Science for resilient livelihoods in dry areas

Land Suitability Mapping for Production of Chickpea, Faba Bean and Malt Barley Varieties in Ethiopia

Demeke Nigussie, Wondafrash Mulugeta, Adamu Molla, Zewdie Bishaw, and Chandrashekhar Biradar

WORKING PAPER June 2019 - 1

ISBN13: 978-92-9127-526-7

Keywords: Chickpea, faba bean, malt barley, land suitability mapping, Ethiopia

Working Papers

Working Papers are one of ICARDA's global public goods; they capture and share knowledge and learning from projects and research partnerships. Each paper is internally reviewed as part of the Center's publishing process.

Suggested citation

Nigussie, D., W. Mulugeta, A. Molla, Z. Bishaw, and C. Biradar. 2019. *Land Suitability Mapping for Production of Chickpea, Faba Bean and Malt Barley Varieties in Ethiopia*. Beirut, Lebanon: International Center for Agricultural Research in the Dry Areas (ICARDA).

About ICARDA

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is a non-profit, CGIAR Research Center that focusses on delivering innovative solutions for sustainable agricultural development in the non-tropical dry areas of the developing world.

We provide innovative, science-based solutions to improve the livelihoods and resilience of resource-poor smallholder farmers. We do this through strategic partnerships, linking research to development, and capacity development, and by taking into account gender equality and the role of youth in transforming the non-tropical dry areas.

Address

Dalia Building, Second Floor, Bashir El Kasser St, Verdun, Beirut, Lebanon 1108-2010.
www.icarda.org

CGIAR
A CGIAR Research Center
cgiar.org

Acknowledgement

This study on suitability maps and publication of this book was supported by the two seeds and technology scaling projects of ICARDA-USAID: i) Better livelihoods for smallholder farmers through knowledge based technology interventions in the highlands of Ethiopia: Increasing the productivity of chickpea in wheat-based cropping system; and, ii) Deployment of malt barley and faba bean varieties and technologies for sustainable food and nutritional security and market opportunities in the highlands of Ethiopia. The authors are grateful for the financial support of ICARDA and USAID, without which this study would not have been possible.

The authors would also like to thank several institutions for providing the valuable information needed to produce this book. These include the Ethiopian Institute of Agricultural Research (EIAR) and the Plant Variety Release, Protection and Seed Quality Control Directorate of the Ministry of Agriculture. Special thanks go to the kind and generous support of chickpea, faba bean and barley breeders at Debre Zeit, Holetta and Kulumsa Agricultural Research Centers (ARCs of EIAR) Debre Birhan Agricultural Research Center (of Amhara Region Agricultural Research Institute). The views and opinions expressed in this book are purely those of the authors and do not necessarily reflect the views of their employers.

Table of contents

List of tables

List of figures

List of acronyms

AHP	Analytic hierarchy process
AIWG	Agronomic Interpretations Working Group
ARARI	Amhara Agricultural Research Institute
BSG	Benishangul Gumuz
DBARC	Debre Berhan Agricultural Research Center
DZARC	Debre Zeit Agricultural Research Center
DEM	Digital Elevation Model
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agricultural Organization
IAR	Institute Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ISRIC	International Soil Reference and Information Centre
LGP	Length of growing period
masl	meters above sea level
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
MoANR	Ministry of Agriculture and Natural Resources
RVT	Regional variety trial
SEA	Soils of East Africa
SNNP	Southern Nations Nationalities and Peoples
SRTM	Shuttle Radar Topography Mission
TSW	Thousand seed weight (g)
USAID	United States Agency for International Development
WBISPP	Woody Biomass Inventory and Strategic Planning Project

Executive summary

Ethiopia's agriculture has been facing recurrent challenges and the country remains food insecure due to its ever-increasing population and chronically low agricultural productivity despite its high biophysical potential. The situation is exacerbated by inappropriate use of agricultural land leading to land degradation, as well as recurrent droughts superimposed by climate variability and change. These challenges require the potential and the constraints of agricultural land to be properly identified for appropriate decision-making for land use planning and sustainable farming.

Different land areas have varying potential and constraints for appropriate and sustainable agricultural use. Information on the potential and constraints of the land will help to identify and develop appropriate technology to target location specific interventions. For crop technology targeting and scaling, the potential of the different areas need to be properly identified and mapped for better crops and crop varieties. Land suitability analysis work enables identification of where and how much potentially suitable land for a crop and crop variety exists in a specific location or in the country at large. It is, therefore, very important to identify and map the extent and distribution of land area that is potentially suitable for a specific crop and crop variety. Cognizant of these facts, the land suitability mapping for selected varieties of chickpea, faba bean and malt barley was initiated to analyze and delineate the land suitability in Ethiopia.

Land suitability analysis is an evaluation and decision-making process involving several biophysical (soils, topography and climatic) factors. Accordingly, the main factors considered in this analysis include climate layers (rainfall and temperature during the growing period and length of growing period-LGP), topography (digital elevation models. i.e. altitude and slope data), soil types and soil properties (pH, depth, texture, and drainage). For classification of the data layers according to the degree of favorability for each variety, existing maps, reports, and other relevant information were reviewed and used in defining the limits of the suitability ranges of the crop varieties. Then, environmental requirements of varieties were defined by means of a set of critical values, which determine the limits between the land suitability levels (classes). The suitability classes were set as S_1 (very suitable), S_2 (moderately suitable), and S_3 (marginally suitable) and N (unsuitable).

The biophysical criteria for specific crops and crop varieties were assigned at pixel level in each layer to reclassify layers for weighted rates. Following this process, each layer was compared among themselves and ranked. The suitability criteria layers were assigned weights to account for their relative importance. The analytic hierarchy process, which relies on pairwise comparison, was used to calculate the weights for the different criteria. The pairwise comparisons scales were assigned through discussion with biophysical experts. The overall suitability is computed by multiplying the selected criteria weight by the assigned sub-criteria score and summing these values in the spatial modeling in the ArcGIS domain (ESRI GIS package). Lands occupied by forests, woodlands and towns (except Addis Ababa, Dire Dawa and Harari) are not excluded in this analysis. Moreover, this work focused only on rainfed areas of the country.

The analysis results show the extent and patterns of the suitable land area available for selected crop varieties of chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), and malt barley (*Hordeum vulgare* L.). The results are presented in the form of tabular data, maps and graphs.

The chickpea varieties used for the analysis are Desi (Mastewal, Naatolii, Teketay) and Kabuli (Arerti, Habru, Kasech, and Yelbey) types. The suitability analysis shows that 0.67, 0.71, 1.4, 2.3, 1.3, 2.4 and 1.2 million ha of the country are highly suitable for Mastewal, Naatolii, Teketay, Arerti, Habru, Kasech and Yelbey, respectively. Moderately suitable areas for these varieties cover 25.2, 11.3, 25.9, 26.4, 26.6, 9.6, 17.1 million ha, in the same order. Oromia region has more moderately suitable land for Arerti and Teketay varieties, with respective shares of up to 40.05 and 38.59%, respectively. In terms of percentage area coverage for each region, Amhara region has the largest proportion of moderately suitable land area.

The faba bean varieties selected for the analysis are Dosha, Gabelcho, Gora, Moti, Dagm, Hachalu and Walki. Highly suitable areas for these varieties include: 23,672 ha for Dosha; 192,836 ha for Gabelcho; 107,740 ha for Gora; 325,660 ha for Moti; 53,968 ha for Dagm; 136,200 ha for Hachalu; and 264,884 ha for Walki. Moderately suitable areas for these varieties cover 5.0,

9.4, 7.2, 15.3, 4.6, 8.8, and 7.5 million ha in the same order across the country. The largest proportion for all varieties is moderately suitable area, while the share of highly suitable is very low. Amhara region has the highest moderately suitable area, particularly for Gabelcho, Moti and Gora, with a share of 31.5, 35.3, and 21.16%, respectively.

For malt barley, the varieties used are Bekoji-1, EH-1847, Grace, Holker, IBON 174/03 and Sabini. Highly suitable areas for these varieties include: 125,332 ha for Bekoji-1; 124,004 ha for EH-1847; 775,312 ha for Grace; 125,356 ha for Holker; 1,677,388 ha for IBON-174/03; and 307,952 ha for Sabini. Moderately suitable areas for these varieties cover 4.3, 4.3, 20.6, 4.3, 11.6 and 16.4 million ha in the same order across the country. The largest proportion for all varieties is moderately suitable, while the share of highly suitable is relatively very low. Oromia region has the highest moderately suitable area for malt barley of which Grace, Sabini and IBON-174/03 each have a share of 35.02, 26.45 and 18.82%, respectively. IBON-174/03 has the highest overall highly suitable area of 1.7 million ha, followed by Grace having 0.8 million ha in the country.

The suitability analysis results show that the currently available improved varieties of chickpea, faba bean and malt barley can be targeted for scaling out in the identified land suitability classes in Ethiopia.

The results of this work are solely based on the biophysical parameters with qualitative thresholds without taking into account socio-economic factors at this stage. Varieties of the three crops (chickpea, faba bean and malt barley) are not mutually exclusive since they often overlap in some locations where they share similar areas of adaptation. Hence, it should be noted that the actual available land for each crop would be lower than that indicated in the maps due to commonly suitable areas. The quality and scale of this work is dependent on the quality of available geospatial data and information of environmental requirements of the different varieties included in this work. Hence, it should be noted that the outputs might not be suitable for applications that demand finer resolutions.

The results of this multiple criteria land suitability analysis for crop varieties can be useful for policymakers for land use planning and decision-making in a way that ensure land resources are used in the most productive and sustainable ways and solve the mismatches between current land use and land suitability for crop varieties.

It is recommended to undertake site-specific analysis to further refine suitable zones for recommending specific crop varieties for scaling at the farming systems level using more detailed and fine resolution datasets when available.

1. Introduction

Ethiopia is characterized by diverse agro-ecologies that sustain its agricultural production and maintain its rich biodiversity. The existence of diverse farming systems, agro-ecologies and its cultural diversity have endowed the country with a biological wealth of species diversity, particularly the crops (IBC 2007). The agriculture sector contributes 42% of gross domestic product (GDP) and provides employment for about 85% of the population, which earn their livelihood directly or indirectly from agriculture (CSA 2016). The major food crops are produced in most regions of the country though production varies, which may be attributed to area devoted to each crop, weather change and a shift in preference for the crops grown (CSA 2015a). Crop yields are inevitably affected by many factors such as weather conditions, farming practices, input use, amount and prices (fertilizers, quality seeds), and use of irrigation (CSA 2015b).

Although agriculture is the backbone of Ethiopian economy with potential for diversification and intensification of farming systems due to its diverse agro-ecology, the agricultural practices has shown little transformation and it is still based on traditional farming systems. As a result of climate change and variability, inappropriate use of agricultural land leading to land degradation, and increasing population, Ethiopia's agriculture has been facing recurrent challenges and the country remains food insecure. Such challenges require the potentials and constraints of the land to be properly identified for appropriate planning and decision-making for a sustainable use.

Agriculture is important as a source of food and income, but how, where and when to cultivate are the main issues that farmers and land managers are confronted with daily (Mokrram et al. 2010). Different agricultural zones in the country have varying potential and constraints for a specific use. Good and reliable information about land resources and their potential for various uses is essential for land use planning (FAO 1993). Accurate and relevant information, appropriate to the scope and scale at which these decisions are made, is needed in order to make informed decisions about crop adaptation zones and resource allocation (Collis and Corbett 1999). Appropriate decision-making on crop production will reduce various risk factors associated with unsustainable land management. If one knows the potential and constraints of a particular area, it is easier to choose or develop appropriate technology for targeting interventions. The limited available arable land cannot be taken for granted which may turn from 'best' to 'worst' irrespective of the kind of land use and management practice without understanding its special requirements and potential use (FAO 1993; Biradar et al. 2019).

Availability of data in the appropriate format is one of the greatest constraints in applied research and this is particularly true for geo-referenced weather and soils data in developing countries (Collis and Corbett 1999). In Ethiopia, no sufficient data and information have been collected and documented systematically on potential and constraints of land resources. Consequently, some agricultural land uses do not match with the actual potential of the land as the limit of environmental adaptation of species and varieties in most cases is not well defined. Even though the agro-ecological zone maps provide such information to some extent, the suitability classes of crops may not coincide with the limits of the established zones (Gobel and Thomas 1999). Therefore, there should be information on the quality and extent of land available for different uses to allocate it for appropriate use. Land can remain the same or may be transformed but cannot be moved, whereas capital, labor, management skills and technology can be moved to where they are needed (FAO 1993).

FAO (1976) defined land suitability as the "fitness of a given type of land for a defined use" be it in its present natural condition or after some improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO 1976). Land suitability classification for agriculture is very important for future planning to help decision-makers and agricultural development planners; and determine how appropriate use of the land in a location is more suitable for certain agricultural use (Singha and Swain 2016).

Geographic Information Systems (GIS) enables a large amount of different geospatial and associated information to be assembled, combined, overlaid, modeled and mapped. It also enables ease of updating and retrieval and to avoid complex and tedious calculations of the data to generate tables and maps. With its huge capability, GIS can be a powerful tool in agricultural planning of an area for land use suitability.

