

Full Length Research

Sowing Date Optimization as a Means to Manage Frost Damage on Barley (*Hordeum vulgare* L.) in Mihur Aklil District of Gurage Zone, Ethiopia

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Accepted 25th July, 2017

Frost is a climatic hazard that causes serious damage to standing crop in temperate, tropical and subtropical climates. In Ethiopia, frost commonly occurs at high altitudes where the atmosphere is thin and radiation is faster. The damage is very serious to crops between October and February when temperature falls below freezing point. The research was conducted in Muhir Aklil district which is found in Gurage zone of Southern Nations Nationalities and Peoples Regional State (SNNPRS) of Ethiopia to determine the optimum sowing date that would minimize frost damage. Among all Peasant Administrations in Mihur Aklil district of Gurage zone, Chinbe is the one with severe frost damage. Randomized Completely Block Design (RCBD) with three replications was used in the study. Experiment was conducted on widely cultivated barley variety (HB-1307). During commencement of the experiment, three frost days with night temperatures of -1, 2 and 3 °C was recorded. On the basis of our test, the result depicted that 7 days after the average sowing date, has scored better yield 5.6 t/ha Furthermore, it assures water requirement of the crop during grain filling stage. It is advised then to sow barley 7 days late after the sowing date of the average farmers.

Keywords: climate hazard, frost, frost days, sowing date.

INTRODUCTION

Background

Global population is increasing at certain rate of variations from continent to continent in the world. This increase in population is relatively high in developing countries compared to developed ones. In contrary to the increase in population, food production in these countries is relatively low resulting in challenges to cope up with food shortage.

This problem of food shortage necessitates to implement intensified agriculture, namely, increasing

productivity of food crops per unit area using improved technologies like improved high yielding varieties and other agricultural inputs. This intensification of agriculture in some cases benefit not only the crops cultivated but also the pests attacking these crops. In addition to the pests which are grouped under biotic factors the changing environment and climatic conditions as component of abiotic factors, in this case frost injury, result in additive effect on the yield reduction.

These constraints are in one or another way related with temperature extremities which can be broadly categorized in high and low temperature limitations. The limiting effect of high temperature on crop production takes two principal forms; limitations of vegetative growth such as for cereal grains and peanuts and adverse effect on fruit settings (Mohammad, 2001). He further described that low temperature (e.g. chilling and freezing) injury can occur in all plants, but the mechanisms and types of damage vary considerably. Many fruit, vegetable and ornamental crops of tropical origin experience physiological damage when subjected to temperatures below about +12.5 °C, hence well above freezing temperatures. The author in his explanation categorizes damage above 0 °C as chilling injury rather than freeze injury. Freeze injury occurs in all plants due to ice formation. Crop plants that develop in tropical climates, often experience serious frost damage when exposed to temperature slightly below zero, whereas most crops that develop in colder climates often survive with little damage if the freeze event is not too severe. Some exceptions are lettuce, which originated in a temperate climate, but can be damaged at temperatures near 0 °C and some subtropical fruits trees that can withstand temperatures to -5 to -8 °C.

It is also discussed that the degree of tolerance shown by a plant to freezing depends largely on the stage of development at which the stress occurs. Before the initiation of flowering parts, usually 8-10 weeks after germination, wheat plants are capable of withstanding extreme cold which might also be applicable to barley (Greg, 2009).

Frost damage occurs when ice forms inside the plant tissue and injures the plant cells. It can occur in annuals (grasses and legumes of forage and silage crops; cereals; oil and root crops; horticultural; and ornamental crops) multi-annuals and perennials (deciduous and evergreen fruit trees). Frost damage may have a drastic effect upon the entire plant or affect only a small part of the plant tissue, which reduces yield, or merely product quality. Further the obvious low temperature limitations leads to killing of plant tissues by freezing through which most tissues can be suddenly destroyed during a period of rapid growth. Low temperature limitations can be manifested in temperature below freezing temperature resulting in the occurrence of frosts (FAO, 2005). It is this effect of frost causing in devastation of barley crop in study area initiating interventions to get rid of or minimize the deficits.

