HALOGENATION FOR IMPROVEMENT OF SEED YIELD AND QUALITY IN CHILLI (*Capsicum annuum* L.)

By

MILU HERBERT

(2018-11-155)

THESIS

DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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Submitted in partial fulfillment of the requirements for the degree of

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Faculty of Agriculture

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DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY

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2020

DECLARATION

I hereby declare that this thesis entitled "**Halogenation for improvement of seed yield and quality in chilli (*Capsicum annuum* L.)**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 19-11-2020

Milu Herbert

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CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Milu Herbert (2018-11-155)**, a candidate for the degree of **Master of Science in Agriculture** with major field in Seed Science and Technology, agree that the thesis entitled **"Halogenation for improvement of seed yield and quality in chilli (*Capsicum annuum* L.)"** may be submitted by **Ms. Milu Herbert,** in partial fulfilment of the requirement for the degree.

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Milu Herbert

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LIST OF ABBREVIATIONS

%	:	per cent
°C	:	degree Celsius
°E	:	degrees east
°N	:	degrees north
ANOVA	:	Analysis of Variance
$CaOCl_2$	:	Calcium oxy chloride
CD	:	Critical difference
cm	:	centimetre
cv.	:	cultivar
DAS	:	Days after sowing
dSm^{-1}	:	deci Siemens per metre
EC	:	electrical conductivity
et al.	:	*et alia* (Latin: 'and others')
G	:	Gauge
g	:	grams
g/kg	:	gram per kilogram
h	:	hours
$HgCl_2$	:	Mercuric chloride
IMSCS	:	Indian Minimum Seed Certification Standard
ISTA	:	International Seed Testing Association
KAU	:	Kerala Agricultural University
kg	:	kilo gram
m	:	metre
mg	:	milli gram
ml	:	milli litre
PDA	:	Potato Dextrose Agar
SEm	:	Standard error of error mean sum of squares
var.	:	variety

Introduction

1. INTRODUCTION

Chilli (*Capsicum annuum* L.) belonging to family Solanaceae is an important spice crop of global importance. It is a native of South America. There are more than 400 different varieties of chillies cultivated all over the world. Within the genus, *C.* a*nnuum, C. baccatum, C. chinense, C. frutescens* and *C. pubescens* are commonly cultivated. Among these, cultivation of *Capsicum annuum* is more popular. It is also called as *hot pepper, cayenne pepper, sweet pepper, bell pepper etc.*

It is extensively cultivated as vegetable in India. Both green and dried chilly fruits are indispensable in Indian diet. It is widely used as spice, condiment, medicine and vegetable owing to its pungency, taste, colour and flavor. It is rich in vitamins especially vitamin A and C and also packed with mineral nutrients such as potassium, magnesium and iron. Some varieties are known for their red coloured fruits attributed to the presence of pigment capsanthin while some others are famous for their biting pungency. The pungency in chilli is due to an alkaloid, capsaicin present in the placenta and pericarp of the fruit which has wide prophylactic and therapeutic uses.

The lion's share in global production of chilli is contributed by India, followed by China. Major Indian states leading in chilli production are Andhra Pradesh, Telangana, Tamil Nadu and Madhya Pradesh. According to 2019-20 first advance estimates, Indian chilli occupies an area of 7.33 lakh hectares with a production of 17.64 lakh tonnes and productivity of 2400 kg per hectare (971 kg per acre). India is not only the largest producer but also the biggest consumer and exporter of chilli in the world. Chilli is the second largest commodity after black pepper (*Piper nigrum* L.) in the International Spice Trade (Yatagiri *et al*., 2017). In Kerala, chilli is cultivated mainly for green chilli purpose.

Chilli is a warm season crop. Seeds often germinate slowly in both normal and stress conditions (Wein, 1999; Demir and Okcu, 2004). The seeds possess non- starchy endosperm which act as mechanical barrier to growing embryo, affecting germination process (Andreoli and Khan, 1999). The seeds exhibit dormancy to varying levels causing hindrance to germination, even if they had attained necessary physiological growth to support germination (Patra *et al*., 2017). Slow germination can lead to susceptibility of seeds and young seedlings to diseases (Samarah *et al*., 2016). Thus chilli seed producers may encounter several obstacles owing to slow germination and infection of seeds resulting in reduced seed yield and quality (Abdullah *et al*., 2017).

Seed deterioration during storage is considered as one of the major factors preventing seeds from normal germination and vigourous growth. Chilli seeds stored under ambient conditions lose viability within an year. This might be attributed to high physiological fragility and thin seed coat, which leads to quick loss of viability and vigour in storage (Manjunatha *et al*., 2008). External factors affecting seed quality during storage are temperature, relative humidity, initial seed moisture and seed microflora. Heavy monsoon and high relative humidity in Kerala lead to increased absorption of moisture by seeds from the surrounding environment. This coupled with high temperature hastens the ageing process of stored seeds, ultimately affecting the viability.

Physiological and pathological deterioration of seed results in poor establishment of crop and low productivity. Therefore use of high quality seed is necessary to combat the problems of seed deterioration. The seeds possessing required standards of purity, germination and other attributes are referred to as quality seeds. The capacity of seeds is completely manifested only when it possesses good quality in terms of physical, physiological, genetic and health aspects.

Although ageing of seeds stored under ambient condition is an inevitable and irreversible process, it can be controlled by adoption of suitable seed invigoration techniques. Seed invigoration indicates an enhancement in seed performance by any post-harvest treatment that concentrate on germinability, storability and better field performance (Basu, 1990). Halogenation is one such seed treatment to manage deterioration process.

Free radical induced lipid peroxidation and loss of membrane integrity are the major causes of seed deterioration resulting in poor performance of seeds (Powell, 1981; Dadlani and Agarwal, 1983; Ramamoorthy and Basu, 1997). Halogens such as chlorine or iodine used in seed treatment formulations act as free radical quenchers. They act on unsaturated fatty acids in cell membrane, stabilizing carbon to carbon double bonds in the membrane lipids and mitigate the production of free radicals that accelerates ageing process. Besides, their antimicrobial action may account partly for controlling the storage fungi, which is one of the major factors affecting quality of seeds during storage (Hunje *et al*., 2007), in addition, seed invigoration with halogenation augments productivity in various crops (Vidyadhar and Singh, 2000).

Halogen treatments along with carrier were found to be more effective in maintaining seed viability during storage. This is because carrier used in halogen formulations retains a part of halogen vapour and this residual vapour is slowly released with the progress of storage (Poonguzhali, 2014).

Investigations undertaken in the Department of Seed Science and Technology, College of Horticulture, Vellanikkara confirmed the positive role of halogens in extending the shelf life of rice (Suganya, 2015) and chilli seeds (Navya, 2016). However the impact of halogenation on growth and field performance of treated seeds are yet to be ascertained.

Hence the present study entitled, 'Halogenation for the improvement of seed yield and quality in chilli (*Capsicum annuum* L.)' was designed with the following objectives,

1. To assess the effect of halogenation on field performance, fruit and seed yield in chilli
2. To assess the effect of halogenation in seed quality
3. To evaluate the storage potential of halogenated seeds under ambient storage conditions

Review of literature

2. REVIEW OF LITERATURE

Chilli is an important warm season vegetable as well as spice crop of India. In Kerala, it is cultivated mainly for green chilli purpose. Chilli seeds exhibit dormancy to different extent and germinate slowly, increasing susceptibility of seeds and young seedlings to diseases (Patra *et al*., 2017). Quick germination and vigorous early seedling growth are necessary for a good crop, and maintenance of seed quality and vigour is a matter of concern for researchers and farmers. Vigour of seeds can be activated through various seed invigoration treatments. Halogenation is one such seed invigoration treatment. Halogens such as chlorine or iodine used in the formulation mitigate seed deterioration by acting as free radical scavengers. Their antimicrobial action may account partly for controlling the storage fungi, which is one of the most influencing factors in storage. In addition, seed invigoration with halogenation augments productivity in various crops.

In this context, the present study entitled, 'Halogenation for the improvement of seed yield and quality in chilli (*Capsicum annuum* L.)' was designed. The literatures related to various aspects of the study are reviewed under the following headings,

2.1. Impact of halogenation on growth parameters and seed yield attributes

2.2. Impact of halogenation on seed quality parameters

2.3. Seed infection during storage

2.1. Impact of halogenation on growth parameters and seed yield attributes

2.1.1. Days to first and 50% flowering

Halogen used	Crop	Highlights of the experiment	Reference
1. KCl + $CaCO_3$ 2. KI + $CaCO_3$	Maize	Fresh seeds (90 per cent germination) and partially aged seeds (seeds subjected to partial ageing at 40 ± 1°C and 100 per cent relative humidity to achieve 75 per cent germination) of maize hybrid BH 1001 were treated with mixture of halogen (30 mg and 50 mg concentrations) and carrier (3g) @3 g/kg of seeds for 72 hours and the treated seeds were used for field studies. Crop raised from halogen treated seeds advanced in flowering and the effect was more pronounced in partially aged seeds treated with KCl @30 mg. Partially aged seeds treated with KCl @30 mg advanced in days to 50 per cent silking and tasseling by two and six days, respectively over the control.	Vidyadhar and Singh (2000)
1. KCl 2. $CaCl_2.2H_2O$	Soybean	Plots sown using seeds of two varieties *viz.*, Phule Kalyani and JS-335 primed with $CaCl_2.2H_2O$ (0.5%) accelerated in days to 50 per cent flowering by three to four days when compared to their control.	Chavan *et al*. (2014)

		In case of plots sown using seeds treated with KCl @10 ppm, the advancement in flowering was by one to two days over the untreated controls.	
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	Aged seeds (*Kharif*, 2015 harvested seeds) of green gram cv. LGG- 460 were treated with $CaCl_2$ (2%) and bleaching powder @2 g/kg. All the treated seeds were then used for field study along with untreated control and fresh seeds (*Rabi*, 2015-16 harvested seeds). Treatment with $CaCl_2$ caused early flowering over untreated aged seeds by one day. Treatment with bleaching powder reduced days to 50 per cent flowering by three days and one day over untreated aged seeds and untreated fresh seeds, respectively.	Leelavathi (2017)
1. $CaCl_2$ 2. KCl	Black gram	A field experiment was conducted with seeds of cv. VBN 3 treated with halogens *viz.*, $CaCl_2$ @2% and KCl @2% along with untreated control. $CaCl_2$ treated seeds were the earliest to flower. The treatment caused advancement in days to first and fifty per cent flowering by seven to nine days when compared to KCl treatment and untreated control.	Kumar (2018)

2.1.2. Plant height

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	One- month old (high vigour) seeds of cv. Mahamaya 1 were dry dressed with bleaching powder @2 g/kg of seeds and iodinated calcium carbonate @3 g/kg of seeds. The treated seeds were subjected to natural ageing for a period of 70 days along with untreated control. Thereafter, the stored seeds were used for field study. The results showed that treatments with bleaching powder and iodinated calcium carbonate enhanced plant height by 0.8 cm and 5 cm respectively over control.	Layek *et al*. (2006)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	Seeds (1 month old) of cv. Deshi BG 240 was treated with calcium hypochlorite (common bleaching powder, @3 g/kg of seed) and iodinated calcium carbonate (30 mg iodine impregnated with 3 g of calcium carbonate, @3 g/kg of seed). A part of the treated seeds were stored for a period of two months under ambient conditions and the other part was subjected to accelerated ageing (93% RH and 40°C) for 18 days. Field experiment was conducted using the naturally aged seeds and biometric observations were recorded at 105 days after sowing. The observations revealed that the treatment with bleaching powder and iodinated calcium carbonate increased the plant height by 1.5 cm and 3.6 cm respectively over control.	Saha *et al*. (2006)

$CaOCl_2$	Okra	Two months old and five month old seeds of cv. Pankaj were given pre-storage and mid storage treatments with bleaching powder @2 g/kg of seeds. The treated seeds were then stored for five months under ambient conditions along with untreated control for natural ageing. Seed treatment with bleaching powder increased plant height by 5 cm over untreated control.	Guha *et al.* (2012)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Black gram	One- month old (high vigour) seeds of cv. Sarada were dry dressed with bleaching powder @2 g/kg seeds and iodinated calcium carbonate @3 g/kg of seeds. After the treatment, the seeds were stored for 190 days under ambient conditions along with untreated control. The treated and untreated seeds that had undergone natural ageing were then used for field studies. The results revealed that the halogen treatment enhanced plant height by 1-1.6 cm over control.	Layek *et al.* (2012)
1. KCl 2. $CaCl_2.2H_2O$	Soybean	Seeds of two varieties *viz.*, Phule Kalyani and JS-335 were primed with halogens such as KCl @10 ppm and $CaCl_2.2H_2O$ (0.5%). A field experiment was conducted using the treated seeds along with untreated controls. Crop raised from seeds treated with $CaCl_2$ was found superior for plant height by 10-11 cm in both varieties when compared to their	Chavan *et al.* (2014)

		controls, while treatment with KCl enhanced plant height by 4-5cm over controls in both the varieties.	
1. $CaCl_2$ 2. $CaOCl_2$	Greengram	Three months aged seeds of cv. LGG- 460 were treated with $CaCl_2$ (2%) and bleaching powder @2 g/kg of seeds. The treated seeds along with untreated aged seeds and untreated freshly harvested seeds were used to conduct field experiment. Observations on plant height when measured at 75 days after sowing revealed that treatment with $CaCl_2$ caused marginal increase in plant height (by 4 cm) over untreated aged seeds. The treatment with bleaching powder enhanced plant height by 10 cm over untreated aged seeds but only a marginal increase of 4.7 cm was observed when compared with untreated freshly harvested seeds.	Leelavathi (2017)
1. $CaCl_2$ 2. KCl	Black gram	Plot sown with seeds of cv. VBN 3 hardened with $CaCl_2$ @2% was superior for plant height by 3-6 cm when compared to those sown with KCl (@2%) seeds and the untreated control seeds.	Kumar (2018)

2.1.3. Branches per plant

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	Seeds of cv. Deshi BG 240 were treated with bleaching powder @3 g/kg and iodinated calcium carbonate @3 g/kg and a part of the treated seeds was subjected to natural ageing for a period of two months along with untreated control. Field studies conducted using the naturally aged seeds showed that plants raised from seeds treated with bleaching powder produced more number of branches (7) when compared with those treated with iodinated calcium carbonate (6) and untreated control (6).	Saha *et al*. (2006)
1. KCl 2. $CaCl_2.2H_2O$	Soybean	Seeds of two varieties *viz.*, Phule Kalyani and JS-335 were primed with KCl @10 ppm and $CaCl_2.2H_2O$ (0.5%). Plots sown with $CaCl_2$ primed seeds of the two varieties were found to have more number of branches per plant (0.84-0.87) when compared with their untreated controls. Plants raised from seeds primed with KCl showed marginal enhancement (0.5-0.6) in number of branches per plant over the untreated controls.	Chavan *et al*. (2014)

1. $CaCl_2$ 2. $CaOCl_2$	Greengram	Three months aged seeds of cv. LGG- 460 were treated with $CaCl_2$ (2%) and bleaching powder @2 g/kg of seeds. The treated seeds along with two controls *viz.*, untreated aged seeds and untreated freshly harvested seeds were raised in field. The treatment with bleaching powder was found superior for number of branches per plant by two to four branches when compared with $CaCl_2$ treatment and the two controls when observed at 75 DAS.	Leelavathi (2017)
1. $CaCl_2$ 2. KCl	Black gram	Seeds of cv. VBN 3 were hardened with $CaCl_2$ @2% and KCl @2% and used for field studies along with untreated control. The crop raised from $CaCl_2$ treated seeds produced higher number of branches per plant (4.6) over KCl treated seeds (3.9) and untreated control (3.7).	Kumar (2018)

2.1.4. Fruits per plant

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	Freshly harvested seeds of cv. Deshi BG 240 were treated with bleaching powder @2g/kg and iodinated calcium carbonate @3 g/kg. A part of the treated seeds was kept for natural ageing under ambient conditions for a period of two months along with the untreated control.	Saha *et al*. (2006)

