Chapter - 5

Discussion

The present investigation “Effect of fluoride toxicity on the growth, yield and sterility behaviour of wheat (Triticum aestivum L.) and barley (Hordeum vulgare L.)” was carried out at C.C.R. (P.G.) College, Muzaffarnagar (U.P.) from 2009 to 2011. The toxic effect of sodium fluoride on wheat (Triticum aestivum L.) var. HD-2009 and PBW-226 and barley (Hordeum vulgare L.) var. K-24 and DL-69 were studied.

Symptomology

Foliar symptoms are the best documented response of plants to fluoride injury. The gross symptoms of fluoride injury are necrotic leaf lesions, burning of leaf tips and margins and chlorosis. Acute fluoride lesions in plants are prominent characteristic depending upon the plant species. Yellow-orange necrotic area at the tips and lamina of the leaves are common. Wheat and barley leaves exhibited tip and marginal necrosis in 45 days old NaF (Sodium Fluoride) treated plants and it increased with increase of plant age upto 60 days. Due to fluoride toxicity in plant is necrosis i.e. death of the leaf tips and margins. The
necrotic lesions developed some times chlorosis is also associated with it (Arya, 1971). Mottling of leaves, bleaching of leaf margins, rolling of leaves are some other characters (Rathore and Agrawal, 1989). Similar symptoms of toxicity have also been found by Arya et al., (1979), Agrawal (1979), Beniwal (1979) and Singh (1992) in various other crops. Symptoms of fluoride toxicity and reduction in yield were noted in paddy, wheat, barley and soybean with 10 - 50 ppm HF (Hydrogen Fluoride) treatments (Yamazoe 1962).

Sunita Kumari and Agrawal (1980) reported that occurrence of less necrosis in NPK applied plants suggests that due to vigorous growth of plants, their leaves bear more cell sap in comparison to the leaves of T₀ level, so the dilution of fluoride taking place to the less toxic or non-toxic level which is insufficient to cause disruption and death of cells. Guderian (1977) suggested that an optimal supply in nitrogen and phosphorus is particularly important in reducing fluoride injury. Burning of tips and margins of wheat and barley leaves is due to the more accumulation of fluoride ions. Zimmerman and Hitchcock (1956), Arya et al., (1979), Agrawal (1979) and Leone (1980) also supported this work.

**Germination**

The present study has revealed interesting aspects of germination of seeds in various concentrations of sodium fluoride.

(1) The germination percentage of control seeds was recorded 97.5 in wheat (*Triticum aestivum* L.) var. HD-2009 and 92.2 in PBW-226. 200 ppm dose of NaF showed 42.3 in HD-2009 and 38.4 in PBW-226. Control plants of barley (*Hordeum vulgare* L.) var. K-24 showed 84.5 % and var. DL-69 91.3 % respectively. 200 ppm showed 21.8 % in K-24 and 25.3 % in DL-69. 500 ppm was found lethal in both varieties of wheat and barley. Due to concentration of ‘F’ ions, there was no seed germination (Table 3 and Fig. 2).
Fluoride is main air pollutant but due to crop residues it gets recycled into the soil where it is persisted for long time and influences the seed germination. The effect of fluoride on seed germination has been studied by various workers (Arya et al., 1978, Agrawal, 1979), Arya and Sunita Kumari (1978) reported the impact of various concentrations of NaF (Sodium Fluoride) on crop seeds. They found that sodium fluoride was toxic on barley (*Hordeum vulgare* L.), pea (*Pisum sativum* L.), corn and tomato (*Lycopersicum esculentum*) to 250 ppm. In general the reduction of germination was reported at 50 ppm concentration. The seed showed threshold (non-toxic effect) response of sodium fluoride upto 10 ppm concentration.

As suggested by Chang and Thompson (1966) that fluoride affects nucleic acids during the growth of seedling roots. They reported that the treatment of corn seeds with fluoride reduces RNA content of 3 mm root tips on a cell basis. Chang (1968) observed the effect of fluoride on nucleotides and ribonucleic acid (RNA) in germinating corn seedling roots. Fluoride alters markedly the base composition of the corn seedling root RNA. The relative content of cytosine decreased as the material was treated with higher levels of fluoride. The ratio of guanine to cytosine was also found to be positively related to fluoride concentrations. Adenine was depressed significantly only by the highest fluoride treatment. West (1962) reported that changes in total RNA ratios induced by fluoride would be a reflection of changes in base

Arya et al., (1981) reported that toxic effects of fluorine on germinating pea seeds were not visible at NaF (Sodium fluoride) concentrations up to 10 ppm, but at 100 - 500 ppm, germination and radical growth were severely impaired, and at 250 and 500 ppm, total inhibition of germination occurred.

Singhvi (1986) decreased germination percentage of seeds of *Pennisetum typhoides* [*Pennisetum americanum*] and *Raphanus sativus* with increase in sodium fluoride concentration from 10 to 250 ppm and decreased at all concentrations. Compared with distilled water; decreases at the higher concentration were smaller in *Pennisetum americanum*. Seedling growth of *Pennisetum americanum* increased at 10 and 25 ppm. Root growth of *Raphanus sativus* increased at 10, 25 and 50 ppm, while shoot growth decreased at all concentrations except 10 ppm.

**Growth Response**
(2) **Shoot height (cm.) per plant:**

The variations in height of wheat and barley plants under the influence of NaF toxicity were found out, which shows a significant trend at 5 % variance ratio.

Shoot height (cm.) per plant in wheat (2010-11) in control was found 65.75 cm. in HD-2009 and 63.95 cm. in PBW-226. Similarly in 200 ppm NaF dose it was 47.45 cm. in HD-2009 and 44.10 cm. in PBW-226. Control plants of barley (*Hordeum vulgare* L.) showed 51.80 cm. in K-24 and 53.18 cm. in DL-69 respectively in the year 2010-11. Similarly 200 ppm showed 40.66 cm. in K-24 and 42.70 cm. in DL-69 (Table 5-9 and Fig. 3-7).

