leaf area index was recorded in direct seeding of untreated seeds under conventional and SRI production systems during both the years (Figure 4.5 a,b).

4.2.1.1.2 Leaf area duration

Leaf area duration was differed by seeding technique and seed priming under conventional method and SRI during both years (Figure 4.6 a,b). Higher leaf area duration was recorded in transplanting with osmoprimed and hydroprimed seeds under conventional and osmoprimed in both transplanting and direct seeding under SRI during the year 2010 (Figure 4.6 a). The least leaf area duration was recorded in transplanting and direct seeding under conventional and SRI, respectively during the same year. However, during the year 2011 maximum leaf area duration was recorded in transplanting of osmoprimed seeds under both conventional and SRI (Figure 4.6 b). Leaf area duration remained superior in direct seeding and transplanting of seeds which were primed with $CaCl_2$ under both production systems than that of hydropriming and untreated seeds in both seeding techniques and production systems during the year 2011 (Figure 4.6 b).

4.2.1.1.3 Crop growth rate (g m^{-2} d^{-1})

Crop growth rate was consistently increased during the active growth period and suddenly declined after 60 days of transplanting at maturity stage during both years (Figure 4.7 a,b). Higher crop growth rate was recorded where transplanting of seeds which were primed with $CaCl_2$ was carried out in both production systems during the year 2010 (Figure 4.7 a). However, the least crop growth rate was recorded in direct seeding where untreated seeds were used under both conventional method and SRI during the year 2010. Similar trend was also recorded for crop growth rate which was influenced by seeding technique and seed priming during the year 2011 (Figure 4.7 b).

4.2.1.1.4 Net assimilation rate (g m^{-2} d^{-1})

Net assimilation rate was differed for seeding technique and seed priming as indicated by the Figure 4.8. Higher NAR was recorded in SRI where transplanting of seedling whose seeds were osmoprimed with $CaCl_2$ was carried out followed by direct seeding with same priming treatment under same production system during both the years (Figure 4.8 a,b). Osmopriming in both direct seeding and transplanting under conventional method of sowing resulted in almost similar NAR during both years. However, the least NAR was recorded where transplanting of seedling whose seeds were not treated was carried out under conventional method during the year 2010 (Figure 4.8 a) and direct seeding of untreated seeds under SRI during the year 2011 (Figure 4.8 b).

4.2.1.2 Discussion

Seeding technique and seed priming influenced the crop growth attributes under both production systems during both the years. In both the production systems, SRI showed more vigorous growth of rice. Similarly, osmopriming with $CaCl_2$ significantly improved the efficiency of stand establishment methods and production systems by improving growth attributes than that of hydropriming and non priming treatments.

Osmopriming with $CaCl_2$ in transplanting significantly improved leaf area index (Figure 4.5 a,b) in both production systems, owing to better leaf development due to efficient resource capture and better utilization (Farooq *et al.*, 2007) than that of poor performance of non primed nursery seedling. Better leaf development is also responsible for improved leaf area duration (Figure 4.6 a,b). Similarly, osmopriming also significantly improved the crop growth rate (Figure 4.7 a,b) and net assimilation rate (Figure 4.8 a,b) in both the production systems during both years. Improved crop growth rate due to osmopriming with $CaCl_2$ seems to be the result of healthier and energetic start of nursery seedling which also resulted in improved leaf area index and ultimately ended in improved net assimilation rate. Paul and Choudhary (1991) also reported improved leaf area index, leaf area duration, crop growth rate and net assimilation rate in wheat seeds due to osmopriming than that of untreated seeds. Similarly, improvement in crop growth attributes due to osmopriming is also evident from the finding of Farooq *et al.* (2006a & b; 2007a & b) who reported significant improvement in growth attributes under both direct seeding and transplanting technique.

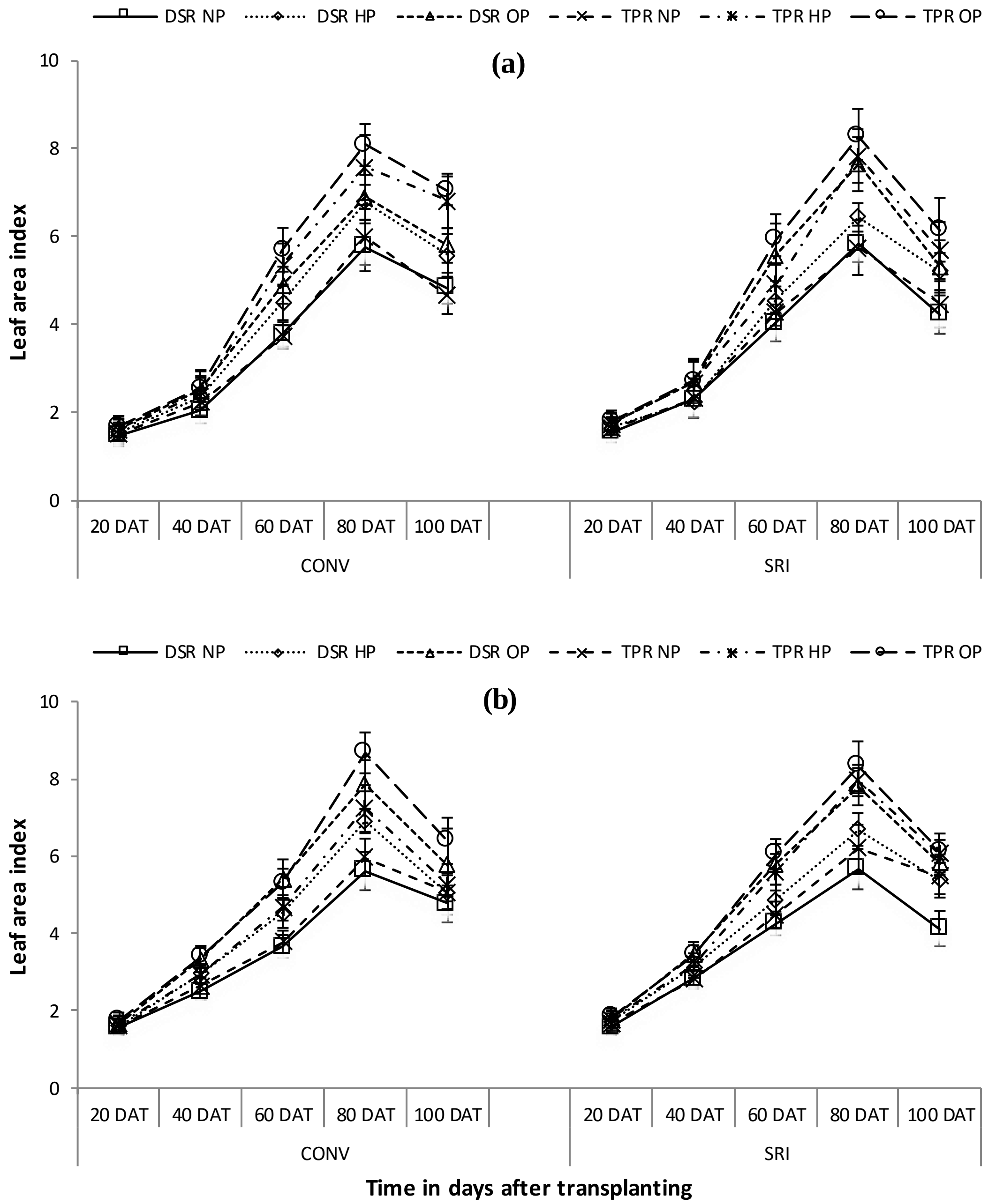


Figure 4.5: Influence of seed priming and seeding technique on leaf area index of Super Basmati grown under different production systems during the year (a) 2010 (b) 2011
CON = conventional method, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, Error bar = standard Error

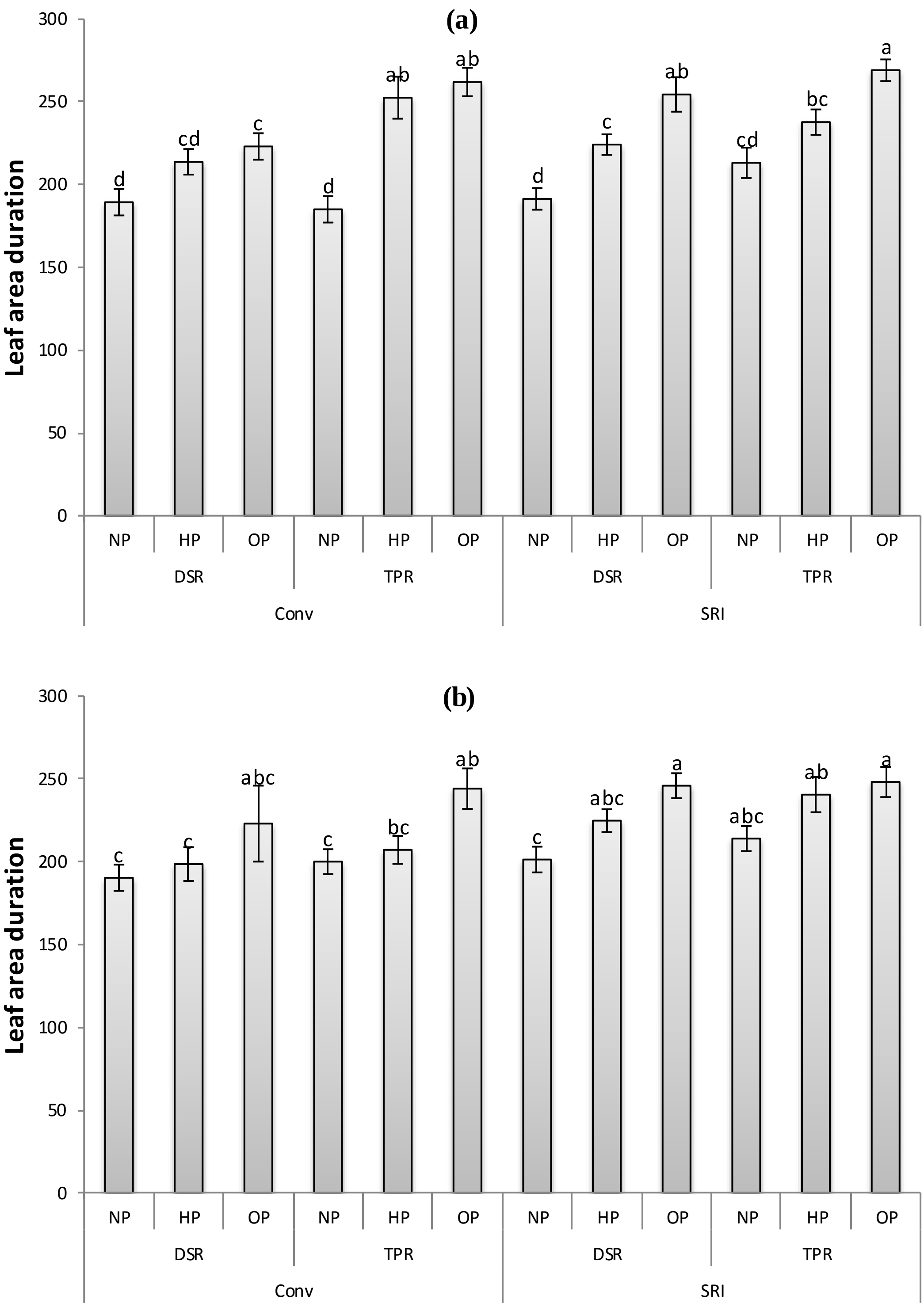


Figure 4.6: Influence of seed priming and seeding technique on leaf area duration of Super Basmati grown under different production systems during the year (a) 2010 (b) 2011
CON = conventional method, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, NP = non primed, HP = hydropriming, OP = osmopriming, Error bar = standard Error