		Plants raised from pre-storage treated naturally aged seeds produced two pods more per plant when compared to control.	
1. KCl 2. $CaCl_2.2H_2O$	Soybean	A field experiment was conducted using seeds of two varieties *viz.*, Phule Kalyani and JS-335 primed with KCl @10 ppm and $CaCl_2.2H_2O$ (0.5 per cent) along with their untreated controls. The results revealed that the plants raised from seeds treated with $CaCl_2$ and KCl produced 10-12 and 6-7 more pods per plant respectively in the varieties over their controls.	Chavan *et al*. (2014)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Soybean	One month old seeds (cv. Soyamax) were dry dressed with common bleaching powder @2 g/kg and iodinated calcium carbonate (30mg iodine impregnated to 2g calcium carbonate) @2 g/kg. The treated seeds along with untreated seeds were subjected to accelerated ageing for a period of 21 days. A field study was conducted using the stored seeds to assess their field performance and productivity. Data on seed yield attributes were recorded 110 days after sowing. Crop raised from seeds treated with iodinated calcium carbonate produced 4-19 more number of pods per plant compared to those produced by plants raised from seeds treated with bleaching powder and untreated control.	Bhattacharya *et al*. (2015)

1. $CaCl_2$ 2. $CaOCl_2$	Green gram	Three months aged seeds of cv. LGG- 460 were treated with $CaCl_2$ (2%) and bleaching powder @2 g/kg. The treated seeds were used for field experiment along with untreated aged seeds and untreated freshly harvested seeds. Plants raised from seeds treated with $CaCl_2$ produced same number of pods as that of freshly harvested seeds and it was superior to untreated aged seeds by four pods. Bleaching powder treatment caused an increase of five pods per plant over untreated aged seeds and untreated fresh seeds.	Leelavathi (2017)
1. $CaCl_2$ 2. KCl	Black gram	Seeds of cv. VBN 3 were treated with $CaCl_2$ @2% and KCl @2% and used for field studies along with untreated control. Crop raised from seeds treated with $CaCl_2$ recorded superior values for number of pods per plant (6 pods) over untreated control whereas KCl treatment caused a marginal enhancement by two pods over control.	Kumar (2018)

2.1.5. Fruit length

$CaOCl_2$	Onion	Freshly harvested seeds of onion (cv. Sukhsagar) were dry dressed with bleaching powder @2 g/kg. The treated seeds along with untreated control were then subjected to accelerated ageing (at 93% RH and 40^{o}C) for five days and natural ageing under ambient conditions for 2.5	Sengupta *et al*. (2005)

		months. Field studies conducted using the stored seeds revealed that the bulbs harvested from plots sown with treated seeds were longer by 6 mm over the control.	
$CaOCl_2$	Okra	Two months old and five months old seeds of cv. Pankaj were treated with bleaching powder @2 g/kg of seeds. The treated seeds were then stored for five months under ambient conditions along with untreated controls for natural ageing. Field experiment was conducted using the stored seeds. The pre- storage and mid- storage treatment with bleaching powder enhanced length of fruit by 1 cm over the untreated controls.	Guha *et al*. (2012)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Soybean	One month old seeds of cv. Soyamax were dry dressed with common bleaching powder @2 g/kg and iodinated calcium carbonate @2 g/kg. The treated seeds along with untreated seeds were subjected to accelerated ageing for a period of 21 days. Field study was conducted with the stored seeds. Plants raised from seeds treated with iodinated calcium carbonate produced pods longer by 0.5-2 mm than treatment with bleaching powder and untreated control.	Bhattacharya *et al*. (2015)
1. $CaCl_2$ 2. KCl	Black gram	Seeds of cv. VBN 3 were treated with $CaCl_2$ @2% and KCl @2%. The treated seeds were then used for field studies along with untreated	Kumar (2018)

		control. Marginal enhancement (0.2-0.4 cm) in pod length was observed in treated seeds over untreated control.	

2.1.6. Fruit weight

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	One- month old seeds of cv. Mahamaya 1 were dry dressed with bleaching powder @2 g/kg and iodinated calcium carbonate @3 g/kg. The treated seeds were subjected to natural ageing for a period of 70 days along with untreated control. Thereafter, the stored seeds were raised. Plants from treated seeds produced pods heavier by 0.03-0.07 g over control.	Layek *et al*. (2006)
$CaOCl_2$	Okra	Two month old and five month old seeds of cv. Pankaj were treated with bleaching powder @2 g/kg. After the pre-storage and mid-storage treatments, the seeds were subjected to natural ageing under ambient conditions for five months along with untreated controls. Crop raised from the treated stored seeds produced pods with fresh weight higher by 1.84 g over untreated control.	Guha *et al*. (2012)

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Black gram	One month old seeds of cv. Sarada were dry dressed with bleaching powder @2 g/kg and iodinated calcium carbonate @3 g/kg. After the treatment, the seeds were stored for 190 days under ambient conditions along with untreated control. The treated and untreated seeds that had undergone natural ageing were then used for field studies. Plots sown with halogen treated seeds recorded higher pod weight (0.06-0.07 g) when compared to untreated control.	Layek *et al*. (2012)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Soybean	One month old seeds of cv. Soyamax were dry dressed with common bleaching powder @2g/kg and iodinated calcium carbonate @2 g/kg. The treated seeds were then subjected to accelerated ageing for a period of 21 days along with untreated seeds. Field studies conducted using the stored seeds revealed that the plants raised from treated seeds produced fruits with pod weight per plant heavier by 1 g compared to control.	Bhattacharya *et al*. (2015)
1. $CaCl_2$ 2. KCl	Black gram	Field experiment conducted using seeds of cv. VBN 3 treated with $CaCl_2$ @2% and KCl @2% along with untreated control revealed that the treated seeds and untreated seeds did not show any difference in performance for pod weight.	Kumar (2018)

2.1.7. Seeds per fruit

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	One- month old seeds of cv. Mahamaya 1 were dry dressed with bleaching powder @2 g/kg and iodinated calcium carbonate @3 g/kg. The treated seeds were subjected to natural ageing under ambient conditions for a period of 70 days along with untreated control. The stored seeds were then used for field study. Pre-storage dry seed treatment with bleaching powder was found superior for number of seeds per pod (1.23) over the treatment with iodinated calcium carbonate (1.05) and untreated control.	Layek *et al*. (2006)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	Seed of cv. Deshi BG 240 were treated with calcium hypochlorite @2 g/kg and iodinated calcium carbonate @3 g/kg and stored under ambient conditions for a period of two months along with untreated control. Field study was conducted using the naturally aged seeds and observations for number of seeds per pod was taken at 105 days after sowing. The results showed that there was no difference in performance of treated seeds and control.	Saha *et al*. (2006)
$CaOCl_2$	Okra	After pre-storage and mid- storage treatments with bleaching powder @2 g/kg, the seeds of cv. Pankaj were subjected to natural ageing under ambient conditions for five months along with untreated controls. Crop	Guha *et al*. (2012)

		raised from the stored seeds that had undergone pre- storage and mid-storage treatment produced 9-11 more seeds per capsule over the untreated control. The effect was more pronounced in pre-storage treatment.	
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Black gram	One month old seeds of cv. Sarada were invigorated with bleaching powder @2 g/kg and iodinated calcium carbonate @3 g/kg and allowed to age naturally under ambient conditions for six months and 10 days along with untreated control. The stored seeds were used to conduct a field experiment. Seeds invigorated with bleaching powder produced higher number of seeds per pod (5.26) followed by control (5.09) and iodinated calcium carbonate (4.84).	Layek *et al*. (2012)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Soybean	One month old seeds of cv. Soyamax were invigorated with common bleaching powder @2g/kg and iodinated calcium carbonate @2 g/kg and subjected to accelerated ageing (93% RH and 40^{o}C) for a period of 21 days along with untreated seeds. Field studies resulted in seeds with bleaching powder and iodinated calcium carbonate recording higher number of seeds per pod (14) than control (13).	Bhattacharya *et al*. (2015)
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	Three months aged seeds of cv. LGG- 460 were treated with $CaCl_2$ (2%) and bleaching powder @2 g/kg. The halogen treated seeds were then	Leelavathi (2017)

		used for field experiment along with untreated aged seeds and untreated freshly harvested seeds. The results revealed that there was an enhancement in the number of seeds per pod produced by crop raised from the treated seeds and the effect was more pronounced in treatment with bleaching powder. Plants raised from aged seeds treated with bleaching powder produced more number of seeds per pod by 0.2-1.4 when compared to that of untreated aged seeds and untreated fresh seeds.	

2.1.8. Seed yield per plant

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	One month old seeds of cv. Mahamaya 1 were dry dressed with bleaching powder @2 g/kg and iodinated calcium carbonate @3 g/kg and thereafter subjected to natural ageing under ambient conditions for a period of two months and 10 days along with untreated control. A field experiment was conducted using the stored seeds. Seeds dry dressed with bleaching powder recorded higher seed yield (12 g/m^2) over control while iodinated calcium carbonate treatment improved in seed yield by 6 g/m^2 over untreated control.	Layek *et al*. (2006)

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	Seed of cv. Deshi BG 240 were dry dressed with calcium hypochlorite and iodinated calcium carbonate. A part of the treated seeds was subjected to natural ageing under ambient conditions for a period of two months along with untreated control. Field study was conducted using the naturally aged seeds and observations for seed yield per plant was taken at 105 days after sowing. The treatment with calcium hypochlorite was found superior in performance (2.4 g) over treatment with iodine (2.02 g) and untreated control (2.02 g).	Saha *et al*. (2006)
$CaOCl_2$	Okra	Seeds of cv. Pankaj were given pre-storage and mid-storage treatments with bleaching powder @2 g/kg. After the treatments, the seeds were subjected to natural ageing under ambient conditions for five months along with untreated controls. Crop raised from the treated seeds showed increment on seed yield per plant by 2.2-2.7 g over the untreated controls.	Guha *et al*. (2012)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Black gram	One month old seeds of cv. Sarada were invigorated with bleaching powder @2 g/kg and iodinated calcium carbonate @3 g/kg. The treated seeds were then stored under ambient conditions for a period of six months and ten days along with untreated control. Field study	Layek *et al*. (2012)

		conducted using the stored seeds showed that the crop raised from the treated seeds produced seed yield higher (6-8 g/m^2) over control.	
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Soybean	One month old seeds of cv. Soyamax were dry dressed with common bleaching powder @2g/kg and iodinated calcium carbonate @2 g/kg. The treated seeds were then subjected to accelerated ageing (93% RH and 40^{o}C) for a period of 21 days along with untreated control. Plants raised from seeds treated with common bleaching powder recorded a seed yield (238.5 g/m^2) numerically superior to iodinated calcium carbonate treatment and untreated control (225.6 g/m^2).	Bhattacharya *et al*. (2015)
$CaOCl_2$	Sunflower	Seeds of cv. Morden was dry dressed with bleaching powder @2 g/kg. Crop raised from treated seeds showed an increment in seed yield by 16 g/m^2 over untreated control.	Saha and Mandal (2016)
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	Three months aged seeds of cv. LGG- 460 invigorated with $CaCl_2$ (2%) and bleaching powder @2 g/kg were used to conduct field experiment along with untreated aged seeds and untreated freshly harvested seeds. Treatment with bleaching powder recorded higher seed yield per pod ((7.5 g) over untreated aged seeds (4.7 g) and untreated freshly harvested seeds (6.9 g).	Leelavathi (2017)

2.1.9. 100 seed weight

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	One month old seeds of cv. Mahamaya 1 dry dressed with bleaching powder @2 g/kg and iodinated calcium carbonate @3 g/kg were subjected to natural ageing under ambient conditions for a period of 70 days along with untreated control. Field experiment conducted revealed that the dry seed treatment with bleaching powder had pronounced effect for improvement of 1000 grain weight (144.8 g) than iodine treatment (142.9 g) over untreated control (142.9 g).	Layek *et al*. (2006)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	Seed of cv. Deshi BG 240 were dry dressed with calcium hypochlorite and iodinated calcium carbonate. The treated seeds and untreated seeds were subjected to natural ageing under ambient conditions for a period of two months and used for field study. Pre-storage halogen seed treatment enhanced 1000 seed weight by 9-12 g over the control.	Saha *et al*. (2006)
$CaOCl_2$	Okra	After the pre-storage and mid- storage treatments with bleaching powder @2 g/kg, the seeds of cv. Pankaj were subjected to natural ageing under ambient conditions for five months along with untreated controls. Field experiment conducted using the stored seeds showed that the plots sown with treated seeds produced seeds with 1000 grain weight heavier by 6-10 g over the untreated controls.	Guha *et al*. (2012)

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Soybean	Halogen treated (common bleaching powder and iodinated calcium carbonate @ 2 g/kg) seeds of cv. Soyamax along with untreated control were subjected to accelerated ageing for a period of 21 days. Crop raised from the treated seeds recorded 1000 grain weight numerically superior by 18-39 g over untreated	Bhattacharya *et al.* (2015)
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	Three months aged seeds of cv. LGG- 460 was treated with $CaCl_2$ (2%) and bleaching powder @2 g/kg. Crop raised from bleaching powder treated seeds recorded 100 seed weight heavier by 0.4-0.1 g over untreated aged seeds and untreated fresh seeds.	Leelavathi (2017)

2.2. Impact of halogenation on seed quality parameters

2.2.1 Germination

Halogen used	Crop	Highlights of the experiment	Reference
$CaOCl_2$	Onion	One month old seeds of cv. Sukhsagar were dry dressed with bleaching powder @2 g/kg. The treated seeds along with untreated control were then subjected to accelerated ageing (at 93% RH and 40^{o}C) for five days and natural ageing under ambient conditions for 2.5 months. After accelerated ageing, halogen treated seeds showed significant increase	Sengupta *et al.* (2005)

		in germination by 31 per cent in comparison to untreated control. At the end of natural ageing the treated seeds recorded nine per cent more germination over control.	
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Chick pea	Pre-storage dry seed invigoration treatments were given to one month old seeds of cv. Mahamaya 1 with halogens (bleaching powder @2 g per kg of seeds and iodinated calcium carbonate @3 g/kg seed) and stored in glass bottle at room temperature to allow for natural ageing under ambient conditions (average relative humidity 92±3.2 per cent and temperature 30±1.6°C) for 70 days. The seeds treated with $CaOCl_2$ and iodinated calcium carbonate recorded higher germination per cent (77% and 72% respectively) over control (50 per cent).	Layek *et al*. (2006)
1. $CaOCl_2$ 2. KI	Chilli	Seeds of two varieties, Byadagi Kaddi and Dyavanur local were treated with $CaOCl_2$ (4 g/kg of seed) and KI (10^{-3}M) and stored for a period of 20 months. At the end of storage period, germination per cent of $CaOCl_2$ treated seeds of Byadagi Kaddi and Dyavanur local were higher by 17 and 20 per cent respectively when compared with their untreated control whereas, KI treated seeds showed germination higher by 21 per cent and 21.33 per cent respectively for the varieties.	Hunje *et al*. (2007)

$[I_2 + CaCO_3]+$ $CaOCl_2$ - 2:1	Sunflower	Seeds of variety Morden were treated with halogen at three different concentrations such as 2g, 3g and 4 g/kg. Treated seeds were subjected to accelerated ageing at 95± 2 per cent RH and 40°C±1°C for seven days along with control. 3 g/kg of seeds was found to be the optimum and the increment of germination per cent were by nine per cent over control.	Narayanan and Prakash (2007)
$CaOCl_2$	Rice	Seeds of the variety Mugad Sugandha was treated with halogen @ 5 g/kg of seeds and stored for a period of 20 months under ambient conditions. The germination per cent varied from 98.05 to 90.56 per cent in treated seeds whereas control recorded only 82 per cent after 20 months of storage.	Raikar *et al*. (2011)
$CaOCl_2$	Okra	Two months old and five months old seeds of cv. Pankaj were treated with $CaOCl_2$ @2 g/kg and the treated seeds were subjected to natural ageing under ambient conditions (RH 65 ± 3.2 per cent and temperature 27 ± 1.6°C) for a period of five months. After the storage period, halogen treated seeds recorded 25-27 per cent more germination than untreated controls.	Guha *et al*. (2012)