The maximum height was recorded of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) in all the treatments of sodium fluoride (Tables 5-9 and Fig. 3-7). There was about 40 % and 37 % reduction in height which was observed in 200 ppm dose of NaF (Sodium fluoride) in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) respectively.

(3) **Number of tillers per plant in wheat (2010-11) in control:**

Number of tillers per plant in wheat (2010-11) in control was recorded 15.0 in HD-2009 and 14.40 in PBW-226. In 200 ppm they were recorded as 8.95 and 8.98 in HD-2009 and PBW-226 respectively. Control plants of barley (*Hordeum vulgare* L.)
showed 14.06 and 14.43 in K-24 and DL-69 respectively in 2010-11. Similarly 200 ppm showed 8.65 and 8.95 in K-24 and DL-69 respectively in 2010-11 (Tables 10-14 and Fig. 8-12).

The reduction in number of tillers was also seen in 100-200 ppm doses of NaF (Tables 10-14 and Fig. 8-12). The reduction in height (cm.) and number of tillers was due to the decrease in number and the size of the cells as suggested by Yamazoe (1962) and Hill and Pack (1960) in crops. Dwarfism was exclusively caused by the effect of fluorine containing emissions in forest trees. Fluorine prevents a height gain and leads to a dense bushy growth. The reduction was due to a decrease in number as well as the size of the cells (Halwachs and Kisser, 1967). Shoot growth was affected and plants became dwarf like, with many weak branches. Most of the fluoride absorbed by the rose plants accumulated in the foliar parts (Brewer et al., 1967). Treshow et al., (1967) presented evidence of a significant growth reduction in Douglas-fir as a result of fluoride. Needle burning and mortality developed when fluoride concentrations of leaves exceeded several hundred ppm.

Arya (1971) reported that the amount of growth suppression was directly related to the concentration of fluoride ions, which were accumulated in various parts of the plants. The reduced number and weight of all parts, including the root system, indicted a definite reduction in the accumulation of
synthesized foods. Further, Arya (1971) has observed that the concentrations of 250 and 500 ppm of NaF in the nutrient solution (Hoagland) caused the death of corn plants after 3 weeks. The plants grown in higher concentrations, developed injury first on the tips of younger leaves and then extended along the leaf margin and finally towards the midrib.

The concentrations of 100 - 200 ppm in mature leaves are associated with significant reduction in yield and total growth (Brewer et al., 1959, 1960, 1961, 1967 and 1969) production significantly, growth reduction in leaves at high fluoride concentrations. Fluoride damage including growth suppression, hidden injury effects, genetic differences, necrotic lesions, chlorosis, bronzing and glazing was noted. Guderian et al., (1969) reported that HF (Hydrogen Fluoride) reduced the growth and yield of tuberous plants as well as peas, beans and lupines showed a higher yield reduction than oats, corn (maize) and summer rape. At the highest fluoride concentrations, necrosis was produced by a general wilting of the plant, most probably as a result of root injury.

The number of tillers were found maximum in control treatment while it reduced in 100 - 250 ppm doses of sodium fluoride. Singh (1992) observed reduced number of tillers in wheat, barley and triticale due to toxicity of ‘F’ ions in 100 - 250 ppm NaF (Sodium Fluoride). Similarly Chaudhry (2004) also
observed similar toxic results in wheat and gram. Kumar (2009) observed maximum number of tillers in 18 genotypes of wheat when optimum dose of NPK was applied. Low doses of fertilizers also reduced number of tillers in wheat. Fluorides may affect the early stages of pigment synthesis or induce the degradation of chloroplast structure.

(4) Number of leaves per plant in wheat (year 2010-11) in control plants was recorded 52.76 in HD-2009 and 50.60 in PBW-226. In 200 ppm the number of leaves was recorded 32.78 and 30.55 in HD-2009 and PBW-226 respectively. Control plants of barley showed 51.65 in K-24 and 52.95 in DL-69 respectively in 2010-11. 200 ppm showed 31.40 and 33.23 in K-24 and DL-69 respectively in 2010-11 (Tables 15-19 and Fig. 13-17).

(5) Leaf area (sq. cm.) per plant in wheat (year 2010-11) in control was found 1345.81 and 1328.71 in HD-2009 and PBW-226 respectively. Similarly in 200 ppm it was 761.16 sq. cm. and 753.43 sq. cm. in HD-2009 and PBW-226 respectively. Control plants of barley showed 1056.31 sq. cm. and 1069.86 sq. cm. in K-24 and DL-69 respectively in the year 2010-11. Similarly 200 ppm showed 609.70 sq. cm. in K-24 and 625.60 sq. cm. in DL-69 (Tables 20-24 and Fig. 18-22).

The results of this study regarding height (cm.) / plant, number of leaves / plant and leaf area (sq. cm.) per plant are in

The number of leaves and leaf area (sq. cm.) per plant was severely affected in higher concentrations of NaF in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). The foliage parts of wheat and barley were also severely affected by sodium fluoride toxicity. In general the burning of leaf margins and tips of leaves and chlorosis were noted in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). 200 ppm showed very reduced number of leaves and leaf area in the present findings.

Biomass (fresh weight and dry weight of plants) was severely affected due to NaF toxicity in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). 100-200 ppm NaF showed very reduced growth of plants in terms of fresh and dry weight (gm.) in the present investigation.