Statement of the Problem

In Ethiopia frost is a very serious hazard to

crops between October and February, but due to the absence of any quantification of the damage done, our understanding remains inadequate and largely conjectural which coincides with time of severe frost occurrence late in the season mostly November and December in Mihur Aklil district and Chinbe peasant administration of Gurage zone. Frost occurs for a very short duration usually in the early morning just before sunrise. The lowest temperature of the day is recorded at this time, when the stored heat from the sun is lost through radiation. Temperature inversion at the base of escarpments and on deep gorges is also a factor in frost occurrence (https://Hail, frost, rainfall patterns and variability _ Ethiopia Fact.htm).

According to the information from district agricultural office of Mihur Aklil, from all peasant administrations included in the district, 8 are prone to frost damage with certain degree of variation in severity. These are Chinbe, Anzire, Abege, Tekle-haymanot, Furcha, Kechin, Megeran, and Yekote in decreasing order of frost damage extent. The frost damage is high during late months of mostly November and December on barley, pea, faba bean, cabbage, potato and lastly onset with a decreasing order of severity. They appeared as if they had been burnt by fire exposed for certain time. The existing temperature is so low which results in burning and death of annual crops.

In Ethiopia it is spoken only that the lowest temperature of the day is recorded but with no actual figure and range of temperature extremities. This makes the condition worse whether here to deal with frost or chilling injury causing damage to different crops. No detail studies were conducted on frost or chilling injury on neither of crops. This was the aim of this work to estimate and identify the problem of frost on barley production and to find interventions as solutions with ultimate relief of the community in the area.

MATERIALS AND METHODS

Description of Study Area

The research was conducted in Muhir Aklil district which is found in Gurage zone of Southern Nations Nationalities and Peoples Regional State (SNNPRS) of Ethiopia. The study area is at top hills of Zebidar mountain chain extending frost occurrence throughout the area of Bozhebar down the street to Butajira, Meskan district in Gurage zone. According to the information from district agriculture office, Mihur Aklil encompasses areas with an altitude up to 3280 m above sea level. Chinbe Peasant Administration is the one subjected to a challenge due to serious frost occurrence with severe damage to crops. From all Peasant

Administrations included in the Mihur Akilil 8 Peasant Administrations are prone to frost damage with certain degree of variation in severity. These are Chinbe, Anzire, Abege, Tekle-haymanot, Furcha, Kechin, Megeran, and Yekote in decreasing order of frost damage extent. The district has an average temperature of 10-15 degree Celsius and rainy months of May first to end of September with annual rainfall of 900-1400mm. The wind intensity is very high in October and November of the year. The frost damage increases late in the season mostly November and December with a severe damage on barley, pea, faba bean, cabbage, potato and lastly inset with a decreasing order of severity (see figure 1).

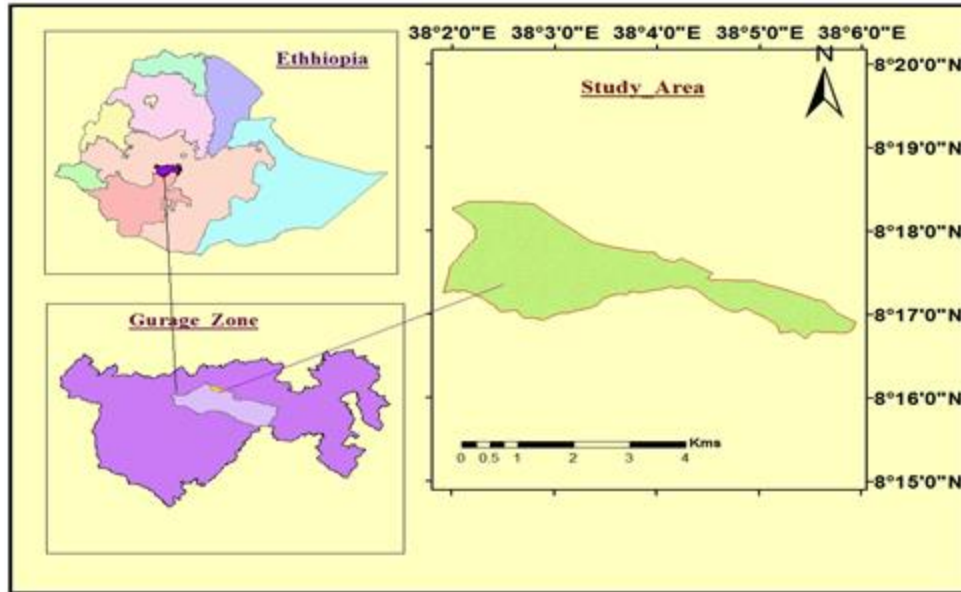


Figure 1: Map of the Study Area

Design of the experiment

The experiment was laid out in RCB design having seven (7) treatments including the check (average sowing date of the farmer, June 22) with three replications. Commonly grown barley variety (HB-1307)