Therefore, GIS has contributed to the speed and efficiency of the overall planning process in agricultural land use suitability, since it enables quick and efficient access to large amounts of information, exhibiting relationships, patterns, and trends that are useful in monitoring land use potential and suitability evaluation. It is useful tool for scaling proven technologies and packages of practices including the specific crops and crop varieties to address the yield and nutritional gaps (Singha and Swain 2016; Low et al. 2018).

To assist crop technology targeting and scaling-up, the potential of different land for different purposes should be identified so it can be allocated for appropriate use. Crops/varieties should be selected based on different objectives addressing quality preferences such as adaptability, yield, tolerance to abiotic and biotic stresses, and market and nutritional values. Land suitability analysis work enables identification of where and how much potentially suitable land for a crop and crop variety exists in a specific location or in the country at large. It is, therefore, very important to map the agricultural land to show the extent and distribution of areas that are potentially suitable for a crop variety. It was within this context that this study was initiated, which attempted to gather and organize various data relevant to environmental requirements of the selected varieties, and analyze and depict the land suitability class for chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.) and malt barley (*Hordeum vulgare* L.) in Ethiopia.

This work is a qualitative, nationwide land suitability analysis; i.e., the results are qualitative without considering socio-economic returns. Hence, the assessment is limited to the evaluation of biophysical factors, such as climate, topography, soils and land use or cover. Moreover, this study focused on only rainfed agriculture. One of the constraints restricting this work to focus on national level suitability pertaining to rainfed areas only is lack of reliable and accurate geospatial data at the required spatial resolution at national level. Hence, the scope of this suitability analysis is limited to the data and analysis components outlined in section 2.

The crops included in the analysis are malt barley, faba bean and chickpea and they are widely grown from mid-altitude areas to the highlands of Ethiopia. Out of the total grain crops area (12,486,270.87 ha) in the country, cereals, pulses and oilseeds covered, respectively, 79.88%, 13.24% and 2.94% during the 2015/16 meher (main) cropping season (CSA 2016). Barley, faba bean and chickpea were planted on 944,401.34 ha (7.56%), 443,966.09 ha (3.56%) and 258,486.29 ha (2.07%), respectively, during the same year.

2. Materials and methods

2.1. Geospatial data used

To carry out a land suitability evaluation, spatial data layers must be prepared. Land suitability analysis is an evaluation and decision-making process involving several biophysical (soils, topography and climatic) factors. Key factors, mainly those related or controlled by bioclimate, vary in time (temporal variability) and vary across the landscape (spatial variability and topography) (AIWG 1995). The main factors considered in this analysis that relates to key plant growth parameters include climate layers (rainfall and temperature during the growing period and length of growing period-LGP), topography (digital elevation models. i.e. altitude and slope data), soil types and soil properties [soil chemical (pH) and physical (depth, texture, and drainage)], administrative boundaries, and infrastructure (roads, towns, and other facilities). Park and lake areas were excluded (restricted) in this land suitability analysis.

In this analysis, greater emphasis was given to climate as it plays a major role in crop production. The climate data used were: rainfall and temperature surface maps (during the growing period) interpolated at a resolution of about 300 m which again resampled to 200 m to match the 200 m analysis resolution; and length of growing period (LGP) from Ministry of Agriculture (MoA) (WBISPP 2004) with a slight modification (i.e. joining the values of dependable length of period and converting to raster (pixel based)). Climatic conditions can vary widely from year to year, and this was addressed by using long-term means; this approach is valid if the aim is to assess overall suitability or potential and not to model crop growth in any one year (AIWG 1995).

The soil data used were soil properties and soil types, which were acquired from two sources. The soil properties were extracted from the Soil and Terrain Database of East Africa and gridded soil database of 250 m (ISRIC, 2015), while the soil type used was from MoA modified by the Woody Biomass Inventory and Strategic

Planning Project (WBISPP, 2004). For the altitude information, the Shuttle Radar Topography Mission (SRTM) 90 m digital elevation model (DEM) database (Jarvis et al. 2008) was used and the same DEM used for topographic analysis such as generating slope maps. This data was resampled to a common spatial resolution of 200 m for the spatial analysis in the GIS domain.

2.2. Methodology

One of the requirements in suitability analysis is identifying and determining the environmental requirements and limitations for various crops.

2.2.1. Defining the limits of crop's environmental requirements

To define the suitability classes according to the land use types, several literatures (e.g. Crop Variety Registers, research reports of EIAR and other organizations in the national agricultural research system) and qualified researchers were consulted. The land evaluations study conducted by FAO (1984) and by Sys et al. (1993) were used as a general guide to derive thresholds for defining the suitability categories.

After collecting information on the environmental requirements of the varieties at various locations, the performance of the various suitability ranges/limits were defined. For classification of the data layers, according to the degree of favorability for each variety, the existing digital and analogue maps, reports, and other relevant information were reviewed and used in defining the limits of the suitability ranges of the crop varieties. Then, environmental requirements of the varieties were defined by means of a set of critical values, which determine the limits between the land suitability levels (classes). The suitability classes, reflecting the degree of suitability, were set as S_1 (very suitable), S_2 (moderately suitable), and S_3 (marginally suitable) and N (unsuitable) based on the assumption indicated in the FAO land suitability classification structure indicated in Table 1. According to FAO classification, S1 corresponds to 85-100% of optimum yield, S2 to 60-85%, S3 to 40 - 60%, N1 to 25 - 40% and N2 to 25 - 0% (Fadlalla and Elsheikh 2016).

Since the analysis is raster (pixel) based, some of the data, which were in vector format (object based), were converted to uniform raster datasets. The important GIS layers of environmental factors affecting the growth of a specific crop were identified and each layers' pixel values were classified and assigned weightage. Following this, the environmental factor layers were compared among themselves and ranked. Based on the rate and rank assigned to each pixel, the land suitability map was computed. The classification of each layer into suitability categories was done using Reclass by Table function in ArcGIS spatial analyst (ESRI GIS package) tool. The reclassification is implemented

Table 1. Structure of the FAO land suitability classification.

Code	Class name	Description
S_1	Highly suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity and will not raise inputs above an acceptable level.
S_2	Moderately suitable	Land having limitations which, in aggregate, are moderately severe for sustained application of a given use; the limitations will reduce productivity and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably low to that expected on S_1 land.
S_3	Marginally suitable	Land having limitations which, in aggregate, are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
N	Not suitable	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs.

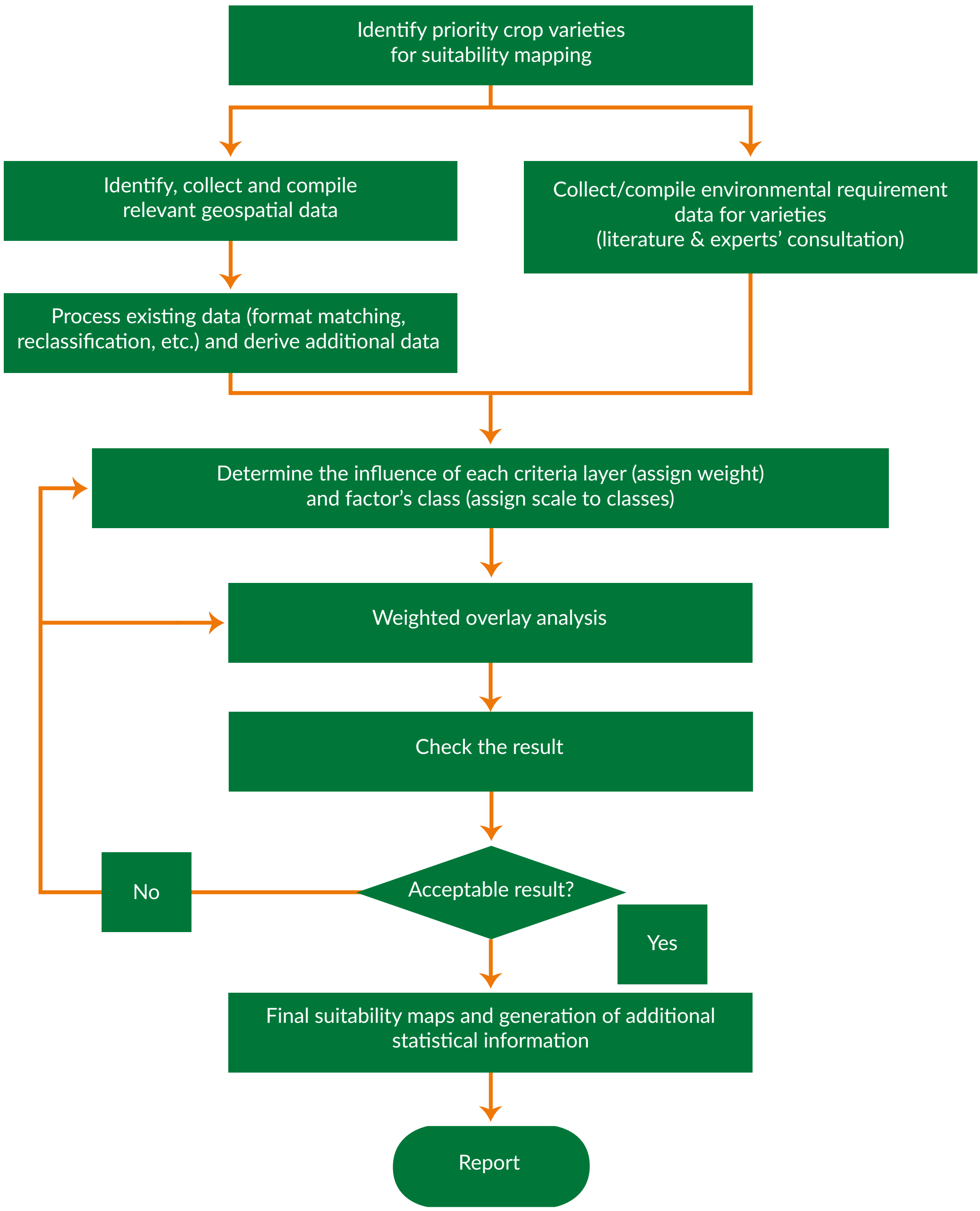
Source: FAO 1976; 1993.

in the model by preparing separate tables for each factor/criteria layer and crop.

2.2.2. Calculation of weight for criteria layers and overall suitability analysis

The overall suitability map is the combined result of the altitude, slope, soil types and soil properties, and the climate layers. The weighted overlay approach built on ArcGIS ModelBuilder was used for the overlay analysis to solve such multi-criteria problems of suitability. The suitability criteria layers were assigned weights to account for their relative importance and overlaid using the weighted overlay tool to produce the overall land suitability map. The purpose of weighting is to express the importance of each factor relative to other factor's effects on crop yield and growth rate (Perveen et al. 2007).

Figure 1. Flowchart of steps for suitability analysis.



The analytic hierarchy process (AHP) developed by Saaty (1987) was used to calculate the weights for the different criteria. AHP relies on pairwise comparisons that assign values based on relative importance of criteria layers. The criteria were evaluated, and numerical scales of measurement were derived through comparing against the goal for importance. The pairwise comparisons scales were assigned through discussion among experts. The overall suitability is computed by multiplying the selected criteria weight (Wi) by the assigned sub-criteria score (Xi) and summing these values in the ArcGIS ModelBuilder (See Eq.1):

$$S = \sum_{i=1}^{n} Wi\, Xi \quad \text{.......................} \quad (\text{Eq.1})$$

Where **S** denotes the final land suitability score, **Wi** denotes the weight of the corresponding suitability criteria, **Xi** denotes the assigned sub-criteria score of **i** suitability criteria and ***n*** is the total number of criteria maps. The final suitability result (maps and tabular data) including the explanatory document are prepared both in softcopy and hardcopy. The flow diagram shows the steps followed (Figure 1).

2.2.3. Crop varieties

Depending on data availability, varietal choice for each crop is based on: the current production and area coverage in the technology transfer; productivity; earliness; plant height for malt barley to meet feed requirement for livestock; grain protein content and seed boldness for malt quality in malt barley; export and local market quality parameters for chickpea and faba bean; and waterlogging and black root rot tolerance for faba bean on Vertisols. The list of varieties included for the three crops in the suitability analysis are listed in Table 2, Table 3 and Table 4.

Table 2. Selected characteristics of chickpea varieties used for land suitability mapping.

Variety	Year of release	Days to flowering after emergence	Days to maturity after planting	Grain yield with recommended management (t/ha)	Thousand grain weight (g)	Plant height at poding (cm)	Recommended altitude (m)
Mastewal	2006	52	122	2.5-3.1	240	40	2,000-2,600
Naatolii	2007	60	115	2.5-3.6	240	41	1,800-2,700
Teketay	2013	50	118	1.8-4.4	310	38	1,800-2,700
Arerti	2000	59	130	0.73-3.2	257	45	1,800-2,600
Habru	2004	60	121	2.4-3.2	319	46	1,800-2,600
Kasech	2011	46	118	2.0-2.5	375	50	1,400-2,000
Yelbey	2006	44	92	0.8-2.3	355	42	1,450-2,300

Source: Crop Variety Register and unpublished regional variety trial (RTV) data submitted to MoA.

Table 3. Selected characteristics of faba bean varieties used for land suitability mapping.