1. $CaOCl_2$ 2. I_2 +$CaCO_3$	Black gram	Seeds of cv. Sarada were dry dressed with bleaching powder @2 g/kg of seeds and iodinated calcium carbonate (30 mg iodine impregnated with 3 g of calcium carbonate) @3 g/kg. The treated seeds were stored for a period of 190 days under ambient conditions. The halogen treated seeds recorded germination per cent higher by 14-19 per cent over control.	Layek *et al*. (2012)
1. $CaOCl_2$ 2. KI	Chilli	Seeds of hot pepper cv. MI-2 were stored for 22 months under accelerated conditions in the presence of halogen, along with untreated control. At the end of storage germination per cent of KI treated seeds were 90.7 per cent. Seed viability using chlorine ($CaOCl_2$), has fallen from 96.6 to 88.0 per cent while in control, the viability declined to 16.7 per cent by the tenth month of storage.	Mathew *et al*. (2013)
$CaOCl_2$ + $CaCO_3$	Rice	Seeds of variety Ptb 39 (Jyothy) were halogenated with $CaOCl_2$ + $CaCO_3$ @3 g each/kg of seed and stored for a period of 15 months. At the end of the storage period, the halogenated seeds recorded the highest germination per cent (72.82%) while it was the least for untreated control (44.32%).	Suganya (2015)
1. $CaOCl_2$ + $CaCO_3$ 2. I_2 + $CaCO_3$	Chilli	Seeds of the varieties Anugraha and Ujwala were dry dressed with halogen through a carrier. The treated and untreated seeds were then	Navya (2016)

		packed in 400G polyethylene bag and stored under ambient conditions for a period of 14 months. In var. Ujwala, at the end of storage highest germination per cent was recorded in seeds treated with iodine crystal + CaCO3 @50 mg each/kg seed (31.83) followed by $CaOCl_2$ + CaCO3 @4g each/kg seed (30.5). In var. Anugraha, at the end of storage period, highest germination per cent was recorded in seeds treated with $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed (39.21) followed by iodine crystal + $CaCO_3$ @100 mg each/kg seed (35.83).	
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	Seed invigoration treatment with $CaCl_2$ (2%) and $CaOCl_2$ @2 g/kg were given to three months aged seeds of the cv. LGG- 460. The treated seeds were stored under ambient conditions for a period of six months. At the end of storage $CaOCl_2$ and $CaCl_2$ treated seeds recorded 10 per cent and five per cent more germination over the control.	Leelavathi (2017)

2.2.2 Seedling length

$CaOCl_2$ and I_2	Sunflower	Seeds of DSH-1 hybrid were treated with $CaOCl_2$ and I_2 @ 2g/kg of seeds and stored for a period of six months. Chlorinated and iodinated seeds produced seedlings longer by 2.4 cm and 0.5 cm respectively than untreated control at the end of storage.	Patil and Deshpande (2004)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Chick pea	Pre-storage treatments were given to one month old (high- vigour) chick pea seed with halogens (bleaching powder @2 g/kg seed and iodinated calcium carbonate @3 g/kg seed). These were then exposed to natural ageing condition for 70 days. Iodination recorded higher seedling length (16.4 mm) followed by chlorination (16.2 mm) and least was recorded for control (13.7 mm).	Layek *et al*. (2006)
1. $CaOCl_2$ 2. KI	Chilli	Seeds of varieties, Byadagi Kaddi and Dyavanur local were treated with $CaOCl_2$ (4 g/kg of seed) and KI (10^{-3} M) and stored for 20 months. At the end of storage, seedling length of seeds treated with $CaOCl_2$ of Byadagi Kaddi and Dyavanur local were higher by 6.24 cm and 5.66 cm respectively over their control. In case of KI treated seeds, the seedling length was higher by 6.51 cm and 3.46 cm for Byadagi Kaddi and Dyavanur local respectively over their controls.	Hunje *et al*. (2007)

$[I_2 + CaCO_3]$+ $CaOCl_2$ - 2:1	Sunflower	Seeds of the variety Morden were treated with halogen at different concentrations in both dry and slurry form. After accelerated ageing for seven days, the treatment with dosage of 3 g/kg of seeds was found optimum for both forms. The halogen treated seeds produced seedlings longer by 3-3.3 cm than the control.	Narayanan and Prakash (2007)
$CaOCl_2$	Okra	Pre- storage and mid-storage treatments of seeds of cv. Pankaj were done with halogen @2 g/kg of seeds. After natural ageing under ambient condition for four months, the halogen invigorated seeds showed improvement on seedling length by 2-6 cm when compared to control.	Guha *et al*. (2012)
1. $CaOCl_2$ 2. I_2 +$CaCO_3$	Black gram	The seeds of the variety Sarada were treated with bleaching powder @2 g/kg seed and iodinated calcium carbonate @3 g/kg seed. The treated seeds were stored for a period of six months and ten days under ambient conditions. The chlorinated and iodinated seeds produced seedlings longer by 15 mm and 11 mm over untreated seeds.	Layek *et al*. (2012)
$CaOCl_2$	Black gram	Fresh (freshly harvested seeds), aged treated (seeds subjected to accelerated ageing for three days and then treated with chlorine) and treated aged (seeds treated with chlorine and then aged artificially for three days) seeds of black gram were invigorated using halogen at two	Poonguzhali and Ramamoorthy (2014)

		different concentrations *viz.*, 2 and 4g of chlorine for three different durations (12, 24, 36h) with and without carrier (2 g/kg seed). Seedlings with longest shoot were produced by fresh seeds exposed to chlorine and carrier for 12 h. The increment was by 1.65cm over the control. In case of aged treated seeds, seeds which were exposed to carrier @2 g and 4 g/kg seed for 12 h produced shoots longer by 4.44 cm and 4.18 cm respectively compared to the control. Similarly, treated aged seeds also recorded higher values (20.2 cm) for chlorine with carrier @2 g exposed for 12 h and it was on par with 24 h without carrier (19 cm), compared to control (14.48 cm).	
$CaOCl_2$	Sunflower	Seeds of cv. Morden in different seed sizes (*viz.* composite, large, medium and small) are treated with halogen @ 2g per kg of seeds and subjected to natural ageing for 180 days. A significant increase in the seedling length of large sized treated seeds by 41.83 mm over control was observed.	Saha and Mandal (2016)
1. $CaOCl_2 + CaCO_3$ 2. $I_2 + CaCO_3$	Chilli	Seeds of the varieties Anugraha and Ujwala were dry dressed with halogen through a carrier and stored under ambient conditions for a period of 14 months along with control.	Navya (2016)

		In case of Anugraha, the mean seedling length of seeds treated with $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed and those treated with I_2 + $CaCO_3$ @100 mg/kg seed were longer by 4.79 cm and 4.49 cm respectively over the control. In the variety Ujwala, mean seedling length was found superior for the treatments I_2 + $CaCO_3$ @50 mg each/kg seed and $CaOCl_2$ + $CaCO_3$ @4 g each/kg seed by 5.53 cm and 5.04 cm respectively when compared with control.	
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	After six months of storage, the seeds of the cv. LGG- 460 treated with $CaCl_2$ (2%) and $CaOCl_2$ @2 g/kg produced seedlings longer by 4.7-5.5 cm over the control.	Leelavathi (2017)

2.2.3. Dry weight

$CaOCl_2$ + CaCO3+ *arappu* leaf powder 5:3:1	Cotton	Seeds of 18 genotypes were treated with chlorine based halogen mixture @3 g/kg seed and subjected to accelerated aging for seven days. The halogen treatment gave 12.8 per cent more dry matter production over control.	Rathinavel and Dharmalingam (2001)
$CaOCl_2$ and I_2	Sunflower	Chlorine and iodine were mixed with seeds @2 g/kg seed and stored for a period of six months. It was observed that seedling dry weight of	Patil and Deshpande (2004)

		chlorinated seeds (46.5 mg) was highest in comparison to iodinated (44.9 mg) and untreated (40.1 mg) seeds.	
[I_2 + $CaCO_3$]+ $CaOCl_2$ - 2:1	Sunflower	The seeds were treated with halogen at three different concentrations such as 2g, 3g and 4g/kg seed. At the end of accelerated ageing for a period of seven days, dry matter production of halogen treated seeds @3 g/kg was found superior by 0.2 mg over untreated control.	Narayanan and Prakash (2007)
$CaOCl_2$	Rice	The seeds of the variety Mugad Sugandha were treated with $CaOCl_2$ @5 g/kg seed and stored for 20 months. The treated seeds produced more dry matter ranging from 281 to 126 mg, whereas in control it ranged 278 mg to 105 mg.	Raikar *et al*. (2011)
1. $CaOCl_2$ 2. KI	Chilli	Seeds of cv. MI-2 were stored for 22 months under accelerated conditions in the presence of halogen, along with untreated control. Dry weight of seedlings failed to show any significant difference even after 22 months of storage. At the end of storage, the treatments produced seedling dry weight higher by nearly 3 mg over untreated control.	Mathew *et al*. (2013)
$CaOCl_2$	Black gram	Seed invigoration treatments were attempted for fresh, aged treated and treated aged seeds of black gram using halogen at two different concentrations *viz.*, 2 and 4 g of chlorine for three different durations (12, 24, 36h) with and without carrier (2 g/kg seed). In case of aged seeds	Poonguzhali and Ramamoorthy (2014)

		heaviest seedlings (0.244 g) were produced by chlorination with carrier and there was an increment of 60 per cent over control.	
$CaOCl_2$	Rice	At the end of the storage period of fifteen months, the seeds halogenated with $CaOCl_2$ + $CaCO_3$@3 g each/kg of seed recorded the highest dry weight (14.65 mg) and it was found to be higher by 2.4 mg over control.	Suganya (2015)
1. $CaOCl_2 + CaCO_3$ 2. $I_2 + CaCO_3$	Chilli	Seeds of the varieties Anugraha and Ujwala were dry dressed with halogen through a carrier and stored under ambient conditions for a period of 14 months along with their control. In case of Anugraha at the end of storage, it was observed that chlorinated seeds (with carrier) @2g/kg seeds were superior for mean seedling dry weight by 5.62 mg over control while iodinated seeds (with carrier) @100 mg/kg seed (13.25 mg) recorded a higher value by 5.21mg over the control. In the variety Ujwala, mean dry weight was found superior for the treatments $I_2 + CaCO_3$ @50 mg each/kg seed and $CaOCl_2 + CaCO_3$ @4 g each/kg seed by 5.37 mg and 5.11 mg respectively over the control.	Navya (2016)
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	Three months aged seeds of the cv. LGG- 460 were treated with $CaCl_2$ (2%) and $CaOCl_2$ @2 g/kg and subjected to natural ageing for six months. At the end of storage period, $CaOCl_2$ treated seeds recorded seedling dry weight higher by 45 mg when compared to control.	Leelavathi (2017)

2.2.4. Vigour Index

$CaOCl_2$ and I_2	Sunflower	Chlorine and iodine were mixed with seeds of the variety DSH-1 @2 g/kg seed and stored for six months. Higher vigour index (VI-I) was noticed in chlorinated seeds (2002) followed by iodinated seeds (1730) while the untreated seeds recorded 1568.	Patil and Deshpande (2004)
1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Bengal gram	One month old (high- vigour) chick pea seeds were treated with bleaching powder @2 g/kg seeds and iodinated calcium carbonate @3 g/kg seeds and subjected to natural ageing for 70 days. The highest vigour index (VI-I) was observed in chlorinated seeds (12474) followed by iodinated seeds (11808) and the least for untreated control (6850).	Layek *et al*. (2006)
1. $CaOCl_2$ 2. KI	Chilli	Seeds of varieties, Byadagi Kaddi and Dyavanur local were treated with $CaOCl_2$ (4 g/kg of seed) and KI (10^{-3} M) stored for 20 months. At the end of storage period, seedling vigour (VI-I) of $CaOCl_2$ treated seeds of Byadagi Kaddi and Dyavanur local were higher by 433 cm and 670 respectively over their control. In case of KI treated seeds, the seedling vigour was higher by 479 and 348 for Byadagi Kaddi and Dyavanur local respectively over their untreated controls.	Hunje *et al*. (2007)
$[I_2 + CaCO_3]+$ $CaOCl_2$ - 2:1	Sunflower	Seeds of variety Morden were treated with halogen at three different concentrations. Treated seeds were subjected to accelerated ageing for	Narayanan and Prakash (2007)

		seven days along with control. Seeds dry treated with halogen mixture @3 g/kg maintained a vigour (VI-I) higher by value of 484 over control.	
$CaOCl_2$	Okra	Pre-storage seed treatment with $CaOCl_2$ @2 g/kg in seeds of cv. Pankaj retained a vigour (VI-I) higher by 457 compared to control over 120 days of storage whereas the mid-storage treatment enhanced vigour by only 167 over control.	Guha *et al*. (2012)
1. $CaOCl_2$ 2. I_2 +$CaCO_3$	Black gram	Seeds of cv. Sarada were treated with bleaching powder @2 g/kg seed and iodinated calcium carbonate @3 g/kg seed. Chlorinated and iodinated seeds recorded vigor indices (VI-I) higher by 3171 and 2278 respectively over control at the end of 190 days of storage.	Layek *et al*. (2012)
1. $CaOCl_2$ 2. KI	Chilli	Seeds of hot pepper cv. MI-2 were stored for 22 months under accelerated conditions in the presence of halogen, along with untreated control. After 22 months, chlorine was most effective for retaining seedling vigour (904.0) followed by iodine (766.4) whereas it was least for untreated control (72).	Mathew *et al*. (2013)
1. $CaOCl_2$ 2. I_2 +$CaCO_3$	Soybean	The seeds dry dressed with common bleaching powder and iodinated calcium carbonate recorded higher vigor index (VI-I) and was found to differ by 4255 and 7045 respectively, from the untreated control.	Bhattacharya *et al*. (2015)

1. $CaOCl_2 + CaCO_3$ 2. $I_2 + CaCO_3$	Chilli	Seeds of the varieties Anugraha and Ujwala were dry dressed with halogen through a carrier and stored under ambient conditions for a period of 14 months along with their untreated control. Anugraha seeds treated with $CaOCl_2 + CaCO_3$ @2 g each/kg seed and $I_2 + CaCO_3$ @100 mg each/kg seed were superior for mean vigour index (VI-II) by a value of 621 and 580 respectively over the control. In case of Ujwala, the mean vigour index was superior for treatments $I_2 + CaCO_3$ @50 mg each/kg seed (1037) and $CaOCl_2 + CaCO_3$ @4 g each/kg seed found higher by values of 421 and 385 respectively over the control.	Navya (2016)
1. $CaCl_2$ 2. $CaOCl_2$	Green gram	The aged seeds (3 months old) of the cv. LGG- 460 treated with $CaOCl_2$ @2 g/kg seed recorded a vigour index (VI-I) numerically superior by 622 when compared to control at the end of six months of storage.	Leelavathi (2017)