Table 1: Treatments of the experiment and their designation

Treatments	Descriptions	Date of Sowing
T1	20 days before the average sowing date	June 2,2015
T2	15 days before the average sowing date	June 08, 2015
T3	7 days before the average sowing date	June 15,2015
T4	Average sowing date	June 22,215
T5	7 days after the average sowing date	June 29/ 2015
T6	15 days after the average sowing date	July 07/2015
T7	20 days after the average sowing date	July 13,2015

was used. The plot size used for each treatment was 4mx5m (20 m²) with spacing of 0.5m between plots and 1m between replications. The treatments used in the research include 7, 15 and 20 days before and after the average sowing date used by the farmers in the area (Table 1).

Data Collected

Plant data on plant height (PH), leaf width (LW), leaf number per plant (LPP), nodes per plant (NPP), length of internode (LI), length of spike (LS), grains per spike (GPS), thousand seed weight (TSW), plant

biomass (PBM) and yield per plot (YLD) was collected for analysis.

Data Analysis

The data were analyzed using Statistical Analysis Software SAS 9.0 version and Mean separation of all parameters was carried out by least significant differences (LSD) at 0.05 probability.

RESULTS AND DISCUSSION

The test on determination of the best/optimum planting time was carried out first and overall by the highly preferred crop barley in 2015 GC. having the idea that optimizing sowing dates together with site selection will be best and most effective method to avoid/minimize frost damage on crops.

Effect of frost on Growth parameters of Barley

In order to differentiate which sowing date is optimum among the treatment levels growth as well as yield parameters are considered for further analysis. Vegetative parameters including plant height, number of leaves, tiller per plant, length of internodes and number of nodes data taken primarily 80 days after emergence, frost has been occurred three days at November 02/03/2015, November 09, 2015 (night) and November 22-23, 2015; 3:30-4:00 evening.

Effect of Frost and Response of Growth parameters in Sowing date trials (Table 2)

Table 2: Results displayed on growth parameters with respect to sowing dates

Treatment	Growth parameter						
	Plant height (cm)	Leaf number /plant	Node per plant	Leaf (cm)	Width	Tiller /plant	Internode length
1	57.027 ^{ab}	5.95 ^a	4.07 ^a	1.65 ^b		9.5 ^{ab}	33.19 ^b
2	75.977 ^a	5.66 ^{ab}	4.2 ^a	1.87 ^a		7.71 ^{bc}	62.04 ^a
3	54.017 ^b	5.037 ^c	4.07 ^a	1.83 ^{ab}		6.87 ^c	51.44 ^{ab}
4	76.983 ^a	5.66 ^{ab}	3.8 ^a	1.94 ^a		10.2 ^a	72.10 ^a
5	69.52 ^{ab}	5.83 ^a	3.13 ^b	1.82 ^{ab}		9.5 ^{ab}	64.21 ^a
6	75.163 ^{ab}	5.75 ^{ab}	3.2 ^b	1.86 ^{ab}		8.5 ^{abc}	59.54 ^a
7	60.820 ^{ab}	5.25 ^{bc}	3.33 ^b	1.75 ^{ab}		8.5 ^{abc}	53.29 ^{ab}
LSD0.05	21.24	0.58	0.44	0.2032		2.02	24.48
CV%	17.8	5.8	6.66	6.3		13.12	24.63

Means within a column followed by the same letter (s) are not significantly different at $p \leq 0.05$ (GLM).

A. Number of nodes per plant

The statistical analysis indicates that there was a significant difference ($p \leq 0.05$) among treatments with regard to number of nodes per plant. Significantly higher number nodes per plant was recorded in T1 (20 days before), T2 (15 days before), T3 (7 days before) and T4

(average sowing date) with no significant variation among the four treatment levels. Whereas, significantly lower number of nodes per plant was recorded in T5 (7 days after), T6 (15 days after) and T7 (20 days after) with no significant variation among the three treatment levels. This shows that early sown barley resulted in

more number of nodes per plant than late sown which in turn scored lesser yield discussed later.