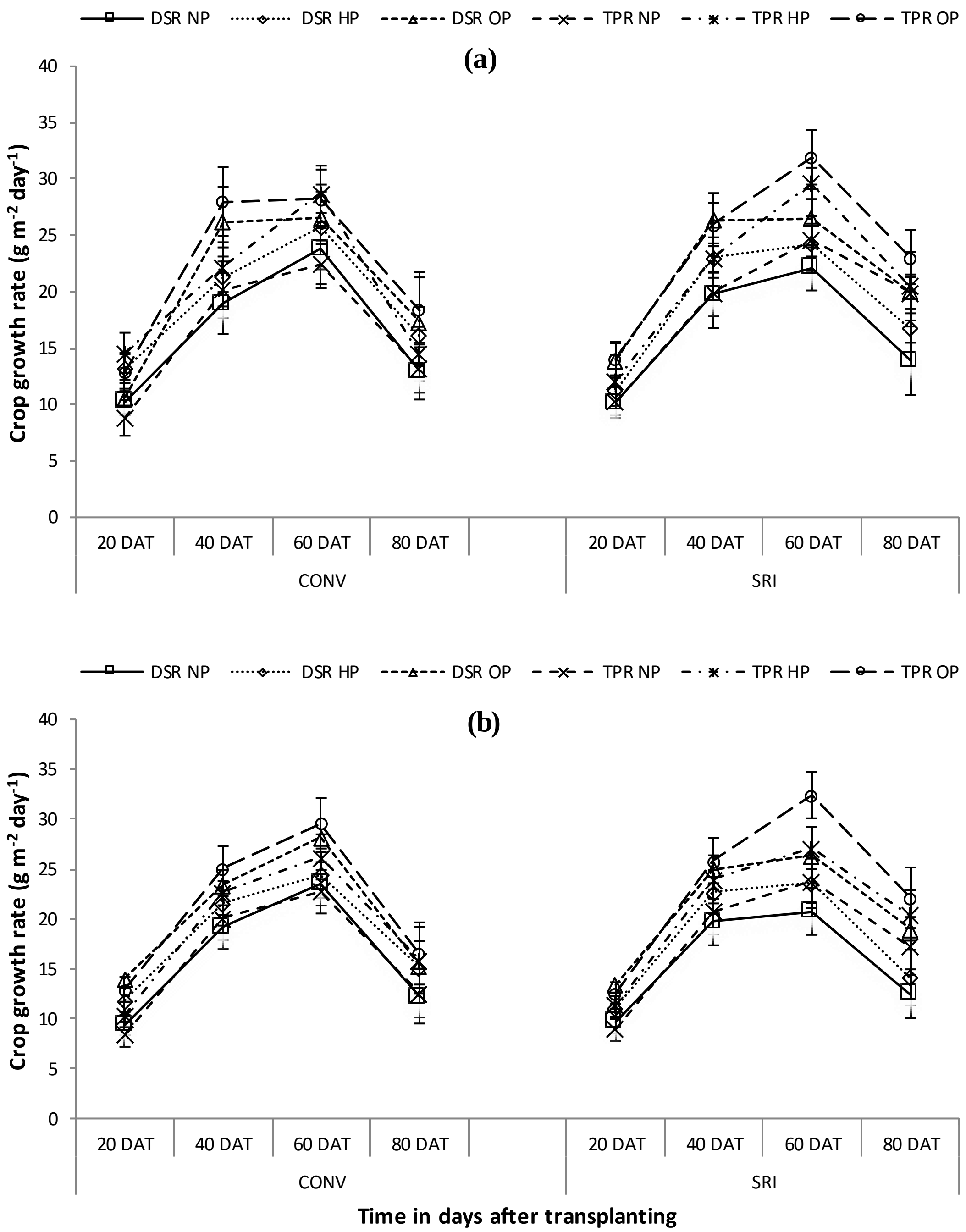
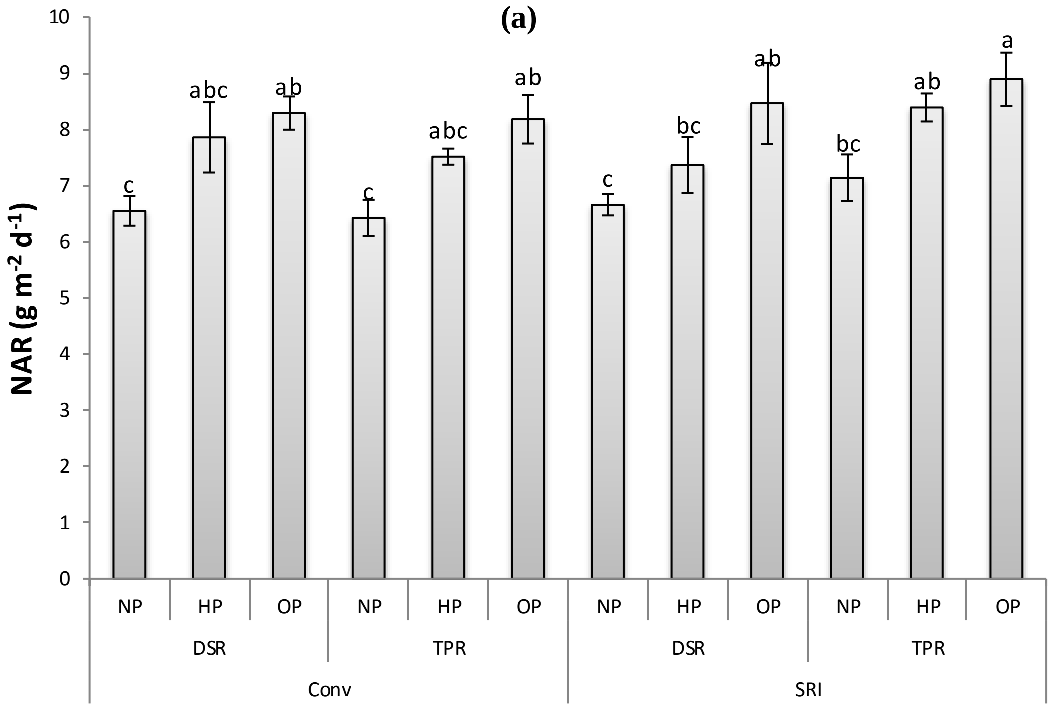


Figure 4.7: Influence of seed priming and seeding technique on crop growth rate of Super Basmati grown under different production systems during the year (a) 2010 (b) 2011
CON = conventional method, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, NP = non primed, HP = hydropriming, OP = osmopriming, Error bar = standard Error



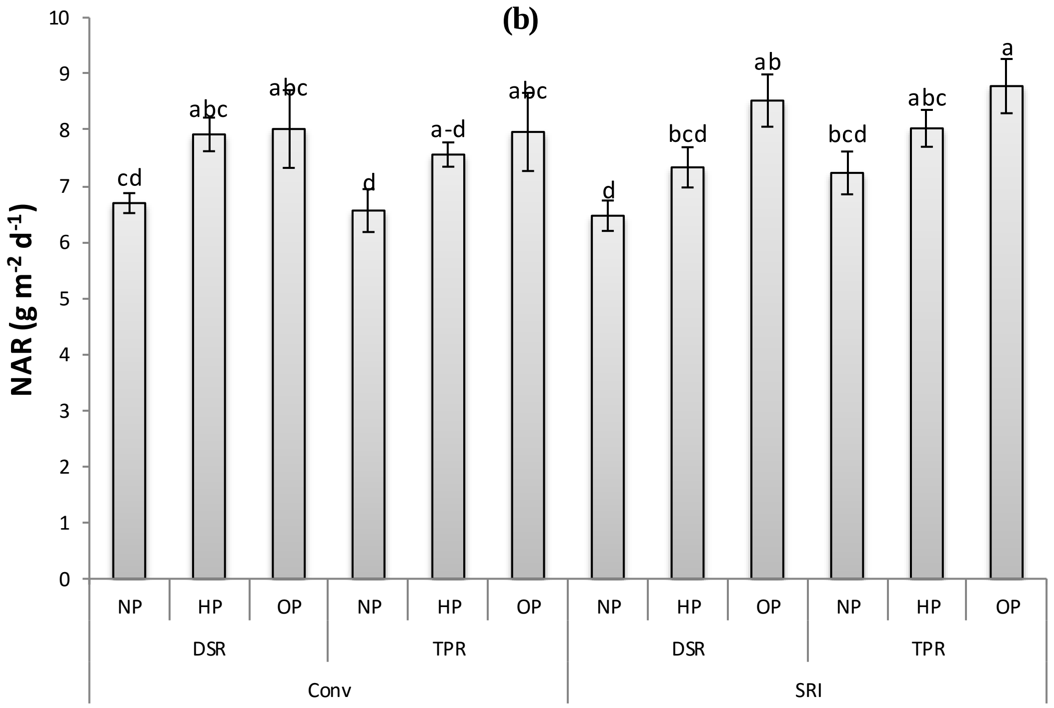


Figure 4.8: Influence of seed priming and seeding technique on net assimilation rate of Super Basmati grown under different production systems during the year (a) 2010 (b) 2011
CON = conventional method, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, NP = non primed, HP = hydropriming, OP = osmopriming, Error bar = standard Error

4.2.2 Phenology

4.2.2.1 Results

4.2.2.1.1 Days to heading

Rice production systems significantly affected days to heading in both the years. However, seeding technique significantly affected days to heading only during 2010 and seed priming significantly affected days to heading in both the years (Table 4.68). Likewise, interaction among production systems, seeding technique and seed priming also differed significantly regarding days to heading (Table 4.68).

SRI significantly took less days to heading than that of conventional method of rice cultivation in both years (Table 4.69). Similarly, transplanted rice significantly took less time to heading than that of direct seeding during the year 2010 (Table 4.69). Osmopriming with $CaCl_2$ significantly lowered the time taken to heading than that of hydropriming and untreated seeds in both years. However, untreated seeds were similar to hydropriming in in taking less time to heading only during the year 2011 (Table 4.70).

The overall interaction of rice production systems, seeding technique and seed priming (Table 4.71) showed that osmopriming with $CaCl_2$ in transplanted rice under SRI significantly took less time to heading during the year 2011. This treatment was statistically at par with osmopriming ($CaCl_2$) in direct seeded rice and hydropriming in both direct seeded and transplanted rice under SRI. However, untreated and hydropriming in direct seeding under conventional method took maximum time to heading during the year 2011 (Table 4.71). This was followed by hydropriming and untreated seeds in transplanted rice under conventional method and osmopriming with $CaCl_2$ in direct seeding under conventional method which were statistically at par with each other during the year 2011 (Table 4.71).

4.2.2.1.2 Heading to maturity (Days)

Rice production systems and seeding technique significantly affected days taken to maturity only during the year 2011 while seed priming was significant only during the year 2010 (Table 4.68). The interaction of seeding technique with seed priming and overall interaction among production systems, seeding technique and seed priming was only significant during the year 2011 (Table 4.68).

In rice production systems, SRI took less time from heading to maturity only during the year 2011 (Table 4.72). However, transplanting technique significantly lowered the time taken from heading to maturity than that of direct seeding during the year 2011

(Table 4.72). Among seed priming treatments, osmopriming with $CaCl_2$ significantly lowered days taken from heading to maturity than untreated seeds and was statistically at par with hydropriming only during the year 2010 (Table 4.73). Interaction of seed priming with seeding technique showed that the least time taken from heading to maturity was recorded where transplanting of seeds primed with $CaCl_2$ was carried out during the year 2011. This was statistically at par with untreated seeds of same seeding technique during the same year (Table 4.73). However, direct seeding with untreated seeds took maximum time from heading to maturity and was at par with hydropriming in same seeding technique during the year 2011 (Table 4.73).

Interaction among production systems, seeding technique and seed priming revealed that least time taken from heading to maturity was recorded where transplanting with untreated and direct seeding with primed ($CaCl_2$) seeds was carried out under SRI during the year 2011 (Table 4.74). Nursery transplantation with untreated seeds and direct seeding of hydroprimed seeds under conventional method took maximum time from heading to maturity during the year 2011. This was followed by direct seeding of osmoprimed ($CaCl_2$) and untreated seeds under conventional method of cultivation during the same year (Table 4.74).

4.2.2.2 Discussion

The phenological attributes in rice cultivars were significantly affected by seeding technique, seed priming and production systems (Table 4.68). In rice cultivation methods SRI took lower days to heading and heading to maturity than that of conventional method during both the years (Table 4.69, Table 4.72). The lower days to heading and heading to maturity in SRI might be due to better growth and development of younger seedling than that of older seedling used in conventional method. In SRI, the younger seedling have potential to resume transplanting shock earlier (Stoop *et al.*, 2002) than older seedling and this might resulted in early completion of all growth stages.

These results are also in line with the findings of Chapagain *et al.* (2011) who reported significant response of SRI management practices and recorded lower days to flowering (by 10 days) and days to maturity (by 8 days) in SRI than conventional method. Among the seed priming treatments, osmopriming with $CaCl_2$ reduced days to heading and heading to maturity (Table 4.70, Table 4.73) during both the years. This seems to be the result of vigorous growth and timely accomplishment of the phonological events (Farooq *et al.*, 2006b).

4.2.3 Agronomic and yield related attributes

4.2.3.1 Results

4.2.3.1.1 Plant height at maturity (cm)

Analysis of variance showed that seeding technique significantly affected the plant height only during the year 2010 (Table 4.68). Neither rice production systems nor seed priming could affect plant height during both the years. Similarly, interaction of production systems with seeding technique and with seed priming, seeding technique with seed priming and overall interaction among production systems, seeding technique and seed priming was also not significant during both the years (Table 4.68).

In seeding technique, maximum plant height was recorded in transplanted rice than that of direct seeded rice during the year 2010 (Table 4.75). No significant difference was recorded for plant height among rice production systems and interaction of rice production systems with seeding technique in both the years (Table 4.75).