(6) Fresh weight (shoot biomass) (gm) / m² in wheat (year 2010-11) in control was found 4364.16 (gm) / m² and 4354.35 (gm) / m² in HD-2009 and PBW-226 respectively. Similarly in 200 ppm fresh weight was 2061.50 and 2053.16 (gm) / m² in HD-2009 and PBW-226 respectively. Control plants of barley
(Hordeum vulgare L.) showed 4316.81 (gm) / m² and 4326.46 (gm) / m² in K-24 and DL-69 respectively in the year 2010-11. Similarly 200 ppm showed 2024.95 and 2034.51 (gm) / m² respectively in K-24 and DL-69 (Tables 25-29 and Fig. 23-27).

(7) Dry weight (shoot biomass) (gm) / m² in wheat (year 2010-11) in control was found 650.31 (gm) / m² and 643.08 (gm) / m² in HD-2009 and PBW-226 respectively. Similarly in 200 ppm dry weight was 305.86 and 298.80 (gm) / m² in HD-2009 and PBW-226 respectively. Control plants of barley showed 640.00 and 643.66 (gm) / m² in K-24 and DL-69 respectively in the year 2010-11. Similarly 200 ppm showed 312.71 and 317.38 (gm) / m² respectively in K-24 and DL-69 (Tables 30-34 and Fig. 28-32).

Kumari Sunita and Agrawal (1980) reported that biomass of Vicia faba and Allium cepa was reduced significantly in 100 - 250 ppm concentrations of NaF (Sodium fluoride). In general the biomass production increases vigorously with increased supply of NPK nutrition.

The leaf injuries, like chlorosis, necrosis, browning and burning adversely affect the physiological functions especially photosynthetic activity of plants, which ultimately suppress the growth, biomass and yield of various crop plants (Hindawi, 1970; Treshow & Pack, 1970). Growth and yield were markedly
depressed and fluoride induced growth reduction was also associated with reduction of quality and quantity of crops (Brewer et al., 1960). The reduction in growth and yield, tissue destruction, low photosynthetic rates, inhibition of enzymes, reduction in chlorophyll and more respiration rates due to fluoride toxicity were observed in tomato (*Lycopersicum esculentum*), potato, carrot and pepper leaves (Hill and Pack, 1960; Hitchcock et al., 1964; Treshow et al., 1967; Brewer et al., 1969; Gillette, 1969; Guderian, 1969 and Pack, 1970).

Growth of crops is affected by sodium fluoride toxicity. The reduction in higher concentrations of fresh and dry weight and productivity were due to less number of leaves, reduced leaf surface area and stunted growth of plants. Thus biomass and productivity are the back bones, to predict the yield of a particular crop. Productivity depends upon the biomass accumulation of crop plants. If biomass is affected by any source, it reflects into low productivity. The higher doses of NaF generally reduce significantly the biomass and productivity / plant / m$^2$ in g / day. The probable cause of low biomass accumulation and productivity may be a disturbed carbohydrate and protein metabolism. Inhibition of enolase, affects on ATP (Adenosine Triphosphate), RNA and DNA, cell elongation and multiplication of F-ions, reduced leaf area, low photosynthetic rates due to chlorosis and necrosis are the main causes of overall suppression of growth, biomass, productivity and yield.
In real sense fluoride is responsible for interfering with leaf area, NAR (Net Assimilation Rate), RGR (Relative Growth Rate), chlorophyll content, total sugar content and some phase of reproduction which reflects in low yield, low biomass accumulation and hence low yield.

(8) Net Assimilation Rate (NAR) on 45 days is adversely affected with an increase in concentration of NaF. In control plants of wheat (*Triticum aestivum* L.) showed 0.828, 0.246 and 200 ppm 0.775, 0.222 NAR mg / day viz. HD-2009 and PBW-226 respectively. In barley (*Hordeum vulgare* L.) var. K-24 and DL-69 it was 0.822, 0.222 in control and in 200 ppm 0.826, 0.232 respectively. More or less similar trend was also found in Relative Growth Rate (RGR) in both varieties of wheat and barley crops (Tables 35-38).

Dependence of NAR on leaf area index has been described by Watson (1952, 1958). He has given the formulae of NAR (Net Assimilation Rate), RGR (Relative Growth Rate), RLGR (Relative Leaf Growth Rate) and LAI (Leaf Area Index) and critically studied the basis of variation in yield and discussed technique of growth analysis. He further reported the variation in NAR due to effect of nitrogen and phosphorus. The NAR is directly proportional to nitrogen contents of plant and influenced severely by deficiency of nitrogen. The deficiency of phosphorus
is also found to affect net assimilation rate. The deficiency of phosphorus causes the delay in senescences etc.


Chang (1968) studied the effect of fluoride on nucleotides and ribonucleic acid in germinating corn seedling roots. Fluoride suppressed root growth to a range of $2 / 3 - 1 / 3$. The relative amount of nucleotides is altered mainly due to triphosphate nucleotides of which ATP is more accumulated. Fluoride induces changes of RNA structure. It is characterised by lower relative content of cytosine and by an increased ratio of cytosine and guanine. Adenine is depressed only in the root tissues treated by the highest fluoride concentration.
Growth and Yield

Guderian (1977) reported that hydrogen fluoride (HF) reduced the growth and yield of tuberous plants, peas, beans and lupins showed a higher reduction than oats, corn and summer rape. Fluoride is responsible for deterioration of leaves, flowers, fruiting and pollen grains. This ultimately leads to loss of economic and biological yield (Harvest Index) of plants (Brewer et al., 1966 and Compton, 1960). The reduction in yield due to fluoride i.e. reduction of flowers and fruits in tomato, citrus, sorghum and bean (Leonard and Graves, 1966 and Brewer et al., 1967), root dry weight (Benedict et al., 1964), weight of above shoots of alfalfa and lettuce (Benedict et al., 1965).

