In recent years many researchers have attempted the problem of PHS in wheat and other cereals throughout the world. Rajeram et.al., (2006) screened 250 genotypes in Toluka (Mexico) with heavy rainfall through mist irrigation conditions and identified 22 genotypes with high tolerance to PHS. Nourinia et.al., (2001), also, evaluated 242 advanced genotypes of wheat under mist irrigation condition and reported 53 tolerant genotypes to pre-harvest sprouting. Ahmadpour Malakshah, (2008) evaluated 235 advanced lines of wheat in similar condition and recorded 118 lines with high tolerance to PHS.

Meanwhile, Ahmadpour Malakshah, (2009) screened 225 genotypes under 21 days of mist irrigation (humidity 50-70%, temperature 25-30°C and rainfall 30-50 mm) and noted 185 lines with high tolerance to PHS. After this Ahmadpour Malakshah, (2011) evaluated 178 advanced and elite lines of wheat out of this 78 lines showed maximum tolerance to PHS. Amongst the selected genotypes, Line N-85-5 (recently named as Gonbad cultivar) had high PHS tolerance along with high grain yield (up to 8 tons per ha). It seems that mist irrigation is one of the best practical methods as environmental marker for identifying wheat genotypes’ tolerance to PHS.

PHS is the phenomenon of germination in physiologically mature grains in the ear or panicle or pod usually under wet conditions shortly before harvest. It is also termed as vivipary, which occurs in a wide range of crops including cereal crops such as wheat, barley, maize and rice, and grain legumes such as soyabean, urad bean and mung bean. It is not only causing reduction in seed yield but also affect seed quality and seed viability, resulting in significant economic losses, causing damage not only in the standing crops but also in the harvested crops heaped in the fields and threshing-yards. Among grain legumes, the incidence of PHS is particularly high in urad bean and mung bean, where yield loss was as high as 60-70%.
Wheat is the main grain crop cultivated in Iran mostly in spring and in autumn, which matures in late spring to early summer. The cultivation of wheat in northern part of Iran is largely determined by climate. The wide geographical distribution of wheat is subjected to markedly different climatic conditions (Dadbakhsh et al., 2013). Because of drought, cold and pre-harvest sprouting in wheat production is considerably reduced in northern Iran (Habibpor et al., 2011; Mousavi, 2012).

**Weather conditions and pre-harvest sprouting**

The pre-harvest sprouting takes place when 10 to 20 mm of rainfall occurs over a period of 30 minutes, followed by grain moisture reaching to 30%, or higher (Oberforster et al., 2012). The detailed knowledge of interaction between genotypes and environment is important to understand PHS in wheat. The different wheat genotypes respond differently to pre-harvest sprouting and to given set of weather conditions, hence prediction of their sensitivity or tolerance to PHS is very difficult (Miao et al., 2013; Wong et al., 2002; Delaethauwer et al., 2013; Kondhare et al., 2012).

Pre-harvest sprouting of cereals in moist zones of Iran such as Sari (Mazandaran province), Gonbad and Gorgan (Golestan province) is very common and occurs every three or four years in 10 years span. In Iran, pre-harvest sprouting occurs mostly in northern regions, because of rainfall and high humidity during harvest season and high humidity during that period.

PHS cause losses in grain yield and end products quality by degradation of native starch granules, negatively affecting the quality of various products made from wheat flour such as breads, cookies and noodles. Wheat flour from sprouted grains exhibits lower swelling power and gelatinize at lower temperature. Bread production is complicated by increased stickiness of the dough, which necessitates special handling in small bakeries and can disrupt operations of large bakeries. The sprouting of grains causes significant reductions in gluten strength of flour, turning it unsuitable for bread making (Corcuera et al., 2007).
The pre-harvest sprouting causes severe economic losses to producers as it reduces yield at harvest. The packing density of sprouted grains is often lower than that of sound grains, resulting in lower test weight, when delivered to the Silo, which entails a monetary penalty to the producers. In most wheat-producing countries, grains delivered to Silo are tested for sprouting damage and depending on its level; it will be given an appropriate grading for marketing of wheat (Depauw et al., 2012).

Previous studies by researchers like Hickey et al., (2009); Barnard et al., (1998); Singh et al., (2014); Rajeram et al., (2006); Ahmadpour Malakshah (2011) indicated that PHS resistance is complex trait affected by environmental factors and is not easy to characterize. They further explained that this trait is quantitatively inherited and shows significant interaction with the environment. They screened many wheat genotypes to identify their tolerance to PHS. Many external and internal factors other than environment and heredity contribute to PHST in wheat. These factors included morphology such as palea, lemma, awns, spike, etc, as well as starch, carbohydrates, sugars, proline and phenol (Groos et al., 2002; Ullrich et al., 2009; Zhang et al., 2011; Hu et al., 2012; Ghanbani and Mir, 2013; Yang et al., 2014).

Similarly major role in PHS is played by total amylase, α-amylase and β-amylase. Scanty research is available regarding PHS in different wheat genotypes in northern part of Iran, hence present study was attempted with following objective.

1. To screen the elite genotypes of wheat for tolerance to pre-harvest sprouting.
2. To conduct field evaluation of selected genotypes for PHS tolerance under different conditions of mist irrigation.
3. To determine physiological and biochemical changes under PHS.