Variety	Year of release	Days to flowering after emergence	Days to maturity after planting	Grain yield with recommended management (t/ha)	Crude protein content (%)	Thousand grain weight (g)	Plant height at heading (cm)	Recommended altitude (m)
Dosha	2009	60	144	2.8-6.2	26.5	797	122	1,800-3,000
Gabelcho	2006	46	160	2.5-6.1	26.5	797	131	1,900-3,000
Gora	2014	47	147	2.2-5.7	24	938	131	1,900-2,800
Moti	2006	40	137	2.8-5.1	27	781	124	1,800-3,000
Dagm	2002	67	152	3.4-3.6	NA	300	86	2,600-3,000
Hachalu	2010	50	141	3.2-4.5	27	890	128	1,900-2,800
Walki	2008	56	140	2.4-5.2	27.5	676	129	1,900-2,800

Source: Crop Variety Register and unpublished RVT data submitted to MoA.

Table 4. Selected characteristics of malt barley varieties used for land suitability mapping.

Variety	Year of release	Days to flowering after emergence*	Grain yield with recommended management (t/ha)	Grain protein content (%)	Thousand grain weight (g)	Plant height at heading* (cm)	Recommended altitude (m)
Bekoji-1	2010	77	3.5-5.0	10.5	46.6	108.8	2,300-2,800
EH-1847	2011	80	3.5-4.4	10.6	46.0	101.2	2,200-2,800
Grace	2013	na	2.4-4.5	10.5	42.0	na	2,000-2,400

Variety	Year of release	Days to flowering after emer-gence*	Grain yield with rec-ommend-ed man-agement (t/ha)	Grain protein content (%)	Thousand grain weight (g)	Plant height at heading* (cm)	Recom-mended altitude (m)
Holker	1979	80	2.4-3.1	10.4	41.1	104.0	2,500-3,000
IBON-174/03	2012	67	3.0-5.7	10.0	46.5	88.2	2,000-2,800
Sabini	2011	72	2.5-4.9	8.5	45.0	87.6	2,300-2,500

na = not available

Source: Crop Variety Register and unpublished RVT data submitted to MoA; *unpublished DBARC data at 2,810 mas.

Table 5. Area (ha) of regional administrative states in Ethiopia*.

Regional states	Area (ha)	Percentage area (%)
Afar	9,562,336	8.45
Amhara	15,563,369	13.75
Benishangul Gumuz (BSG)	5,000,357	4.42
Gambella	2,570,136	2.27
Oromia	32,449,413	28.66
Somali	31,561,965	27.88
SNNP	11,289,986	9.97
Tigray	5,020,658	4.43
Addis Ababa	55,069	0.05
Dire Dawa	105,556	0.09
Harari	37,165	0.03
Total	**113,216,009**	**100**

Note: *The total area includes all agriculture, forest, water, town, and other lands bounded within the boundary of each regional state; Addis Ababa, Dire Dawa and Harari are city administrations with limited agricultural land for crop production.

3. Results and discussion

The results of the land suitability analysis are presented in the subsequent sections (based on statistical data of the area coverage) showing the extent and patterns of land area available for the selected crop varieties of chickpea, faba bean, and malt barley.

3.1. Area for suitability mapping

In the land suitability map for chickpea, faba bean and malt barley varieties, we first consider and present previous EIAR works on crop level suitability analysis to help readers compare the variety level suitability analysis results with the crop level suitability mapping. Therefore, we first present the crop level land suitability map (Nigussie 2014; Nigussie 2016; Nigussie 2018) followed by variety level land suitability map work undertaken in the two projects. When comparing the crop-level with the variety level suitability analysis results, it should be noted that the source of the difference may not necessarily be adaptation area. Since the crop and variety level suitability analysis were done with different expertise and periods, the human judgment difference on determining the suitability class ranges and assigning weights, could also somehow have contributed to the difference. For example, Vertisols were not included in S_1 and S_2 suitability classes for malt barley, since malt barley is more sensitive to waterlogging which significantly reduces productivity and quality even under provision of improved drainage technology compared with food barley.

The results of the land suitability analysis are presented below in the form of maps, tabular data and graphs. The percentage area coverage of suitability for each regional state is computed based on their respective total area indicated in Table 5.

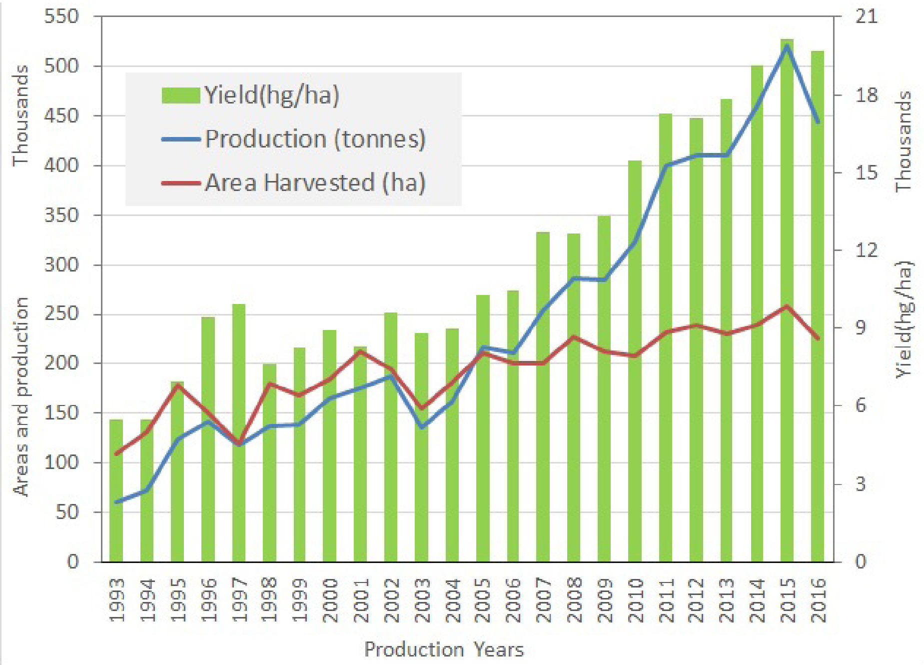
3.2. Chickpea (*Cicer arietinum* L)

There are two types of chickpea produced globally including in Ethiopia, namely; desi and kabuli chickpeas. Kabuli chickpea has larger size cream-colored seed with a thin seed coat, whereas the desi type has a smaller size, mostly reddish brown-colored seed (but varying from black to reddish brown) with a thick seed coat. On average, chickpea production globally consists of about 75% of desi and 25% of kabuli types (Agricultural and Agri-food Canada 2004).

Ethiopia is the largest producer of chickpea in Africa and is ranked fifth globally in 2017 (FAOSTAT 2019). Figure 2 shows the trends in area, production, and productivity of chickpea in Ethiopia. According to FAOSTAT (2018), chickpea area has increased from 109,750 ha in 1993 to 225,608 ha in 2016 with an increase in production from 60,085 tons to 444,146 tons at an increase in productivity from 0.547 tons to 1.97 tons ha^{-1}. This shows an increment of 105.6%, 639.2% and 259.6% in area harvested, production and productivity, respectively. For chickpea, potential (favorable) environments include mid to high altitude areas ranging from 1500-2400 masl (meters above sea level) that receive 700-1200 mm annual rainfall. Moisture stress environments represent low to mid-altitude ranging from 700-1500 masl receiving less rainfall annually with relatively moisture deficit during the growing periods. Chickpea can be grown on different soil types if good drainage is ensured. Well-aerated sandy to sandy loam soils and black cotton soils with a pH

Chickpea seed production © ICARDA

Figure 2. Area harvested, production and productivity of chickpea in Ethiopia.



Note: hg is hectogram; one hectogram is equivalent to 100 g. Source: FAOSTAT (2018).

ranging from 5 to 7, or even higher, are suitable but salinity and sodicity should be avoided. However, to achieve optimum growth, well-drained black soils (usually Vertisols) are considered as the most suitable soil type (EIAR 2017).

In Ethiopia, chickpea with thousand seed weight (TSW) below 200 g is considered as small; between 200-380 g is medium; and greater than 380 g is considered as large seeded. Chickpea varieties released between 1990 and 2000 showed an increase in seed weight of 31.9% and 12% for kabuli and desi, respectively. Remarkable progress has been achieved in genetic gain for seed size in the chickpea breeding program because of the primary focus on the development of large-seeded kabulis due to world market demand (Bekele et al. 2015). Seed size is the most important quality trait for Kabuli types as larger seeds fetch higher premium price in international trade (Gaur et al. 2007).

3.2.1. Crop level land suitability for chickpea

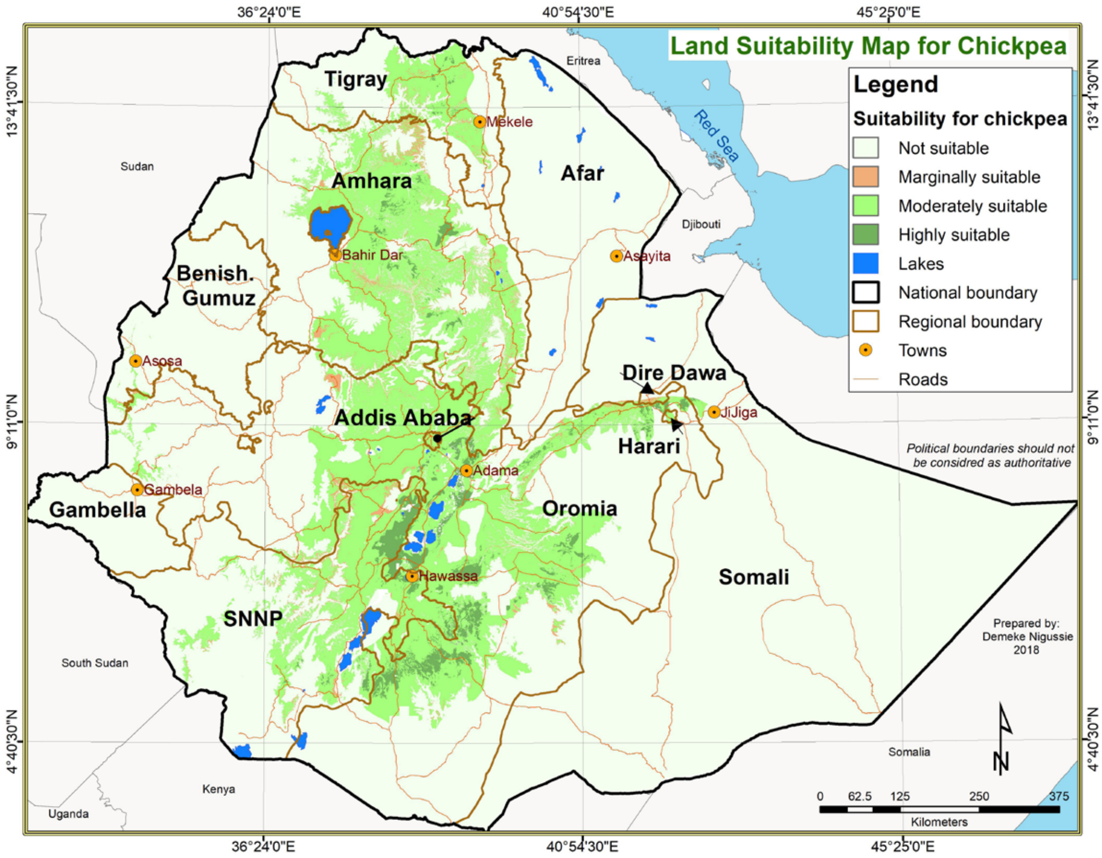
The crop level suitability analysis results for chickpea are shown in Figure 3 and Table 6. The results of this analysis show that the highly and moderately suitable areas are wider than that of most of the individual variety level suitability analysis. This is with the exception of Mastewal and Habru that have moderately suitable lands bigger than the crop level area, and Ararti and Kasech that have highly suitable areas. Even though the chickpea varieties are released for specific adaptation areas, they are adapted from lowland to highlands due to their phenological elasticity. Likewise, the varieties developed for short season/moisture stress areas are also adapted from mid to high altitudes for exploiting favorable environments. However, the crop level highly suitable land areas of chickpea are still larger than the highly suitable land area for most individual varieties. This is expected because the environmental range boundaries for the different suitability class thresholds are defined considering broader ranges of adaptation to encompass the adaptation ranges of most of the varieties currently available.

3.2.2. Variety level land suitability for chickpea

Mastewal (ICCV-92006)

Mastewal is a desi type chickpea variety introduced from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and tested and released by Debre Berhan Agricultural Research Center of Amhara Region Agricultural Research Institute (ARARI) in 2006. This variety yields, on average, 3.0 and 1.9 tons ha^{-1} in research and farmers' fields, respectively (MoARD 2006). It has a medium seed size (TSW of 240 g) in comparison with the chickpea varieties released before Mastewal

Figure 3. Land suitability map for chickpea.



Source: Nigussie (2018).

Table 6. Area of land under different suitability classes for chickpea by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	206,884	1.34	6,759,484	43.66	394,688	2.55	8,122,488	52.46
Oromia	1,167,484	3.9	9,685,144	32.37	248,568	0.83	18,818,876	62.9
SNNP	406,908	3.83	3,605,024	33.94	187,052	1.76	6,422,968	60.47
Tigray	27,268	0.55	1,459,352	29.46	63,376	1.28	3,404,436	68.71
Afar	0	0	29,384	0.35	460	0.01	8,407,408	99.65
BSG	0	0	82,468	1.64	12,040	0.24	4,941,076	98.12
Gambella	0	0	1,888	0.06	44	0	2,990,684	99.94
Somali	0	0	111,588	0.32	2,312	0.01	34,697,740	99.67
Total	1,808,544	1.61	21,734,332	19.36	908,540	0.81	87,805,676	78.22

Source: Nigussie (2018).