Chang and Thompson (1966) reported that fluoride also reduced the rate of cell division in roots. In maize roots fluoride affected RNA content. Fluoride decreased ribosomal RNA in proportion to fluoride concentration. Hill and Pack (1960) noted the reduction in growth and yield, tissue destruction, low photosynthesis, inhibition of enzymes, reduction in chlorophyll and more respiration rates due to fluoride toxicity in tomato, potato, carrot and pepper rates. Yamazoe (1962) showed that 25 ppm HF is enough to cause significant reduction in paddy and barley while 50 ppm HF is enough for wheat reduction. Sunita Kumari and Agrawal (1980) and Rathore and Agrawal (1989) observed the loss due to fluoride pollution on growth and yield of vegetable crops. Sharma (1988) reported the effect of HF (Hydrogen
Fluoride) fumigation in *Triticum aestivum*, *Brassica Jincea* and *phaseolus aureus* plants. Gristan (1994) reported the toxic effect of HF on grain crops in South East Ukraine.

Buckenham *et al.*, (1983) reported the effects of aerial pollutants on the growth and yield of spring barley. Open topped chambers were used to determine the effect of field concentration of aerial pollutants on the growth and yield of spring barley. Cleaning the air increased the straw and grain yields. Due to pollutants the yield was reduced by suppressing the productive tillers. Kumar (1992) showed the effect of sodium fluoride (NaF) toxicity on onion (*Allium cepa* L.) 100 - 250 ppm showed toxic effect on number of leaves, leaf area, growth, biomass and productivity. The yield of bulbs was tremendously decreased at higher doses of NaF.

Arya (1997) reported the effect of fluoride toxicity on the growth and yield of onion under varying levels of N, P and K nutrition. The general trend indicates that low NPK fertilizer levels have increased the susceptibility of plant to pollution whereas the higher nutrition levels have decreased the susceptibility, the toxic effect of sodium fluoride (NaF) may be minimised by applying the appropriate quantity of N, P and K fertilizers to the soil i.e. $N_2 P_2 K_2$ and $N_3 P_3 K_3$.

Chaudhary (2002) studied the effect of sodium fluoride on sugarbeet and garlic. She found the toxic effect of 100 - 150 ppm doses of sodium fluoride (NaF) on the growth and yield of above crop plants.
Toxic effect of NaF was also found on chlorophyll content, total sugar and energy content.

Juneau et al., (2000) studied the fluorescence phenomenon in greening barley leaves. Effects of sodium fluoride (NaF) on the fluorescence pattern of greening leaves are presented. Singh et al., (2001) studied the effect of sodium fluoride on growth and yield of wheat (*Triticum aestivum* L.). Wheat cv. HD 2329 was sown and raised in a field irrigated with 0, 25, 50, 100, and 200 ppm sodium fluoride in an experiment. Germination decreased from 95 to 81.85% with increasing concentrations of sodium fluoride. Plants irrigated with 100 and 200 ppm of sodium fluoride exhibited significant reduction in height (60.8 and 58.4 cm. respectively) compared with the control plants (68.8 cm). Lower concentrations of sodium fluoride inhibited leaf elongation while higher concentrations caused elongation and narrowing of leaves. Chlorosis and necrosis of leaves also resulted from high concentrations of sodium fluoride. Number of tillers and number of flowers / ears were gradually reduced with increasing sodium fluoride concentration while ear length reduction was directly proportional to the concentration of sodium fluoride. Lowest number of seeds / plant (54.6 seed / plant) and 100 grain weight (4.78 g) were observed at 200 ppm treatment of sodium fluoride. Total yield decreased from 6.02 g / plant in the plant in the control to 3.2 and 3.01 g / plant, respectively.
(9) Number of ears was found comparatively less in sodium fluoride treated plants. In the treated plants number of tillers and the ears were about the same (Table 39).

(10) The number of seeds (grains) per spikelet was severely affected with higher concentrations of NaF. Some spikelets were without grains (seeds) or less number of seeds (grains) due to toxicity of NaF (Table 40).

(11) The yield of seeds (grains) / m² is significantly reduced in higher concentrations of NaF than control plants (Table 41 and Fig. 33).

The number of ears per plant and number of seeds per spikelet were found maximum in control plants and they were reduced in 100 - 250 ppm doses of NaF (Sodium fluoride) in wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and triticale (Singh, 1992) and also in wheat (*Triticum aestivum* L.) and chickpea (*Cicer arietinum* L.) (Chaudhry 2004). Proper doses of NPK increased number of ears, number of seeds per spikelet and yield / plant (Kumar 2009).

(12) The test weight (1000 seed weight) was also significantly reduced in treated plants in comparison to control (Table 42 and Fig. 34).

Seed yield and 1000 seed weight (test weight) were studied in the present investigation in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). Control plants showed maximum
results and 200 ppm obtained data for these characters. Similar results were obtained by Arya (1971), Arya (1997), Malik (1997), Kumar (2000), Nimesh (2001) and Tyagi (2004). Chaudhry (2004) conducted experiments on wheat and chickpea. He reported that 100 - 200 ppm doses of NaF (Sodium Fluoride) significantly reduced the yield and test weight in wheat and chickpea. Singh (2005) also obtained similar results in soybean (\textit{Glycine max} L. Merill) and broad bean (\textit{Vicia faba} L.).

(13) The productivity in gm / plant / day in wheat and barley crops are also reduced in higher concentrations of NaF in comparison to control. The maximum productivity was estimated in control plants while minimum was determined in F_S (200 ppm) of NaF (Tables 43-46).

Productivity per plant and per m^2 showed maximum results in control treatment and 200 ppm obtained minimum data for productivity / plant and / m^2 in wheat (\textit{Triticum aestivum} L.) and barley (\textit{Hordeum vulgare} L.). Singh (1992) and Chaudhry (2004) also showed similar findings for 200 - 250 ppm doses of NaF (Sodium Fluoride) in wheat (\textit{Triticum aestivum} L.), barley (\textit{Hordeum vulgare} L.), triticale and chickpea (\textit{Cicer arietinum} L.). Singh (2005) also found similar results in soybean (\textit{Glycine max} L. Merill) and broad bean (\textit{Vicia faba} L.).