**Significant findings and conclusion**

The significant findings and conclusions emerged from the present investigation are given in nutshell.
Screening of wheat genotypes for tolerance to pre-harvest sprouting

- Significant genetic diversity for PHS tolerance exists in 40 selected genotypes of wheat.
- The genotypes in the first cluster such as, N-87-2, N-87-6, N-87-9, N-87-18, N-86-22, N-86-25, N-86-32) had shown more tolerance to pre-harvest sprouting during 21 days of mist irrigation, without any remarkable reduction in kernel weight.
- The reduction in grain yield after MI was attributed to kernel weight and days to PHS.
- The kernel colour is not a valuable marker to select tolerance of wheat genotypes to PHS, as reported by previous workers.
- Specific morphological traits such as lemma, palea, spike type (vertical, horizontal or curved), spikelets (open or close), density of spikelets, awns and lodging contribute very much to PHS in wheat genotypes.
- The physiological, biochemical and enzymological changes in wheat genotypes are also playing a key role in PHS.
- Significant and negative correlation (r=0.77**) exists between kernel colour and tolerance to pre-harvest sprouting.
- Significant and positive correlation (r=0.85**) was found between duration of maturity and tolerance of genotypes to PHS.
- The late maturity genotypes of wheat had more tolerance to pre-harvest sprouting.

Field evaluation of selected wheat genotypes for tolerance to PHS under MI.

- The selected five genotypes of wheat during field evaluation such as, i) Nai60, ii) N-80-19, iii) N-87-12, iv) N-86-12 and v) N-87-8, when subjected to 7, 14 and 21 days of mist irrigation, moisture (50-70%), mist (30-50 mm) and temperature (25-30°C) for 8 hours per day, responded very differently to PHS.
- With increasing mist irrigation period, humidity and rainfall the grain yield in sensitive genotypes of wheat was reduced highly and this character can be used as an indicator for selecting PHS tolerance in wheat genotypes.
The unique features of wheat genotypes like seed size and weight, harvest index, percentage of damage and severity of damage had shown positive correlation with mist irrigation period.

The changes in mist irrigation duration had no any negative effect on grain yield of wheat genotype N-86-12 and therefore this variety is marked as highly tolerant to PHS.

In PHS sensitive varieties the kernel size, (11.03) and weight (1.311), biological yield (58.8) and grain yield (32.96) was highly reduced with increasing period of MI. However damage severity (11.03) and percentage (0.172) was increased.

**Physiological and biochemical aspects of pre-harvest sprouting**

- Significant correlation was observed between the physiological as well as biochemical parameters and duration MI.
- Increase in duration of mist irrigation caused decrease in carbohydrates, starch, phenol, proline, protein and yield which caused reduction in quality, quantity and economic yield.
- However total amylase, $\alpha$-amylase and $\beta$-amylase and sugar contents were increased with increasing period of MI.
- The correlation coefficient between phenol and starch was negative with $\alpha$- amylase as well as $\beta$- amylase, which had confirmed the inhibitory effect of phenol on starch hydrolysis, which helped to select PHS tolerant genotypes such as N-86-12 and Nai60.
- The levels of phenol and starch as well as the activity of $\alpha$-amylase in wheat grains are the reliable indicators of tolerance of a variety to PHS.
- The contents of starch, proteins, total chlorophylls, chlorophyll a and b, carbohydrates, phenols, and proline had shown positive correlation with grain yield after mist irrigation.
- While sugars, total amylase, $\alpha$-amylase as well as $\beta$- amylase and duration of mist irrigation had shown negative correlation with grain yield.

**Regression relationship between MI x Yield, Amylase activity and biochemical attributes**.
Sugars, total amylase, $\alpha$-amylase as well as $\beta$-amylase had shown increased linearly regression with increased duration of mist irrigation while values of carbohydrates, starch, protein, phenol, and yield had shown decreased linearly regression with increased duration of mist irrigation.

**Gene expression of $\alpha$-amylase activity during pre-harvest sprouting**

- The variety N-87-8 showed very high level of gene expression of $\alpha$-amylase and subsequently elevated level of its activity, indicating that the variety is highly sensitive to PHS.
- The sensitiveness of this variety to PHS was also supported by morphological characters such as lemma, palea, spike type, awns, etc.
- The variety Nai60 showed low level of gene expression for $\alpha$-amylase and hence it was highly tolerant to PHS.
- The wheat varieties like N-87-8 and N-87-12 had shown medium level of gene expression of $\alpha$-amylase activity and hence these genotypes are considered as medium tolerant to PHS.

**Conclusion.**

From the significant findings of present investigation it may be concluded that mist irrigation to wheat is most practicable and highly suitable method for screening the PHS tolerance / sensitiveness of different genotypes, which is a complex trait, depending on genotype and the interaction between the environment and genotype. The PHS tolerance, being a highly complex phenomenon, it is difficult to predict, because different traits such as genetics, morphology, physiology, biochemistry and molecular biology as well as enzymology are involved in it. The PHS tolerance and sensitiveness of wheat genotypes is decided by type of spike, spikelet, (open or close), its density, lemma, palea, awns, plant height and lodging.

Equally important are the organic constituents such as carbohydrates, sugars, starch, proteins and stress tolerant antioxidants like proline and phenol in predicting the tolerance or sensitiveness of wheat genotypes to PHS. Along with these activities of total amylase, $\alpha$-amylase, $\beta$-amylase and level of gene expression of these
Summary and Conclusion

Enzymes is highly crucial to decide the PHS tolerance / susceptibility. All above parameters are playing key role in predicting the PHS tolerance or sensitiveness of wheat genotypes.

Finally on the basis of results of present investigation the genotypes N-86-12 and Nai60 may be recommended to the farmers of northern part of Iran as these are PHS tolerant varieties, which can grow well under PHS conditions, without loss in grain yield and quality. However further repeated trials in different locations are necessary to release these lines for cultivation under PHS conclusive climate.