B. Tiller per plant /TPP/

ANOVA showed that there was a significant difference ($p \leq 0.05$) with regard to number of tillers per plant at different sowing dates. The barley sown on June 22 (T4) has produced more number of tillers 10.2 with significant variation from T3, 7 days before the average sowing date and T2, 15 days before the average date. However T4 with highest mean score number of tillers has no significant difference when compared with rest treatments.

C. Leaf number /plant /LPP/

The maximum mean number of leaves per plant 5.95 leaves was recorded by barley crop sown at June 2, 2015 (T1), 20 days before the average sowing date of the farmer and sown at June 29/ 2015 (T5), 7 days after the average date, with 5.83 though both treatments have no significant difference with respect to leaf growth. The minimum mean number of leaves 5.03 leaves was recorded at barley sown at June 15/2015 GC (T3). There is similarity with the above least plant height obtained. This study is in agreement with the study on wheat that reveals even if freezing occurs and causes leaves to be injured, this injury to developing foliage will not affect the crop yield because of the compensation ability of the crop (Youiang and Ellison, 1996). This might be applicable for barley as one of cereal crops and coincides with earlier and late sown barley crops will be attacked by frost occurring at the same day might injure both but with certain variation and probably the same compensation ability since better yield is obtained by barley sown at June 29/ 2015 (T5), 7 days after the average date, with 5.83 as seen below. In this study earlier sown barley crops have shown more number of leaves at 20 days before the average sowing date of the farmer with 5.95 leaves even if this does not assure the better yield obtained with earlier harvesting which coincides with our result.

Effect of Frost on Yield parameters with respect to sowing date

The Barley crop, variety HB-1307 has reached harvesting stage at different times based on their sowing date. This varies from November 23/2015-December 14/2015 GC. T3 treatment sown 7 days before the

average sowing date of the farmer, namely June 15/2015 GC and T2 15 days before the average sowing date, June 08, 2015 GC were harvested primarily at November 23, 2015 GC. This indicates that the crop has reached maturity earlier before frost occurrence. Both treatments T2 and T3 has emerged at June 15/2015 and June 22/2015 GC after sowing at June 08/2015 and June 15/2015 respectively. Since T2 and T3 are the experimental plots exhibiting crops sown 15 days and 7 days before the average sowing date of the farmer. The intensity of the frost can be judged from potato and enset plants damaged by the frost after its occurrence (see plate 1 and table 3 below).

A. Thousand seed weight

Based on statistical analysis there is significant difference between treatments with respect to thousand seed weight. Accordingly barley T5, sown at June 29/ 2015, 7 days after the average sowing date, has scored the highest mean thousand seed weight, with value of 63.33 followed by T7 with value of 58.33, sown 20 days after the average sowing date. Treatments with late sowing date T5, T6 and T7 has no significant variation even though thousand seed weight counted exhibit differences. However Treatment T5, has significant variation from the average sowing date of the farmer (T4) sown at June 22/2015 GC and with The minimum value of 50gm, and the rest earlier sown treatments with no variation with one another.

B. Grains per spike (GPS)

From the point of view of number of grains per spike there is a significant difference between treatments at $p < 0.05$. The highest number of grains is recorded in treatment 6 sown at July 07/2015 with a value of 71.84 followed by treatment 5 June 22/ 2007 and 7 July 12/2015 with values of 64.33 and 62.72 respectively and even with no significant difference between these three treatments. Treatment 6 sown at July 07/2015 and 5 sown at June 29/ 2015 is then very highly significant in comparison to treatments 4, sown at June 22/2015 GC 3, June 15/2015 GC 2 and 1. The least number of grains is scored by treatment 3 and this with no considerable difference from treatment 2 and treatment 4. There is very significant variation between treatment 6 and 5 with those of 2, 4 and 1. This indicates in any way that earlier sowing dates cannot be tolerated if it is thought to obtain a better yield as far as the treatments after sowing dates of the farmer allows barley crops get adequate water during grain filling stage. This cannot assure however



Plate 1: Damage of frost on Enset (*Ensete ventricosum*) and Potato (*Solanum tuberosum*)

Table 3: The reaction of treatments with respect to yield parameters due to sowing dates