\textbf{Photochemical Response}
The chlorophyll content in leaves decreases in case of NaF treated plants. A gradual fall in the chlorophyll content was observed upto 200 ppm in the leaves of the plants tested during this investigation. A reduction in chlorophyll would have to be reflected in the photosynthetic process or yield (Table 47 and Fig. 35).

The maximum values of chlorophyll content of leaves in mg /g of dry weight were observed in control and minimum in 200 ppm in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). McNulty and Newman (1961) reported that NaF prevents the accumulation of chlorophyll ‘a’ and ‘b’ and photochlorophyll in bean leaves. Singh (2005) also reported similar findings in soybean (*Glycine max* L. Merill) and broad bean (*Vicia faba* L.).

(1) Chlorophyll contents in the leaves are tremendously decreased with an increase in dose of NaF upto 200 ppm. Chlorosis in leaves developed due to fluoride toxicity in mesophyll tissues of the leaves (Table 47 and Fig. 35 show the data on 60th day).

The chlorophyll content was observed to be tremendously decreased in 200 ppm concentration of NaF. The data in Table indicate the toxic effect of sodium fluoride. It is supposed that in the deficient supply of nitrogen, plants become stunted and under such conditions plants are not capable of conserving assimilates into protoplasm. Phosphorus is also the constituent of nucleic
acid and phospholipids. It thus helps in the synthesis of protein and the richest energy compound (Table 47 and Fig. 35).

The fluoride is found to cause hindrance in chlorophyll content, enzyme activity and other biochemical activities (Garber, 1966). Data on the reduction of chlorophyll content of peach and Prune foliage due to fluoride contamination atmosphere have been collected by McNulty and Newman (1956).

Chlorophyll consists of tetraprol ring of nitrogen and Mg ion in between the phytol tail remains attached to it. Chlorophyll is of two types 'a' and 'b'. Chlorophyll 'a' is mainly responsible for photosynthesis and thus productivity. The loss of chlorophyll due to fluoride toxicity resulted into chlorosis of leaves in different plants. (McNulty and Newman, 1961, Arya 1971, Arya et al., 1979, Singh 1992, Malik 1997, Arya 1997, Kumar 1998 and Nimesh 2001). The mechanism and significance of that fact are not clear but the presence of chlorosis a visible symptom of fluoride injury in some species, may be regarded as a manifestation of altered structure and therefore, function of chloroplast. McNulty and Newman (1961) observed the prevention of accumulation of chlorophyll 'a' and chlorophyll 'b' in NaF (Sodium Fluoride) treated leaves of bean. The fluoride also thought to deteriorate the internal structure of chloroplast and thylakoid. Treshow (1970) found the reduction of Mg$^+$ ion due to fluoride. Menser et al., (1965) observed the reduction in
chlorophyll contents of mutant plants. The fluorides may affect the early stages or pigment synthesis, or induce the degradation of chloroplast structure.

(2) Total nitrogen and protein contents are also severely affected in 100 - 200 ppm concentrations of sodium fluoride. The maximum nitrogen and protein contents were estimated in control plants and minimum were recorded in 200 ppm NaF treated plants in both varieties of wheat and barley (Tables 48-49 and Fig. 36-37).

Nitrogen is the most distinctive element in proteins and nucleotides in plants. Phosphorus is the part of all nucleotides and phospholipids. Both nitrogen and phosphorus contents of plants may be adversely affected by NaF (Sodium Fluoride) toxicity. The growth and Net Assimilation Rate (NAR) of plants depend upon the supply of nitrogen and phosphorus through their root system. NAR is affected only by severe nitrogen deficiency and that over a wide range of higher levels of nitrogen supply (Tables 48-49 and Fig. 36-37).

Asthir et al., (2000) studied differential response of carbon and nitrogen metabolism to fluoride application in fruiting structures of chickpea (Cicer arietinum). The effects were studied of sodium fluoride (10 and 50 mol m - 3) on the activities of sucrose metabolizing enzymes, transaminases and glutamine synthetase [glutamate - ammonialigase] in relation to metabolism
in the fruiting structures (pod wall, seed coat and cotyledons) of chickpeas cv. GL 769. Detached reproductive shoots were cultured in a liquid medium. Addition of fluoride to the culture medium significantly decreased starch content of the cotyledons and increased total free sugars (mainly reducing sugars) in the pod wall and seed coat, and sucrose in the cotyledons. The activity of soluble invertase [beta - fructofuranosidase] was stimulated in the pod wall but reduced in the cotyledons. However, soluble protein content of both the pod wall and the cotyledons increased in conjunction with an increase in the activities of glutamate - oxaloacetate transaminase, glutamate - pyruvate transaminase and glutamine synthetase. Disruption of starch biosynthesis under the influence of fluoride and the resulting accumulation of free sugars possibly resulted in their favoured utilization in nitrogen metabolism.

Sharma (1988) described the effect of hydrogen fluoride (HF) fumigation in Triticum aestivum, Brassica juncea and Phaseolus aureus plants. Unwin (1985) studied the effects of atmospheric fluoride pollution in United Kingdom and possible effects upon cereals and bean i.e. wheat, barley and pulses. Cho et al., (1988) studied the effects of hydrogen fluoride gas on plant growth and yield of rice. The yield losses affected by HF (Hydrogen Fluoride) fumigation at panicle initiation stage was higher than those at active tillering stage. The SO₂ (Sulphur Dioxide) contents in leaves increased by HF (Hydrogen Fluoride)
fumigation, and the CaO and P$_2$O$_5$ contents in leaves increased at the low level of fumigation but decreased at a high level.