4.2.3.1.2 Productive tillers (m^{-2})

Rice production systems significantly differed regarding productive tillers during both years. Similarly, seeding technique and seed priming also significantly affected productive tillers in both the years (Table 4.68). Interaction of production systems with seeding technique was significant during both the years while interaction of seeding technique with seed priming was only significant during the year 2011 (Table 4.68). Interaction of production system with seed priming and overall interaction among production systems, seeding technique and seed priming was not significant during both the years (Table 4.68).

In rice production systems, higher productive tillers were recorded in SRI than that of conventional method of cultivation during both years (Table 4.76). Similarly, transplanting technique outperformed than direct seeding regarding productive tillers during both years (Table 4.76). Interaction of rice production systems and seeding technique revealed that maximum number of productive tillers were recorded where transplanting was carried out under SRI in both years. This was followed by transplanting under conventional and direct seeding under SRI during the year 2010 and direct seeding under SRI and transplanting conventional during the year 2011. The least productive tillers were recorded in direct seeding under conventional method of cultivation during both the years (Table 4.76).

Among seed priming treatments maximum productive tillers were recorded in osmopriming with $CaCl_2$ followed by hydropriming and least productive tillers were recorded where untreated seeds were sown in both years (Table 4.77). Interaction of seeding technique with seed priming indicated that maximum productive tillers were recorded in transplanting with primed seeds ($CaCl_2$) followed by hydropriming under same seeding technique and direct seeding of seeds osmoprimed with $CaCl_2$ during the year 2011. However, the least productive tillers were recorded in direct seeded untreated seeds during the year 2011 (Table 4.77).

4.2.3.1.3 Unproductive tillers (m^{-2})

The analysis of variance (Table 4.78) indicated that rice production systems and seeding technique only differed significantly regarding unproductive tillers during the year 2010 (Table 4.78). However, interaction of seeding technique with seed priming was only significant for unproductive tillers during the year 2011 (Table 4.78).

Rice production systems only differed during the year 2010 for unproductive tillers and less unproductive tillers were recorded in SRI than that of conventional method of cultivation (Table 4.79). Similarly, transplanting also resulted in less unproductive tillers than that of direct seeding during the same year (Table 4.79).

Interaction of seeding technique and seed priming indicated that maximum unproductive tillers were recorded in hydropriming under transplanting and osmopriming with $CaCl_2$ under direct seeding during the year 2011 (Table 4.80). This was followed by untreated seeds sown under direct seeding and hydropriming under direct seeding during the same year. Hydropriming under direct seeding and osmopriming with $CaCl_2$ under transplanting were similar statistically for unproductive tillers during the same year (Table 4.80).

4.2.3.1.4 Panicle length (cm)

Seeding technique differed significantly for panicle length only during the year 2010 while seed priming affected panicle length significantly during both the years (Table 4.78). However, rice production systems and all interaction were not significant regarding panicle length in both years (Table 4.78).

For seeding technique, more panicle length was recorded in transplanting than that of direct seeding during the year 2010 (Table 4.81). However, among seed priming treatments, osmopriming with $CaCl_2$ resulted in maximum panicle length during both years and was statistically at par with hydropriming only during the year 2011. The least panicle length was recorded in plots where untreated seeds were sown during both years (Table 4.81).

4.2.3.1.5 Kernels per panicle

Both rice production systems and seed priming differed significantly regarding kernels per panicle in both years. However, seeding technique significantly affected kernels per panicle only during the year 2011 (Table 4.78). Interaction of production systems with seed priming and seeding technique with seed priming was significant only during the year 2010 and 2011, respectively (Table 4.78).

In rice production systems, maximum kernels per panicle were recorded under SRI than that of conventional method of cultivation during both years (Table 4.82). Among seed priming treatments, higher kernels per panicle were recorded in osmopriming with $CaCl_2$ followed by hydropriming while least kernels per panicle were recorded in untreated seeds during both years (Table 4.82). Interaction of production systems with seed priming indicated that maximum kernels per panicle were recorded in osmopriming with $CaCl_2$ under SRI followed by hydropriming under same production system and osmopriming under conventional method during the year 2010 (Table 4.82). Osmopriming with $CaCl_2$ and hydropriming were statistically at par with each other while least kernels per panicle were recorded in untreated seeds under both production systems during the same year (Table 4.82).

In seeding technique, more kernels per panicle were recorded in transplanting than that of direct seeding during the year 2011 (Table 4.83). Interaction of seeding technique with seed priming indicated that maximum kernels per panicle were recorded in transplanting of nursery seedling which were primed with $CaCl_2$ followed by hydropriming under same seeding technique and hydropriming under direct seeding during the same year. Osmopriming with $CaCl_2$ under direct seeding was statistically at par with hydropriming under transplanting while least kernels per panicle were recorded in untreated seeds which were direct seeded during the same year (Table 4.83).

4.2.3.1.6 1000-kernel weight (g)

Analysis of variance revealed (Table 4.78) that rice production systems, seeding technique and seed priming significantly differed regarding 1000 kernel weight during both the years (Table 4.78). Interaction of rice production systems with seeding technique was only significant during the year 2010. Similarly, overall interaction among rice production systems, seeding technique and seed priming affected 1000 kernel weight significantly only during the year 2011 (Table 4.78).

Between rice production systems, higher 1000 kernel weight was recorded in SRI than that of conventional method of cultivation during both years (Table 4.84). Similarly, more 1000 kernel weight was recorded in transplanting that that of direct seeding during both years (Table 4.84). Interaction of rice production systems with seeding technique indicated that maximum 1000 kernel weight was recorded where nursery was transplanted under SRI followed by direct seeding under same method of cultivation and transplanting under conventional method during the year 2010 (Table 4.84). The least 1000 kernel weight was recorded where direct seeding was carried out under conventional method of cultivation during the same year (Table 4.84).

Among seed priming treatments, maximum 1000 kernel weight was recorded in osmopriming with $CaCl_2$ followed by hydropriming and least 1000 kernel weight was recorded where untreated seeds were used during both years (

Table 4.85). The overall interaction indicated that maximum 1000 kernel weight was recorded in SRI where transplanting of osmoprimed ($CaCl_2$) seeds was carried during the year 2011 (Table 4.86). This was followed by transplanting of hydroprimed and direct seeding of hydroprimed seeds under same cultivation method, transplating of osmoprimed seeds and direct seeding of same priming treatment under conventional method during the same year. However, the least 1000 kernel weight was recorded in direct seeded untreated seeds under conventional method of cultivation during the same year (Table 4.86).

Table 4.68: Analysis of variance for the influence of production system, seeding technique and seed priming on days to heading, heading to maturity, plant height and productive tillers of Super Basmati

		Mean sum of squares							
		Days to heading		Heading to maturity (days)		Plant height (cm)		Productive tillers (m^{-2})	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Method (M)	1	136.1*	272.3**	3.36	106.8**	14.69	121.0	20117**	25281**
$Error_1$	2	2.19	1.0	26.69	0.86	4.78	71.58	15.53	193
Seeding (S)	1	160.4*	124.69	0.25	28.44*	51.36*	93.44	37056**	8773.4**
M × S	1	25.0	2.25	30.25	11.11	1.36	5.44	1213.4*	4053.4*
$Error_2$	4	18.56	22.72	5.17	1.86	5.11	12.36	93.14	211.6
Seed Priming (P)	2	296.3**	54.19**	109.4**	6.58	85.44	20.58	21246**	18397**
M × P	2	2.78	18.58	2.03	10.53	2.11	4.08	173.7	33.6
S × P	2	31.44	17.69	3.08	31.19*	0.11	50.36	59.1	492*
M × S × P	2	0.33	35.08*	1.75	73.69**	1.44	2.19	168.9	140.4
$Error_3$	16	10.68	6.72	5.47	3.83	25.03	25.93	131.3	112.7

SOV = source of variation, df = degree of freedom, * = significant ($P<0.05$), ** = highly significant ($P<0.01$), ns = non significant
Year effect was significant for days to heading and productive tillers (m^{-2})

Table 4.69: Influence of production system and seeding technique on days to heading of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	87.2	84.7	85.9 A	91.2	87.0	89.1 A
SRI	85.0	79.1	82.1 B	85.2	82.0	83.6 B
Means	86.1 A	81.9 B		88.2	84.5	
Means (Year)	84.0 B			86.4 A		

LSD_{2010} (M) = 2.1, LSD_{2010} (S) = 4.0, LSD_{2011} (M) = 1.4, LSD (Year) = 1.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.70: Influence of production system and seed priming on days to heading of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	91.8	86.8	89.3 A	89.8	87.2	88.5 A
Hydropriming	84.8	81.5	83.2 B	90.0	82.7	86.3 AB
Osmopriming	81.2	77.8	79.5 C	87.5	81.0	84.3 B

LSD_{2010} (P) = 2.9, LSD_{2011} (P) = 2.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.71: Influence of production system, seeding technique and seed priming on days to heading of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	91.3	92.3	88.0	85.7	93.0 a	86.7 bcd	90.0 ab	84.3 cd
Hydropriming	86.7	83.0	84.7	78.3	94.0 a	86.0 bcd	82.7 de	82.7 de
Osmopriming	83.7	78.7	82.3	73.3	86.7 bcd	88.3 bc	83.0 de	79.0 e

LSD_{2011} (M×S×P) = 4.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.72: Influence of production system and seeding technique on heading to maturity of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	33.2	34.9	34.1	37.3	34.4	35.9 A
SRI	35.7	33.7	34.7	32.8	32.1	32.4 B
Means	34.4	34.3		35.1 A	33.3 B	

LSD_{2011} (M) = 1.3, LSD_{2011} (S) = 1.3
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.73: Influence of seeding technique and seed priming on heading to maturity of Super Basmati

Seed priming	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
Non primed	38.0	37.3	37.7 A	37.5 a	32.0 c	34.8
Hydropriming	33.2	34.2	33.7 B	35.3 ab	33.5 bc	34.4
Osmopriming	32.2	31.3	31.8 B	34.8 b	31.8 c	33.3

LSD_{2010} (P) = 2.02, LSD_{2011} (S×P) = 2.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, DSR = direct seeded rice, TPR = transplanted rice

Table 4.74: Influence of production system, seeding technique and seed priming on heading to maturity of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	37.7	38.0	38.3	36.7	35.3 bc	39.7 a	34.0 cd	30.0 e
Hydropriming	31.7	34.7	34.7	33.7	39.0 a	31.7 de	35.3 bc	31.7 de
Osmopriming	30.3	32.0	34.0	30.7	37.7 ab	32.0 cde	29.0 e	34.7 bcd

LSD_{2011} (M×S×P) = 3.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.75: Influence of production system and seeding technique on plant height of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	121	124	123	119	121	120
SRI	123	125	124	122	126	124
Means	122 B	124 A		120	124	

LSD_{2010} (S) = 2.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.76: Influence of production system and seeding technique on productive tillers of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	386 d	439 b	413 B	380 d	390 c	385 B
SRI	422 c	498 a	460 A	412 b	465 a	438 A
Means	404 B	468 A		396 B	428 A	
	436 A			412 B		

LSD_{2010} (M) = 5.7, LSD_{2010} (S) = 9.0, LSD_{2010} (M×S) = 12.6, LSD_{2011} (M) = 19.9, LSD_{2011} (S) = 13.5, LSD_{2011} (M×S) = 1.5, LSD (Year) = 14.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.77: Influence of seeding technique and seed priming on productive tillers of Super Basmati

Seed priming	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
Non primed	357	422	390 C	355 e	385 d	370 C
Hydropriming	414	482	448 B	409 c	428 b	418 B
Osmopriming	441	501	471 A	425 b	470 a	448 A

LSD_{2010} (P) = 9.9, LSD_{2011} (P) = 9.2, LSD_{2011} (S×P) = 13.0
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, DSR = direct seeded rice, TPR = transplanted rice

Table 4.78: Analysis of variance for the influence of production system, seeding technique and seed priming on unproductive tillers, panicle length, kernels per panicle and 1000 kernel weight of Super Basmati

		Mean sum of squares							
		Unproductive tillers (m^{-2})		Panicle length (cm)		Kernels per panicle		1000 kernel weight (g)	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Method (M)	1	2010**	100	6.0	0.28	126.2**	3271**	79.5*	110.64**
$Error_1$	2	18.78	896.3	2.85	4.91	0.23	2.02	2.95	0.48
Seeding (S)	1	4830.3*	196	15.3*	15.47	30.3	53.5**	13.8**	27.3**
M × S	1	23.36	1133.4	5.37	1.69	4.55	1.73	1.91**	0.003
$Error_2$	4	306.22	1496.6	1.53	2.40	6.34	1.10	0.08	0.27
Seed Priming (P)	2	290.3	28.78	78.46**	72.1**	305.1**	156.1**	49.7**	105.8**
M × P	2	153.36	354.33	0.36	3.99	13.6*	2.86	4.67	2.39
S × P	2	28.58	2904.3**	1.75	1.05	1.11	5.41*	0.94	2.30
M × S × P	2	41.36	28.78	0.76	0.50	3.28	3.12	2.80	2.75*
$Error_3$	16	642.10	399.64	1.98	4.01	3.18	1.18	2.09	0.69