2.2.5. Electrical conductivity

1. $CaOCl_2$ 2. KI	Chilli	Seeds of varieties, Byadagi Kaddi and Dyavanur local were treated with Calcium oxy chloride (4 g/kg seed) and KI (10^{-3} M) stored for 20 months. At the end of storage, electrical conductivity of $CaOCl_2$ treated seeds of Byadagi Kaddi and Dyavanur local were lower by 1.458 dSm^{-1} and 0.534 dSm^{-1} respectively over their untreated control whereas, for	Hunje *et al*. (2007)

		the seeds treated with KI, the value was lower by 1.562 $dSm^{-1}$and 0.446 dSm^{-1} respectively over their control.	
$CaOCl_2$	Rice	The seeds of the variety Mugad Sugandha were treated with halogen @5 g/kg seed and stored for 20 months. At the end of storage, the electrical conductivity of treated seeds was lower by 0.255dSm^{-1} compared to control.	Raikar *et al*. (2011)
$CaOCl_2$	Okra	Seeds were subjected to pre- storage and mid-storage treatment of with $CaOCl_2$ @2 g/kg seed. After natural ageing under ambient conditions for four months, the pre-storage treated seeds recorded an EC lower by value of 0.08 dSm^{-1} compared to control while the mid-storage halogen treatment reduced EC of seed leachate by 0.31 dSm^{-1} compared to control.	Guha *et al*. (2012)
[I2 + $CaCO_3$]+$CaOCl_2$ 2:1	Sesame	Dry seed treatment with halogen mixture @4 g/kg were done to the seeds of cv. VRI 1. The treated seeds were stored in cloth bag and 700 gauge polythene bag under ambient conditions for a period of 10 months. At the end of storage, seeds stored in 700 gauge polythene bag registered electrical conductivity lower by 0.029-0.035 dSm^{-1} in comparison with control.	Narayanan and Prakash (2015)

1. $CaOCl_2$ 2. $I_2 + CaCO_3$	Soybean	After 21 days of accelerated ageing, seeds dry dressed with common bleaching powder and iodinated calcium carbonate recorded electrical conductivity values lower by 0.03 dSm^{-1} and 0.09 dSm^{-1} respectively when compared to control.	Bhattacharya *et al*. (2015)
$CaOCl_2$	Sunflower	Seeds of cv. Morden in different seed sizes were treated with halogen @2 g/kg seed and subjected to natural ageing for six months. Electrical conductivity of halogenated seeds were lower by 0.043 dSm^{-1} compared to untreated control.	Saha and Mandal (2016)
1. $CaOCl_2 + CaCO_3$ 2. $I_2 + CaCO_3$	Chilli	Seeds of varieties Anugraha and Ujwala were dry dressed with halogen through a carrier and stored under ambient conditions. In Anugraha seeds, electrical conductivity of untreated control was found higher by 0.955 dSm^{-1} and 0.889 dSm^{-1} respectively over seeds treated with $CaOCl_2 + CaCO_3$ @2g each/kg seed and $I_2 + CaCO_3$ @ 100 mg/kg seed, at the end of storage. In case of Ujwala, electrical conductivity of seeds treated with $I_2 + CaCO_3$ @50 mg each/kg seed and $CaOCl_2 + CaCO_3$ @4 g each/kg seed were lower by 0.476 dSm^{-1} and 0.42 dSm^{-1} respectively from the control.	Navya (2016)

2.3. Seed infection during storage

According to an estimate, more than 90 per cent of the field crops grown in the world are propagated through seeds, and all are attacked by devastating seed borne pathogens (Ahmed *et al.*, 2006). During storage, viability and vigour are lost due to many biotic factors like microflora. The storage fungi cause considerable damage and are responsible for deterioration and reduction in storage potential of seed (Pedireddy *et al*., 2018).

De Frietas *et al.* (2000) reported that, there was a decline in viability of seeds and an increase in incidence of storage fungi with increase in storage period of cotton seeds. Species of *Aspergillus*, *Alternaria*, *Rhizoctonia*, *Fusarium*, *Phoma* and *Chaetomium* adversely affected germination and emergence in soybean seeds (Raj *et al.*, 2002).

Groundnut stored in gunny bag had shown higher infection (18.3% in JL-24 and 16.17% in TMV-2) of *A. flavus, A. niger, Fusarium* sp. and *Penicillum* sp. which lead to the reduction in germination and vigour index (Krishnappa *et al*., 2003).

Basavaraju *et al.* (2004) reported that lower germination per cent (47%) with lower vigour index (470) in sunflower was observed in seeds infected severely by *Plasmopara halstedii*, a seed borne pathogen.

Seeds of vegetables are more vulnerable to attack by pathogens and quickly deteriorate during storage (Hamim *et. al*., 2014). Infected seeds serve as a source of primary infection and establishment of plant diseases and thus, have adverse effect on seed health. Seed pathogens get introduced into new areas, increasing the inoculum source in the field.

Aspergillus flavus, *Aspergillus niger*, *Fusarium* spp. and *Cladosporium* associated with the seed samples significantly reduced percent germination in tomato (Chohan, 2017).

2.3.1. Various seed pathogens reported in chilli

Seed pathogens	References
Alternaria sp., *Fusarium* sp., *Aspergillus* sp., *Colletotrichum* spp.	Anjili (2005) Kavitha (2007)
Colletotrichum capsici, *Cercospora* spp., *Aspergillus* spp., *Alternaria* spp. and *Pencillium* spp.	Hemannavar *et al*. (2009)
Aspergillus niger, Aspergillus flavus, Colletotrichum capsici, Alternaria alternate, Fusarium oxysporum, Curvularia lunata, Macrophomina phaseolina, Penicillium citrinum, and *Rhizopus nigricans.*	Jogi *et al*. (2010)
Alternaria alternata, *Aspergillus flavus*, *Aspergillus niger*, *Aspergillus ustus*, *Cladosporium cladosporidies, Curvularia lunata, Fusarium oxysporum, Fusarium roseum*, *Helminthosporium tetramera* and *Trichoderma viride*	Sumanth *et al*. (2010)
Aspergillus flavus, A. niger, A. fumigatus, Alternaria alternata, *Drechslera hawiinesis*, *Fusarium moniliforme*, *F. oxysporum and F. solani*.	Sitara and Hasan (2011)
Curvularia lunata, Rhizopus stolonifer,Colletotrichum capsici, Fusarium moniliforme and *Aspergillus flavus*.	Alam *et al.* (2014)
Alternaria alternata, *A. solani, Aspergillu flavus, A. niger, Cercospora capsici, Colletotrihum capsici, Drechslera hawiinesis, Fusarium oxysporum, F. solani, Leveillula taurica, Macrophomina phaseolina, Rhizoctonia solani, Phytophthora capsici* and *Pythium* spp.	Hussain *et al*. (2014)
Colletotrichum capsici, C. gloeosporioides, C. acutatum, Alternaria alternata, Fusarium sporotrichioides and F. oxysporum.	Santoshreddy *et al*. (2014)

Blotter Method : *Colletotrichum capsici* (3.45%), *Aspergillus niger* (6.00%), *Aspergillus flavus* (6.33%), *Alternaria alternate* (5.37%), *Rhizopus* sp. (8.38%) and *Fusarium* sp. (4.06%). Agar plate method: *Colletotrichum capsici* (3.41%), *Aspergillus niger* (5.91%), *Aspergillus flavus* (5.96%), *Alternaria alternate* (6.41%), *Rhizopus* sp. (5.50%) and *Fusarium* sp. (4.05%).	Jat (2015)
Aspergillus niger, Aspergillus flavus, Pencillium spp., and *Alternaria* spp.	Navya (2016)
Aspergillus spp., *Pencillium* spp. and *Alternaria* spp.	Sandhya (2016)
Aspergillus niger, A. flavus , *Rhizopus* spp. , *Fusarium solani* , *Colletotrichum capsici* and *Penicillium* spp.	Chauhan *et al.* (2018)
Aspergillus niger, Aspergillus flavus, *Alternaria* spp., *Mucor* spp.	Gayathri (2019)

Materials and methods

3. MATERIALS AND METHODS

The present research on 'Halogenation for improvement of seed yield and quality in chilli (*Capsicum annuum* L.)' was undertaken in the Department of Seed Science and Technology, College of Horticulture, Kerala Agricultural University (KAU), Vellanikkara, Thrissur during the year 2018-2020. The study aimed to assess the impact of halogenation on growth and field performance of treated seeds, as well as its influence on quality of seeds during ambient storage. The storage studies were conducted for a period of six months (February 2020 to August 2020). The details of the materials used and the methods adopted during the course of the study are explained in this chapter.

3.1. Location and climate

The experiment was conducted at the Department of Seed Science and Technology, College of Horticulture, Kerala Agricultural University (KAU), Vellanikkara, Thrissur, which is located 40 m above MSL at 10^{o} 54' N latitude and 76^{o} 28' E longitude. The site experiences humid tropical climate. The monthly mean meteorological data recorded during the course of study (July 2019 to August 2020) are presented in Appendix I.

3.2. Experimental material

The experiment was conducted using freshly harvested seeds of chilli variety Anugraha, obtained from Vegetable and Fruit Promotion Council Keralam (VFPCK), Alathur. Details of the genotype are presented in Appendix II.

3.3. Experimental details

The study was conducted as two experiments:

Experiment I: Effect of halogenation on seed yield

Experiment II: Seed storage studies

3.3.1. Experiment I

Effect of halogenation on seed yield

a) Layout

The experiment was laid out in Randomized Block Design (RBD) with five treatments and four replications. The spacing adopted was 0.45 m x 0.45 m and size of a plot was 4.05 m x 2.25 m (Plate 1).

b) Treatments

T_1 : Control (Untreated)

T_2 : $CaOCl_2$ + $CaCO_3$ (2g each /kg seed)

T_3 : $CaOCl_2$ + $CaCO_3$ (4g each /kg seed)

T_4 : Iodine crystal + $CaCO_3$ (50mg each /kg seed)

T_5 : Iodine crystal + $CaCO_3$ (100mg each /kg seed)

Calcium oxy chloride ($CaOCl_2$) and iodine crystal (I_2) were used as the halogen source. Seeds were treated with halogens indirectly through a carrier, calcium carbonate ($CaCO_3$) at two different doses. The halogen- carrier mixture was prepared by mixing equal quantity of analytical grade halogens and dehydrated calcium carbonate ($CaCO_3$). The seeds were then incubated with halogen-carrier mixture for five days as per the procedure given by Dharmalingam (1995) and Anjalidevi (1998) so as to impregnate the seeds with halogen.

3.3.2. Observations

To assess the effect of halogenation on the growth and field performance of crop, growth and yield attributes as well as their component characters were noted. Observations were recorded on five randomly selected (tagged) plants in each replication (experimental unit) and the average was calculated. The details of the observations are as under:-

a) Days to first flowering

The number of days taken from the date of sowing to the emergence of first flower in the tagged plants was recorded and average number of days to first flowering was computed.

b) Days to 50 per cent flowering

The number of days taken from the date of sowing to the emergence of 50 per cent flowers in the tagged plants was recorded and average was calculated.

c) Plant height

The main shoot length was measured at maturity. The distance from ground level to tip of main shoot was measured using a metre scale and the average plant height was recorded in centimetres (cm).

d) Branches per plant

The number of branches per plant were counted at the time of last harvest and the average was recorded.

e) Fruits per plant

The number of fruits picked from the tagged plants was counted and the average number of fruits per plant was recorded.

f) Fruit length (cm)

The distance from proximal end to the distal end of the fruit gives the fruit length. The length of ten fruits picked from each tagged plants of each replication was measured using a metre scale and the average fruit length was recorded in centimetres (cm).

g) Fruit weight at maturity (g)

Fresh weight of fruits harvested from the tagged plants was recorded using a weighing balance and the average fruit weight was expressed in grams (g).

h) Seeds per fruit

Seeds from five fruits selected randomly from the tagged plants were carefully separated and counted manually. The average number of seeds per fruit was then worked out.

i) Seed yield per plant (g)

Weight of seeds extracted from the selected fruits was measured immediately after extraction using digital weighing balance and the average was computed in grams (g).

j) 100 seed weight (g)

Hundred seeds were selected randomly from each seed lot, weighed and expressed in grams (g).

3.3.3. Experiment II

Seed storage studies

Seeds obtained from the five treatments of Experiment I were dried separately to a moisture content less than eight per cent, bagged in 700 gauge polyethylene bag and stored under ambient conditions for six months. Samples were drawn at monthly intervals and various quality parameters were analysed. The experiment was laid out in Completely Randomized Block Design (CRD) with five treatments and four replications. The packing size was 5g seeds per pack.

3.3.4 Observations

Seed samples from each replication of each treatment were drawn randomly for analysis of quality parameters. Observations on seed germination per cent (%), seedling root length (cm), seedling shoot length (cm), seedling dry weight (g), seedling vigour and electrical conductivity (EC) of seed leachate (dSm^{-1}) were recorded at monthly intervals. Seed microflora and seed moisture (%) observations were recorded at the start and end of storage period. The procedure for determining the seed quality parameters are detailed hereunder.

a) Germination per cent (%)

Germination test was conducted using between paper method as prescribed by ISTA (2001). Roll towel was the substratum used for the test. Hundred seeds in four replications were drawn from each replication. The seeds were arranged on the moistened paper towel and covered with another layer of wet paper towel and rolled together. The rolled paper towels were placed in upright position in a bucket containing water. The experimental set up was maintained at a constant temperature of 25 ± 2°C and 95 ± 2 per cent relative humidity. The number of normal seedlings were counted on the 14^{th} day and expressed in per cent.

$$\text{Germination per cent (\%)} = \frac{\text{No. of normal seedlings}}{\text{Total number of seedlings}} \times 100$$

b) Seedling shoot length (cm)

Ten normal seedlings were randomly selected from each replication at the end of the germination test (14^{th} day). The length between the collar portion and the tip of the shoot was measured and the mean value expressed in centimetres (cm).

c) Seedling root length (cm)

The length between the collar region and the tip of the primary root of the seedlings used to measure the shoot length was measured and the mean value recorded in centimetres (cm).

d) Seedling dry weight (mg)

The seedlings used for growth measurements were placed in a butter paper cover and dried in a hot air oven maintained at 85 ± 1°C for 24 h. The dried seedlings were cooled in a desiccator for 45 min, weighed and expressed in milligrams (Copeland and McDonald, 2001).

e) Vigour indices

The vigour indices (Vigour index I and Vigour index II) were computed by using the formula suggested by Abdul-Baki and Anderson (1973) and Bewly and Black (1994) and expressed as whole number.

Vigour index I = Germination (%) x Seedling length (cm)

Vigour index II = Germination (%) x Seedling dry weight (mg)

f) Electrical conductivity (EC) of seed leachate (dSm^{-1})

Four replications of thirty seeds were randomly drawn from each treatment and used for recording electrical conductivity (EC) of seed leachate. The seeds were first surface sterilized with $HgCl_2$ (0.1%) for 5-10 minutes and then washed thoroughly with distilled water. Later these were soaked in 25 ml distilled water in beakers and incubated at 25°C ± 1°C. Stirring of the solution was done occasionally. The beakers were kept covered to avoid contaminants and to reduce evaporation. After 24 hours, the leachate was decanted to another beaker for recording the reading. Electrical conductivity (EC) of seed leachate was estimated using digital conductivity meter with a cell constant of 0.1.

g) Seed moisture (%)

Two replicates of four gram seeds were used for determining the moisture content (ISTA, 1976). Modified ISTA low constant temperature oven method was followed. The aluminium cup and lid were weighed to accurately 4 decimal places. The samples were placed uniformly over the base of the dish and weighed along with the cup and lid. Place the samples in the oven at 103 ± 2°C after removing the lid. The samples were heated for

17 ± 1 hour. After heating, the aluminium cup was closed using the lid and placed in the desiccator for about 30 to 45 minutes. The cups were then weighed using an analytical balance. The moisture content was determined using the equation below and expressed as per cent (ISTA, 1999).

$$\text{Moisture content (\%)} = \frac{M2 - M3}{M2 - M1} \times 100$$

Where,

M1 = Weight of the aluminium cup with lid alone

M2 = Weight of the aluminium cup with lid + Sample before drying

M3 = Weight of the aluminium cup with lid + Sample after drying.

h) Seed infection (%)

Seed infection was recorded by using blotter paper method and agar plate method (Plate 2 and Plate 3) as detailed below.

1) Blotter paper method

Presence of microflora on seeds were recorded using blotter method as prescribed by ISTA (1999). Three layers of sterilized moistened blotter paper were placed on sterilized petriplate. Four replications of ten seeds from each treatment were placed equidistantly on the blotter paper lined petriplates under aseptic condition of laminar air flow chamber. The plates were incubated for seven days at 20 ± 2^{o}C in an alternate cycle of 12 h darkness and 12 h light. On the eighth day, the seeds were examined and number of infected seeds were counted and expressed in per cent. The slides of the growth were prepared and observed under stereo binocular microscope for identification of the pathogen.