(3) Phosphorus content was found maximum in control and minimum in 200 ppm dose of NaF. It was affected due to NaF toxicity proportionately in the treatments from F$_1$ to F$_5$ (Table 50 and Fig. 38).

The fluoride toxicity causes reduction in photosynthesis (Thomas, 1958; Kozlowski and Keller, 1966; Woltz, 1964 and Vennesland and Turkinglon, 1966). Chang (1975) found in citrus that fluoride inhibits Hill reaction and photosynthesis and causes reduction of NADP and oxidation of cytochromes. Thomas and Hendricks (1956) and Thompson et al., (1967) studied the effect of fluoride and reported reduction in photosynthesis and inhibition of Hill reaction. Ballantyne (1972) found inhibition of both photosynthesis and respiration in fluoride treated plants. Increase of respiration by fluoride has been reported by various workers in many plants e.g. in Chlorella leaves (McNulty and Lords, 1960), in Pea (Pisum sativum) var. Alaska and also in wheat seedlings by (Lustinec et al., 1964). Yu and Miller (1967) equated the action of fluoride with that of DNP in case of soybean leaves. They observed that both fluoride and DNP similarly influence respiration of soybean leaves. McNulty (1964) observed that the NaF concentrations increase the respiratory rate of bean leaf discs from healthy plants by about 25 % without
causing visible damage. Higher concentrations of fluoride reduced oxygen uptake long before visible symptoms appeared. Fluoride inhibition of the Hill reaction in bean (*Phaseolus vulgaris*) and chloroplast was noted. NaF concentrations up to $2.00010^5$ M resulted in an increased respiration as high as 60% above normal.

(4) Energy content was also affected adversely in higher concentrations of NaF. Maximum energy content was obtained in control plants and minimum in $F_5$ (200 ppm) treatment in both varieties of wheat and barley (Table 51 and Fig. 39).


(5) Pollen and ovule sterility percentage were tremendously affected with NaF toxicity. 200 ppm concentration showed maximum sterility percentage viz. pollen and ovule in wheat and barley
varieties. Control plants were found fertile and no sterility was observed or very low sterility percentage was found (Tables 52-53 and Fig. 40-41).

Pollen sterility in sporocytes of spikelets (anthers) of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) increased in case of NaF treated plants. A gradual increase in pollen sterility was observed upto 200 ppm of the plants tested during this investigation. Reduced pollen sterility percentage was recorded in control plants of wheat and barley in the present investigation.

Similarly ovule sterility was observed in control and NaF treated plants of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). Maximum ovule sterility was found in 100 to 200 ppm doses of sodium fluoride and minimum in control plants in the present investigation.

Fluoride is found to cause hindrance in development of pollen mother cell (PMC) as reported by Mohamed (1968). The chromosomal aberrations and other cytogenetic abnormalities are often associated with fluoride toxicity (Mohamed, 1968; Arya and Rao, 1978, Grover and Dhingra, 1987) in tomato (*Lycopersicum esculentum*), pea (*Pisum sativum* L.) and onion (*Allium cepa* L.) respectively. Parthenocarpic fruits are the seedless fruits which develop without fertilization. Parthenocarpic fruits were developed with the spray of 100 - 250 ppm
concentrations of NaF (sodium fluoride) solution on tomato (*Lycopersicum esculentum*) plants (Arya, 1971). Fluoride is found to cause cytogenetic aberrations which lead to pollen and ovule sterility, which is evidenced by the research work of Arya (1971) in two varieties of pea (*Pisum sativum* L.) and barley (*Hordeum vulgare* L.) and Arya and Rao (1980) in pea. Pollen and ovule sterility in pea, barley, maize and tomato were found with the spray of 100 - 250 ppm NaF solutions.

Yamazoe (1962) reported that Chlorophyll in the parenchyma of paddy leaves was decolourized, cytoplasm and cell membranes were decomposed and the injured part became chlorotic. Typical symptoms of plant damage by fluorides are mottling of the leaves, bleaching of the leaf margin and tips, and necrosis of the leaves. Soluble NaF (Sodium Fluoride) or KF (Potassium Fluoride) dust on plants reduces the chlorophyll content of plant (Garber, 1966). Chlorosis in vegetation was also observed by Gillette (1969), Hill and Pack (1960), Menser *et al.*, (1965) controlled by the protein synthesis, as found by Chang and Thompson (1966). Phosphorus content of crop plants is also affected with various doses of sodium fluoride (NaF). It is probably due to the retardation in the enzymatic activity of phytase which affected the phytin phosphorus as reported by Chang (1967).

Kumar (2000) reported the effect of sodium fluoride (NaF) toxicity on the growth and productivity of pea (*Pisum sativum* L.), barley (*Hordeum vulgare* L.) and tomato (*Lycopersicum esculentum*). He conducted the experiments at R.M.P. (P.G.) College, Narsan.
(Hardwar), Uttarakhand (India) during the years (1997 - 98 and 1998 - 99). Toxic effect of sodium fluoride (100 - 250 ppm) was found very harmful on the growth and yield attributes of these crop plants. Toxic effect was also found on chlorophyll, nitrogen, protein, total sugar, amino-acids, energy content, sterility behaviour and chromosomal irregularities.