Treatment	Yield parameter				
	Number of Grains/Spike	Thousand Weight (g)	seeds	Length of the spike (cm)	Yield (qt/ha)
1	54.61 ^{bc}	53.33 ^{bc}		7.72 ^a	21.18 ^c
2	48.83 ^c	51.67 ^{bc}		6.53 ^b	27.15 ^{bc}
3	45.73 ^c	55 ^{bc}		7.45 ^{ab}	39.10 ^b
4	49.05 ^c	50 ^c		7.4 ^{ab}	37.95 ^b
5	64.33 ^{ab}	63.33 ^a		7.53 ^{ab}	55.87 ^a
6	71.84 ^a	56.67 ^{abc}		7.2 ^{ab}	34.2 ^{bc}
7	62.72 ^{ab}	58.33 ^{ab}		7.7 ^{ab}	37.58 ^b
LSD0.05	12.9	7.56		1.17	14.11
CV%	12.79	7.66		8.97	21.93

Means within a column followed by the same letter (s) are not significantly different at $p \leq 0.05$ (GLM).

the more number of grains per spike results again better yield since the weight of the seeds has to be considered as it is confirmed above T5 has scored the maximum mean thousand seed weight sown 7 days after the average sowing date of the farmer.

C. Grain yield

The treatments have shown significant differences on yield with respect to sowing date of barley in the presence of frost damage at a date of November 02/2015, November 09/2015 (night) and November 22-23/2015 night 3:30-4:00 (night). Among all treatments T5 has shown highly significant results of 5.59 t/ha sown 7 days after the average sowing date of the farmer and harvested at 04/04/08 followed by again T3 sown 7 days before the average sowing date and harvested between November 23/-December 02/2015

GC with a value of 3.91 t/ha. In both treatments the yield obtained is comparatively higher than that of barley yield at national level, which is estimated to be 12 qt/ha CSA (2005).

The least yield was recorded by T1, sown 20 days before the average date with a value of 2.12 t/ha but with no significant difference with T2, again barley sown at 15 days before the average sowing date in contrary with T3, barley sown 7 days before the average date and T4, the average sowing date, namely June 22, 2015.

RECOMMENDATION AND CONCLUSION

On the basis of the result from the experiment it is possible to decide that earlier sowing from the average date of the farmer will not benefit to obtain better yield. From the analysis T5 resulted the best yield

which is 7 days after the average sowing date. It is again better to use to consider T3 which is 7 days before the average date. It is not recommended 20 and 15 days earlier sowing date to assure escaping of the flowering time of the crop but with also water requirement while grain filling phase of barley. If farmers are obliged to sow barley lately due to some reasons it is better to use T 5 and T 6 which gives lesser yield which is also explained by (Gusra, L. V' eNo o, CoNNoR' B' J. (1987) as if seeding is delayed to avoid killing frosts, early-maturing, lower yielding varieties must be sown.

As described by the authors, in addition to reducing yield, frosts may induce lesions which provide a means of infection by bacteria and fungi as it is even told by farmers as the recognition on the presence of foully smell during the presence of frost or freeze damage on barley. The above authors describe also frosted wheat may 'not be suitable for milling and is often graded as feed and even frost at the soft dough stage can result in poor seed germination which is not included in this study (Gusra, L. V' eNo o, CoNNoR' B' J. (1987).

According to the study of Masresha *et.al.* (2012) Ethiopian upland barely landraces investigated in their study showed considerable differences in their response to subfreezing temperatures and in their acclimation potential to cold. The critical temperatures for survival for most of the samples tasted have ranged between -5.5 and -8.8°C. Because there are no earlier reports on frost tolerance of tropical barley races, the present values may be compared to published values for barley from temperate regions.

This test has contained only released varieties which suit the very highland agro-ecologies and since there is no tests again conducted on this issue except the above authors, even under laboratory condition. Our recommendation is better barley of commonly cultivated varieties are they shall be sown with the relatively best days on the basis of our test, namely 7 days after the average sowing date of the farmer. It is important to incorporate cropping practices like cover such as mulch, intercropping and fertilization which strengthen crops from damage by frost and freeze.