Figure 4. Land suitability map for chickpea *var*. Mastewal.

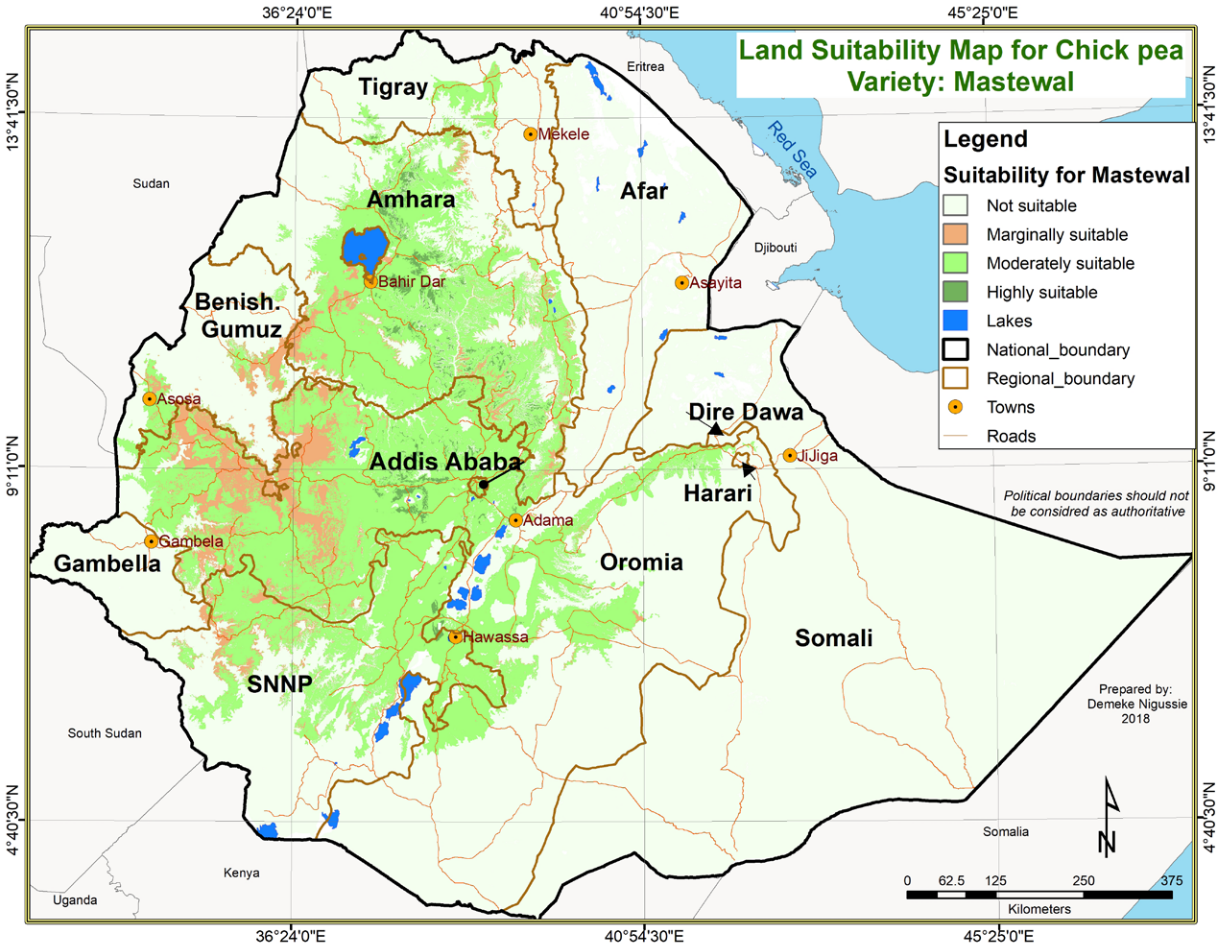


Table 7. Area of land under different suitability for Mastewal variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	419,300	2.69	7,603,708	48.86	677,736	4.35	6,862,625	44.09
Oromia	225,988	0.7	11,994,180	36.96	2,315,952	7.14	17,913,293	55.2
SNNP	20,584	0.18	4,862,344	43.07	410,092	3.63	5,996,966	53.12
Tigray	5,232	0.1	472,764	9.42	20,088	0.4	4,522,574	90.08
Afar	0	0	6,488	0.07	13,592	0.14	9,542,256	99.79
BSG	0	0	554,984	11.1	519,736	10.39	3,925,637	78.51
Gambella	0	0	15,520	0.6	33,044	1.29	2,521,572	98.11
Somali	0	0	5,264	0.02	1,088	0	31,555,613	99.98
Total	671,104	0.59	25,515,252	22.58	3,991,328	3.53	82,840,536	73.30

(Table 2). It is an early maturing variety and can be potentially used in double cropping in areas with a short rainy season (*belg*) or using supplemental irrigation. In the local market, it is preferred for its relatively larger seed size than the local varieties and for its light red color. The variety is relatively tolerant to wilt and root rot fungal diseases.

The variety level suitability analysis and mapping results for this variety are shown in Figure 4 and Table 7. When compared with the overall crop level suitability result of chickpea (Figure 3 and Table 6), the highly suitable lands are still smaller than that of the crop level suitability. The highly suitable lands are in the west-central highlands of Ethiopia largely found in parts of Amhara and Oromia and SNNP regional states. The moderately suitable and marginally suitable areas of Mastewal variety is mainly covering most of Amhara and Oromia, and central and northern SNNP.

Naatolii (ICCX-910112-6)

Naatolii is a desi chickpea variety developed and released by Debre Zeit Agricultural Research Center (DZARC) of EIAR in 2007. The grain yields ranged from 2.5-3.5 tons ha^{-1} in the research field (MoARD 2007). It is a high yielding and short duration chickpea variety resistant to fusarium wilt disease in waterlogging Vertisol areas. However, it is recommended to advance the planting date and drain excess water from the field. There are local and foreign market demands to meet producing chickpea varieties like Naatolii, although the supply is very limited as its production has not yet expanded. It has a local market preference due to its light golden seed color and medium seed size of 240g (Table 2). The variety level suitability analysis and mapping results for this variety are shown in Figure 5 and Table 8. The moderately suitable and highly suitable areas for this variety cover large parts of Amhara followed by mainly central Oromia. It covers also part of central Tigray and northern SNNP to a smaller extent. Compared with the overall (crop level) suitability result of chickpea, this variety has relatively smaller coverage.

Teketay (ICCX-940002-F5-242P-1-1-1)

Teketay is a desi chickpea variety developed and released by DZARC in 2013. This variety yields, on average, 2.0 to 2.7 and 1.6 to 2.2 tons ha^{-1} at research stations and on farmers' fields, respectively, with a medium seed size and an average TSW of 310 g (Table 2; MoA 2013). The observed yield potential on farmers' fields during the 2015-2018 ICARDA scaling project was by far higher than the yield reported for release, which was attributed to sub-optimal crop management and weather conditions in the selected test locations during nationwide testing for release.

The variety level suitability analysis and mapping results for this variety are shown in Figure 6 and Table 9. The result shows that the moderately and highly suitable areas for this variety cover large parts of east-central Amhara followed by central Oromia. It also covers a smaller part of central Tigray and northern SNNPR. Compared with the overall crop level suitability map of chickpea, it covers a relatively small area of suitable lands.

Arerti (FLIP 89-84C)

Arerti is a Kabuli chickpea variety introduced from ICARDA and released by DZARC in 1999/2000. This variety yields, on average, 1.6 to 5.2 and 1.8 to 4.7 tons ha^{-1} in research and farmers' fields, respectively, with 257 g of TSW (Table 2), being medium in seed size. It is widely grown in the country and is a dominant chickpea variety in production as the result of national level pre-scaling up activities by EIAR in addition to its merits.

The variety level suitability analysis and mapping results for this variety are shown in Figure 7 and Table 10. Compared with the overall crop level suitability result of chickpea, the highly and moderately suitable areas of Arerti variety is large, covering most of Amhara, Oromia, SNNPR and part of central Tigray. The result shows that the highly suitable areas are larger in Amhara region when compared with the crop level suitability maps and they are mainly found in central Amhara and Oromia. Highly suitable lands are larger than the crop level suitability, which is about 1.81 million ha, while that of Arerti variety is 2.29 million ha, which is the second largest next to Kasech with 2.4 million ha compared with other chickpea varieties analyzed.

Habru (FLIP-88-42C)

Habru is a kabuli chickpea variety introduced from ICARDA and released by DZARC in 2004. This variety yields, on average, 2.4 to3.2 tons ha^{-1} in research field with TSW of 319 g (Table 2; MoARD 2004), being medium in seed size, even though it has a relatively larger seed size than chickpea varieties considered,

Figure 5. Land suitability map for chickpea *var*. Naatolii.

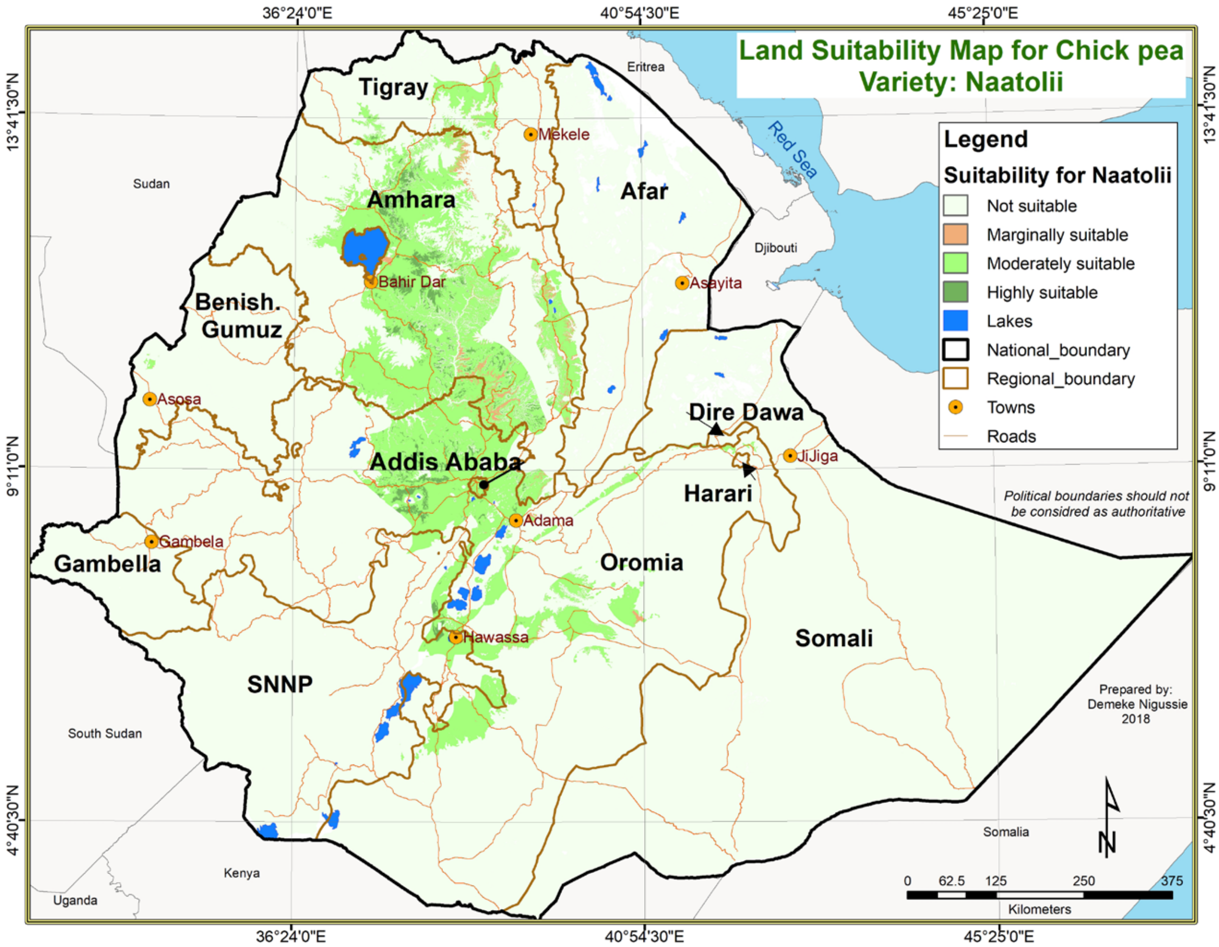


Table 8. Area of land under different suitability for Naatolii variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	453,120	2.91	5,733,520	36.84	276,976	1.78	9,099,753	58.47
Oromia	235,504	0.73	4,544,288	14	50,560	0.16	27,619,061	85.11
SNNP	20,580	0.18	544,856	4.83	1,156	0.01	10,723,394	94.98
Tigray	5,388	0.11	472,384	9.41	20,052	0.4	4,522,834	90.08
Afar	0	0	856	0.01	596	0.01	9,560,884	99.98
BSG	0	0	13,220	0.26	612	0.01	4,986,525	99.72
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	0	0	4,480	0.01	748	0	31,556,737	99.98
Total	714,592	0.63	11,313,604	10.01	350,700	0.31	100,639,324	89.05

Figure 6. Land suitability map for chickpea *var*. Teketay.