SOV = source of variation, df = degree of freedom, * = significant (P≤5%), ** = highly significant (P≤1%), ns = non significant (P>5%)
Year effect was only significant for 1000 kernel weight

Table 4.79: Influence of production system and seeding technique on unproductive tillers of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	136	111	124 A	128	112	120
SRI	119	98	109 B	113	120	116
Means	128 A	105 B		120	116	

LSD_{2010} (M) = 6.2, LSD_{2010} (S) = 16.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.80: Influence of seeding technique and seed priming on unproductive tillers of Super Basmati

Seed priming	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
Non primed	128	106	117	124 ab	111 ab	117
Hydropriming	124	98	111	105 b	135 a	120
Osmopriming	131	111	121	132 a	101 b	117

LSD_{2011} (S×P) = 24.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, DSR = direct seeded rice, TPR = transplanted rice

Table 4.81: Influence of seeding technique and seed priming on panicle length of Super Basmati

Seed priming	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
Non primed	21.0	21.8	21.4 C	21.6	23.3	22.5 B
Hydropriming	24.0	24.9	24.5 B	25.1	26.7	25.9 A
Osmopriming	25.3	27.5	26.4 A	26.8	27.5	27.2 A
Means	23.4 B	24.7 A		24.5	25.8	

LSD_{2010} (S) = 1.2, LSD_{2010} (P) = 1.2, LSD_{2011} (P) = 1.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, DSR = direct seeded rice, TPR = transplanted rice

Table 4.82: Influence of production system and seed priming on kernels per panicle of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	72.4 d	74.3 d	73.3 C	73.3	78.6	76.0 C
Hydropriming	79.0 c	82.3 b	80.6 B	77.7	83.4	80.6 B
Osmopriming	79.9 c	86.1 a	83.0 A	79.5	86.6	83.1 A
Means	77.1 B	80.9 A		76.9 B	82.9 A	

LSD_{2010} (M) = 0.7, LSD_{2010} (P) = 1.5, LSD_{2010} (M×P) = 2.2, LSD_{2011} (M) = 2.04, LSD_{2011} (P) = 1.0
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.83: Influence of seeding technique and seed priming on kernels per panicle of Super Basmati

Osmopriming	2010		2011	
	DSR	TPR	DSR	TPR
Non primed	72.0	74.6	75.3 e	76.7 d
Hydropriming	79.9	81.3	78.6 c	82.6 b
Osmopriming	82.2	83.8	82.1 b	84.1 a
Means	78.0	79.9	78.7 B	81.1 A

LSD_{2011} (S) = 1.0, LSD_{2011} (S×P) = 1.3
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, DSR = direct seeded rice, TPR = transplanted rice

Table 4.84: Influence of production system and seeding technique on 1000 kernel weight of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	14.9 d	15.7 c	15.3 B	13.4	15.1	14.3 B
SRI	17.4 b	19.1 a	18.3 A	16.9	18.6	17.8 A
Means	16.1 B	17.4 A		15.2 B	16.9 A	

LSD_{2010} (M) = 2.5, LSD_{2010} (S) = 0.3, LSD_{2010} (M×S) = 0.4, LSD_{2011} (M) = 1.0, LSD_{2011} (S) = 0.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.85: Influence of production system and seed priming on 1000 kernel weight of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	13.7	15.3	14.5 C	11.5	14.0	12.8 C
Hydropriming	15.5	18.8	17.2 B	14.9	18.6	16.8 B
Osmopriming	16.5	20.5	18.5 A	16.4	20.7	18.6 A
Means (Year)	14.8 B			18.0 B		

LSD_{2010} (P) = 1.3, LSD_{2011} (P) = 0.7, LSD (Year) = 1.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.86: Influence of production system, seeding technique and seed priming on 1000 kernel weight of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	13.1	14.4	15.3	15.3	10.2 h	12.9 g	13.8 fg	14.3 efg
Hydropriming	15.3	15.7	17.7	20.0	14.7 ef	15.2 ef	17.9 cd	19.4 b
Osmopriming	16.2	16.8	19.1	21.9	15.4 e	17.5 d	19.1 bc	22.3 a

LSD_{2011} (M×S×P) = 1.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

4.2.3.1.7 Kernel yield (t ha^{-1})

Kernel yield was significantly affected by rice production systems, seeding technique and seed priming during both the years (Table 4.87). However, interaction of rice production systems with seeding technique was only significant during the year 2010 (Table 4.87). Likewise, overall interaction of rice production systems, seeding technique and seed priming significantly affected kernel yield only during the year 2011 (Table 4.87).

Rice production systems differ significantly for kernel yield and maximum kernel yield was recorded in SRI than that of conventional method of cultivation during both years (Table 4.88). Similarly, kernel yield was also influenced significantly by seeding technique where transplanting outperformed than that of direct seeding in both years (Table 4.88). Interaction of production systems with seeding technique also influenced kernel yield significantly where maximum kernel yield recorded in transplanting under SRI followed by direct seeding under same cultivation method and transplanting under conventional method during the year 2010 (Table 4.88). The least kernel yield was recorded where direct seeding was carried out under conventional method of cultivation and was at par with transplanting of nursery seedling under same method of cultivation during the same year (Table 4.88).

Seed priming treatments vary significantly for kernel yield and higher kernel yield was recorded in osmopriming with $CaCl_2$ followed by hydropriming and least kernel yield was recorded in untreated seeds during both years. However, osmopriming with $CaCl_2$ was statistically at par with hydropriming regarding kernel yield only during the year 2010 (Table 4.89).

Interaction among cultivation method, seeding technique and seed priming indicated that maximum kernel yield was recorded in SRI where transplanting of nursery seedling primed with $CaCl_2$ was carried out during the year 2011 (Table 4.90). This was followed by direct seeding of osmoprimed seeds under the same cultivation method, transplanting of hydroprimed seeds under same cultivation method, direct seeding of hydroprimed seeds under conventional method and transplanting of untreated seeds under same cultivation method during the same year. However, direct seeding and transplanting of hydroprimed seeds under SRI and osmoprimed seeds under conventional method and transplanting of hydroprimed seeds under conventional method were statistically at par with each other during the same year. The least kernel yield was recorded in direct seeding of untreated seeds under conventional method during same year (Table 4.90).

4.2.3.1.8 Straw yield (t ha^{-1})

Rice production systems significantly differed for straw yield only during the year 2010 whereas seeding technique and seed priming affected straw yield significantly during both the years (Table 4.87). Interaction of rice production systems with seeding technique for straw yield was only significant during the year 2011. Similarly, interaction of rice production systems with seed priming was only significant during the 2010 and overall interaction of production systems, seeding technique and seed priming was only significant during the year 2011 (Table 4.87).

In rice production methods, higher straw yield was recorded in SRI than that of conventional method of cultivation during the year 2010 (Table 4.91). Between seeding techniques, transplanting outperformed than that of direct seeding in both the years (Table 4.91). Interaction of production systems with seeding technique indicated that maximum straw yield was recorded where transplanting was carried out under SRI followed by transplanting under conventional method during the year 2011 (Table 4.91). However, transplanting under conventional and direct seeding under SRI were similar statistically while minimum straw yield was recorded in direct seeding under conventional method of cultivation during the same year (Table 4.91).

Among seed priming treatments, higher straw yield was recorded in osmopriming with $CaCl_2$ followed by hydropriming and least straw yield was recorded where untreated seeds were used during both years (Table 4.92). However, osmopriming and hydropriming were statistically similar regarding straw yield during the year 2011. Interaction of production systems with seed priming revealed that higher straw yield was recorded in osmopriming with $CaCl_2$ under SRI and is statistically similar to untreated seeds under same cultivation method during the year 2010 (Table 4.92). This was followed by hydropriming under conventional method and least straw yield was recorded where untreated seeds were used under conventional method of cultivation during the same year (Table 4.92).

Overall interaction among production systems, seeding technique and seed priming revealed that maximum straw yield was recorded in transplanting of osmoprimed ($CaCl_2$) seeds under SRI and was at par with hydropriming under same seeding technique and cultivation method, osmopriming in transplanted rice under conventional and direct seeded rice under SRI during the year 2011 (Table 4.93). However, the least straw yield was recorded in hydropriming and osmopriming in direct seeded rice under conventional method of cultivation during the same year (Table 4.93).

4.2.3.1.9 Harvest index (%)

Harvest index differed significantly by rice production systems and seeding technique only during the year 2010. However, seed priming affected harvest index significantly during both the years (Table 4.87). Interaction of rice production systems with seeding technique and seed priming affected harvest index significantly only during the year 2010 (Table 4.87). The overall interaction among rice production systems, seeding technique and seed priming was only significant during the year 2011 (Table 4.87).

In rice production systems, highest harvest index was recorded under SRI than that of conventional method during the year 2010 (Table 4.94). Transplanting also improved harvest index than that of direct seeded rice during the same year (Table 4.94). Interaction of production systems with seeding technique revealed that maximum harvest index was recorded in transplanting under SRI during the year 2010. This was followed by direct seeding under conventional and SRI while the least harvest index was recorded in transplanting under conventional method during the same year (Table 4.94).

Harvest index was also influenced significantly by seed priming treatments where osmopriming with $CaCl_2$ outperformed than that of hydropriming and untreated seeds during both years (Table 4.95). However, osmopriming and hydropriming were statistically similar regarding harvest index during the year 2010 (Table 4.95).

The overall interaction of production systems, seeding technique and seed priming indicated that maximum harvest index was recorded in transplanting of osmoprimed seeds ($CaCl_2$) under SRI during the year 2011 (Table 4.96). This was followed by osmopriming in direct seeding under both conventional method and SRI, hydropriming in direct seeding under conventional method, osmopriming in transplanting under same cultivation method and hydropriming in direct seeding under SRI during the same year. However, least harvest index was recorded in both direct seeding and transplanting under conventional method during the same year (Table 4.96).

4.2.3.2 Discussion

Both rice production systems and seed priming, significantly improved productive tillers, kernels per panicle, 1000 kernel weight, kernel yield, straw yield and harvest index during both years (Table 4.78, Table 4.86).

In production systems, SRI resulted in improved growth, kernel yield and quality attributes than that of conventional method during both the years. This seems to be due to the management practices of SRI that provided better soil environment for vigorous and robust root growth and also resulted increased nutrient supply towards the aerial part of plant. One of the aspect of SRI is younger seedling age which might have resulted in increased productive tiller (Table 4.76) due to the inverse relation between tiller production and length of phyllochron (Nemato *et al.*, 1995). Similarly, greater tiller production might have resulted in improved kernel yield, straw yield and harvest index in SRI than that of conventional method.

The improvement in yield might be the result of improved nutrient supply due to robust root growth and higher production of tillers (Nayak *et al.*, 2006). The improvement in yield in SRI is also reported in some recent research work in different countries (Namara *et al.*, 2008; Sato & Uphoff, 2007; Kabir & Uphoff, 2007). Higher yields in SRI might be due to the changes in management practices which facilitated soil nutrients supply, improved aeration and increased activity of soil biota (Lin *et al.*, 2009; Thakur *et al.*, 2010; Zhao *et al.*, 2009) which might have resulted in stronger root development and ultimately higher plant growth.

Improved kernel yield due to osmopriming might be the result of improved productive tillers (Table 4.77), kernels per panicle (Table 4.82) and 1000 kernel weight (

Table 4.85). The increased tiller production due to osmopriming is seems to be the result of higher germination percentage (Farooq *et al.*, 2006a). Similarly, improvement in plant growth and development due to osmopriming with $CaCl_2$ is likely due to the crucial role of Ca^{2+} in membrane integrity, transport across plasmalemma and enzyme activities (Taiz & Zeiger, 2006). The increased straw yield owing to osmopriming with $CaCl_2$ seems due to the improved crop growth rate (Figure 4.7) and net assimilation rate (Figure 4.8). This improvement in kernel and straw yield might be due to the ealier and uniform germination (Farooq *et al.*, 2006).