These testes have several gaps in that the intensity of the frost or freeze damage is not measured. It is clear that the occurrence of a single day frost is however sufficient to devastate crops resulting in even 100 % yield loss. It is tried to analyze the yield which can be obtained with the presence of 3 days frost damage. At the same time whether the involvement of the ice nucleating active bacteria and which among them involved is not considered. Additionally the temperature should also be quantified below the freezing point causing frost and freeze damage not only on barley but also to other crops beyond the days for continuous

cropping season. It will be suggested to include barley germplasms in IBC Ethiopia for analysis on their frost withstanding characteristics and formation of INA bacteria types and their degree of contribution for frost and freeze formation on the plants and even in the soil (Steven E. *et.al.*,1982).

Forecasting and monitoring methods should have to be installed so that early passive protection methods which are economically feasible and available can be employed. Based on cropping period of barley harvesting period should be considered. The use of frost Monitoring and forecasting application is essential in that the satellite datasets provide a daily map of frost potential. It is spoken from automation of development including forecasting to provide warning 72 hours in advance of a frost event. There is also an email links so that they can see current and previous datasets and like the Kenya Ministry of Agriculture and Kenya Ministry of Water and Irrigation and maps' color schemes to forecast frost prone pocket areas. In general it is advised to use near real-time nighttime land-surface temperature datasets from NASA's satellites, the Frost Monitoring and Forecasting application maps and displays areas affected by frost for Ethiopia. These capabilities could be extended to incorporate additional datasets such as crop-specific warnings or targeted geographic areas. This is probably one to manage by Wolkite University to benefit not only the community of Gurage and even frost subjected pocket areas wherever in Ethiopia [https://\(SERVIR: Frost Monitoring and Forecasting in Africa\)](https://(SERVIR: Frost Monitoring and Forecasting in Africa)). So our country can use this opportunity to signalize and warn farmers existing in frost subjected areas.

LIST OF ABBREVIATIONS

FAO: Food and Agriculture Organization
GPS: Grains per spike
HARC: Holleta Agriculture Research Centre
IBC: Institute of biodiversity conservation
INA: Ice nucleation active bacteria
Kph: Kilometer per hour
LPP: Leaves Number per plant
LS: Length of the spike
LW: Leaf width
NPP: Nodes per plant
PA: Peasant administration
PBM: Plant biomass
PEHF: Post emergence heading frost
PH: Plant height
SAS: Statistical analytical software
TPP: Tiller per plant
TSW: Thousand seed weight
YLD: Grain yield

m.a.s.l: Meters above sea level

ACKNOWLEDGEMENT

It is my pleasure to work on solutions for difficulties linked with the welfare of human beings everywhere. Being a part I was surprised as we were in Mihur Aklil looking the sudden damage of almost every crops attacked by frost which initiates our University Research and Community Service Vice President and the Director to find solutions and intervene. So this work might give a bit relief from the damage of frost if farmers will be in a position to practice it as recommended with further works as permanent solution. It is therefore to say again thanks to Wolkite University and considerably District Agriculture Office of Mihur Aklil, Expertise and above all Development agents of Chinbe PA. Lastly I would like to acknowledge also farmers Tsegaye Demsis and Ayele with whom I have worked with honest and good Approach. Indeed I will and must appreciate my families for encouraging to come up with this final work.

Authors

I declare that I participated in the design of the experiment, Data collection and analysis until the final write up entitled "Sowing Date Optimization as a Means to Manage Frost Damage on Barley (*Hordeum Vulgare* L.) In Mihur Aklil District Of Gurage Zone, Ethiopia, and that I have seen and approved the final version.

I also declare that I have no conflict of interest in connection with this paper other than any noted in the covering letter to the editor.