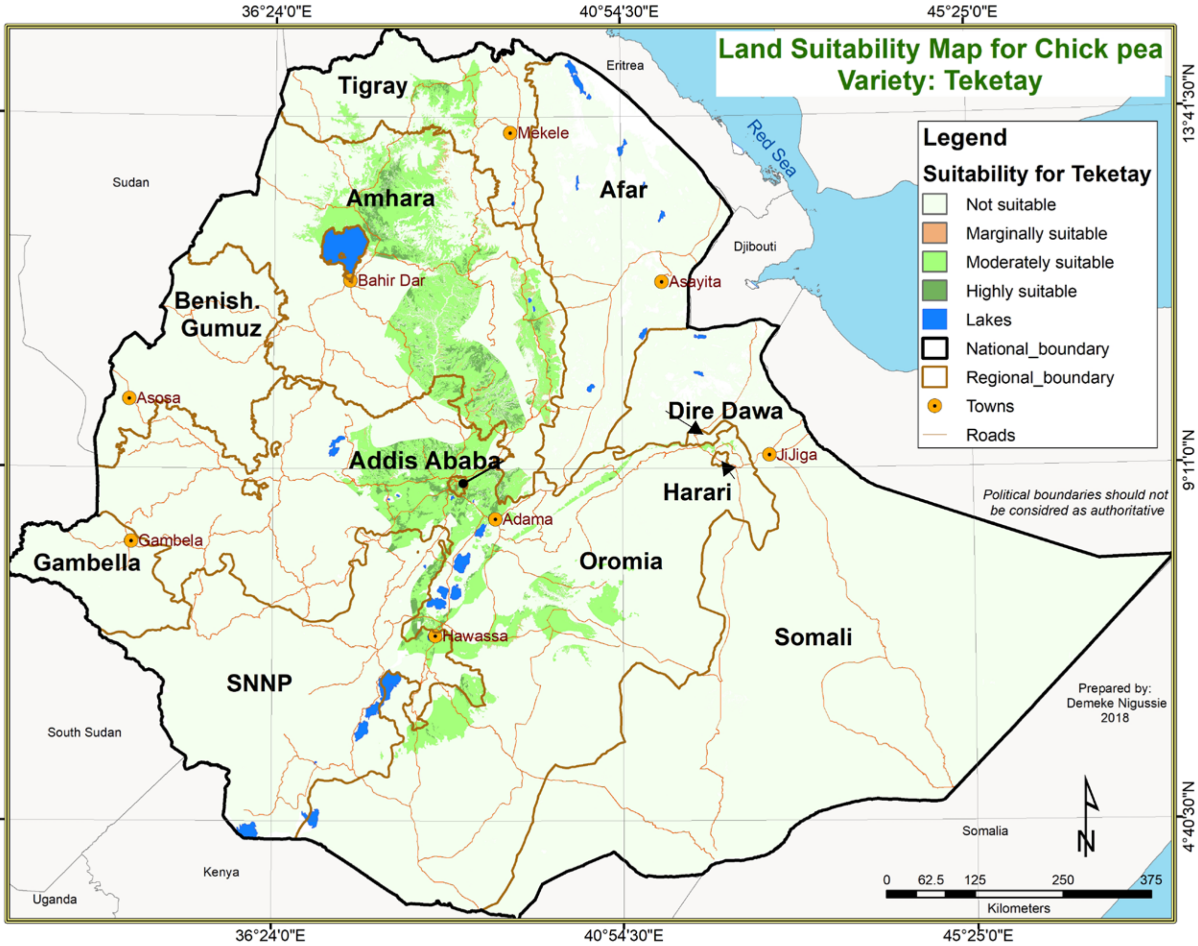


Table 9. Area of land under different suitability for Naatolii variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	714,396	4.59	7,640,040	49.09	346,308	2.23	6,862,625	44.09
Oromia	471,908	1.45	12,511,392	38.56	1,552,820	4.79	17,913,293	55.20
SNNP	160,792	1.42	4,748,356	42.06	383,872	3.40	5,996,966	53.12
Tigray	31,104	0.62	466,124	9.28	856	0.02	4,522,574	90.08
Afar	0	0.00	7,056	0.07	13,024	0.14	9,542,256	99.79
BSG	0	0.00	494,752	9.89	579,968	11.60	3,925,637	78.51
Gambella	0	0.00	20,292	0.79	28,272	1.10	2,521,572	98.11
Somali	0	0.00	5,840	0.02	512	0.00	31,555,613	99.98
Total	1,378,200	1.22	25.893,852	22.91	2,905,632	2.57	82,840,536	73.30

Figure 7. Land suitability map for chickpea *var*. Arerti.

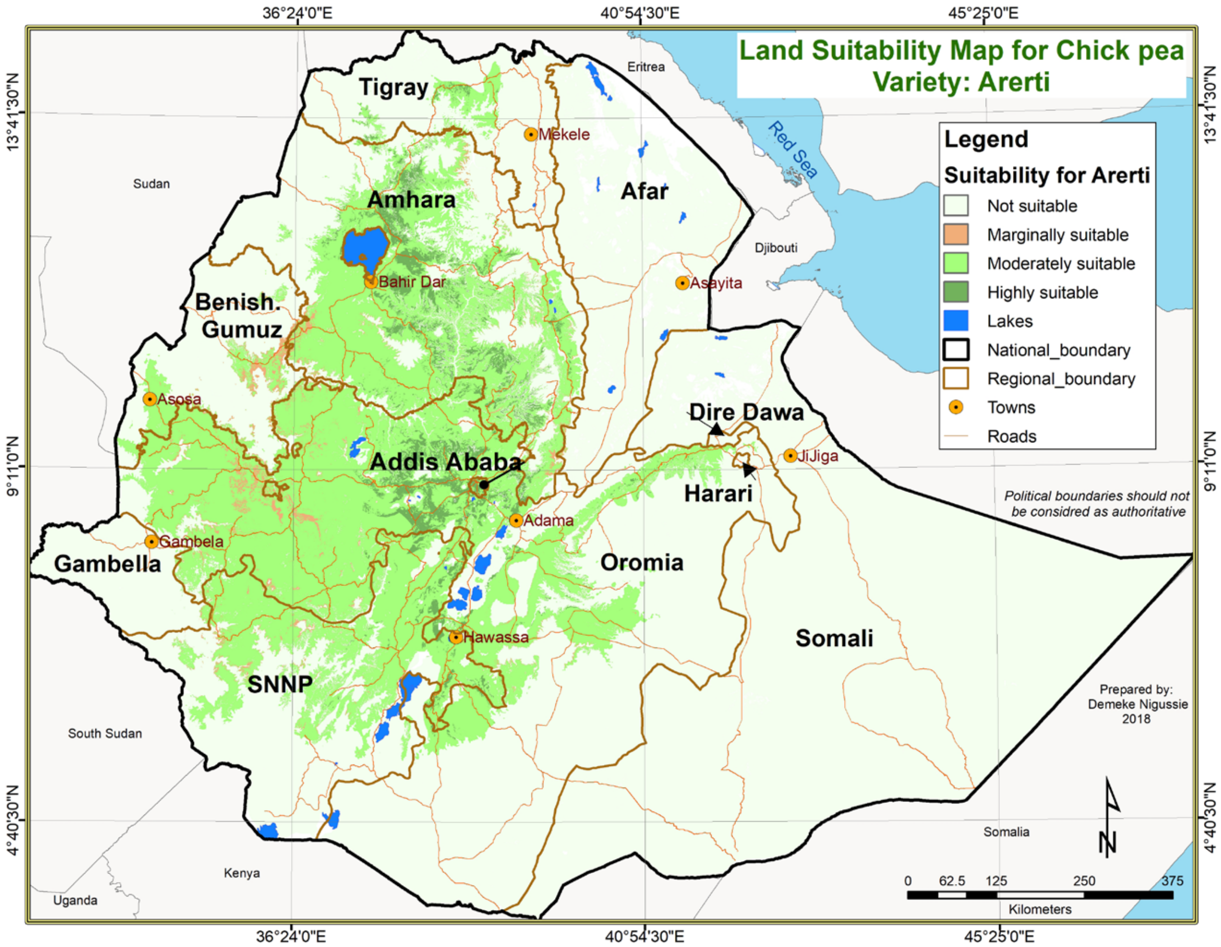


Table 10. Area of land under different suitability for Arerti variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	1,121,812	7.21	7,069,028	45.42	188,360	1.21	7,184,169	46.16
Oromia	940,676	2.9	12,995,936	40.05	377,828	1.16	18,134,973	55.89
SNNP	180,972	1.6	4,962,804	43.96	117,688	1.04	6,028,522	53.4
Tigray	44,156	0.88	449,700	8.96	784	0.02	4,526,018	90.15
Afar	0	0	8,612	0.09	11,468	0.12	9,542,256	99.79
BSG	0	0	852,780	17.05	221,940	4.44	3,925,637	78.51
Gambella	0	0	42,756	1.66	5,808	0.23	2,521,572	98.11
Somali	0	0	5,800	0.02	552	0	31,555,613	99.98
Total	2,287,616	2.02	26,387,416	23.35	924,428	0.82	83,418,760	73.81

Figure 8. Land suitability map for chickpea *var*. Habru.

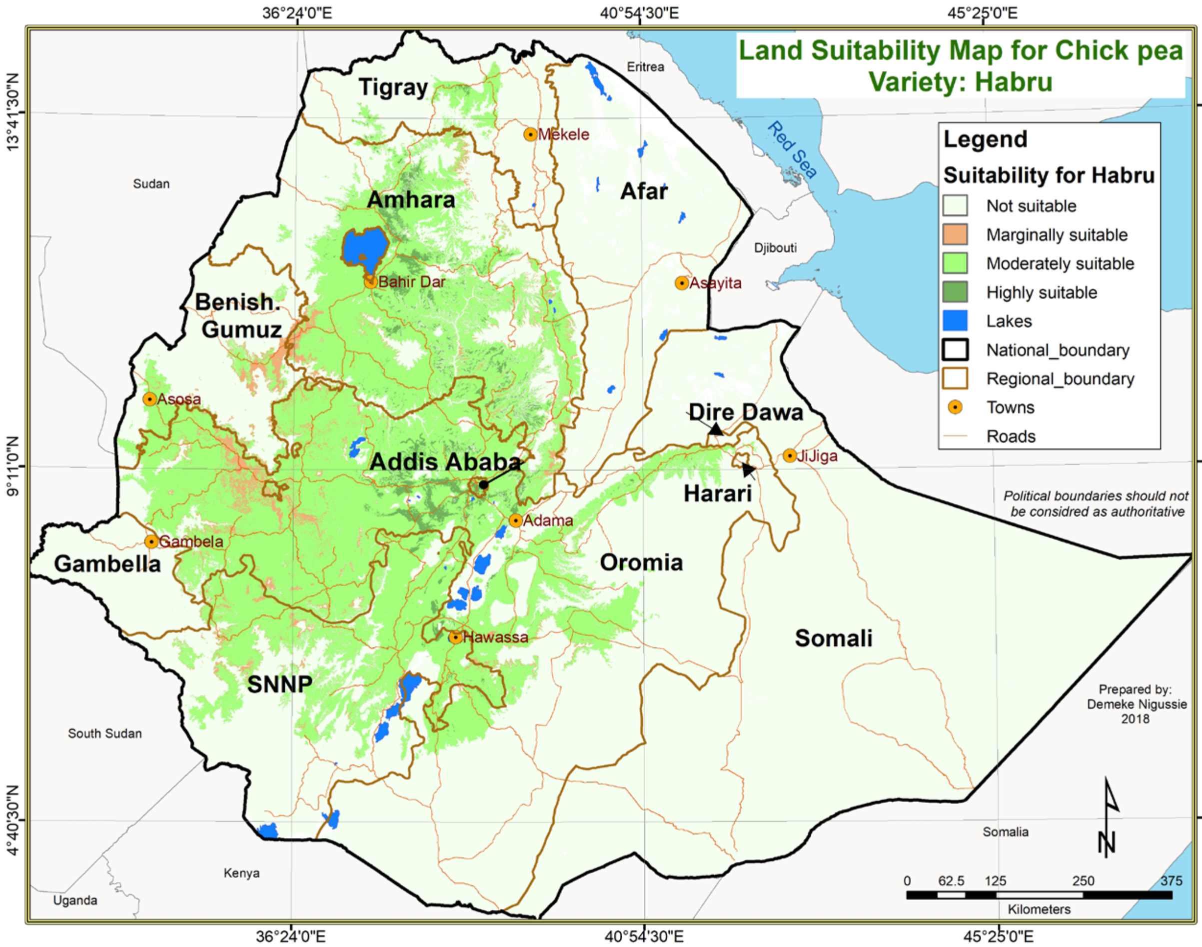


Table 11. Area of land under different suitability for Habru variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	640,304	4.11	7,358,364	47.28	380,532	2.45	7,184,169	46.16
Oromia	570,968	1.76	12,947,872	39.9	778,932	2.4	18,151,641	55.94
SNNP	58,832	0.52	4,985,464	44.16	217,168	1.92	6,028,522	53.4
Tigray	23,372	0.47	465,844	9.28	5,424	0.11	4,526,018	90.15
Afar	0	0	5,984	0.06	14,096	0.15	9,542,256	99.79
BSG	0	0	755,380	15.11	319,340	6.39	3,925,637	78.51
Gambella	0	0	40,912	1.59	7,652	0.3	2,521,572	98.11
Somali	0	0	5,532	0.02	820	0	31,555,613	99.98
Total	1,293,476	1.14	26,565,352	23.51	1,723,964	1.53	83,435,428	73.82

except Yelbey, in this land suitability analysis. It has got wide adaptation and is a dominant variety as a result of national level pre-scale up activities by EIAR in addition to its biological merits, such as better performance in both moisture stress and mid to high altitude areas. This variety is moderately resistant to wilt.