Nimesh (2001) conducted experiments on the effect of fluoride toxicity on pea (*Pisum sativum* L.) and barley (*Hordeum vulgare* L.) at M.S. College, Saharanpur (U.P.) during the years 1999 and 2000. The concentrations of sodium fluoride were found toxic 100 and 200 ppm on plant height, number of branches, leaves, leaf area, NAR (Net Assimilation Rate), RGR (Relative Growth Rate), biomass, yield and test weight (1000 seeds weight) of pea (*Pisum sativum* L.) and barley (*Hordeum vulgare* L.). The effect on chlorophyll content was found severe on 60th day of sowing. Chlorosis, necrosis and burning of leaf tips and margins were also observed by 200 ppm NaF dose. Total nitrogen percentage, protein content, phosphorus, total sugar, amino-acids and energy content were tremendously affected by 100 - 200 ppm NaF treatments. Pollen and ovule sterility percentage were found more in 200 ppm dose of NaF when compared with control plants. Chromosomal aberrations in mitosis and meiosis stages were also recorded in 100 - 200 ppm NaF doses in pea and barley.

was sown and raised in a field irrigated with 0, 25, 50, 100 and 200 ppm sodium fluoride in an experiment conducted in Uttar Pradesh, India during 1998 - 2000. Germination decreased from 95 to 81.85 % with increasing concentrations of sodium fluoride. Plants irrigated with 100 and 200 ppm of sodium fluoride exhibited significant reduction in height (60.8 and 58.4 cm, respectively) as compared with the control plants (68.8 cm.). Lower concentrations of sodium fluoride inhibited leaf elongation while higher concentrations caused elongation and narrowing of leaves. Chlorosis and necrosis of leaves also resulted from high concentrations of sodium fluoride. Number of tillers and number of flowers / ear were gradually reduced with increasing sodium fluoride concentrations while ear length reduction was directly proportional to the concentration of sodium fluoride, lowest number of seeds / plant (54.6 seed / plant) and 100 grain weight 4.78 g were observed at 200 ppm treatment of sodium fluoride, total yield decreased from 6.02 g / plant in the control to 3.2 and 3.01 g / plant, respectively.

Saini (2003) conducted the experiments on four varieties of onion (Allium cepa L.) at C.C.R. (P.G.) College, Muzaffarnagar (U.P.) during the years (2000 to 2002). The cultivars were Pusa Red, Agrifound light red, Early Grano and Pusa Madhavi. The effect of sodium fluoride on the growth and yield of onion was studied for 2 years. The best performance was recorded of Pusa Madhavi and worst performance was seen in Pusa red variety. The effect of fluoride toxicity was also studied on chlorophyll, nitrogen, protein percentage, phosphorus and energy
content. In general the effects of 100 - 200 ppm doses of NaF were found harmful to the onion plants.

Chaudhry (2004) studied the effect of fluoride toxicity on the growth, productivity and sterility behaviour of wheat and chick pea. The experiments were conducted at C.C.R. (P.G.) College farm Muzaffarnagar (U.P.), India from 2002 - 2003. The growth characters viz. germination, plant height, number of leaves, productive tillers, leaf area, NAR (Net Assimilation Rate), RGR (Relative Growth Rate), fresh and dry weight of plants, productivity and 1000 seeds weight were studied. The effect of NaF toxicity on growth and yield characters was recorded. 100 - 200 ppm doses were found harmful and toxic to the plants. Determination of chlorophyll, nitrogen, protein percentage, phosphorus and energy content were also studied. The effect of fluoride on biochemical characters discussed above and sterility behaviour was found significantly toxic on both the cereal and pulse crop plants.

Tyagi (2004) studied the ecophysiological response of urdbean (Vigna mungo L.) to fluoride toxicity. The experiments were conducted on four cultivars of urdbean (T-9, PU-19, Pant U-30 and Pant U-35) in the years 2002 and 2003 at C.C.R. (P.G.) College farm, Muzaffarnagar (U.P.), India. The effect of 100 - 200 ppm of NaF was found toxic on growth and yield parameters. Severe effect was also noted on the nodule number, fresh and dry weight of nodules and also the formation of nodules. The effect of sodium fluoride (NaF) toxicity was also
discussed on biochemical characters as well as sterility percentage (Pollen and ovule).

Sharma (2005) reported the effect of fluoride on physiological response of Brassica juncea L. The experiments on oil seed crop were conducted at C.C.R. (P.G.) College, Muzaffarnagar (U.P.), India during the years 2003 to 2005. Two varieties RH-30 and Varuna were studied. The best performance of Varuna was recorded. The effect on growth and yield attributes was observed due to fluoride toxicity. 100 - 200 ppm doses were found more toxic in comparison of 10, 25 and 50 ppm doses of NaF. All the growth, yield, biochemical characters and sterility behaviour showed similar effect as discussed above by Chaudhry (2004) and Tyagi (2004). The effect of NaF toxicity was found very severe on oil content of Indian mustard (Brassica juncea L).

Rawat (2005) conducted two years (2002 and 2003) experiments at C.C.R. (P.G.) College, Muzaffarnagar (U.P.), India to show the effect of fluoride toxicity on the growth, yield and sterility behaviour of mungbean (Vigna radiata (L.) Wilczek). Two genotypes of Mungbean, Pant Mung - 4 and Narendra - 1 were tried to show the effect of sodium fluoride (10 ppm - 200 ppm) on these plants. Toxic effect was noted of 100 - 200 ppm doses of NaF (Sodium Fluoride) on all the growth and yield characters. The effect on nodule formation, nodule number, fresh and dry weight of nodules was very severe. Chlorophyll, nitrogen percentage, protein content, phosphorus, energy content and sterility
percentage of pollen and ovule were tremendously affected by 100 - 200 ppm doses of sodium fluoride.

Singh (2005) studied the effect of fluoride toxicity on growth, yield and sterility behaviour of soybean (*Glycine max* L. Merill) and broad bean (*Vicia faba* L.). The experiments were conducted at D.A.V. (P.G.) College, Muzaffarnagar (U.P.), India, during the years 2003 and 2004. All the growth and yield characters including nodule development in both the legumenous crops were critically studied. 100 - 200 ppm of NaF doses were found toxic to the treated plants. Chlorophyll content, nitrogen, protein, phosphorus percentage, energy content and sterility percentage (pollen and ovule both) were also tremendously affected by NaF concentrated doses.