REFERENCES

- Aduugna Abdi (2006) Barley genetic resources collection and conservation in Ethiopia ;in Proceedings of the 2nd National Barley Research and Development Review Workshop, Holetta Agricultural Research Centre, Ethiopia 28–30 November 2006; Institute of Biodiversity Conservation (IBC), P.O. Box 15838, Addis Ababa, Ethiopia.
- Alanstair H Fitter and Robert K.M. (2002) Environmental physiology of plants, third edition, Academic press a division of Harcourt, Inc. UK
- Alberta Agriculture and Forestry (2001): Protection against Frost Damage published to the web on August 20, 2002. Last Reviewed/Revised on March 11, 2015 seen March 29/2017 5:02
- Bayeh Mulatu and Berhane Lakew (2006); Barley research and development in Ethiopia – an overview; in Proceedings of the 2nd National Barley Research and Development Review Workshop Ethiopian Institute of Agricultural Research (EIAR), Holetta Agricultural Research Center (HARC), P.O. Box 2003, Addis Ababa, Ethiopia
- CSA, 2005. Federal Democratic Republic Ethiopia: Central statistics Authority, Agricultural sample survey 2004/5 (1997E.C) (September 2004-February 2005) Vol. I. Report on Area and Production of crops (private peasant holdings, Meher season) Statistical Bulletin 331. Addis Ababa, May, 2005.pp.1-48.
- Effect of frost on cereal and grain crops (2013): published by State of government Victoria; Department of Environment and primary industries, 1 Spring Street Victoria ISSN 1329
- FAO (2005) Natural Resource Management and Environment Department Frost protection: fundamentals, practice, and economics - Volume 1 and 2.
- Frost and freeze damage-to crops (2015), Tri State Neighbor, 309 W 43rd St. Siqux Falls, SD.
- Greg B. (2009); in Effect of frost on cereal and grain crops (2013): published by State of government Victoria; Department of Environment and primary industries, 1 Spring Street Victoria ISSN 1329
- Gusra, L. V' eNo o,CoNNor' B' J. (1987) : Frost tolerance of wheat, oats, barley,canola and mustard and the role of ice-nucleating bacteria. Can' J. Plant Sci' 67:1 155-1 165.
- Harpal S. Mavi and Graeme J.Tupper (2004) Agrometeorology, principles and application of climate studies in Agriculture; by Haworth Press Inc. USA
- https://Hail, frost, rainfall patterns and variability _ Ethiopia Fact.htm
- [https://\(SERVIR: Frost Monitoring and Forecasting in Africa\)](https://(SERVIR: Frost Monitoring and Forecasting in Africa))
- <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140012929.pdf> March 29, 2017 4:37 PM
- SERVIR GLOBAL <http:// Frost Monitoring and Forecasting in Africa March 29, 2017 4:37 PM>
- <http://apps.rcmrd.org/>: Frost Monitoring and Forecasting in Africa 29, 2017 4:37 PM
- Janet Anderson (2015): SERVIR Project Helps African Farmers Combat Frost Marshall Space Flight Center, Huntsville, Ala. 256-544-0034
- Janet S. H. Lorv, David R. Rose, and Bernard R. Glick (2014) :Bacterial Ice Crystal Controlling Proteins, Department of Biology, University of Waterloo, Waterloo, ON, Canada N2L 3G1

- Kathy Demchak (2007): Frost Protection: Tips And Techniques, Department of Horticulture, Pennsylvania State University
- Linda Reddick: Identification and prevention of frost or freeze damage, Kingman area Master gardener; The University of Arizona-College of Agriculture and Life Sciences, Arizona Cooperative extension -The University of Arizona Mohave County Cooperative Extension at 101 E. Beale Street
- Mark P. Buttner And Penny S. Amy (1989): Survival Of Ice Nucleation-Active And Genetically Engineered Non- Ice-Nucleating *Pseudomonas Syringae* Strains After Freezing: Department Of Biological Sciences And Environmental Research Center, University Of Nevada, Las Vegas, Nevada 89154 ; Applied And Environmental Microbiology, July 1989, P. 1690-1694 0099-2240/89/071690-05\$02.00/0
- Masresha Fetene, Yemane Gebre-Egziabher and Erwin Beck (2012): Comparison of the Frost Resistance of Barley (*Hordeum Vulgare* L.) Landraces of Upland Ethiopia Using Electrolyte-Leakage and Chlorophyll Fluorescence; *Ethiop. J. Sci.*, 35 (1):41–50, 2012
- Mohammad Pessaraki (2001), *Handbook of Plant and Crop physiology*. (Second edition revised and expanded): The University of Arizona, Tucson, Arizona
- STEVEN E. LINDOW', DEANE C. ARNY, AND CHRISTEN D. (1982) Bacterial Ice Nucleation: A Factor in Frost Injury to Plants' UPPER Department of Plant Pathology, University of Wisconsin and Plant Disease Resistance Unit, Agricultural Research Service, United States Department of Agriculture (C. D. U.); Madison, Wisconsin 53706
- T.M. Frederiks, J.T. Christopher, M.W. Sutherland and A.K. Borrell (2015); Post-head-emergence frost in wheat and barley: defining the problem, assessing the damage, and identifying resistance; Review paper in *Journal of Experimental Botany*