Compared with the overall crop level suitability result of chickpea, shown in Figure 3 and Table 6, the suitable areas of Habru variety (see Figure 8 and Table 11) is large, covering most of Amhara, Oromia, SNNP and part of central Tigray. The result shows that the highly suitable areas are larger in Amhara region when compared with the crop level suitability maps and they are mainly found in central Amhara and Oromia. Highly suitable areas are still large in the crop level suitability which is about 1.8 million ha, while that of Habru variety is 1.29 million ha which is the third largest compared with other chickpea varieties.

Kasech (FLIP-95-31C)

Kasech is a kabuli chickpea germplasm introduced from ICARDA and released by the Sirinka Agricultural Research Center (SARC) of ARARI in 2011. This variety yields, on average, 2.0 to2.5 and 1.6 to2.0 tons ha^{-1} in research and farmers' field, respectively, with a TSW of 275g (Table 2; MoA 2011). Even though it is low yielding, Kasech is an early maturing variety which is well adapted to moisture stress areas.

The variety level suitability analysis and mapping results for this variety are shown in Figure 9 and Table 12. The variety has the largest highly suitable land (2.395 million ha) compared with both the crop and variety level suitability analysis results. These areas are found in Amhara to a relatively large extent followed by Oromia, Tigray and SNNP. The combined highly suitable and moderately suitable areas of the Kasech variety is, however, still smaller than the crop level suitability and other varieties considered in this analysis.

Yelbey (ICCV-14808)

Yelbey is a kabuli chickpea germplasm introduced from ICRISAT and tested and released by SARC of ARARI in 2006. This variety yields, on average, 1.8 and 1.4 tons ha^{-1} in research and farmers' fields, respectively, with a TSW of 355 g (Table 2; MoARD 2006). It is medium seed size chickpea, though with the largest seed size among the varieties used for land suitability analysis in this work. It is relatively resistant to wilt and root rot. Although its productivity is low, it is early maturing and well adapted to moisture stress areas.

Compared with the overall crop level suitability result of chickpea, shown in Figure 3 and Table 6, the suitable areas of Yelbey variety are smaller than that of the crop level results, mostly covering the central highlands of the country; stretching from most of central Tigray, central and west of Amhara, central Oromia to large parts of northern SNNP (Figure 10 and Table 13). The results show that the highly suitable areas are the fourth largest (1.22 million ha), when compared with the variety level suitability results and they are found in Amhara to a relatively large extent followed by Oromia and SNNP.

Summary of potential suitable areas and major administrative zones

The major administrative zones with highly suitable (S_1) and moderately suitable (S_2) land areas take the large proportion for chickpea varieties (Table 14). For each variety, fifteen zones are listed in decreasing order of suitable areas for S_1 and S_2.

Figure 9. Land suitability map for chickpea *var*. Kasech.

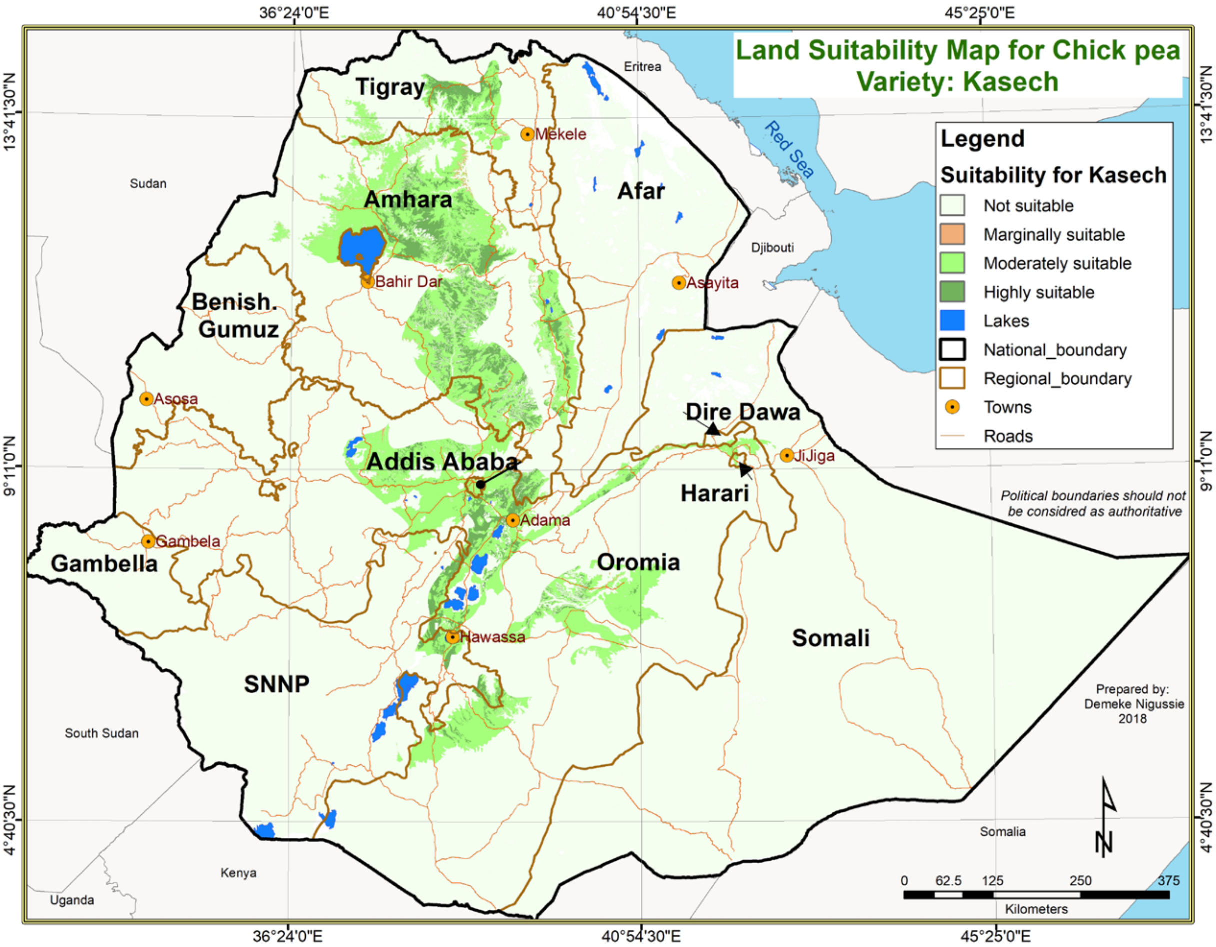


Table 12. Area of land under different suitability for Kasech variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	1,366,880	8.78	4,255,224	27.34	59,320	0.38	9,881,945	63.49
Oromia	587,344	1.81	4,441,420	13.69	23,752	0.07	27,396,897	84.43
SNNP	200,124	1.77	323,188	2.86	128	0	10,766,546	95.36
Tigray	240,732	4.79	568,680	11.33	3,620	0.07	4,207,626	83.81
Afar	0	0	2,740	0.03	184	0	9,559,412	99.97
BSG	0	0	0	0	0	0	5,000,357	100
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	60	0	24,360	0.08	3,244	0.01	31,534,301	99.91
Total	2,395,140	2.12	9,615,612	8.508	90,248	0.08	100,917,220	89.29

Figure 10. Land suitability map for chickpea *var*. Yelbey.

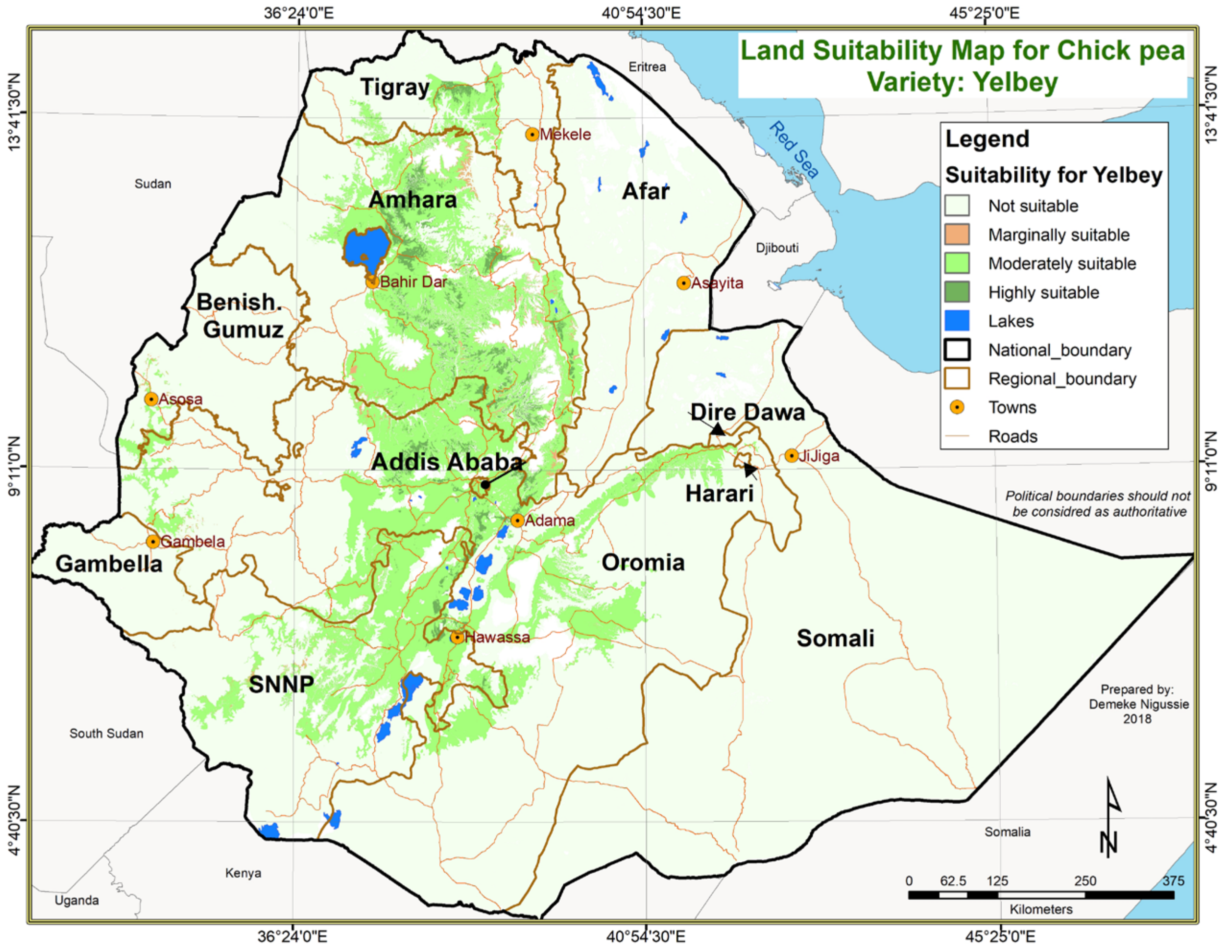


Table 13. Area of land under different suitability for Yelbey variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	764,752	4.91	6,053,652	38.9	221,004	1.42	8,523,961	54.77
Oromia	303,224	0.93	6,683,624	20.6	52,672	0.16	25,409,893	78.31
SNNP	66,468	0.59	3,520,984	31.19	46,832	0.41	7,655,702	67.81
Tigray	88,532	1.76	630,236	12.55	4,832	0.1	4,297,058	85.59
Afar	16	0	8,888	0.09	11,888	0.12	9,541,544	99.78
BSG	0	0	147,912	2.96	20,068	0.4	4,832,377	96.64
Gambella	0	0	3,056	0.12	1,448	0.06	2,565,632	99.82
Somali	0	0	6,172	0.02	180	0	31,555,613	99.98
Total	1,222,992	1.08	17,054,524	15.09	358,924	0.32	94,381,780	83.51

Table 14. Land suitability for chickpea varieties.