Table 4.87: Analysis of variance for the influence of seedling age and seed priming on kernel yield, straw yield and harvest index of fine rice cultivars

		Mean sum of squares					
		Kernel yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Method (M)	1	0.64**	0.72**	2.44**	3.55	7.06*	5.50
$Error_1$	2	0.002	0.001	0.003	0.24	0.19	0.47
Seeding (S)	1	0.29**	0.13*	1.11*	4.66**	3.15*	3.17
M × S	1	0.13**	0.00	0.16	0.91**	12.18**	4.15
$Error_2$	4	0.01	0.01	0.09	0.03	0.19	0.56
Seed Priming (P)	2	0.60**	1.43**	1.85**	0.25*	11.13**	61.92**
M × P	2	0.00	0.03	0.97**	0.05	3.95**	1.48
S × P	2	0.003	0.002	0.14	0.10	1.23	0.24
M × S × P	2	0.001	0.04*	0.09	0.39*	0.80	5.75**
$Error_3$	16	0.02	0.01	0.11	0.07	0.60	0.65

SOV = source of variation, df = degree of freedom, * = significant (P<0.05), ** = highly significant (P<0.01), ns = non significant
Year effect was not significant

Table 4.88: Influence of production system and seeding technique on kernel yield of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	3.53 c	3.61 c	3.57 B	3.48	3.6	3.55 B
SRI	3.73 b	4.00 a	3.86 A	3.76	3.89	3.83 A
Means	3.62 B	3.80 A		3.63 B	3.75 A	

LSD_{2010} (M) = 0.1, LSD_{2010} (S) = 0.1, LSD_{2010} (M×S) = 0.1, LSD_{2011} (M) = 0.05, LSD_{2011} (S) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.89: Influence of production system and seed priming on kernel yield of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	3.32	3.65	3.49 B	3.18	3.47	3.33 C
Hydropriming	3.61	3.89	3.75 A	3.62	3.81	3.72 B
Osmopriming	3.75	4.04	3.90 A	3.82	4.20	4.02 A

LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.90: Influence of production system, seeding technique and seed priming on kernel yield of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	3.33	3.35	3.46	3.75	3.11 f	3.36 e	3.46 e	3.48 e
Hydropriming	3.51	3.56	3.74	4.04	3.33 e	3.62 d	3.78 c	3.85 c
Osmopriming	3.82	3.83	3.99	4.45	3.62 d	3.93 c	4.07 b	4.34 a

LSD_{2011} (M×S×P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.91: Influence of production system and seeding technique on straw yield of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	13.0	13.5	13.2 B	12.7 c	13.8 b	13.2
SRI	13.6	13.8	13.7 A	13.7 b	14.1 a	13.9
Means	13.3 B	13.7 A		13.2 B	13.9 A	

LSD_{2010} (M) = 0.1, LSD_{2010} (S) = 0.1, LSD_{2011} (S) = 0.2, LSD_{2011} (M × S) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.92: Influence of production system and seed priming on straw yield of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	12.6 d	13.6 b	13.1 C	13.2	13.6	13.4 B
Hydropriming	13.0 c	13.7 ab	13.4 B	13.2	13.9	13.6 AB
Osmopriming	14.0 A	13.8 AB	13.9 A	13.3	14.0	13.7 A

LSD_{2010} (P) = 0.3, LSD_{2010} (M × P) = 0.4, LSD_{2011} (P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.93: Influence of production system, seeding technique and seed priming on straw yield of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	12.3	13.0	13.5	13.7	12.9 de	13.4 c	13.3 cd	13.9 ab
Hydropriming	12.7	13.3	13.6	13.9	12.5 e	13.9 ab	13.7 bc	14.1 ab
Osmopriming	13.9	14.0	13.8	13.9	12.7 e	14.0 ab	13.9 ab	14.2 a

LSD_{2011} (M × S × P) = 0.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.94: Influence of production system and seeding technique on harvest index of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	27.4 b	26.8 c	27.1 B	27.5	26.2	26.8
SRI	27.1 bc	28.9 a	28.0 A	27.6	27.7	27.6
Means	27.3 B	27.8 A		27.5	26.9	

LSD_{2010} (M) = 0.6, LSD_{2010} (S) = 0.4, LSD_{2010} (M × S) = 0.6, LSD_{2011} (M) = 0.1, LSD_{2011} (S) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.95: Influence of production system and seed priming on harvest index of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	26.4	26.5	26.4 B	24.2	25.5	24.8 C
Hydropriming	27.9	28.3	28.1 A	27.5	27.5	27.5 B
Osmopriming	27.0	29.2	28.1 A	28.8	29.9	29.4 A

LSD_{2010} (P) = 0.7, LSD_{2010} (M × P) = 0.9, LSD_{2011} (P) = 0.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.96: Influence of production system, seeding technique and seed priming on harvest index of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	27.2	25.7	25.5	27.4	24.0 h	24.4 h	26.0 fg	25.0 gh
Hydropriming	28.3	27.4	27.6	29.0	28.3 cd	26.7ef	27.5 de	27.4 de
Osmopriming	26.7	27.4	28.2	30.2	30.1 ab	27.5 de	29.2 bc	30.6 a

LSD_{2011} (M × S × P) = 1.4
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

4.2.4 Grain and grain quality attributes

4.2.4.1 Results

4.2.4.1.1 Opaque grains (%)

The analysis of variance table revealed that seed priming influenced opaque grains significantly during both years while rice production systems differed only during the year 2010 (Table 4.97). There was no effect of seeding technique on opaque grains during both years. Similarly, interaction of rice production systems with seeding technique and seed priming was also not significant in both years (Table 4.97). Likewise, Interaction of seeding technique with seed priming and overall interaction of rice production systems, seeding technique and seed priming also not influenced opaque grains during both years (Table 4.97).

Rice production systems differ significantly regarding opaque grains and significantly lowered opaque grains were recorded in SRI than that of conventional method during the year 2010 (Table 4.98). Among seed priming treatments, osmopriming with $CaCl_2$ significantly reduced opaque grains followed by hydropriming and higher opaque grains were recorded in untreated seeds during both years (Table 4.98).

4.2.4.1.2 Abortive grains (%)

Abortive grains was affected significantly by rice production systems and seed priming in both years while seeding technique influenced abortive grains only during the year 2010 (Table 4.97). In the same way, interaction of rice production systems with seeding technique also influenced abortive grains only during the year 2011 (Table 4.97). However, interaction of rice production systems with seeding technique and seeding technique with seed priming and overall interaction of production systems, seeding technique and seed priming were not differed significantly for abortive grains during both years (Table 4.97).

Abortive grains were significantly reduced in SRI than that of conventional cultivation method during both years (Table 4.99). However, between seeding techniques, transplanting significantly reduced abortive grains than that of direct seeding during the year 2010 (Table 4.99). Interaction of rice production system and seeding technique indicated that transplanting under SRI significantly lowered the abortive grains than direct seeding under SRI and both direct seeding and transplanting under conventional method during the year 2011. The maximum abortive grains were recorded where transplanting was carried out under conventional method during the same year (Table 4.99).

Among Seed priming treatments, significantly lowered abortive grains were recorded in osmopriming with $CaCl_2$ followed by hydropriming and untreated seeds where abortive grains were higher than osmopriming during both years (Table 4.100). However, no significant variation was recorded in interaction of rice production systems and seed priming for abortive grains during both year (Table 4.100).

4.2.4.1.3 Normal grains (%)

Analysis of variance (Table 4.97) showed rice production systems, seeding technique and seed priming significantly affected normal grains during both years. However, interaction of rice production system with seeding technique only differed significantly during the year 2011 regarding normal grains (Table 4.97). Interaction rice production systems with seed priming, seeding technique with seed priming and overall interaction among rice production systems, seeding technique and seed priming didn't differ significantly for normal grains during both years (Table 4.97).

Maximum normal grains were recorded in SRI than that of conventional method during both years (Table 4.101). Similarly, in seeding techniques, higher normal grains were recorded in transplanting than that of direct seeding during both years (Table 4.101). Interaction of production systems and seeding technique revealed that higher normal grains were recorded where transplanting was carried out under SRI followed by direct seeding under SRI and transplanting under conventional method during the year 2011. The least normal grains were recorded where direct seeding was carried out under conventional method and was at par with transplanting under same cultivation method during same year (Table 4.101).

Among seed priming treatments, higher normal grains were recorded where seeds were osmoprimed ($CaCl_2$) followed by hydropriming and least normal grains were recorded where seeds used were untreated during both years (Table 4.102). However, no significant variation was recorded in interaction of rice production systems with seed priming during both years (Table 4.102).

4.2.4.1.4 Chalky grains (%)

Seed priming influenced chalky grains significantly during both years (Table 4.97). However, rice production systems and seeding technique only differed during the year 2010 for chalky grains (Table 4.97). Neither interaction of rice production systems with seeding technique nor with seed priming could influence chalky grains significantly in both years. Similarly, interaction of seeding technique with seed priming and overall interaction of rice production systems, seeding technique and seed priming didn't differ significantly regarding chalky grains during both years (Table 4.97).

Significantly lowered chalky grains were recorded in SRI than that of conventional cultivation method during the year 2010 (Table 4.103). Similarly, in seeding techniques, less chalky grains were recorded in transplanting than that of direct seeding during the same year (Table 4.103). However, interaction of rice production systems and seeding technique could not influence chalky grains significantly during both years (Table 4.103).

Table 4.97: Analysis of variance for the influence of seedling age and seed priming on abortive grains, normal grains, chalky grains and grain protein contents of fine rice cultivars

		Mean sum of squares							
		Opaque grains (%)		Abortive grains (%)		Normal grains (%)		Chalky grains (%)	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Method (M)	1	22.56*	38.2	1.90*	2.12*	234.6*	128.4*	143.8**	14.63
$Error_1$	2	0.94	9.23	0.004	0.09	2.86	1.40	0.89	1.67
Seeding (S)	1	0.23	8.51	0.34*	0.01	40.75*	17.08*	35.12*	1.86
M × S	1	0.84	3.67	0.13	0.36**	2.30	12.02*	4.53	7.03
$Error_2$	4	1.27	1.22	0.04	0.01	2.44	1.38	2.63	1.29
Seed Priming (P)	2	111.8**	70.12**	2.47**	2.20**	161.5**	142.1**	46.31**	8.89*
M × P	2	0.26	0.47	0.03	0.03	1.14	2.48	0.81	1.40
S × P	2	1.31	2.11	0.01	0.01	2.35	6.83	0.41	1.75
M × S × P	2	0.24	0.22	0.03	0.01	5.54	4.92	2.10	0.74
$Error_3$	16	5.45	3.25	0.06	0.07	5.27	2.83	4.90	1.66

SOV = source of variation, df = degree of freedom, * = significant ($P<0.05$), ** = highly significant ($P<0.01$), ns = non significant
Year effect was only significant for normal grains

Table 4.98: Influence of production system and seed priming on opaque grains of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	19.1	17.2	18.2 A	18.1	16.3	17.2 A
Hydropriming	15.2	13.9	14.5 B	15.8	13.9	14.8 B
Osmopriming	12.8	11.3	12.1 C	13.6	11.1	12.3 C
Means	15.7 A	14.1 B		15.8	13.7	

LSD_{2010} (M) = 1.4, LSD_{2010} (P) = 2.0, LSD_{2011} (P) = 1.6
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.99: Influence of production system and seeding technique on abortive grains of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	2.58	2.50	2.54 A	2.33 b	2.50 a	2.42 A
SRI	2.24	1.93	2.08 B	2.04 c	1.82 d	1.93 B
Means	2.41 A	2.22 B		2.19	2.16	

LSD_{2010} (M) = 0.1, LSD_{2010} (S) = 0.2, LSD_{2011} (M) = 0.4, LSD_{2011} (M×S) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.100: Influence of production system and seed priming on abortive grains of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	2.97	2.61	2.79 A	2.88	2.37	2.62 A
Hydropriming	2.49	2.04	2.26 B	2.40	1.84	2.12 B
Osmopriming	2.17	1.61	1.89 C	1.96	1.59	1.77 C

LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.101: Influence of production system and seeding technique on normal grains of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	56.4	58.0	57.2 B	59.2 c	59.4 c	59.3 B
SRI	61.0	63.6	62.4 A	61.8 b	64.3 a	63.1 A
Means	58.7 B	60.9 A		60.5 B	61.9 A	

LSD_{2010} (M) = 2.4, LSD_{2010} (S) = 1.5, LSD_{2011} (M) = 1.7, LSD_{2011} (S) = 1.1, LSD_{2011} (M×S) = 1.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.102: Influence of production system and seed priming on normal grains of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	53.4	58.5	56.0 C	55.5	59.2	57.4 C
Hydropriming	57.3	63.0	60.2 B	60.6	63.5	62.1 B
Osmopriming	61.0	65.5	63.3 A	61.7	66.4	64.1 A

LSD_{2010} (P) = 2.0, LSD_{2011} (P) = 1.5
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.103: Influence of production system and seeding technique on chalky grains of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	25.0	23.8	24.4 A	22.2	22.6	22.4
SRI	21.7	19.0	20.4 B	21.8	20.5	21.1
Means	23.4 A	21.4 B		22.0	21.6	

LSD_{2010} (M) = 1.4, LSD_{2010} (S) = 1.5, LSD_{2010} (M × S) = 0.6, LSD_{2011} (M) = 0.1, LSD_{2011} (S) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.104: Influence of production system and seed priming on chalky grains of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	26.2	22.8	24.5 A	23.3	22.1	22.7 A
Hydropriming	24.1	19.9	22.0 B	22.6	20.7	21.6 AB
Osmopriming	22.9	18.5	20.7 B	21.3	20.7	21.0 B

LSD_{2010} (P) = 2.0, LSD_{2011} (P) = 1.1

Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

4.2.4.1.5 Grain length (cm)

Seed priming affected grain length significantly during both years while seeding technique could influence grain length significantly only during the year 2010 (Table 4.105). Neither rice production systems and nor interactions of rice production systems with seeding technique and with seed priming could influence grain length significantly during both years (Table 4.105). Similarly, interaction of seeding technique with seed priming and overall interaction among rice production systems, seeding technique and seed priming didn't differ significantly in both years (Table 4.105).