2) Agar plate method

Potato dextrose agar (20 ml) was poured into sterilized petri plates under aseptic conditions. Seeds were surface sterilized using 0.1% sodium hypochlorite and subsequently washed with sterile distilled water thrice. These were then placed in the set media equidistantly under the laminar airflow. Four replications of ten seeds from each treatment were used in the agar plate method. The petri plates were packed in a polyethylene cover and kept under bell jar for incubation for a period of six days. After incubation, the number of infected seeds were observed and recorded as per cent. The pathogen growth was examined under stereo binocular microscope.

3.4. Statistical analysis

Statistical analysis of the data on various seed quality parameters was performed using Web Agri Stat Package (WASP) developed by Indian Council of Agricultural Research for completely randomized design and significant test by Duncan's Multiple Range Test (DMRT). The treatment efficacy criteria expressed as per cent and the numbers having low counts and zero values were transformed to square root of (x + 0.5) before analysis of variance (ANOVA). Data obtained were subjected to analysis of variance (ANOVA).

3.4.1. ANOVA for Randomized Block Design

The data recorded in each observation under Experiment I were analyzed using ANOVA so as to test the differences between two or more independent groups.

Source of variation	Degree of freedom (df)	Sum of squares (SS)	Mean square MS = SS/df	Computed F value
Replication	r-1	RSS	RMS	RMS/EMS
Treatment	t-1	TrSS	TrMS	TrMS/EMS
Error	(r-1) (t-1)	ESS	EMS	
Total	n-1	TSS		

3.4.2. ANOVA for Completely Randomized Design

The data recorded in each observation under Experiment II were analyzed using ANOVA so as to test the differences between two or more independent groups.

Source of variation	Degree of freedom (df)	Sum of squares (SS)	Mean square MS = SS/df	Computed F
Treatment	t – 1	TrSS	TrSS	TrSS/EMS
Error	n– t	ESS	EMS	
Total	n – 1	TSS		

Where,

r= No. of replications

t = No. of treatments

n =Total number of observations

TrSS = Sum of squares of treatment

ESS = Sum of squares of error

TSS = Sum of squares of total

RMS = Mean square of replication

TrMS = mean square of treatments

EMS = Mean square of error

3.4.3. Pair wise comparison using DMRT test

Duncan's multiple range test (DMRT) was used for experiments that require the evaluation of all possible pairs of treatment means, especially when the total number of treatment is large.

Computation of numerical boundaries that allow for the classification of difference between any two treatments or means as significant or non-significant is done. However, unlike the LSD test in which only a single value is required for any pair comparison at a prescribed level of significance, the DMRT requires computation of a series of values, each corresponding to a specific series, of pair comparisons. The following steps are followed for ranking the data (Gomez and Gomez, 1976).

Step 1: Rank all the treatment means in decreasing (or increasing) order. It is customary to rank the treatment means according to the order of preference.

Step 2: The standard error of error mean sum of squares (SEm) was calculated by using the formula

$$\text{SEm} = \sqrt{\frac{2EMS}{r}} \times 100$$

where, 'EMS' is the error mean sum of squares and 'r' is the number of replications.

Step 3: Compute the (t-1) values of the shortest significant ranges as:

$$\text{Rp} = \frac{(rp)(\text{SEm})}{\sqrt{2}}$$

For p = 2, 3…, t

Where,'t' is the total number of treatments, 's' is the standard error of the mean difference computed in step 2, 'r' values are the tabular values of the significant ranges, and 'p' is the distance in rank between the pairs of treatment means to be compared (*i.e.*, p = 2 for the two means with consecutive rankings and p = t for the highest and lowest means).

Step 4: Identify and group together all treatment means that do not differ significantly from each other.

Step 5: Use the alphabet notation according to the ranking to present the test results.

3.4.4. Ranking and scoring

In order to identify treatments that are effective for improvement of seed yield and quality, scoring and ranking were carried out for all the characters studied under experiment I and for germination and vigour indices in experiment II. Based on DMRT, the treatments were ranked in descending order for all the characters except for days to first and 50 per cent flowering where the ranking was done in ascending order. The score for each treatment was calculated by adding up the ranks obtained in all the thirteen characters under consideration.

Results

4. RESULTS

The present study on 'Halogenation for improvement of seed yield and quality in chilli (*Capsicum annuum* L.)' was undertaken in the Department of Seed Science and Technology, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur. The research was conducted to assess the impact of halogenation on field performance and seed yield as well as its influence on seed storage quality using seeds of chilli variety Anugraha.

Results obtained from the field and storage studies are presented in this chapter.

4.1. Effect of halogenation on growth parameters and seed yield attributes

4.1.1. Analysis of variance

The analysis of variance revealed highly significant differences among the treatments for fruits per plant, fruit weight, seed yield per plant and hundred seed weight, while no significant differences were evident in days to first flowering, days to 50 per cent flowering, plant height, branches per plant, fruit length and seeds per fruit (Table 1).

4.1.2. Days to first flowering

Days taken for the emergence of first flower varied from 62 days (T_3- $CaOCl_2$ + $CaCO_3$ @4g each/kg seed) to 64 days (T_1- control) among the treatments.

4.1.3. Days to 50 per cent flowering

The days to 50 per cent flowering ranged from 64 days (T_3- $CaOCl_2$ + $CaCO_3$ @4g each/kg seed) to 68 days (T_1- control) among the treatments. The variations were statistically non-significant.

4.1.4. Plant height (cm)

The mean plant height varied from 52.45 cm (T_4- Iodine crystal + $CaCO_3$ @50mg each /kg) to 59.06 cm (T_5- Iodine crystal + $CaCO_3$ @100mg each /kg) among the treatments.

Table 1: Analysis of variance for growth parameters and seed yield attributes

	Mean sum of squares									
	Days to first flowering	Days to 50 per cent flowering	Plant height (cm)	Branches per plant	Fruits per plant	Fruit length (cm)	Fruit weight (g)	Seeds per fruit	Seed yield per plant (g)	100 seed weight (g)
Replications	4.600	2.533	61.816	3.682	31.250	0.389	0.001	24.317	7.773	0.000
Treatments	1.425^{NS}	7.950^{NS}	34.511^{NS}	1.058^{NS}	1656.925**	0.453^{NS}	0.217**	36.375 ^{NS}	210.031**	0.003**
Error	3.892	9.617	21.995	3.094	15.292	0.489	0.002	11.608	1.879	0.000
CV (%)	3.146	4.670	8.472	5.258	3.506	10.722	3.975	5.951	5.012	3.314

* Significant at 5% level of significance

** Highly significant at 1% level of significance

NS Non-significant

Table 2: Effect of halogenation on growth parameters in chilli variety Anugraha

Treatment	Days to first flowering	Days to 50 per cent flowering	Plant height (cm)	Branches per plant
T_1- Control	64.00	68.00	53.80	32.82
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	63.00	66.00	57.92	33.37
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	62.00	64.00	53.54	34.25
T_4- Iodine + $CaCO_3$ (50mg)	62.00	67.00	52.45	33.31
T_5- Iodine + $CaCO_3$ (100mg)	63.00	66.00	59.06	33.50
Mean	63.00	66.00	55.35	33.45
SEm	3.89	9.61	21.99	3.09
CD (0.05)	NS	NS	NS	NS

Table 3: Effect of halogenation on seed yield parameters in chilli variety Anugraha

Treatment	Fruits per plant	Fruit length (cm)	Fruit weight (g)	Seeds per fruit	Seed yield per plant (g)	100 seed weight (g)
T_1- Control	84.75^{c}	6.05	1.04^{d}	53.00	17.96^{d}	0.40^{b}
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	128.00^{a}	6.41	1.56^{a}	61.00	35.12^{a}	0.45^{a}
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	126.25^{a}	6.45	1.44^{b}	58.25	33.10^{a}	0.45^{a}
T_4- Iodine + $CaCO_3$ (50mg)	94.50^{b}	6.88	1.07^{cd}	58.25	22.12^{c}	0.40^{b}
T_5- Iodine + $CaCO_3$ (100mg)	124.25^{a}	6.80	1.13^{c}	55.75	28.41^{b}	0.41^{b}
Mean	111.55	6.52	1.24	57.25	27.34	0.42
SEm	15.29	0.48	0.00	11.60	1.87	0.00
CD (0.05)	6.02	NS	0.07	NS	2.11	0.02

4.1.5. Branches per plant

The treatments did not differ significantly for mean number of branches per plant and the values ranged from 32.82 (T_1- control) to 34.25 (T_3- $CaOCl_2$ + $CaCO_3$ @4g each /kg seed) among the treatments.

4.1.6. Fruits per plant

The data on mean number of fruits per plant (Table 3) revealed that there existed significant variation among the treatments. The mean number of fruits per plant ranged from 84.75 (T_1) to 128 (T_2). T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (126.25) and T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (124.25) and T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed, were found to be on par with each other. Lower values were recorded in T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (94.5) and T_1- control (84.75).

4.1.7. Fruit length (cm)

The treatments did not exhibit any significant influence for the trait. The mean fruit length ranged between 6.05 cm (T_1- control) and 6.885 cm (T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg seed).

4.1.8. Fruit weight (g)

There existed significant differences among the treatments for the trait and the mean fruit weight varied from 1.04 g to 1.56 g. The highest fruit weight was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (1.56g) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4 g each /kg (1.44g). Other significant treatments include T_5- Iodine crystal + $CaCO_3$ @100 mg each /kg (1.13g) which was on par with T_4- Iodine crystal + $CaCO_3$ @50 mg each /kg (1.07g). T_1 (control) recorded the least mean fruit weight (1.04 g).

4.1.9. Seeds per fruit

Non-significant differences were observed among the treatments for number of seeds per fruit and it varied from 53 (T_1- control) to 61 (T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds).

4.1.10. Seed yield per plant (g)

The data on mean seed yield per plant presented in Table 3 revealed that the treatments exhibited significant differences in their performance for the character. The mean seed yield per plant varied from 35.12 g (T_2) to 17.96 g (T_1). Significantly higher seed yield per plant was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds (35.12 g). T_2 was statistically on par with T_3- $CaOCl_2$ + $CaCO_3$ @4 g each /kg (33.1 g). A lower value was observed in T_5-Iodine crystal + $CaCO_3$ @100 mg each/kg (28.4 g) followed by T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (22.12 g). The least seed yield per plant was obtained from T_1- control (17.96 g).

4.1.11. Hundred seed weight (g)

The mean hundred seed weight was significantly influenced by the treatments. Hundred seed weight ranged between 0.40 g (T_1 and T_4) and 0.45 g (T_2 and T_3). Higher values for the seed weight were recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds and T_3- $CaOCl_2$ + $CaCO_3$ @4 g each /kg (0.45g). T_5 (Iodine crystal + $CaCO_3$ @100 mg each /kg) recorded a lower value (0.41g) which was found to be on par with the least value recorded in T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg and T_1- control (0.40 g).

4.2. Seed storage studies

Seeds obtained from the previous experiment were dried to less than eight per cent moisture content and stored in polythene covers (700G) under ambient conditions for a period of six months. The seed storage study was conducted as completely randomized block design with four replications each of the five treatments and the seed quality parameters were evaluated at monthly intervals.

4.2.1. Initial seed quality

The initial seed quality parameters were assessed prior to commencement of the storage study and presented in Table 4.

4.2.1.1. Germination (%)

The treatments did not show any significant differences for germination per cent before storage. The initial germination per cent ranged between 71.25 per cent (T_1- control) and 85.25 per cent (T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds).

4.2.1.2. Seedling shoot length (cm)

There existed significant variations for the parameter among the treatments. The seedling shoot length varied from 5.33 cm (T_1) to 5.87 cm (T_2). The highest value was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds (5.87 cm) which was on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (5.79 cm). T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (5.45 cm) and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (5.39 cm) were statistically on par with the least value recorded in control (T_1- 5.33 cm).

4.2.1.3. Seedling root length (cm)

The initial mean seedling root length varied non-significantly from 9.07 cm (T_1- control) to 9.78 cm (T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds) among the treatments. Among the iodine treatments, T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg) recorded higher value (9.53 cm).

4.2.1.4. Seedling dry weight (mg)

Influence on initial mean seedling dry weight was found to be non-significant among the treatments and the parameter varied from 24 mg (T_1- control) to 24.4 mg (T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds). Mean seedling dry weight of T_5 (Iodine crystal + $CaCO_3$ @100 mg each /kg) and T_4 (Iodine crystal + $CaCO_3$ @50 mg each /kg) were 24.35 g and 24.32 g respectively.

4.2.1.5. Vigour index I

The initial mean vigour index ranged from 1025.00 (T_1) to 1335.00 (T_2) among the treatments. Highest value was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds (1335.00) which was found statistically on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (1233.00). Control recorded the least value (1025.00) which was on par with T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (1103.00).

Table 4: Effect of halogenation on seed quality parameters before storage in chilli variety Anugraha

Treatment	Germination per cent (%)	Shoot length (cm)	Root length (cm)	Dry weight (mg)	Vigour Index I	Vigour Index II	Electrical conductivity (dSm^{-1})	Moisture content (%)	Seed infection (%)	
									Agar plate method	Blotter paper method
T_1- Control	71.25 (57.64)	5.33^{c}	9.07	24.00	1025^{c}	1709^{c}	1.23^{a}	6.72	22.50 $(28.22)^{a}$	2.50 $(9.05)^{a}$
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	85.25 (67.91)	5.87^{a}	9.78	24.40	1335^{a}	2079^{a}	1.07^{d}	6.32	7.50 $(15.82)^{b}$	0.00 $(0.90)^{b}$
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	74.5 (59.80)	5.45^{bc}	9.36	24.05	1103^{bc}	1792^{bc}	1.15^{bc}	6.45	7.50 $(15.82)^{b}$	0.00 $(0.90)^{b}$
T_4- Iodine + $CaCO_3$ (50mg)	79.25 (63.05)	5.39^{c}	9.42	24.32	1171^{b}	1928^{abc}	1.17^{ab}	6.55	17.50 $(24.53)^{a}$	2.50 $(9.05)^{a}$
T_5- Iodine + $CaCO_3$ (100mg)	80.50 (64.20)	5.79^{ab}	9.53	24.35	1233^{ab}	1958^{ab}	1.08^{cd}	6.40	5.00 $(12.88)^{b}$	0.00 $(0.90)^{b}$
Mean	78.15	5.57	9.53	24.22	1173	1893	1.14	6.49	12.00	2.50
SEm	24.71	0.06	0.20	0.13	8855.84	23303.29	0.00	0.17	6.54	0.45
CD (0.05)	NS	0.37	NS	NS	141.80	230.02	0.07	NS	3.85	1.01

*Figures in parentheses are transformed values

4.2.1.6. Vigour index II

The treatments exhibit significant differences for vigour index II varying from 1709.00 (T_1) to 2079.00 (T_2). T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seed) recorded the highest value (2079.00) which was statistically on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (1958.00)and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (1928.00). Control recorded the lowest vigour index (1709.00) and it was on par with T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (1792.00).

4.2.1.7. Electrical conductivity of seed leachates (dSm^{-1})

Effect of the treatments on initial electrical conductivity of seed leachates varied significantly and the parameter ranged from 1.07 dSm^{-1} (T_2) to 1.23 dSm^{-1} (T_1). Least electrical conductivity was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed (1.07 dSm^{-1}) which was statistically on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg seed (1.08 dSm^{-1}) whereas T_4- Iodine crystal + $CaCO_3$ @50 mg each /kg (1.17 dSm^{-1}) found to be on par with control which recorded the highest value (1.23 dSm^{-1}).

4.2.1.8. Moisture content (%)

Non-significant differences were observed among the treatments for initial seed moisture content. It varied from 6.32 per cent (T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed) to 6.72 per cent (T_1- control).