Varieties	Suitability classes	Area (ha)	Major administrative zones
1. Mastewal	S_1	671,104	South Gonder, West Shewa, North Gonder, East Gojam, South Wollo, South West Shewa, North Shewa of Amhara Region, North Shewa of Oromia Region, West Arsi, West Gojam, Alaba, Sidama, East Shewa, Western, Arsi
	S_2	25,515,252	Jimma, North Gonder, West Shewa, East Gojam, South Wollo, West Gojam, North Shewa of Amhara Region, Arsi, Ilubabor, North Shewa of Oromia Region, South Gonder, East Wellega, West Arsi, Keffa, Bale
2. Naatolii	S_1	714,592	South Gonder, West Shewa, North Gonder, East Gojam, South West Shewa, South Wollo, North Shewa of Amhara Region, North Shewa of Oromia Region, West Arsi, West Gojam, Alaba, Sidama, East Shewa, Western, Arsi
	S_2	11,313,604	North Gonder, East Gojam, West Shewa, South Gonder, North Shewa of Oromia Region, South Wollo, North Shewa of Amhara Region, West Gojam, Bale, East Shewa, South West Shewa, North Wollo, Guji, West Arsi, Arsi
3. Teketay	S_1	1,378,200	South Gonder, West Shewa, North Gonder, South Wollo, North Shewa of Amhara Region, East Shewa, South West Shewa, North Shewa of Oromia Region, Sidama, East Gojam, West Arsi, North Wollo, Gurage, Selti, Arsi
	S_2	25,893,852	Jimma, North Gonder, West Shewa, Ilubabor, West Gojam, East Gojam, South Wollo, North Shewa of Amhara Region, Arsi, East Wellega, North Shewa of Oromia Region, South Gonder, West Wellega, West Arsi, Keffa
4. Arerti	S_1	2,287,616	West Shewa, South Gonder, North Gonder, South West Shewa, South Wollo, East Gojam, North Shewa of Amhara Region, North Shewa of Oromia Region, East Shewa, West Arsi, North Wollo, Gurage, West Gojam, Region 14, Sidama
	S_2	26,387,416	West Gojam, North Gonder, East Gojam, South Gonder, North Shewa of Oromia Region, West Shewa, South Wollo, North Shewa of Amhara Region, Bale, Guji, East Shewa, West Arsi, Arsi, North Wollo, Sidama
5. Habru	S_1	1,293,476	West Shewa, South Gonder, South West Shewa, North Gonder, North Shewa of Amhara Region, South Wollo, East Gojam, East Shewa, North Shewa of Oromia Region, Region 14, West Gojam, North Wollo, Gurage, West Arsi, Sidama
	S_2	26,565,352	Jimma, Ilubabor, North Gonder, East Wellega, West Gojam, West Shewa, East Gojam, South Wollo, West Wellega, Arsi, North Shewa of Oromia Region, North Shewa of Amhara Region, South Gonder, Keffa, West Arsi

Varieties	Suitability classes	Area (ha)	Major administrative zones
6. Kasech	S_1	2,395,140	South Gonder, South Wollo, North Shewa of Amhara Region, East Shewa, North Gonder, North Wollo, Central, North Western, West Harerge, Sidama, East Gojam, Arsi, West Arsi, Selti, Wag Himra
	S_2	9,615,612	Jimma, North Gonder, Ilubabor, West Shewa, East Wellega, West Wellega, West Gojam, Bale, East Gojam, South Gonder, Arsi, Keffa, North Shewa of Oromia Region, Kelem Wellega, Gamo Gofa
7. Yelbey	S_1	1,222,992	North Gonder, South Gonder, North Shewa of Amhara Region, West Shewa, South Wollo, East Shewa, East Gojam, North Wollo North Western, Central, North Shewa of Oromia Region, West Arsi, Sidama, Oromia, Selti
	S_2	17,054,524	North Gonder, West Shewa, East Gojam, South Wollo, South Gonder, North Shewa of Amhara Region,North Shewa of Oromia Region ,Arsi, Bale, Jimma, Gamo Gofa,South West Shewa, Gurage, West Gojam, Sidama

3.3. Faba bean (*Vicia faba* L.)

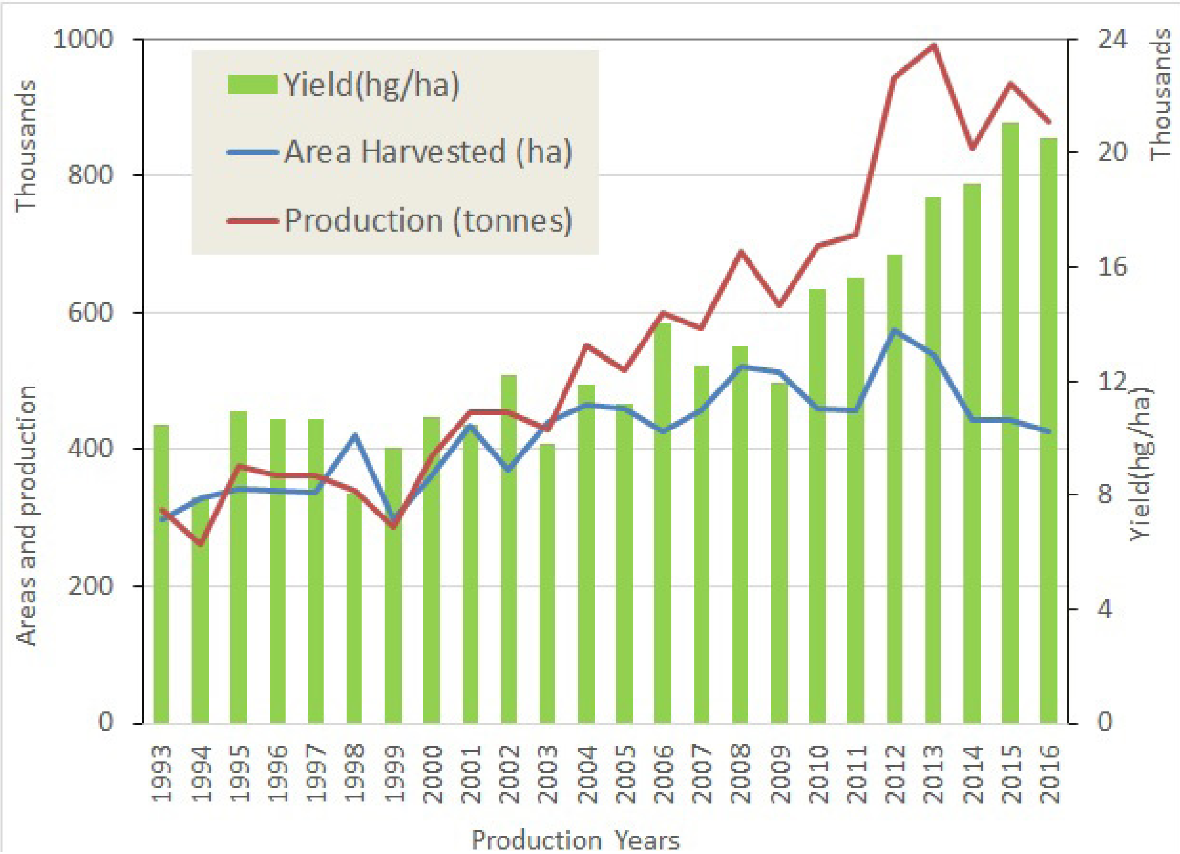
Faba bean is one of the important legume crops in the highlands of Ethiopia, which is considered the second largest center of crop diversity after Afghanistan. Ethiopia is also one of the major faba bean producing countries in the world, next to China (Tafere et al. 2012; Ermias and Addisu 2013). Figure 11 shows the trends in area harvested, production and productivity of faba bean. According to FAOSTAT (2018), the production area for faba bean has increased from 298,490 ha in 1993 to 427,697 ha in 2016 with an increase in production from 312,405 tons to 878,010 tons with a productivity increase from 1.05 tons to 2.05 tons ha^{-1}. This shows an increment of 43.3%, 181.1% and 96.15% in area harvested, production and productivity, respectively. Large seed size is considered as an important seed quality for better market demand and value. According to ICARDA, faba bean varieties are grouped into three seed size categories based on TSW as large (> 1200 g), medium (700-1200 g) and small (< 700 g). However, in Ethiopia, the classification based on TSW is slightly different: large (> 800 g), medium (500-800 g); and small (< 500 g).


Faba bean seed production © ICARDA

3.3.1. Crop level land suitability for faba bean

The crop level suitability analysis results are presented in Figure 12 and Table 15. The results show that the areas for different suitability classes of faba bean are larger

Figure 11. Area harvest, production and productivity of faba bean.



Note: hg is hectogram; one hectogram is equivalent to 100 g

Source: FAOSTAT (2018).

than that of most individual varieties. This is expected because the environmental range boundaries for the different suitability class thresholds are defined considering broader ranges of adaptation to encompass the adaptation ranges of most of the varieties currently available.

3.3.2. Variety level land suitability for faba bean

Dosha (Coll 155/00-3)

Dosha is a variety developed and released by Holleta Agricultural Research Center (HARC) of EIAR in 2009. This variety yields, on average, 2.8 to 6.2 and 2.3 to 3.9 tons ha^{-1} in research and farmers' fields, respectively (MoARC 2009). It has a TSW of 797 g, which is medium seed size, according to ICARDA classification, and other important agronomic traits are presented in Table 3. The variety is moderately resistant to chocolate spot and rust.

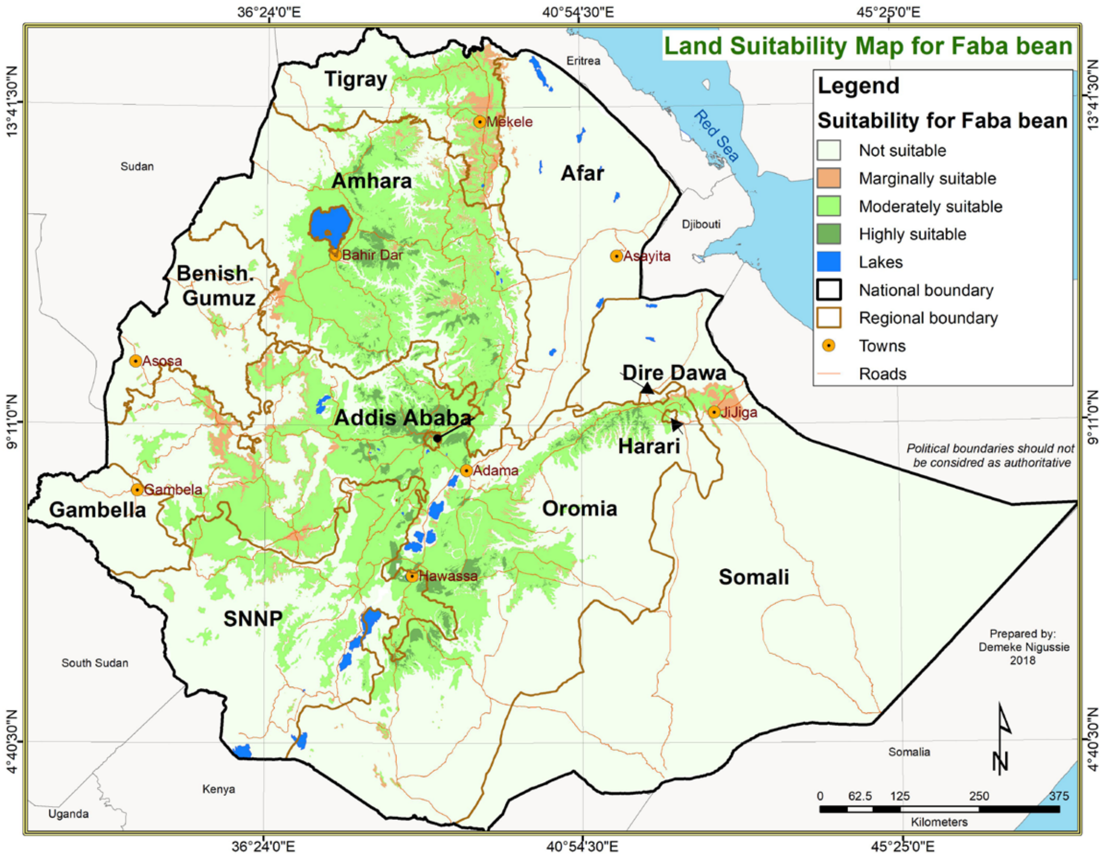
The suitability analysis and mapping results for this variety are shown in Figure 13 and Table 16. When compared with the overall (crop level) suitability map of faba bean shown in Figure 12 and Table 15, the suitable areas of Dosha variety is small, mostly covering western parts of Amhara and Oromia regional states.

Gabelcho (EH96009-1)

Gabelcho is a variety developed and released by HARC of EIAR in 2006. This variety yields, on average 2.5-6.1 and 2.0-3.0 tons ha^{-1} in research and farmers' fields, respectively (MoARD 2006), with a TSW of 797 g, being medium seed size. If surplus production is available, it can be used for export as it has specific market niches. Like most other varieties considered in the analysis, Gabelcho is also moderately resistant to chocolate spot and rust with a higher TSW next to Gora variety; it is released for soils with good drainage (Table 3).

The suitability analysis and mapping results for this variety are shown in Figure 14 and Table 17. When compared with the overall crop level suitability map of faba bean, the suitable areas of the Gabelcho variety is still small. Nevertheless, it has a wider area coverage

Figure 12. Land suitability map for faba bean.



Source: Nigussie (2018).