Rice production systems significantly varied for grain length where maximum grain length was recorded in transplanting than that of direct seeding during the year 2010 (Table 4.106). Among seed priming treatments, higher grain length was recorded where seeds were primed with $CaCl_2$ followed by hydropriming and untreated seeds during both years. However, osmopriming and hydropriming were statistically similar for grain length only during the year 2011 (Table 4.106).

4.2.4.1.6 Grain width (cm)

Grain width was affected significantly by seed priming in both years while rice production systems could influence grain length significantly only during the year 2010 (Table 4.105). Neither seeding technique nor interaction of seeding technique with seed priming could affect grain width significantly during both years (Table 4.105). Similarly, interaction of rice production systems with seeding technique and with seed priming and overall interaction among rice production systems, seeding technique and seed priming was also not significant during both years (Table 4.105).

In rice production systems, significantly higher grain width was recorded in SRI than that of conventional sowing method during the year 2010 (Table 4.107). Among seed priming treatments, maximum grain width was recorded where seeds were osmoprimed with $CaCl_2$ and was statistically at par with hydropriming during both years. However least grain width was recorded where untreated seeds were used during both years (Table 4.107).

4.2.4.1.7 Grain length width ratio

Analysis of variance (Table 4.105) showed that grain length width ratio was affected by seed priming only during the year 2011. Neither rice production systems nor seeding technique could differ regarding grain length width ratio in both years. Similarly, interaction of rice production systems with seeding technique and with seed priming, seeding technique with seed priming and overall interaction of rice production systems, seeding technique and seed priming was also non significant for grain length width ratio during both years (Table 4.105).

Mean comparison indicated that grain length width ratio was significantly lowered where seeds were osmoprimed with $CaCl_2$ than that of hydropriming and untreated seeds during the year 2011. However, osmopriming with $CaCl_2$ was statistically at par with hydropriming during the same year (Table 4.108). Neither rice production systems nor interaction of production systems with seed priming could affect grain length width ration significantly during both years (Table 4.108).

4.2.4.1.8 Grain water absorption ratio

Analysis of variance (Table 4.105) indicated that seed priming significantly affected grain water absorption ratio in both years. However, rice production systems affected grain water absorption ratio only during the year 2010. Neither seeding technique nor interaction of seeding technique with seed priming and with rice production systems could affect grain water absorption ratio significantly in both years (Table 4.105). Similarly, interaction of production systems with seed priming and overall interaction among production systems, seeding technique and seed priming didn't differ significantly regarding grain water absorption ratio in both years (Table 4.105).

Higher grain water absorption ratio was recorded in SRI than that of conventional method of cultivation during the year 2010 (Table 4.109). Among seed priming treatments, maximum grain water absorption ratio was recorded in both osmopriming ($CaCl_2$) and hydropriming during both the years. However, the least ratio was recorded where untreated seeds were used during both years (Table 4.109).

Table 4.105: Analysis of variance for influence of different seedling age and seed priming on grain amylose contents, grain length, grain width and grain length width ratio of fine rice cultivars

		Mean sum of squares							
		Grain length (cm)		Grain width (cm)		Grain length width ratio		Grain water absorption ratio	
SOV	df	2010	2011	2010	2011	2010	2011	2010	2011
Method (M)	1	0.51	0.81	0.12*	0.14	0.22	0.19	0.27*	0.28
$Error_1$	2	0.36	0.11	0.01	0.10	0.58	0.72	0.01	0.06
Seeding (S)	1	0.19**	0.19	0.07	0.01	0.32	0.03	0.01	0.15
M × S	1	0.02	0.05	0.00	0.03	0.04	0.28	0.08	0.02
$Error_2$	4	0.00	0.05	0.05	0.07	0.52	0.43	0.02	0.06
Seed Priming (P)	2	1.79**	1.11**	0.50**	0.58**	1.99	2.37*	0.93**	0.98**
M × P	2	0.01	0.00	0.01	0.01	0.10	0.02	0.02	0.01
S × P	2	0.04	0.00	0.00	0.01	0.02	0.07	0.01	0.00
M × S × P	2	0.03	0.06	0.02	0.00	0.28	0.05	0.01	0.02
$Error_3$	16	0.07	0.07	0.06	0.06	0.78	0.57	0.12	0.07

SOV = source of variation, df = degree of freedom, * = significant (P<0.05), ** = highly significant (P<0.01), ns = non significant
Year effect was not significant

Table 4.106: Influence of seeding technique and seed priming on grain length of Super Basmati

Seed priming	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
Non primed	6.32	6.47	6.39 C	6.37	6.51	6.44 B
Hydropriming	6.80	6.83	6.81 B	6.77	6.89	6.83 A
Osmopriming	7.04	7.29	7.17 A	6.95	7.13	7.04 A
Means	6.72 B	6.86 A		6.70	6.85	

LSD_{2010} (S) = 0.1, LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, DSR = direct seeded rice, TPR = transplanted rice

Table 4.107: Influence of production system and seed priming on grain width of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	1.29	1.34	1.32 B	1.32	1.40	1.36 B
Hydropriming	1.47	1.63	1.55 A	1.58	1.68	1.63 A
Osmopriming	1.65	1.80	1.72 A	1.69	1.89	1.79 A
Means	1.471 B	1.588 A		1.53	1.66	

LSD_{2010} (M) = 0.1, LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.108: Influence of production system and seed priming on length width ratio of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	4.98	5.04	5.01	4.89	4.82	4.86 A
Hydropriming	4.60	4.31	4.46	4.31	4.19	4.25 AB
Osmopriming	4.33	4.10	4.22	4.11	3.87	3.99 B
Means	4.64	4.48		4.44	4.30	

LSD_{2011} (P) = 0.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.109: Influence of production system and seed priming on grain water absorption ratio of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	3.69	3.77	3.73 B	3.68	3.80	3.74 B
Hydropriming	3.98	4.18	4.08 A	4.02	4.26	4.14 A
Osmopriming	4.16	4.40	4.28 A	4.21	4.38	4.29 A
Means	3.94 B	4.12 A		3.97	4.15	

LSD_{2010} (M) = 0.1, LSD_{2010} (P) = 0.3, LSD_{2011} (P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

4.2.4.1.9 Kernel protein contents (%)

Kernel protein contents were differed significantly by rice production systems and seed priming during both years while seeding technique only affected kernel protein contents during the year 2011 (Table 4.110). Interaction of production systems with seeding technique and seed priming, seeding technique with seed priming and overall interaction among production systems, seeding technique and seed priming was not significant for kernel protein contents in both years (Table 4.110).

Rice production systems significantly varied for kernel protein contents and maximum kernel protein contents were recorded in SRI than that of conventional method of cultivation during both years (Table 4.111). Seeding techniques only differ during 2011, where higher kernel protein contents were recorded in transplanting than that of direct seeding (Table 4.111).

Among seed priming treatments, substantial improvement in kernel protein contents was recorded where seeds were osmoprimed ($CaCl_2$) followed by hydropriming and least protein contents were recorded where untreated seeds were used during both years (Table 4.112). However, no significant variation among the interaction means of production systems with seed priming for kernel protein contents during both years (Table 4.112).

4.2.4.1.10 Kernel amylose contents (%)

Kernel amylose contents were affected by rice production systems, seeding technique and seed priming in both years (Table 4.110). Similarly, interaction of production systems with seeding technique was also significant for kernel amylose contents in both years. However, overall interaction of production systems, seeding technique and seed priming was only significant during the year 2010 (Table 4.110). Neither interaction of production systems with seed priming nor interaction of seeding technique with seed priming could influence kernel amylose contents significantly during both years (Table 4.110).

Rice production systems significantly differed for kernel amylose contents where lower amylose contents were recorded in SRI than that of conventional method during both years (Table 4.113). Similarly, in seeding techniques, lower amylose contents were recorded in transplanting than that of direct seeding during both years (Table 4.113). Interaction of rice production system with seeding technique indicated that maximum amylose contents were recorded in both direct seeding and transplanting under conventional method and were statistically at par with each other than that of SRI during both years (Table 4.113). However, the least amylose contents were recorded in where transplanting was carried out under SRI during both the years. This was also statistically at par with direct seeding under SRI only during the year 2011 (Table 4.113).

Among seed priming treatments, maximum kernel amylose contents were recorded in osmopriming with $CaCl_2$ than that of hydropriming and untreated seeds during both years (Table 4.114). However, no significant variation was recorded in interaction means of production systems with seed priming for kernel amylose contents during both years (Table 4.114).

The overall interaction of production systems, seeding technique and seed priming indicated that maximum amylose contents were recorded in both transplanting and direct seeding under SRI where seeds were primed with $CaCl_2$ during the year 2010 (Table 4.115). This was followed by hydropriming in direct seeding under SRI and direct seeding under SRI with untreated seeds during the same year. However, hydropriming in both direct seeding and transplanting under SRI, osmopriming in direct seeding and transplanting under conventional and hydropriming in transplanting under conventional method were statistically at par with each other. Similarly, untreated seeds in both direct seeding and transplanting under SRI, untreated seeds in transplanting under conventional and hydropriming in direct seeding under conventional method were also statistically at par with each other. The least amylose contents were recorded in untreated seeds in direct seeding under conventional method during the same year (Table 4.115).

4.2.5 Leaf chlorophyll contents

4.2.5.1.1 Chlorophyll a contents

Seeding technique and seed priming showed significant impact on chlorophyll a contents during both years (Table 4.110). However, rice production systems influenced chlorophyll a contents only during the year 2011. Interaction of rice production systems with seed priming only differed significantly during the year 2010 (Table 4.110). Interaction of rice production systems with seed priming, seeding technique with seed priming and overall interaction of production systems, seeding technique and seed priming didn't differ significantly for chlorophyll a contents in both years (Table 4.110).

In rice production systems, higher chlorophyll a contents were recorded in SRI than that of conventional method only during the year 2011 (Table 4.116). Similarly, in seeding techniques, higher chlorophyll a contents were recorded in transplanting than direct seeding during both years (Table 4.116). Rice production system interaction with seeding technique indicated that maximum chlorophyll a contents were recorded in transplanting under SRI followed by transplanting under conventional method and direct seeding under SRI during the year 2010 (Table 4.116). However, the least chlorophyll a contents were recorded in direct seeding under conventional method and statistically similar to direct seeding under SRI during the same year (Table 4.116).

Among seed priming treatments, maximum chlorophyll a contents were recorded in osmopriming with $CaCl_2$ than that of hydropriming and untreated seeds during both years (Table 4.117). However, the least chlorophyll a contents were recorded in non primed treatment during both years (Table 4.117).

4.2.5.1.2 Chlorophyll b contents

Chlorophyll b contents in rice leaves were influenced significantly by rice production systems, seeding technique and seed priming during both years (Table 4.110). However, seeding technique affected chlorophyll b contents significantly only during the year 2010. Likewise, interaction of production systems with seeding technique and overall interaction of rice production systems, seeding technique and seed priming was only significant during the year 2010. Interaction of rice production systems with seed priming also significantly affected chlorophyll b contents only during the year 2011 (Table 4.110).

Chlorophyll b contents were recorded more in SRI than that of conventional method during both years (Table 4.118). In seeding techniques, higher chlorophyll b contents were recorded in transplanting than direct seeding during the year 2010 (Table 4.118). Interaction of production systems with seeding technique revealed that maximum chlorophyll contents were recorded in transplanting under SRI than that of direct seeding under both SRI and conventional method and transplanting under conventional method during the same year. The least chlorophyll b contents were recorded in direct seeding under conventional which was at par with transplanting under conventional method during the year 2010 (Table 4.118).