4.2.1.8. Seed infection (%)

Existence of significant differences in seed infection were observed among the treatments, before storage. In agar plate method, the mean seed infection varied from five per cent (T_5) to 22.50 per cent (T_1). T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg seed recorded lowest seed infection (5%). It was on par with T_2- $CaOCl_2$ + $CaCO_3$ @2g each/kg and T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (7.50%) whereas higher seed infection was observed in T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (17.50%). T_4 was statistically on par with control that had recorded the highest seed infection (22.50%). In blotter paper method, control (T_1) and T_4 (Iodine crystal + $CaCO_3$ @50 mg each/kg seeds) had recorded the highest seed infection (2.50%) while no infection was observed in T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg), T_3 ($CaOCl_2$ + $CaCO_3$ @4 g each /kg) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg seed).

4.2.2. Seed quality assessment during storage

4.2.2.1. Germination (%)

The effect of halogenation treatments on germination per cent during the course of storage is presented in Table 5. Significant differences were observed among the treatments for germination per cent from first month of storage. The treatments had recorded the highest mean germination per cent at the end of four months of storage and then the parameter reduced gradually irrespective of the treatments with the advancement of storage period. Highest germination per cent was observed in T_2- $CaOCl_2$ + $CaCO_3$ @2g each/kg seeds (96.25%) during the fourth month of storage and the least germination per cent was recorded in control (71.25%) at the end of storage.

During the fourth month, germination recorded by T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds (96.25%) was found to be on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (94.25%) followed by T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (93.75%). Lower germination was recorded in T_3- $CaOCl_2$ + $CaCO_3$ @4g each /kg (90.75%) and the least value was observed in control (86.00%).

At the end of storage, T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each /kg) recorded higher germination per cent (85.25% and 83.5% respectively) and they were found statistically on par with each other. T_4 (Iodine crystal + $CaCO_3$ @50 mg each /kg) recorded a lower value (80.5%) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (77.25%) and the least germination was recorded in control (71.25%).

All treatments including the control maintained the MSCS (Minimum Seed Certification Standard) of 60 per cent germination till the end of six months of storage and during the last month germination ranged between 71.25 per cent (T_1) and 85.25 per cent (T_2).

Table 5: Effect of halogenation on germination (%) in chilli variety Anugraha

Treatment	Months of storage (M)				
	M1	M3	M4	M5	M6
T1- Control	72.00 (58.06)[d]	82.25 (65.11)[c]	86.00 (68.10)[c]	79.75 (63.26)[d]	71.25 (57.58)[d]
T2- $CaOCl_2$ + $CaCO_3$ (2g)	85.25 (67.42) [a]	93.50 (75.44)[a]	96.25 (79.29)[a]	92.25 (73.90)[a]	85.25 (67.41)[a]
T3- $CaOCl_2$ + $CaCO_3$ (4g)	76.25 (64.16)[c]	88.75 (70.42)[b]	90.75 (72.31)[b]	82.50 (65.32)[cd]	77.25 (61.54)[c]
T4- Iodine + $CaCO_3$ (50mg)	81.00 (64.43)[b]	90.00 (71.60)[b]	93.75 (75.73)[ab]	85.25 (67.46)[bc]	80.50 (63.80)[b]
T5- Iodine + $CaCO_3$ (100mg)	83.75 (66.28)[ab]	91.50 (73.18)[ab]	94.25 (76.21)[a]	88.50 (70.25)[b]	83.50 (66.07)[a]
Mean	79.65	89.20	92.20	85.65	79.55
SEm	2.04	4.52	6.67	3.54	1.61
CD (0.05)	2.15	3.21	3.89	2.83	1.91

* Figures in parentheses are arc-sine transformed values

Table 6: Effect of halogenation on seedling shoot length (cm) in chilli variety Anugraha

Treatment	Months of storage (M)				
	M1	M3	M4	M5	M6
T_1- Control	5.22	5.00	4.70[c]	4.41[b]	4.20[c]
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	5.76	5.47	5.58[a]	5.32[a]	5.13[a]
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	5.40	5.20	5.08[b]	4.79[ab]	4.46[bc]
T_4- Iodine + $CaCO_3$ (50mg)	5.28	5.10	5.08[b]	5.03[a]	4.49[b]
T_5- Iodine + $CaCO_3$ (100mg)	5.36	5.22	5.31[ab]	5.05[a]	4.70[b]
Mean	5.41	5.20	5.15	4.92	4.59
SEm	0.18	0.19	0.03	0.13	0.03
CD (0.05)	NS	NS	0.27	0.55	0.28

Table 7: Effect of halogenation on seedling root length (cm) in chilli variety Anugraha

Treatment	Months of storage (M)				
	M1	M3	M4	M5	M6
T_1- Control	8.83	8.97	8.28	6.00[c]	5.11[d]
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	9.23	9.30	8.98	8.91[a]	7.17[a]
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	8.93	8.22	8.24	7.73[b]	5.75[cd]
T_4- Iodine + $CaCO_3$ (50mg)	8.83	8.50	8.45	8.09[ab]	6.07[bc]
T_5- Iodine + $CaCO_3$ (100mg)	9.23	9.22	8.92	8.63[ab]	6.49[ab]
Mean	9.01	8.84	8.57	7.87	6.12
SEm	0.34	0.42	0.36	0.55	0.23
CD (0.05)	NS	NS	NS	1.11	0.73

4.2.2.2. Seedling shoot length (cm)

The treatments exhibited significant variations for seedling shoot length from the fourth month of storage (Table 6). Seedling shoot length gradually reduced with the increase in storage period. The highest value was recorded by T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg in the first month (5.76 cm) and the least value was observed in control at the end of storage (4.20 cm).

In the fourth month, T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) had recorded the highest shoot length (5.58 cm). It was found to be on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (5.31 cm). T_4 (Iodine crystal + $CaCO_3$ @50mg each/kg) and T_3- $CaOCl_2$ + $CaCO_3$ @4g each/kg recorded a lower value (5.08 cm) and the lowest shoot length was recorded in control (4.70 cm).

At the sixth month of storage, better performance for seedling shoot length was observed in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (5.13 cm) among all the treatments. Lower values were recorded in T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (5.31 cm) and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (4.49 cm). These were on par with T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (4.46) while the least value was recorded in control (4.20 cm).

4.2.2.3. Seedling root length (cm)

Seedling root length differed significantly among the treatments in the fifth and sixth months of storage (Table 7). The mean seedling root length showed gradual decline with advancement of storage irrespective of the treatments. The highest value was recorded by T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg and T_5- Iodine crystal + $CaCO_3$ @100 mg each /kg in the first month (9.23 cm) and the least value was observed in control at the end of storage (5.11 cm).

In the fifth month of storage, higher seedling root length was recorded by T_2- $CaOCl_2$ + $CaCO_3$ @2g each/kg (8.91 cm). It was on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (8.63 cm) and T_4- Iodine crystal + $CaCO_3$ @50 mg each /kg (8.09 cm) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4 g each /kg (7.73 cm), while control recorded the least value (6.00 cm).

At the end of storage, the mean seedling root length was observed to be higher in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (7.17 cm) on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (6.49 cm) followed by T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (6.07 cm). T3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg recorded a lower value (7.73 cm) and found to be on par with control which recorded the lowest root length (5.11 cm).

4.2.2.4. Seedling dry weight (mg)

The mean seedling dry weight (Table 8) reduced gradually over the months of storage. Significant differences among the treatments for the parameter were observed from fourth month of storage.

In the sixth month, higher seedling dry weight was observed in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (22.00 mg) which was on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (21.50 mg), T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (21.00 mg) and T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (20.50 mg). The lowest seedling dry weight was recorded in control (17.25).

4.2.2.5. Vigour index I

From the data on vigour index I presented in Table 9, it is clearly evident that the treatments significantly differed for the parameter throughout the course of storage. The mean vigour index I declined gradually to the end of storage after attaining a peak in the fourth month (1185).

Over the months of storage, vigour index I was found to be significantly higher in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (1049) followed by T_5- Iodine crystal + $CaCO_3$ @100 mg each /kg (934). Lower value for the parameter was recorded in T_4- Iodine crystal + $CaCO_3$ @50mg each /kg (850). It was on par with T_3- $CaOCl_2$ + $CaCO_3$ @4g each /kg (790) whereas control recorded the least value (664).

4.2.2.5. Vigour index II

Effect of halogenation on vigour index II during the storage period is presented in Table 10. There existed significant variations among the treatments for the parameter throughout the storage period. From fourth month onwards there was a decline in vigour index II.

Table 8: Effect of halogenation on seedling dry weight (mg) in chilli variety Anugraha

Treatment	Months of storage (M)				
	M1	M3	M4	M5	M6
T_1- Control	22.75	22.42	22.10[b]	20.92[b]	17.25[b]
T_2- $CaOCl_2 + CaCO_3$ (2g)	23.77	23.57	23.37[a]	23.20[a]	22.00[a]
T_3- $CaOCl_2 + CaCO_3$ (4g)	23.37	23.12	22.87[a]	22.70[a]	20.50[a]
T_4- Iodine + $CaCO_3$ (50mg)	23.50	23.25	23.00[a]	22.72[a]	21.00[a]
T_5- Iodine + $CaCO_3$ (100mg)	23.75	23.38	23.02[a]	22.90[a]	21.50[a]
Mean	23.43	23.15	22.87	22.48	20.45
SEm	0.59	0.28	0.15	0.12	2.31
CD (0.05)	NS	NS	0.59	0.53	2.29

Table 9: Effect of halogenation on Vigour index I in chilli variety Anugraha

Treatment	Months of storage (M)				
	M1	M3	M4	M5	M6
T_1- Control	1012.00[d]	1,150.00[b]	896.00[d]	831.00[d]	664.00[d]
T_2- $CaOCl_2 + CaCO_3$ (2g)	1279.00[a]	1,383.00[a]	1,371.00[a]	1313.00[a]	1049.00[a]
T_3- $CaOCl_2 + CaCO_3$ (4g)	1094.00[cd]	1,165.00[b]	1,136.00[c]	1035.00[c]	790.00[c]
T_4- Iodine + $CaCO_3$ (50mg)	1171.00[bc]	1,263.00[ab]	1,230.00[bc]	1119.00[bc]	850.00[c]
T_5- Iodine + $CaCO_3$ (100mg)	1221.00[ab]	1,321.00[a]	1,290.00[ab]	1213.00[ab]	934.00[b]
Mean	945.00	1056.00	1185.00	1102.00	857.00
SEm	4041.55	6700.58	6926.46	7590.88	1625.83
CD (0.05)	95.79	123.34	125.40	131.28	60.75

In the last month of storage, highest value for vigour index II was observed in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed (1876.00) which was statistically on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (1794). T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (1690.00) found to be on par with the lower value of T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (1584) while control recorded the least value (1226.00).

4.2.2.6. Electrical conductivity (EC) of seed leachates (dSm^{-1})

Electrical conductivity of seed leachates (Table 11) varied significantly among the treatments throughout the storage period. The conductivity gradually increased over the months of storage irrespective of the treatments. Lowest mean electrical conductivity was recorded in the first month (1.21 dSm^{-1}) and the highest towards the end of storage (1.48 dSm^{-1}).

In the first month, electrical conductivity of seed leachate was observed highest in control (1.30 dSm^{-1}) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4g each /kg (1.25 dSm^{-1}) and T_4- Iodine crystal + $CaCO_3$ @50mg each /kg (1.22 dSm^{-1}). They were on par with each other. The least value for EC of seed leachate (1.12 dSm^{-1}) was recorded in T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg seed. It was on par with T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (1.18 dSm^{-1}).

At the end of storage, T_1- control had recorded the highest electrical conductivity (1.68 dSm^{-1}) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg seeds (1.50 dSm^{-1}) whereas T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) recorded the least value (1.36 dSm^{-1}). T_2 was on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (1.39 dSm^{-1}) and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (1.44 dSm^{-1}).

4.2.2.7. Seed moisture content (%)

Seed moisture content at the end of storage is presented in Table 12. The treatments did not exhibit significant variations for seed moisture content at the end of storage. However there was a marginal increase in seed moisture content in all the treatments in comparison with the value at the start of storage.

Table 10: Effect of halogenation on Vigour index II in chilli variety Anugraha

Treatment	Months of storage (M)				
	M1	M3	M4	M5	M6
T_1- Control	1637.00^{d}	1843.00^{d}	1900.00^{d}	1668.00^{c}	1226.00^{d}
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	2027.00^{a}	2203.00^{a}	2249.00^{a}	2054.00^{a}	1876.00^{a}
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	1782.00^{c}	2052.00^{c}	2076.00^{c}	1873.00^{b}	1584.00^{c}
T_4- Iodine + $CaCO_3$ (50mg)	1903.00^{b}	2092.00^{bc}	2156.00^{bc}	1937.00^{b}	1690.00^{bc}
T_5- Iodine + $CaCO_3$ (100mg)	1987.00^{ab}	2139.00^{ab}	2170.00^{ab}	211.002^{a}	1794.00^{ab}
Mean	1867.00	2066.00	2110.00	1929.00	1634.00
SEm	4115.10	2397.72	2897.45	3595.67	11530.41
CD (0.05)	96.66	73.78	81.11	90.35	161.80

Table 11: Effect of halogenation on electrical conductivity (dSm^{-1}) of seed leachates in chilli variety Anugraha

Treatment	Months of storage (M)			
	M1	M4	M5	M6
T_1- Control	1.30^{a}	1.48^{a}	1.56^{a}	1.68^{a}
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	1.18^{bc}	1.30^{b}	1.35^{b}	1.36^{c}
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	1.25^{ab}	1.41^{ab}	1.47^{ab}	1.50^{b}
T_4- Iodine + $CaCO_3$ (50mg)	1.22^{ab}	1.38^{ab}	1.41^{b}	1.44^{bc}
T_5- Iodine + $CaCO_3$ (100mg)	1.12^{c}	1.31^{b}	1.37^{b}	1.39^{bc}
Mean	1.21	1.38	1.43	1.48
SEm	0.00	0.00	0.01	0.01
CD (0.05)	0.09	0.11	0.12	0.12

4.2.2.8. Seed infection (%)

The data on mean seed infection percent in each treatment at the end of storage is presented in Table 12. The parameter showed significant variations among the treatments.

In agar plate method significantly lower seed infection was observed in T_5- Iodine crystal + $CaCO_3$ @100 mg each /kg (12.50%) followed by T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (25.00%) and T3- $CaOCl_2$ + $CaCO_3$ @4 g each /kg (25.00%). Control (67.50%) and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (65.00%) were found inferior with significantly higher seed infection.

Similar observations were recorded in blotter paper method. Lower seed infection was observed in T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (20.00%) followed by T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (22.50%) and T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (30.00%). These were on par with each other, while T_1- control recorded highest seed infection (70.00%). T_1 was on par with T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (62.50%). *Aspergillus flavus* and *Aspergillus niger* were observed in all the treatments. In addition *Rhizopus* sp. was observed in treatments T_1, T_2 and T_3.