Singh (2006) worked on the effect of sodium fluoride toxicity on cluster bean (*Cyamopsis tetragonoloba* L.) Var. Pusa Navbahar and lentil (*Lens esculenta*) Var. K-75. The experiments were conducted at S.S.V. College, Hapur, Ghaziabad (U.P.), India during the years (2004 and 2005). Toxic effect of 100-200 ppm doses was observed on growth and yield characters. The effect on bio-chemical characters e.g. chlorophyll, nitrogen, protein, phosphorus, energy content and sterility percentage of pollen and ovule was also found toxic and harmful to the plants. The yield of both the crop plants decreased tremendously of pods / plant and seeds / plant.
Saini and Singh (2005) studied the effect of sodium fluoride on the growth of different varieties of onion (*Allium cepa* L.). Field experiment was conducted at C.C.R. (P.G) College, Muzaffarnagar (U.P.), India during Rabi season 2000 to 2002 to find out a suitable onion cultivar to different levels of NaF (10, 25, 50, 100 and 200 ppm) was applied to different varieties, (Pusa Red, Agrifound Light Red, Early Grano and Pusa Madhavi). Maximum growth was recorded by control in all the four varieties of onion. When the comparison of four varieties was done, it was found that maximum growth was recorded in variety Pusa Madhavi (V4 - 46.20 cm. height / plant) in 2001 season and in 2002 season (V4 - 48.25 cm. height / plant). Variety Pusa Madhavi is the best for obtaining maximum growth on onion.

Malik *et al.*, (2008) studied the effect of sodium fluoride on morphological characters i.e. nodules / plant, leaf area / plant, pods / plant, seed / pod, test weight and yield / plant of Urdbean Var. T-9. The experiment was conducted for two years. Simple randomized block design was followed and taking five treatments of NaF (Sodium Fluoride) such as 10, 25, 50, 100, 250 ppm with control for four replications. The results were recorded on an average basis taking five plants for each treatment in each block. On the basis of observations the results were found significant. Reduction in all characters in treated plants in higher concentration i.e. 100 - 250 ppm NaF in *Vigna mungo* in comparison to the control.
Malik and Arya (2008) reported the effect of fluoride toxicity on morphological characters i.e. height, leaves, nodules/plant, leaf area/plant, pods/plant, seeds/pod, test weight and yield/plant of Mungbean var. PS-16. The experiment was conducted for two years at R.M.P. (P.G.) College, Narsan (Hardwar), India. Simple randomized block design was followed by taking five treatments of NaF such as 10, 25, 50, 100, 250 ppm along with control for four replications. The results were recorded on an average basis taking five plants for each treatment in each block. On the basis of observations, the results were found significant. Reduction in all characters in treated plants was observed in higher concentrations i.e. 100-250 ppm NaF in *vigna radiata* in comparison to the control.

Malik and Arya (2008) reported the effect of fluoride toxicity on chlorophyll content present in green leaves on 60th day of urdbean var. T-9 and mungbean PS-16 for two years. Protein percentage and energy content of oven dried plant material at harvest was also estimated of urdbean and mungbean in both the years. Simple R.B.D. was followed with four replications and six treatments including control. The concentrations of sodium fluoride were taken as 10, 25, 50, 100 and 250 ppm. On the basis of findings the results were found significant. The higher concentrations 100-250 ppm NaF doses, were found toxic in urdbean var. T-9 and mungbean var. PS-16.

Singh and Chaudhary (2007) evaluated the degree of association between yield components and plant traits with grain yield and to
determine direct and indirect effects of yield components and plant traits on grain yield in 90 wheat genotypes grown under moisture stress conditions. Data were recorded for plant height, ear length, tillers per metre, grain weight per spike, 1000-kernel weight, biological yield, grain yield per metre and harvest index. Sharma et al., (2004) analysed combining ability in the F₁ and F₂ generations of a diallel cross in six-rowed barley (Hordeum vulgare L.). Grakh and Singh (2006) studied 60 genotypes of bread wheat, comprising 15 parents and their 45 hybrids to determine the combining ability of the total biomass, grain yield and harvest index. Mohammad and Khan (2007) examined the genetic mechanisms for controlling biomass, protein content and grain yield. Eight parent lines of wheat (Triticum aestivum L.) were crossed in all possible combinations. It seems that single plant selection in segregating generations would be effective for improving the plant traits. Singh et al., (2007) conducted a study to identify the desirable parents and crosses and to find out the gene action for grain yield and yield components in bread wheat (Triticum aestivum L.).

Kumar (2009) worked on genetic studies in wheat (Triticum aestivum L.) at C.C.R. (P.G.) College, Muzaffarnagar (U.P.). Among 18 genotypes HD-2009 and PBW-226 were found prominent for growth and yield parameters. The performance of plant height (cm.) and number of tillers per plant were more or less similar in HD-2009 and PBW-226. As regards the yield characters HD-2009 was found better than PBW-226. According to mean table the performance of these two
genotypes for yield was found maximum in comparison of rest 16 genotypes.

Neeru (2011) conducted her experiments at C.C.R. (P.G.) College, Muzaffarnagar (U.P.) from 2008-2010. The effect of sodium fluoride toxicity was studied on germination, growth, yield and biochemical parameters of cowpea (*Vigna sinensis* L.). The toxic effect of NaF was observed on two varieties of cowpea i.e. Russian Giant and Pusa Komal. Control treatment showed best performance of Russian Giant variety. The toxic effect of NaF was seen on germination, growth and yield parameters. The effect was also seen on nitrogen, protein, phosphorus, Chlorophyll content, energy content and pollen and ovule sterility percentage. Control plants were found better than 100 - 200 ppm NaF doses.