Among seed priming treatments, higher chlorophyll a contents were recorded in osmopriming with $CaCl_2$ than that of hydropriming and untreated seeds during both years (Table 4.119). Interaction of production systems with seed priming indicated that maximum chlorophyll b contents were recorded in osmopriming ($CaCl_2$) under SRI followed by same priming treatment under conventional method, hydropriming and untreated seeds under SRI during the year 2011 (Table 4.119). Hydropriming under SRI and conventional method was statistically at par with each other during the same year. However, the least chlorophyll b contents were recorded in untreated seeds sown under conventional method during the same year (Table 4.119).

The overall interaction among production systems, seeding technique and seed priming indicated that higher chlorophyll b contents were recorded where osmopriming ($CaCl_2$) in transplanted rice was carried out under SRI during the year 2010 (Table 4.120). This was followed by hydropriming in transplanting under SRI, osmopriming in direct seeded rice under both SRI and conventional methods, osmopriming in transplanted rice under conventional and hydropriming in direct seeding under SRI during the same year. The least chlorophyll b contents were recorded where untreated seeds in direct seeding were sown under conventional method during the same year (Table 4.120).

4.2.5.1.3 Chlorophyll a/b

Analysis of variance (Table 4.110) reveled that seed priming treatments differed significantly regarding chlorophyll a/b contents during both years. However, rice production systems and seeding technique could not affect chlorophyll a/b contents significantly in both years. Interaction of production systems with seed priming also differed significantly for chlorophyll a/b contents during both years. Neither interaction of seeding technique with seed priming nor overall interaction among production systems, seeding technique and seed priming could influence chlorophyll a/b contents during both years (Table 4.110).

Among seed priming treatments, lower chlorophyll a/b contents were recorded in both osmopriming and hydropriming than that of untreated seeds during 2010 and osmopriming than that of hydropriming and untreated seeds during 2011 (Table 4.121). Interaction of sowing methods with seed priming indicated that significantly lowered chlorophyll a/b contents were recorded in osmopriming ($CaCl_2$) and hydropriming under SRI during the year 2010 and osmopriming under both SRI and conventional during the year 2011 (Table 4.121). Osmopriming and hydropriming under SRI were statistically at par with untreated seeds under SRI and osmoprimed under conventional method during 2010. Similarly, hydropriming under both SRI and conventional methods and untreated seeds under SRI were also statistically at par with each other during the year 2011 (Table 4.121).

4.2.5.1.4 Total Chlorophyll contents

Rice production systems, seeding technique and seed priming significantly differed for total chlorophyll contents during both the years (Table 4.110). However, interaction of production systems with seeding technique was only significant during the year 2010 while interaction of production systems with seed priming was only significant during the year 2011 (Table 4.110). Neither interaction of seeding technique with seed priming nor overall interaction of production systems, seeding technique and seed priming was significant regarding total chlorophyll contents during both years (Table 4.110).

Total chlorophyll contents were affected by rice production systems where SRI gave higher total chlorophyll contents than that of conventional method during both years (Table 4.122). Similarly, transplanting outperformed regarding total chlorophyll contents than that of direct seeded rice during both years (Table 4.122). Interaction of production systems with direct seeding revealed that higher total chlorophyll contents were recorded in transplanting under SRI followed by transplanting under conventional method and direct seeding under SRI during the year 2010 (Table 4.122). However, the least total chlorophyll contents were recorded in direct seeding of untreated seeds during the same year (Table 4.122).

Among seed priming treatments, maximum total chlorophyll contents were recorded in osmopriming with $CaCl_2$ than that of hydropriming and untreated seeds during both the years (Table 4.123). Interaction of production systems with seed priming indicated that higher total chlorophyll contents were recorded in osmopriming with $CaCl_2$ under SRI followed by same priming treatment under conventional method, hydropriming under SRI and conventional method, and untreated seeds under SRI during the year 2011 (Table 4.123). The least total chlorophyll contents were recorded where untreated seeds were sown under conventional method of cultivation during the same year (Table 4.123).

Table 4.110: Analysis of variance for influence of different seedling age and seed priming on kernel amylose contents, kernel length, kernel width and kernel length width ratio of fine rice cultivars

		Mean sum of squares											
		Kernel protein contents (%)		Kernel amylose contents (%)		Ch. a contents (mg g^{-1} FW)		Ch. b contents (mg g^{-1} FW)		Ch. a/b ratio		Total ch. contents (mg g^{-1} FW)	
SOV	**df**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Method (M)	1	0.69**	0.68*	27.2**	29.2**	0.02	0.16*	0.57*	0.33*	1.24	0.54	0.80*	0.93**
$Error_1$	2	0.00	0.03	0.03	0.10	0.02	0.01	0.02	0.01	0.12	0.05	0.02	0.00
Seeding (S)	1	0.05	0.15*	4.75*	15.7**	0.49**	0.05*	0.20**	0.03	0.03	0.01	1.31**	0.17*
M × S	1	0.02	0.01	2.98*	4.55*	0.02*	0.00	0.09*	0.03	0.01	0.06	0.18**	0.02
$Error_2$	4	0.01	0.01	0.25	0.38	0.00	0.00	0.01	0.01	0.02	0.03	0.00	0.02
Seed Priming (P)	2	1.62**	1.74**	45.7**	71.9**	1.43**	0.78**	1.30**	1.44**	0.80**	1.51**	5.45**	4.27**
M × P	2	0.00	0.00	0.49	0.11	0.02	0.00	0.03	0.05*	0.30*	0.34**	0.04	0.04*
S × P	2	0.00	0.01	0.35	1.03	0.01	0.00	0.00	0.02	0.07	0.03	0.01	0.02
M × S × P	2	0.02	0.03	2.54**	0.63	0.01	0.00	0.05*	0.03	0.08	0.04	0.08	0.02
$Error_3$	16	0.01	0.02	0.31	0.72	0.01	0.01	0.01	0.01	0.05	0.02	0.04	0.01

SOV = source of variation, df = degree of freedom, * = significant (P<0.05), ** = highly significant (P<0.01), ns = non significant
Ch. = Chlorophyll, FW = fresh weight
Year effect was not significant

Table 4.111: Influence of production system and seeding technique on kernel protein contents of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	7.59	7.61	7.60 B	7.64	7.74	7.69 B
SRI	7.81	7.94	7.88 A	7.88	8.04	7.97 A
Means	7.70	7.77		7.77 B	7.89 A	

LSD_{2010} (M) = 0.02, LSD_{2011} (M) = 0.3, LSD_{2011} (S) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.112: Influence of production system and seed priming on kernel protein contents of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	7.20	7.48	7.34 C	7.29	7.55	7.43 C
Hydropriming	7.66	7.96	7.82 B	7.71	8.03	7.88 B
Osmopriming	7.93	8.19	8.06 A	8.06	8.31	8.19 A

LSD_{2010} (P) = 0.1, LSD_{2011} (M) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.113: Influence of production system and seeding technique on kernel amylose contents of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	26.2 a	26.1 a	26.1 A	27.1 a	25.0 b	26.1 A
SRI	25.1 b	23.7 c	24.4 B	24.6 bc	24.0 c	24.3 B
Means	25.6 A	24.9 B		25.8 A	24.5 B	

LSD_{2010} (M) = 0.2, LSD_{2011} (S) = 0.5, LSD_{2010} (M × S) = 0.7, LSD_{2011} (M) = 0.5, LSD_{2011} (S) = 0.6, LSD_{2011} (M × S) = 0.8
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.114: Influence of production system and seed priming on kernel amylose contents of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	25.9	28.1	27.0 A	26.5	28.2	27.4 A
Hydropriming	25	26.4	25.7 B	24.7	26.4	25.6 B
Osmopriming	22.3	23.9	23.1 C	21.5	23.5	22.5 C

LSD_{2010} (P) = 0.5, LSD_{2011} (S) = 0.2, LSD_{2011} (P) = 0.7
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.115: Influence of production system, seeding technique and seed priming on kernel amylose contents of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	25.9 b	25.9 b	27.7 a	28.4 a	25.9	27.2	26.9	29.5
Hydropriming	24.2 c	25.8 b	26.2 b	26.6 b	24.4	25	25.8	26.9
Osmopriming	21.2 d	23.5 c	24.3 c	23.6 c	21.5	21.5	22.4	24.7

LSD_{2010} (M × S × P) = 1.0
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice

Table 4.116: Influence of production system and seeding technique on chlorophyll a contents of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	2.48 c	2.67 b	2.57	2.56	2.65	2.61 B
SRI	2.48 c	2.76 a	2.62	2.70	2.76	2.74 A
Means	2.48 B	2.71 A		2.63 B	2.71 A	

LSD_{2010} (S) = 0.03, LSD_{2010} (M×S) = 0.04, LSD_{2011} (M) = 0.12, LSD_{2011} (S) = 0.04
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, FW = fresh weight

Table 4.117: Influence of production system and seed priming on chlorophyll a contents of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	2.20	2.25	2.23 C	2.32	2.44	2.39 C
Hydropriming	2.66	2.64	2.65 B	2.69	2.82	2.76 B
Osmopriming	2.85	2.96	2.91 A	2.80	2.94	2.87 A

LSD_{2010} (P) = 0.1, LSD_{2011} (P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, FW = fresh weight

Table 4.118: Influence of production system and seeding technique on chlorophyll b contents of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	1.26 c	1.31 bc	1.29 B	1.28	1.28	1.29 B
SRI	1.41 b	1.66 a	1.54 A	1.41	1.53	1.48 A
Means	1.34 B	1.49 A		1.34	1.41	

LSD_{2010} (M) = 0.2, LSD_{2010} (S) = 0.1, LSD_{2010} (M×S) = 0.1, LSD_{2011} (M) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, FW = fresh weight

Table 4.119: Influence of production system and seed priming on chlorophyll b contents of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	0.88	1.23	1.06 C	0.86 e	1.19 d	1.02 C
Hydropriming	1.36	1.57	1.47 B	1.36 c	1.44 c	1.40 B
Osmopriming	1.61	1.80	1.71 A	1.63 b	1.80 a	1.72 A

LSD_{2010} (P) = 0.1, LSD_{2011} (P) = 0.1, LSD_{2011} (M×P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, FW = fresh weight

Table 4.120: Influence of production system, seeding technique and seed priming on chlorophyll b contents of Super Basmati

Seed priming	2010				2011			
	CON		SRI		CON		SRI	
	DSR	TPR	DSR	TPR	DSR	TPR	DSR	TPR
Non primed	0.78 h	0.98 g	1.15 fg	1.32 ef	0.85	0.87	1.13	1.23
Hydropriming	1.34 ef	1.39 de	1.48 cde	1.68 b	1.28	1.44	1.38	1.50
Osmopriming	1.67 bc	1.56 bcd	1.62 bc	1.98 a	1.72	1.54	1.72	1.87

LSD_{2010} (M×S×P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, FW = fresh weight

Table 4.121: Influence of production system and seed priming on chlorophyll a/b contents of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	2.57 a	1.85 bc	2.21 A	2.71 a	2.08 b	2.39 A
Hydropriming	1.96 b	1.68 c	1.82 B	1.99 b	1.97 b	1.98 B
Osmopriming	1.77 bc	1.66 c	1.72 B	1.72 c	1.65 c	1.69 C
Means	2.10	1.72		2.14	1.89	

LSD_{2010} (P) = 0.2, LSD_{2010} (M×P) = 0.3, LSD_{2011} (P) = 0.1, LSD_{2011} (M×P) = 0.2
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification

Table 4.122: Influence of production system and seeding technique on total chlorophyll contents of Super Basmati

Production systems	2010			2011		
	DSR	TPR	Means	DSR	TPR	Means
CON	3.74 d	3.98 b	3.86 B	3.84	3.93	3.89 B
SRI	3.90 c	4.42 a	4.16 A	4.12	4.30	4.21 A
Means	3.82 B	4.20 A		3.98 B	4.12 A	

LSD_{2010} (M) = 0.2, LSD_{2010} (S) = 0.1, LSD_{2010} (M×S) = 0.1, LSD_{2011} (M) = 0.1, LSD_{2011} (S) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, DSR = direct seeded rice, TPR = transplanted rice, FW = fresh weight

Table 4.123: Influence of production system and seed priming on total chlorophyll contents of Super Basmati

Seed priming	2010			2011		
	CON	SRI	Means	CON	SRI	Means
Non primed	3.08	3.49	3.29 C	3.19 f	3.63 e	3.41 C
Hydropriming	4.03	4.21	4.13 B	4.05 d	4.27 c	4.16 B
Osmopriming	4.47	4.76	4.62 A	4.43 b	4.74 a	4.59 A

LSD_{2010} (P) = 0.2, LSD_{2011} (P) = 0.1, LSD_{2011} (M×P) = 0.1
Means sharing same letter are statistically indistinguishable at probability level of 5%, LSD = least significant difference, CON = conventional, SRI = system of rice intensification, FW = fresh weight

4.2.6 Economic and marginal analysis

4.2.6.1 Net field benefits

Economic analysis of rice production systems and seeding techniques either untreated or primed with water and $CaCl_2$ during the year 2010 and 2011 is given in Table 4.124, Table 4.126, respectively. It is clear from both the tables that osmopriming with $CaCl_2$ in both direct seeding and transplanting under both production systems increased the net benefits than that of non primed and hydroprimed seeds during both the years. However, maximum net returns or field benefits were obtained transplanting of nursery seedling whose seeds were primed with $CaCl_2$ was carried out under SRI during both years followed by hydropriming under same seeding technique and same cultivation method during the year 2010 (Table 4.124) and osmopriming with $CaCl_2$ in direct seeding under SRI during the year 2011 (Table 4.126). In comparison with production systems, SRI gave higher net field benefits than conventional flooding during both years. However, the least net field benefits were recorded in direct seeding of non primed seeds under conventional method of sowing.