Table 12: Effect of halogenation on seed moisture and seed infection at the end of storage period in chilli variety Anugraha

Treatments	Seed moisture content (%)	Seed infection (%)		Fungi observed
		Agar plate method	Blotter paper method	
T_1- Control	8.07	67.50 (55.24)[a]	70.00 (56.78)[a]	*Aspergillus flavus*, *Aspergillus niger* *Rhizopus* sp.
T_2- $CaOCl_2$ + $CaCO_3$ (2g)	7.60	25.00 (29.88)[b]	22.50 (28.22)[bc]	*Aspergillus flavus*, *Aspergillus niger* *Rhizopus* sp.
T_3- $CaOCl_2$ + $CaCO_3$ (4g)	7.70	25.00 (29.88)[b]	30.00 (33.05)[b]	*Aspergillus flavus*, *Aspergillus niger* *Rhizopus* sp.
T_4- Iodine + $CaCO_3$ (50mg)	7.75	65.00 (53.77)[a]	62.50 (52.27)[a]	*Aspergillus flavus* *Aspergillus niger*
T_5- Iodine + $CaCO_3$ (100mg)	7.62	12.50 (20.46)[c]	20.00 (26.19)[c]	*Aspergillus flavus* *Aspergillus niger*
Mean	7.75	39.00	41.00	-
SEm	0.14	13.42	16.69	-
CD (0.05)	NS	5.52	6.15	-

* Figures in parentheses are arc-sine transformed values

Table 13: Ranking of halogen treatments based on growth, seed yield and seed quality parameters

Treatments	T1	T2	T3	T4	T5
Growth and seed yield parameters	**Ranks**				
Days to first flowering	5	4	1	2	3
Days to 50 per cent flowering	4	2	1	3	2
Plant height (cm)	3	2	4	5	1
Branches per plant	2	4	1	5	3
Fruits per plant	5	1	2	4	3
Fruit length (cm)	5	4	3	1	2
Fruit weight (g)	5	1	2	4	3
Seeds per fruit	4	1	2	2	3
Seed yield per plant (g)	5	1	2	4	3
Hundred seed weight (g)	4	1	1	3	2
Score	**42**	**21**	**18**	**29**	**25**
Seed quality parameters					
Germination per cent (%)	5	1	4	3	2
Vigour index I	5	1	4	3	2
Vigour index II	5	1	4	3	2
Score	**15**	**3**	**12**	**9**	**6**
Total score	**57**	**24**	**30**	**38**	**31**

Discussion

5. DISCUSSION

Seed quality is of paramount importance in any seed production programme. During storage, seed quality is affected by many factors like seed moisture content, relative humidity, temperature, initial seed quality, physical and chemical composition of seed, gaseous exchange, storage structure and packaging materials. Physiological and pathological deterioration of seeds due to ageing results in poor establishment of crop and low productivity. Hence, pre-sowing seed treatments with advantage of invigoration, protection and production will be of immense use to farmers. Halogenation is one such seed invigoration treatment that helps to augment productivity and maintain quality of seeds during storage.

The results of the present study entitled 'Halogenation for the improvement of seed yield and quality in chilli (*Capsicum annuum* L.)', conducted at the Department of Seed Science and Technology, College of Horticulture, Vellanikkara are discussed in this chapter in line with the findings of earlier researchers.

5.1. Effect of halogenation on growth parameters and seed yield attributes

The results obtained from the experiment on effect of halogenation on growth parameters and seed yield attributes revealed that seed yield attributes such as fruits per plant, fruit weight, seed yield per plant and hundred seed weight were significantly influenced by treatments.

5.1.1. Days to first and 50 per cent flowering

Initiation of floral buds indicate a transition from vegetative to reproductive phase. Days to flowering is influenced by endogenous genetic factors as well as environmental factors such as day length, temperature and stress. Plants respond to various stimuli either by flowering early to produce seeds for next generation or delay flowering by slowing down metabolism (Cho *et al*., 2017).

Days taken for first flowering and 50 per cent flowering varied from 62 days (T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg seed) to 64 days (T_1- control) and 64 days (T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg seed) to 68 days (T_1- control) respectively among the treatments and the variations were statistically non-significant.

Vidyadhar and Singh (2000) observed that halogen treatments on freshly harvested seeds of maize failed to show significant differences for days to flowering whereas the treatment effect was more pronounced and significant in case of partially aged seeds. Similar observations were reported by Chavan *et al*. (2014) in soybean.

The vigorous performance of freshly harvested seeds would have dominated the influence of treatments on performance for days to flowering.

5.1.2. Plant height (cm)

The treatments exhibited non-significant differences on mean plant height and the parameter varied from 52.45 cm (T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg) to 59.06 cm (T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg).

Plant height being a quantitative character may be altered by various physical seed enhancement techniques. The non- significant influence of the treatments may be due to interaction of genetic characters with the treatment effects (GxE). The results are in line with the findings of Guha *et al*. (2012) in okra and Layek *et al*. (2012) in black gram.

5.1.3. Branches per plant

The treatments did not exhibit significant influence on mean number of branches per plant and the value ranged from 32.82 (T_1- control) to 34.25 (T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg seed).

Development of branches is a dynamic process influenced by a number of genetic and environmental factors (McSteen and Leyser, 2005). The non-significant influence of the treatments on mean number of branches per plant might be a result of varietal interaction with the treatment effects. Similar observations were also reported by Saha *et al*. (2006) in Bengal gram and Chavan *et al*. (2014) in soybean.

5.1.4. Fruits per plant

There existed significant variations among the treatments for mean number of fruits per plants (Fig. 1). The parameter ranged from 84.75 (T_1) to 128 (T_2). T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (126.25), T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg

(124.25) and T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed, were found to be on par with each other. Lower values were recorded in T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (94.5) and T_1- control (84.75).

Early vigour due to halogens manifested in reproductive growth. Naraynan *et al*. (2011) opined that the positive effect could be due to increased photosynthesis resulting from the invigorative action of halogen.

The better performance of T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) and T_3 ($CaOCl_2$ + $CaCO_3$ @4 g each /kg) could be due to the positive role of chlorine which performed more or less similar to iodine in seed invigoration, combined with beneficial effects of calcium on growth and yield attributes. The results obtained were in harmony with the research findings of Saha *et al*. (2006) in Bengal gram, Bhattacharya *et al*. (2015) in soybean, Leelavathi (2017) in green gram and Kumar (2018) in black gram.

5.1.5. Fruit length (cm)

Mean fruit length did not differ significantly among the treatments and the parameter ranged between 6.05 cm (T_1- control) and 6.885 cm (T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg). The non- significant effect of halogen treatments on fruit length was also reported by Sengupta *et al*. (2005), Guha *et al*. (2012) in okra and Bhattacharya *et al*. (2015) in soybean.

5.1.6. Fruit weight (g)

There existed significant differences among the treatments for the trait and the mean fruit weight varied from 1.04 g to 1.56 g (Fig. 2). The highest fruit weight was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (1.56g) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4 g each /kg (1.44g). Other significant treatments include T_5- Iodine crystal + $CaCO_3$ @100 mg each /kg (1.13g) which was on par with T_4- Iodine crystal + $CaCO_3$ @50 mg each /kg (1.07g). T_1 (control) recorded the least mean fruit weight (1.04 g).

Invigorative action of halogens effect physiological performance in plants leading to positive manifestation in yield attributing characters. Naraynan *et al*. (2011) reported that physiological parameters such as Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) were found higher for plants raised from halogen treated seeds in sesame, sunflower and ground nut. Vidyadhar and Singh (2000) observed increased cob growth rate due to chloride seed treatment in freshly harvested seeds of maize over iodine treatment and control and opined that it might be due to contribution of accumulated carbohydrates and photosynthates.

Better performance of T_2 ($CaOCl_2$ + $CaCO_3$ @2g each/kg) and T_3 ($CaOCl_2$ + $CaCO_3$ @4g each /kg) for fruit weight could be due to rapid dry mater accumulation induced by chloride invigoration. The results were in conformity with the observations of Layek *et al*. (2006) in Bengal gram, Bhattacharya *et al*. (2015) in soybean, Layek *et al*. (2012) and Kumar (2018) in black gram.

5.1.7. Seeds per fruit

Non-significant differences were observed among the treatments for number of seeds per fruit and it varied from 53 (T_1- control) to 61 (T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds). The results are in line with findings of Saha *et al*. (2006) in Bengal gram and Bhattacharya *et al*. (2015) in soybean.

5.1.8. Seed yield per plant (g)

Significantly higher seed yield per plant was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds (Fig. 3). T_2 (35.12 g) was statistically on par with T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (33.1 g). A lower value was observed in T_5-Iodine crystal + $CaCO_3$ @100 mg each/kg (28.4 g) followed by T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (22.12 g). The least seed yield per plant was obtained from T_1- control (17.96 g).

The seed yield advantage in T_2- $CaOCl_2$ + $CaCO_3$ @2g each/kg seeds and T_3- $CaOCl_2$ + $CaCO_3$ @4g each/kg over other treatments and control may be attributed to the effect of the halogen on reproductive growth. Higher early seedling vigour and better crop growth induced by halogenation may result in increased rate of photosynthesis and carbohydrate accumulation (Vidyadhar and Singh, 2000; Naraynan *et al*., 2011). The observations were in accordance with findings of Layek *et al*. (2006) in Bengal gram, Layek *et al*. (2012) in black gram, Bhattacharya *et al*. (2015) in soybean, Saha and Mandal (2016) in sunflower and Leelavathi (2017) in green gram.

5.1.9. Hundred seed weight (g)

The mean hundred seed weight was significantly influenced by the treatments (Fig. 4). Hundred seed weight ranged between 0.40 g (T_1 and T_4) and 0.45 g (T_2 and T_3). Higher values for the seed weight were recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds and T_3- $CaOCl_2$ + $CaCO_3$ @4 g each /kg (0.45g). T_5 (Iodine crystal + $CaCO_3$ @100 mg each /kg) recorded a lower value (0.41g) which was found to be on par with the least value recorded in T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg and T_1- control (0.40 g).

Better performance for the parameter was observed in T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds) and T_3 ($CaOCl_2$ + $CaCO_3$ @4 g each/kg seeds). This may be due to the increased accumulation of nutrients in the seeds over those obtained from other treatments and control. Superiority of halogen treatment in enhancement of seed weight could be related to their positive role in biometric and physiological performance of plants.

The results obtained were in conformity with the findings of De *et al*. (2003) in wheat, Layek *et al*. (2006) in Bengal gram, Guha *et al*. (2012) in okra, Layek *et al*. (2012) in black gram, Bhattacharya *et al*. (2015) in soybean and Leelavathi (2017) in green gram.

5.2. Seed storage studies

5.2.1. Initial seed quality

The results obtained on initial quality of seeds obtained from experiment I revealed that there existed significant differences among the treatments for parameters such as shoot length, vigour indices, electrical conductivity of seed leachates and seed infection.

5.2.1.1. Germination (%)

The treatments did not show any significant differences for germination per cent before storage. The initial germination per cent ranged between 71.25 per cent (T_1- control) and 85.25 per cent (T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds).

5.2.1.2. Seedling shoot length (cm)

The highest value was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds (5.87 cm) which was on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (5.79 cm). T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (5.45 cm) and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (5.39 cm) were statistically on par with the least value recorded in control (T_1- 5.33 cm).

Superior performance of T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seeds) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg) can be attributed to better quality of the seeds produced from the halogen treatments in experiment I. The results are in conformity with the findings of Vidyadhar and Singh (2000) in maize and (Naraynan *et al*., 2011) in ground nut, sesame and sunflower.

5.2.1.3. Vigour indices

The treatments, T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seed), T_5 (Iodine crystal + $CaCO_3$ @100mg each /kg) and T_4 (Iodine crystal + $CaCO_3$ @50 mg each/kg) recorded higher vigour whereas it was lower for control and T_3 ($CaOCl_2$ + $CaCO_3$ @4 g each/kg). Better performance of seeds obtained from halogen treatments of experiment I might be due to higher initial vigour of the plants induced by the treatments and subsequent accumulation of higher nutrients in seed (Naraynan *et al*., 2011).

5.2.1.4. Electrical conductivity of seed leachates (dSm^{-1})

Least electrical conductivity was recorded in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed (1.07 dSm^{-1}) which was statistically on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg seed (1.08 dSm^{-1}) whereas T_4- Iodine crystal + $CaCO_3$ @50 mg each /kg (1.17 dSm^{-1}) found to be on par with control which recorded the highest value (1.23 dSm^{-1}).

Better performance of T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed (1.07 dSm^{-1}) and T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg may be accounted for high quality of seeds obtained from the respective treatments in the field experiment. Lower electrical conductivity of seed leachates in the treatments is an indication of enhanced seed quality and lower pathogenicity rendering cell membrane integrity resulting from the carry over effect of halogenation. The results are in line with the findings of Rathinavel and Dharmalingam (2002) in cotton and Hunje *et al*. (2007) in chilli.

5.2.1.5. Seed infection (%)

Existence of significant differences in seed infection were observed among the treatments, before storage. In agar plate method, the mean seed infection varied from five per cent (T_5) to 22.50 per cent (T_1). T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg seed recorded lowest seed infection (5%). It was on par with T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg and T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (7.50%) whereas higher seed infection was observed in T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (17.50%). T_4 was statistically on par with control that had recorded the highest seed infection (22.50%).

In blotter paper method, control (T_1) and T_4 (Iodine crystal + $CaCO_3$ @50 mg each/kg seeds) had recorded the highest seed infection (2.50%) while no infection was observed in T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg), T_3 ($CaOCl_2$ + $CaCO_3$ @4 g each /kg) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg seed).

Seed infection at the start of storage can be due to the adverse weather conditions such as heavy rain and high relative humidity prevailed during the time of fruit harvest and seed extraction favouring growth of microorganisms.

Superior performance of T_2 ($CaOCl_2$ + $CaCO_3$ @2g each/kg), T_3 ($CaOCl_2$ + $CaCO_3$ @4g each /kg) and T_5 (Iodine crystal + $CaCO_3$ @100mg each /kg seed) can be because of enhanced quality of the seeds resulting from positive effect of halogenation rendering protection against microbial action (Rathinavel and Dharmalingam, 2001; Hemashree *et al*., 2011; Kumar, 2014; Poonguzhali and Ramamoorthy, 2014; Navya, 2016).

5.2.2. Seed quality assessment during storage

5.2.2.1. Germination (%)

Significant differences were observed among the treatments for germination per cent from first month of storage. The treatments recorded the highest mean germination per cent at the end of four months of storage and then the parameter reduced gradually irrespective of the treatments with the advancement of storage period (Fig. 5). Such gradual reduction in germination per cent with progress of seed ageing was earlier observed by Hunje *et al*. (2007), Mathew *et al*. (2013), Navya (2016) and Gayathri (2019) in chilli.

At the end of storage, T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each /kg) recorded higher germination per cent (85.25% and 83.5% respectively) and they were found statistically on par with each other. T_4 (Iodine crystal + $CaCO_3$ @50 mg each /kg) recorded a lower value (80.5%) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (77.25%) and the least germination was recorded in control (71.25%). All treatments including the control maintained the MSCS (Minimum Seed Certification Standard) of 60 per cent germination till the end of six months of storage.

Superior performance of the treatments, $CaOCl_2$ + $CaCO_3$ @2 g each/kg (T_2), Iodine crystal + $CaCO_3$ @100 mg each/kg (T_5) and Iodine crystal + $CaCO_3$ @50 mg each/kg (T_4) for germination per cent over the months of storage may be attributed to better quality of the seeds obtained from the respective treatments in experiment I.

The mode of action of halogens as anti-oxidants in controlling lipid peroxidation in cell membrane besides acting as free radical controlling agents are possible reasons for viability extension during seed storage (Pryor and Lasswell, 1975; Mandal and Basu,1986). Beneficial effect of halogen in maintaining higher germination during storage was reported by Sengupta *et al.* (2005) in onion, Hunje *et al*. (2007), Mathew *et al*. (2013) and Navya (2016) in chilli, Narayanan and Prakash (2007) in sunflower, Suganya (2015) in rice and Leelavathi (2017) in green gram.

5.2.2.2. Seedling shoot length (cm)

The treatments exhibited significant variations for seedling shoot length from the fourth month of storage. Seedling shoot length gradually reduced with the increase in storage period (Fig. 6).

At the sixth month of storage, better performance for seedling shoot length was observed in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (5.13 cm) among all the treatments. Lower values were recorded in T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (5.31 cm) and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (4.49 cm). These were on par with T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (4.46) while the least value was recorded in control (4.20 cm).

Increased seedling shoot length in treatment with $CaOCl_2$ + $CaCO_3$ @2 g each/kg might be accounted for enhanced quality of seeds owing to action of chlorine in the field experiment. The results are in agreement with the findings of Patil and Deshpande (2004) in sunflower, Layek *et al*. (2012) in black gram, Navya (2016) in chilli.