4.2.6.2 Marginal rate of return

It is clear from the Table 4.125, Table 4.127 that higher marginal rate of return was obtained where transplanting of seedling which were osmoprimed with $CaCl_2$ was carried out under SRI than that of hydropriming or non primed seeds under both SRI and conventional method of cultivation during both the years. This was followed by hydropriming under with same seeding technique and production system and hydropriming in direct seeding under SRI during both the years (Table 4.125, Table 4.127).

4.2.6.3 Discussion

Rice production systems and seed priming with $CaCl_2$ significantly affected the kernel attributes which include opaque, abortive, normal and chalky kernels (Table 4.97), kernel dimensions (Table 4.105) and kernel quality (Table 4.110) during both years. Rice production systems and seed priming improved kernel attributes due to the better nutrient and moisture supply (Thakuria and Choudhary, 1995) in SRI than that of conventional system and later was responsible for poor root growth due to flooded water condition which caused root degeneration more prominent at reproductive stage. This might have resulted in improved normal kernels (Table 4.101, Table 4.102) and reduced opaque (Table 4.98), abortive (Table 4.99, Table 4.100) and chalky kernels (Table 4.103, Table 4.104) owing to osmopriming with $CaCl_2$.

Improvement in kernel attributes due to osmopriming with $CaCl_2$ seems to be the result of improved net assimilation rate (Figure 4.8) that resulted in better translocation of photoassimilates towards the panicle. Similarly, improvement in kernel water absorption ratio seems to be the result of improved kernel dimension and protein contents (Table 4.112). These results are also supported by the findings of Farooq *et al.* (2006 a, b) and Rehman *et al.* (2011) and they reported improvement in kernel quality of rice by seed priming with $CaCl_2$ and other salts.

4.2.7 Conclusion

The interaction among seed priming, seeding technique and production systems indicated that transplanting of seedling which were osmoprimed with $CaCl_2$ (1.5% soln.) remained best under SRI by improving kernel yield 13.6% and 6.6% than that of direct seeding under both conventional method and SRI. This treatment resulted in higher net field benefits (Rs. 126869 and 123528) and higher marginal rate of return (12354 and 14784) during the year 2010 and 2011, respectively.

Table 4.124: Economic analysis of rice as affected by seeding technique and seed priming under different production systems during the year 2010

	Conventional method						System of rice intensification						Remarks
	Direct seeding			Transplanting			Direct seeding			Transplanting			
	NP	HP	OP	NP	HP	OP	NP	HP	OP	NP	HP	OP	
Kernel yield	3.33	3.51	3.82	3.35	3.56	3.83	3.46	3.74	3.99	3.75	4.04	4.45	t ha^{-1}
Adjusted yield	3.00	3.16	3.44	3.02	3.20	3.45	3.11	3.37	3.59	3.38	3.64	4.01	10% less than actual
Value	101149	106616	116033	101756	108135	116336	105098	113603	121196	113906	122715	135169	Rs. 1350/40 kg
Gross benefits	101149	106616	116033	101756	108135	116336	105098	113603	121196	113906	122715	135169	Rs. ha^{-1}
Cost of $CaCl_2$	-	-	100	-	-	100	-	-	100	-	-	100	Rs. 100 kg^{-1}
Cost of priming	-	200	200	-	200	200	-	200	200	-	200	200	Aeration pump & container rent Rs. 50/ day each
Irrigation cost	12000	12000	12000	13600	13600	13600	7200	7200	7200	7200	7200	7200	Rs. 800/ irrigation
Labor cost	400	400	400	800	800	800	400	400	400	800	800	800	Rs. 200/ man ha^{-1}
Cost that vary	12400	12600	12700	14400	14600	14700	7600	7800	7900	8000	8200	8300	Rs. ha^{-1}
Net benefits	88749	94016	103333	87356	93535	101636	97498	105803	113296	105906	114515	126869	Rs. ha^{-1}

NP = non primed, HP = hydropriming, OP = osmopriming with $CaCl_2$

Table 4.125: Marginal analysis of rice as affected by seeding technique and seed priming under different production systems during the year 2011

Production systems	Seedling technique	Seed priming	Costs that vary (Rs. ha^{-1})	Marginal cost (Rs. ha^{-1})	Net benefits (Rs. ha^{-1})	Marginal net (Rs. ha^{-1})	Marginal rate of return (%)
Conventional method	Direct seeding	NP	12400	-	88749	-	-
		HP	12600	200	94016	5268	5268
		OP	12700	100	103333	9316	9316
	Transplanting	NP	14400	1700	87356	0	D
		HP	14600	200	93535	6179	6179
		OP	14700	100	101636	8101	8101
System of rice intensification	Direct seeding	NP	7600	-	97498	-	-
		HP	7800	200	105803	8305	8305
		OP	7900	100	113296	7494	7494
	Transplanting	NP	8000	100	105906	0	D
		HP	8200	200	114515	8609	8609
		OP	8300	100	126869	12354	12354

NP = non primed, HP = hydropriming, OP = osmopriming with $CaCl_2$

Table 4.126: Economic analysis of rice as affected by seeding technique and seed priming under different production systems during the year 2011

	Conventional method						System of rice intensification						Remarks
	Direct seeding			Transplanting			Direct seeding			Transplanting			
	NP	HP	OP	NP	HP	OP	NP	HP	OP	NP	HP	OP	
Kernel yield	3.11	3.33	3.62	3.36	3.62	3.93	3.46	3.78	4.07	3.48	3.85	4.34	t ha^{-1}
Adjusted yield	2.80	3.00	3.26	3.02	3.26	3.54	3.11	3.40	3.66	3.13	3.47	3.91	10% less than actual
Value	94466	101149	109958	102060	109958	119374	105098	114818	123626	105705	116944	131828	Rs. 1350/40 kg
Gross benefits	94466	101149	109958	102060	109958	119374	105098	114818	123626	105705	116944	131828	Rs. ha^{-1}
Cost of $CaCl_2$	-	-	100	-	-	100	-	-	100	-	-	100	Rs. 100 kg^{-1}
Cost of priming	-	200	200	-	200	200	-	200	200	-	200	200	Aeration pump & container rent Rs. 50/ day each
Irrigation cost	12000	12000	12000	13600	13600	13600	7200	7200	7200	7200	7200	7200	Rs. 800/ irrigation
Labor cost	400	400	400	800	800	800	400	400	400	800	800	800	Rs. 200/ man ha^{-1}
Cost that vary	12400	12600	12700	14400	14600	14700	7600	7800	7900	8000	8200	8300	Rs. ha^{-1}
Net benefits	82066	88549	97258	87660	95358	104674	97498	107018	115726	97705	108744	123528	Rs. ha^{-1}

NP = non primed, HP = hydropriming, OP = osmopriming with $CaCl_2$

Table 4.127: Marginal analysis of rice as affected by seeding technique and seed priming under different production systems during the year 2011

Production systems	Seedling technique	Seed priming	Costs that vary (Rs. ha^{-1})	Marginal cost (Rs. ha^{-1})	Net benefits (Rs. ha^{-1})	Marginal net (Rs. ha^{-1})	Marginal rate of return (%)
Conventional method	Direct seeding	NP	12400	-	82066	-	-
		HP	12600	200	88549	6483	6483
		OP	12700	100	97258	8709	8709
	Transplanting	NP	14400	1700	87660	0	D
		HP	14600	200	95358	7698	7698
		OP	14700	100	104674	9316	9316
System of rice intensification	Direct seeding	NP	7600	-	97498	-	-
		HP	7800	200	107018	9520	9520
		OP	7900	100	115726	8709	8709
	Transplanting	NP	8000	100	97705	0	D
		HP	8200	200	108744	11039	11039
		OP	8300	100	123528	14784	14784

NP = non primed, HP = hydropriming, OP = osmopriming with $CaCl_2$

Chapter 5

SUMMARY

Field study was conducted to evaluate the role of seed priming in improving the performance of system of rice intensification. Two field experiments were conducted at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan. The first experiment was conducted to evaluate the role of seed priming in improving the performance of nursery seedling for SRI. Two rice cultivars viz. Super Basmati and Shaheen Basmati, three seedling age viz. 2, 3 and 4 weeks old seedling, and osmopriming with untreated seeds used as control were used in this experiment. The second experiment was conducted to evaluate the role of seed priming in improving the performance of direct seeding in SRI. Two rice production systems viz. SRI and conventional method of cultivation, two seeding techniques viz. direct seeding and transplanting, and three seed priming treatments viz. non primed, hydropriming and osmopriming were used in this experiment. Both the experiment were laid out in randomized completely block design with split split plot arrangement having net plot size of 6m × 3m and experimental units were repeated thrice. The objective of the study was to evaluate the role of seed priming in different aged nursery seedling of two fine rice cultivars and seeding techniques. Data on allometry and crop growth, phenology, agronomic and yield related attributes, kernel dimension and quality attributes was recorded following the standard procedures. The data were statistically analyzed using Fisher's analysis of variance technique and least significant difference test at 5% probability level was used to compare the treatments' means. Brief description of the results is as under:

5.1 Experiment No. 1: *Evaluating the role of seed priming in improving the performance of nursery seedling for system of rice intensification*

Rice cultivars, seedling age and seed priming significantly improved the leaf area index, crop growth rate, leaf area duration and net assimilation rate during both the years. Two weeks old seedling performed better than 3 and 4 weeks old seedling especially when primed with $CaCl_2$ (1.5% soln.) by improving all the growth attributes which include tiller production, kernels per panicle, 1000 grain weight, kernel yield, straw yield and harvest index during both the years.

Seedling age and osmopriming also significantly improved the kernel dimensions and kernel quality attributes during both the years. Two weeks old seedling whose seeds were osmoprimed with $CaCl_2$ improved the kernel length, kernel width, normal kernels, kernel protein contents and amylose contents and also improved leaf chlorophyll contents during both the years.

5.2 Experiment No. 2: *Evaluating the role of seed priming in improving the performance of direct seeding in system of rice intensification*

Rice production systems, seeding technique and seed priming significantly improved the leaf area index, crop growth rate, leaf area duration and net assimilation rate during both the years. Transplanting of nursery seedling which were osmoprimed with $CaCl_2$ under SRI significantly improved all the growth attributes which include tiller production, kernels per panicle, 1000 grain weight, kernel yield, straw yield and harvest index than that of direct seeding under both production systems as well as hydropriming and non primed seeds.

Rice production systems, seeding technique and seed priming also significantly improved the kernel dimensions and kernel quality attributes during both the years. Transplanting of seedling whose seeds were osmoprimed with $CaCl_2$ improved the kernel length, kernel width, normal kernels, kernel protein contents and amylose contents and also improved leaf chlorophyll contents under SRI than that of direct seeding under both conventional method and SRI during both the years.

Future research thrusts

SRI involves less water application and alternate wetting and drying. It is important to find the critical stages of plant growth and water requirements at those stages to avoid yield losses. At times when water availability and thus evapotranspiration fall below a certain point, the value of crop output can fall to zero-either because the crop dies or because the product is of such low quality as to be unmarketable (Perry and Narayanamurthy, 1998). Areas for further research include understanding the causes and effects of better root development under SRI, and the potential impacts on yield. We must also study the standard dose of chemical and bio fertilizers needed under SRI and the optimum number of plants per unit area in different agro-climates.

In SRI intermittent irrigation application results in aerobic and anaerobic soil conditions which have key impact on soil microbial life (Stoop, 2011). There is a need to study the effect of fluctuating aerobic and anaerobic conditions on microbial populations, their activity, C and N dynamics, green house gas emission and crop N supply. How SRI practices affects the diversity and functioning of the microbial populations and of these populations in turn on crop performance with consideration of the role of micronutrients (Uphoff, 2013).

Roots are the key to second green revolution and there is a need to breeding crop plants with deeper and bushy roots ecosystems which could simultaneously improve both the soil structure and its steady-state carbon, water and nutrient retention, as well as improved plant yields.

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