5.2.2.3. Seedling root length (cm)

Seedling root length differed significantly among the treatments in the fifth and sixth months of storage. Similar to seedling shoot length, the mean seedling root length showed gradual decline with advancement of storage irrespective of the treatments (Fig. 7).

At the end of storage, the mean seedling root length was observed to be higher in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (7.17 cm) on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (6.49 cm) followed by T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (6.07 cm). T3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg recorded a lower value (7.73 cm) and found to be on par with control which recorded the lowest root length (5.11 cm). Similar results were observed by Patil and Deshpande (2004) in sunflower, Layek *et al*. (2012) in black gram, Navya (2016) in chilli.

5.2.2.4. Seedling dry weight (mg)

The mean seedling dry weight reduced gradually over the months of storage (Fig. 8). Significant differences among the treatments for seedling dry weight were observed from the fourth month onwards to the end of storage. The treatments exhibited only marginal variations among them.

In the sixth month, higher seedling dry weight was observed in T_2- $CaOCl_2$ + $CaCO_3$ @2 g each/kg (22.00 mg) which was on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (21.50 mg), T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (21.00 mg) and T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg (20.50 mg). The lowest seedling dry weight was recorded in control (17.25).

Based on their study in halogenated chilli seeds, Mathew *et al*. (2013) reported that seedling dry weight was proven to be a less sensitive parameter in estimation of seed quality as there was no significant differences between chlorine and iodine treated seeds even after 22 months.

Higher dry matter production in seedlings of halogenated seeds were observed by Rathinavel and Dharmalingam (2001) in cotton, Narayanan and Prakash (2007) in sunflower and Raikar *et al*. (2011) in rice.

5.2.2.5. Vigour indices

Seedling vigour is a physiological condition which depends on quantum of reserve metabolites and activity of enzymes and growth regulators. Since vigour index measure totality of germination and seedling growth, it is considered as a good indicator of seedling vigour.

The treatments exhibited significant differences for seedling vigour throughout the storage. Seedling vigour declined substantially with the progress of storage irrespective of the treatments (Fig. 9 and Fig. 10). Similar trend was reported by Adersh (2018) in okra, Athulya (2019) in oriental pickling melon, Gayathri (2019) in chilli. Progressive decline in seedling vigour during storage is attributed to reduced synthetic activity and depletion of food reserves due to ageing phenomenon (Shakuntala, *et al.*, 2012).

Seeds obtained from halogen treatments in experiment I produced highly vigorous seedlings during storage and this might be due the invigorative and anti-microbial action of halogen resulted in good initial seed quality. Chlorine and iodine possess potentiality to retain seed quality (Bhattacharya and Basu, 1990).

Pronounced increase in seedling vigour is often attributed to activation of growth promoting substances and translocation of secondary metabolites to the developing seedlings. Physiologically active substances activate embryo and other related structures causing increased water absorption and formation of efficient roots, ultimately resulting in higher vigour index (Renganayaki and Ramamoorthy, 2015).

At the end of storage, seedling vigour was found significantly higher for T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) followed by T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg). Mathew *et al*. (2013) reported that after 22 months of storage highest seedling vigour was observed in chilli seeds stored with chlorine followed by seeds treated with iodine.

The pronounced effect of chlorine over iodine in retaining higher seedling vigour during storage might be attributed to its higher reactivity than iodine. Similar observations were reported by Patil and Deshpande (2004) in sunflower, Layek *et al*. (2006) in Bengal gram, Layek *et al*. (2012) in Black gram, and Navya (2016) in chilli.

5.2.2.6. Electrical conductivity of seed leachates (dSm^{-1})

Electrical conductivity of seed leachates is a measure of cell membrane integrity and considered as a good indicator of seed viability during storage. It is negatively correlated with vigour and viability of seeds. Electrical conductivity of seed leachates enhanced upon storage irrespective of the treatments (Fig. 11).

Biochemical analysis about seed deterioration suggest disrupted membrane activity during ageing process as a factor causing leakage of cellular solutions during seed soaking resulting in loss of metabolic energy for membrane transport system (Copeland and Mc Donald, 1995). Thus high electrical conductivity of seed leachates is an indication of rapid loss of electrolytes such as amino acids and organic acids from seed due to poor integrity of cellular membrane resulting from lipid auto-oxidation or enzymes or seed infection by fungi and insects (Pammenter *et al.*, 1974).

. The treatments had significant influence on electrical conductivity of seed leachates during storage. At the end of storage, T_1- control had recorded the highest electrical conductivity (1.68 dSm^{-1}) followed by T_3- $CaOCl_2$ + $CaCO_3$ @4 g each/kg seeds (1.50 dSm^{-1}) whereas T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) recorded the least value (1.36 dSm^{-1}). T_2 was on par with T_5- Iodine crystal + $CaCO_3$ @100 mg each/kg (1.39 dSm^{-1}) and T_4- Iodine crystal + $CaCO_3$ @50 mg each/kg (1.44 dSm^{-1}).

Similar observations on chlorine and iodine treatments registering lower electrical conductivity during seed storage have been reported by Hunje *et al*. (2007) and Navya (2016) in chilli, Narayanan and Prakash (2015) in sesame, Bhattacharya *et al*. (2015) in soybean. This was due to the action of halogens in maintaining cell membrane integrity rendering less susceptibility to peroxidative and free radical reactions.

5.2.2.7. Seed moisture content (%)

Seed moisture is an intrinsic seed character affected by genetic and environmental fluctuations. It is an important factor influencing seed quality during storage (Gomathi, 2009)

The treatments did not exhibit significant variations for seed moisture content at the end of storage. However there was a marginal increase in seed moisture content in all the treatments when compared with the initial value at the start of storage. This might be accounted for moisture impervious nature of the packaging material (700G polythene cover) used.

5.2.2.8. Seed infection (%)

Pathogen free seeds are pre-requisites for a healthy seed crop. Disease transmission occur through seeds when pathogens get associated either in the field or in the post-harvest storage environment. Mould or fungal growth in stored seeds can considerably degrade seed quality by reducing germination per cent and viability along with loss of carbohydrates, proteins and oil content and increase in free fatty acid content (Verma *et al*., 2003; Kakde and Chavan, 2011). Tropical climate characterised by high temperature and relative humidity along with unscientific storage conditions can aid fungal growth ultimately leading to total loss of seed quality during storage.

Seed infection eventually increased with progress of storage period in all the treatments. Patra *et al*. (2000) reported progressive decline in seed viability and gradual increase in pathogen activity, sugar and moisture content in groundnut with the advancement of storage. Higher infection of mycoflora with increase in leaching of sugars and electrical conductivity was observed in soybean seeds that had lost its viability (Shelar, 2000).

Seed infection per cent at the end of storage differed significantly among the treatments. In both agar plate and blotter paper methods, T_5 (Iodine crystal + $CaCO_3$ @100 mg each /kg seed) and T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) were found superior with lower infection whereas T_4 (Iodine crystal + $CaCO_3$ @50 mg each/kg) and control recorded higher infection (Fig. 12).

Aspergillus flavus and *Aspergillus niger* were observed in all the treatments. In addition *Rhizopus* sp. was observed in treatments T_1, T_2 and T_3. Similar observations were recorded by Jogi *et al*. (2010), Alam *et al.* (2014), Jat (2015), Navya (2016), Sandhya (2016), Chauhan *et al.* (2018), Gayathri (2019) in chilli.

Anti-microbial action of halogens account partly for controlling storage fungi, which is one of the major factors affecting quality of seed in storage. Poonguzhali and Ramamoorthy (2014) observed fungus free seeds upon ageing using halogen treatment in black gram and stated that halogens provide protection against pathogens during storage.

The beneficial effect of halogen in reducing seed infection have been reported by Hemashree *et al*. (2011) in cotton, Hunje *et al*. (2007) and Navya (2016) in chilli.

5.2.3. Ranking and scoring

Based on the scores obtained by each treatment for growth parameters and seed yield attributes in chilli (Table 13) it is clearly evident that the treatment T_3 ($CaOCl_2$ + $CaCO_3$ @4 g each/kg seed) performed best for growth and seed yield parameters and it was followed by T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seed) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg seed).

In case of seed quality parameters, the scores obtained by each treatment revealed that the treatment T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seed) performed superior among all the treatments and it was followed by T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg seed) and T_4 (Iodine crystal + $CaCO_3$ @50 mg each/kg). Suganya (2015) in rice variety Jyothy has confirmed the positive role of halogenation with $CaOCl_2$ + $CaCO_3$ @3 g each/kg seed in retaining higher seedling vigour and viability during ambient storage.

Even though seed treatment with $CaOCl_2$ + $CaCO_3$ @4 g each/kg seed (T_3) was found best in improving growth and seed yield attributes, it could record only lower germination per cent and vigour indices at the end of storage in comparison with T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seed) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg seed). However, seed treatment with $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed (T_2) was found to have multiple benefits of enhancement of growth and seed yield parameters and maintenance of seed quality during storage. Hence, it can be concluded that seed treatment with $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed have pronounced effect in improving seed yield and quality in chilli.

Growth and yield attributes of a crop depend largely on the germination and vigour potential of the seeds used for sowing. Seed treatment influence micro environment of each seed and provide opportunity in supplying micro and macro nutrients and also protection of the crop from pests and diseases during the earlier stages.

Many of the recommended seed treatments do not come into practice among small and marginal farmers because of difficulty in adoption of the treatments or non-availability or expensive nature of treatment materials. Pre- sowing seed treatment with halogen is easy adoptable as it can be done along with routine post- harvest handling of seeds. Since wet seed treatments can reduce storage potential, technologically dry seed treatment is more feasible for commercial application.

Halogen treatment should be considered as a best methodology since it demands lesser input cost including electric charges (Dharmalingam, 1982). Market price of bleaching powder is Rs. 25/kg, iodine crystal costs approximately Rs. 2/g and cost of calcium carbonate is nearly Rs. 1/g. The total seed treatment cost including the cost of chemicals, seeds (Rs. 2000/kg) and labour charge may be worked out to a meagre value. Thus seeds can be stored under ambient conditions for periods extending over one or more seasons at relatively low cost with minimum reduction in seed quality. Hence halogen seed treatment will be of immense use to farming community as it aids in improving seed quality and longevity at a low expense.

As chlorine is more reactive than iodine, its beneficial effect when used as seed treatment is more pronounced even at lower doses. Moreover, bleaching powder and calcium carbonate are easily available and less expensive. Hence, seed treatment with $CaOCl_2$ + $CaCO_3$ @2g each/kg seed can be recommended to improve seed yield and quality in chilli as it is a simple and cost effective treatment which can be easily adopted by both large and small scale farmers.

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Appendices

Appendix I: Monthly meteorological data from June 2019 to August 2020

Months	Temperature (^0C)		Relative Humidity (%)	Rainfall (mm)	Rainy days	Mean sunshine hours (hrs/day)	Wind speed (kmph)
	Mean Maximum	Mean minimum					
July 2019	30.4	22.8	85	654.4	21	2.6	1.7
August 2019	29.5	21.9	89	977.5	24	1.5	1.5
September 2019	31.2	22	85	419.0	19	3.3	1.4
October 2019	32.4	21.4	80	418.4	16	5.5	1.8
November 2019	32.9	21.7	71	205.0	5	7.5	4
December 2019	32.3	22.1	63	4.4	1	6.7	8.7
January 2020	34.1	22.4	60	0	0	9.4	5.9
February 2020	35.5	23.2	54	0	0	9.5	5.3
March 2020	36.4	24.4	65	33.4	2	8.5	2.8
April 2020	36.4	24.7	71	44.7	4	8.1	2.5
May 2020	35	25.2	77	59.6	5	6.1	2.2
June 2020	31.1	23.7	85	427.2	20	2.5	1.3
July 2020	30.5	23.2	87	563	21	2.8	1.1
August 2020	30.2	23.1	87	607.7	17	3.1	1.8

Appendix II: Details of variety Anugraha

Parentage	Ujwala x Pusa jwala
Special features	High yielding, early maturing, bacterial wilt resistant chilli variety released from the KAU suitable for cultivation in Kerala condition. Plants are of medium stature with attractive long green medium pungent fruits, which turn deep red on ripening. Average fruit weight is 3.6 g. Average yield is 27 t/ha.
Year of release	2003

Halogenation for improvement of seed yield and quality in chilli (*Capsicum annuum* L.)

By

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ABSTRACT OF THE THESIS

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Kerala Agricultural University, Thrissur

DEPARTMENT OF SEED SCIENCE AND TECHNOLOGY

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2020

Halogenation for improvement of seed yield and quality in chilli (*Capsicum annuum* L.)

Abstract

The research on 'Halogenation for improvement of seed yield and quality in chilli (*Capsicum annuum* L.)' was undertaken in the Department of Seed Science and Technology, College of Horticulture, Kerala Agricultural University (KAU), Vellanikkara, Thrissur, during the year 2018-2020. The study aimed to assess the impact of halogenation on growth and field performance of treated seeds, as well as its influence on seed quality during ambient storage.

The study comprised of two experiments. In experiment I, the field performance of halogenated chilli seeds was assessed. Freshly harvested seeds of chilli variety Anugraha treated with different doses of halogens indirectly through a carrier were the treatments used. The experiment was laid out in a Randomised Block Design (RBD) with four replications and five treatments viz., T_1: Control (Untreated), T_2: $CaOCl_2$ + $CaCO_3$ (2 g each/kg seed), T_3: $CaOCl_2$ + $CaCO_3$ (4 g each /kg seed), T_4: Iodine crystal + $CaCO_3$ (50 mg each/kg seed), T_5: Iodine crystal + $CaCO_3$ (100 mg each/kg seed). Observations on growth and yield parameters were recorded at appropriate growth stages.

The results revealed that seed yield attributes such as fruits per plant, fruit weight, seed yield per plant and hundred seed weight were significantly influenced by the treatments. Among the $CaOCl_2$ treatments, T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seed) recorded higher values for fruits per plant, fruit weight and seed yield per plant. Of the two seed invigoration treatments with iodine, T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg) performed superior for fruits per plant, fruit weight, seed yield per plant and hundred seed weight.

Seeds obtained from Experiment I were used for seed storage studies (Experiment II). The seeds were dried to a moisture content less than eight per cent, bagged in 700 gauge polyethylene bag and stored under ambient conditions for six months. Samples were drawn at monthly intervals and various seed quality parameters

were analysed. The experiment was laid out in Completely Randomized Block Design (CRD) with five treatments (T_1 to T_5 as in experiment I) and four replications.

Seed quality parameters such as germination per cent, vigour indices and seedling dry weight declined with the progress of storage, whereas electrical conductivity of seed leachates increased over the storage period. Significant differences were observed among the treatments for germination per cent from first month onwards to the end of storage. All treatments including the control maintained MSCS (Minimum Seed Certification Standard) of 60 per cent germination till the end of six months of storage. At the end of storage, T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) followed by T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg) recorded higher germination per cent and vigour indices.

The influence of halogen treatments on seed infection was found significant at the start and end of storage. Treatments, T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg seed) and T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg) were found superior with lower infection.

In order to identify treatments effective for improvement of seed yield and quality, scoring and ranking were carried out for all the characters studied under experiment I and for germination per cent and vigour indices in experiment II. While considering the total score obtained by the treatments for both the experiments, T_2 ($CaOCl_2$ + $CaCO_3$ @2 g each/kg seed) was found to have multiple benefits of enhancement of growth and seed yield attributes and maintenance of seed quality during storage. T_2 was followed by T_3 ($CaOCl_2$ + $CaCO_3$ @4 g each/kg seed) and T_5 (Iodine crystal + $CaCO_3$ @100 mg each/kg).

Hence, it is concluded that seed treatment with $CaOCl_2$ + $CaCO_3$ @2 g each/kg seed was effective in improving seed yield and quality in chilli variety Anugraha. The treatment is simple and chemicals are easily available hence farmer friendly. The study may be extended to other chilli varieties to standardise the dosage for recommendation.