Table 15. Area of land under different suitability classes for faba bean.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	635,268	4.14	8,085,316	52.8	450,684	2.94	6,157,636	40.17
Oromia	1,080,008	3.62	10,241,276	34.3	844,448	2.83	17,675,972	59.23
SNNP	165,244	1.56	3,609,584	34.1	78,536	0.74	6,738,564	63.62
Tigray	1,908	0.04	1,552,112	31.5	522,676	10.6	2,855,468	57.89
Afar	0	0	17,780	0.21	82,980	0.99	8,238,976	98.79
BSG	0	0	98,088	1.96	59,432	1.19	4,855,040	96.86
Gambella	0	0	52,260	1.76	4,420	0.15	2,918,540	98.09
Somali	0	0	89,832	0.26	202,460	0.58	34,410,444	99.16
Total	1,882,428	1.67	23,746,248	21.01	2,245,636	1.99	83,850,640	74.19

Source: Nigussie (2018).

Figure 13. Land suitability map for faba bean *var*. Dosha.

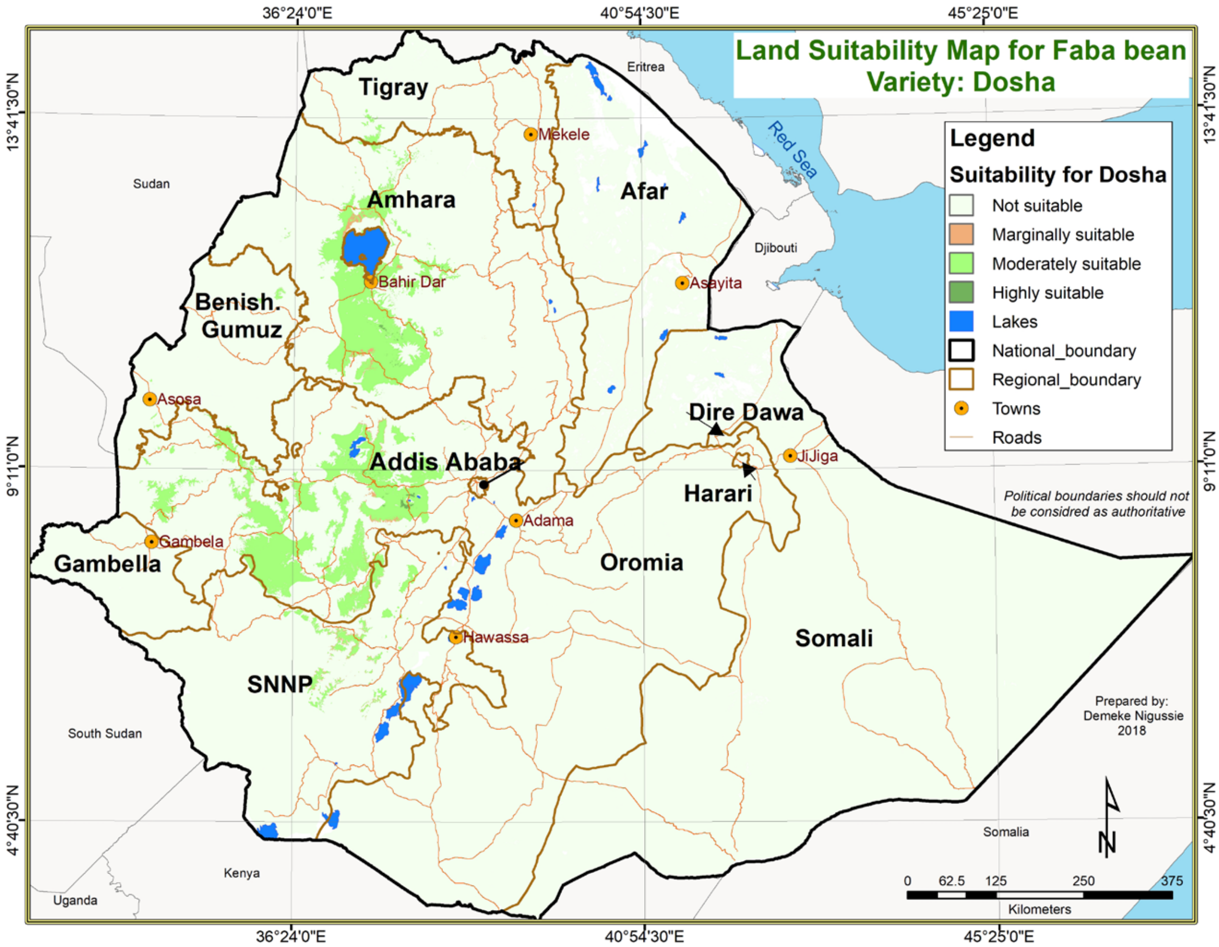


Table 16. Area of land under different suitability for Dosha variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	8,220	0.05	1,918,680	12.33	49,884	0.32	13,586,585	87.3
Oromia	15,348	0.05	2,691,584	8.29	50,908	0.16	29,691,573	91.5
SNNP	0	0	343,836	3.05	34,720	0.31	10,911,430	96.65
Tigray	100	0	40,460	0.81	0	0	4,980,098	99.19
Afar	0	0	0	0	0	0	9,562,336	100
BSG	4	0	26,996	0.54	0	0	4,973,357	99.46
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	23,672	0.02	5,021,556	4.44	135,512	0.12	107,837,480	95.42

Figure 14. Land suitability map for faba bean *var*. Gabelcho.

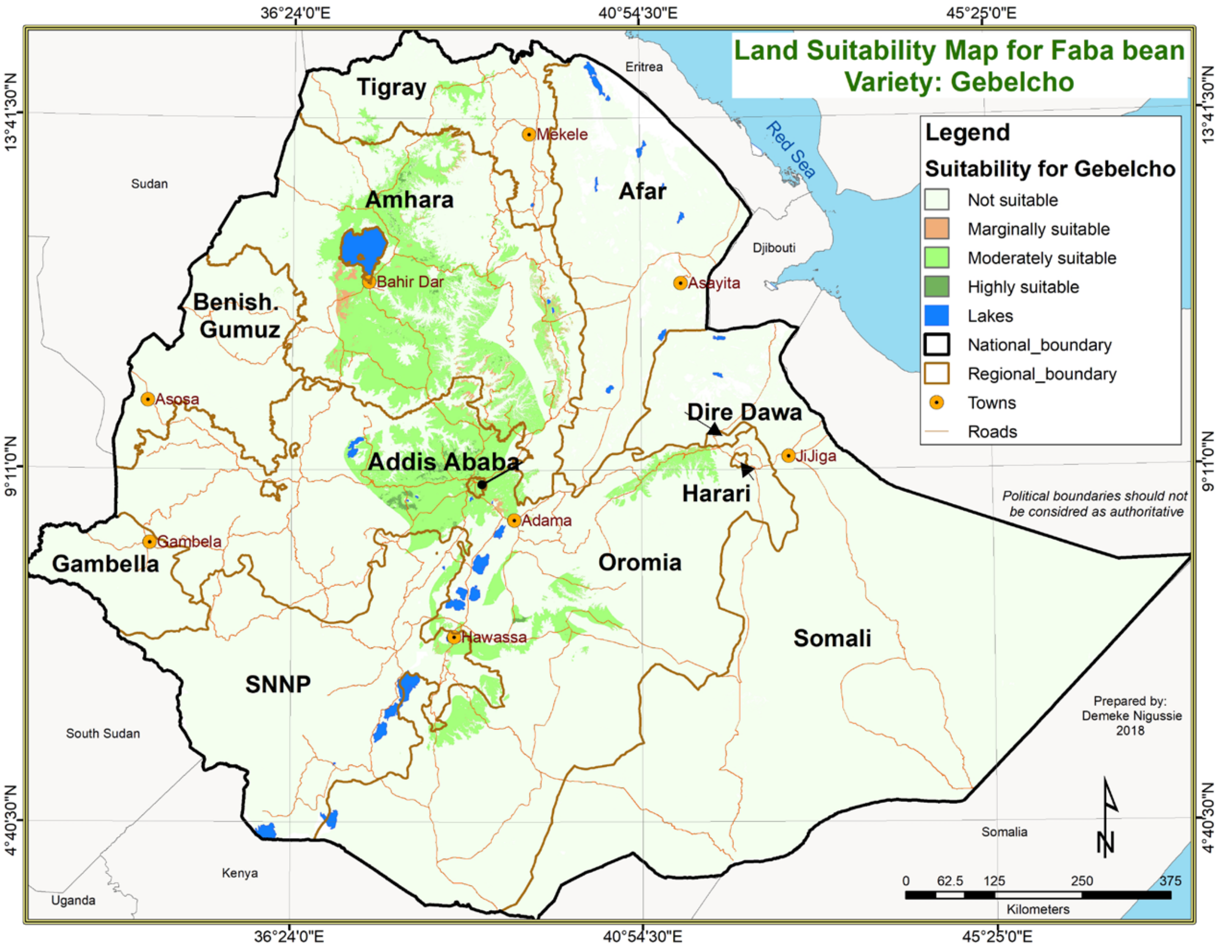


Table 17. Area of land under different suitability for Gabelcho variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	57,700	0.37	4,903,888	31.51	245,648	1.58	10,356,133	66.54
Oromia	131,300	0.4	3,895,960	12.01	52,472	0.16	28,369,681	87.43
SNNP	388	0	393,576	3.49	5,480	0.05	10,890,542	96.46
Tigray	3,448	0.07	213,644	4.26	1,452	0.03	4,802,114	95.65
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	2,372	0.05	220	0	4,997,765	99.95
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	0	0	168	0	96	0	31,561,701	100
Total	192,836	0.17	9,409,608	8.33	305,368	0.27	103,110,408	91.23

in Amhara and central Oromia, which are large parts of the central highlands, and extending to the Harerghie highlands in eastern parts of the country.

Gora (EK 01024-1-2)

Gora is a variety developed and released by Kulumsa Agricultural Research Center (KARC) of EIAR in 2013. This variety yields, on average, 2.2 to 5.7 and 2.0 to 4.0 tons ha^{-1} in research and farmers' fields, respectively, with a high TSW of 938 g (Table 3; MoA 20014). The variety is moderately resistant to chocolate spot and rust.

The suitability analysis and mapping results for this variety are shown in Figure 15 and Table 18. When compared with the overall crop level suitability map of faba bean shown in Figure 12 and Table 15, the suitable areas of Gora variety is small, mostly covering western parts of Amhara and Oromia, and northern parts of SNNP regional states.

Moti (EH95078-6)

Moti is a variety developed and released by HARC of EIAR in 2006. This variety yields, on average, 2.8 to 5.1 and 2.3 to 3.5 tons ha^{-1} in research and farmers' fields, respectively, with a TSW of 781 g (MoARD 2006). The variety is moderately resistant to chocolate spot and rust and matures early (Table 3), which means it is suitable to areas with a short cropping season that have moderate rainfall.

The variety level suitability analysis and mapping results for this variety are shown in Figure 16 and Table 19. When compared with the overall crop level suitability map of faba bean, the suitable areas of Moti variety is still small. However, it has a better area coverage in large parts of the central highlands and extends to the Harerghie highlands in the east and south-west of the country.

Dagm (Grarjarso 89-8)

Dagm is a variety developed and released by Debre Berhan Agricultural Research Center (DBARC) (ex Sheno Agricultural Research Center) of ARARI in 2002. This variety is released for Vertisols and is believed to perform better than other varieties on Vertisols using broad bed and furrows (BBF) drainage method, like Hachalu and Walki varieties which have also been released for Vertisols. Its adoption, however, is limited to heavy black soil and its promotion is low at national level. This variety yields, on average, 2.8 to6.2 tons ha^{-1} in research fields (NAIA 2003). It is small seeded with TSW of 300 g TSW (Table 3). The variety is highly tolerant to black root rot and chocolate spot. Due to its small seed size, it is sold in local markets to prepare popular dishes, such as shiro wot.

The variety level suitability analysis and mapping results for this variety are shown in Figure 17 and Table 20. When compared with the overall crop level suitability map of faba bean shown in Figure 12 and Table 15, the suitable areas of Dagm variety are very small, mostly covering western parts of Amhara and Oromia regions and small patches in SNNP region.

Hachalu (EH00102-4-1)

Hachalu is a variety developed and released by HARC of EIAR in 2010. This variety is also released for Vertisols and has performed better in grain yield and TSW than other varieties released by EIAR in previous years. However, it is less tolerant to waterlogging than Dagm. This variety yields, on average, 3.2 to 4.5 and 2.4 to 3.5 tons ha^{-1} in research and farmers' fields, respectively, having a medium seed size with TSW of 890 g (Table 3; MoA 2010). It has the largest seed size compared to other faba bean varieties released for Vertisols and those released, except Gora, for light soils. The variety is tolerant to black root rot, chocolate spot and rust.

The variety level suitability analysis and mapping results for this variety are shown in Figure 18 and Table 21. When compared with the overall crop level suitability map of faba bean, the suitable areas of Hachalu variety is small, mostly covering the western part of Amhara and Oromia regions and the northern part of SNNP region.

Walki (EH96049-2)

Walki is a variety developed and released by HARC of EIAR in 2008. This variety is also released for Vertisols. It yields, on average, 2.4-5.2 and 2.0-4.2 tons ha-1 at research and farmers' fields, respectively (MoARD 2008). Walki performs better on light Vertisols compared to varieties which need well-drained soil but should be supported by BBF on heavy Vertisols. It also performs well on drained soil even if it is released for Vertisols. Besides, it has a higher seed size with TSW 676 g compared to Dagm. The variety is moderately resistant to chocolate spot and rust.

Figure 15. Land suitability map for faba bean *var*. Gora.

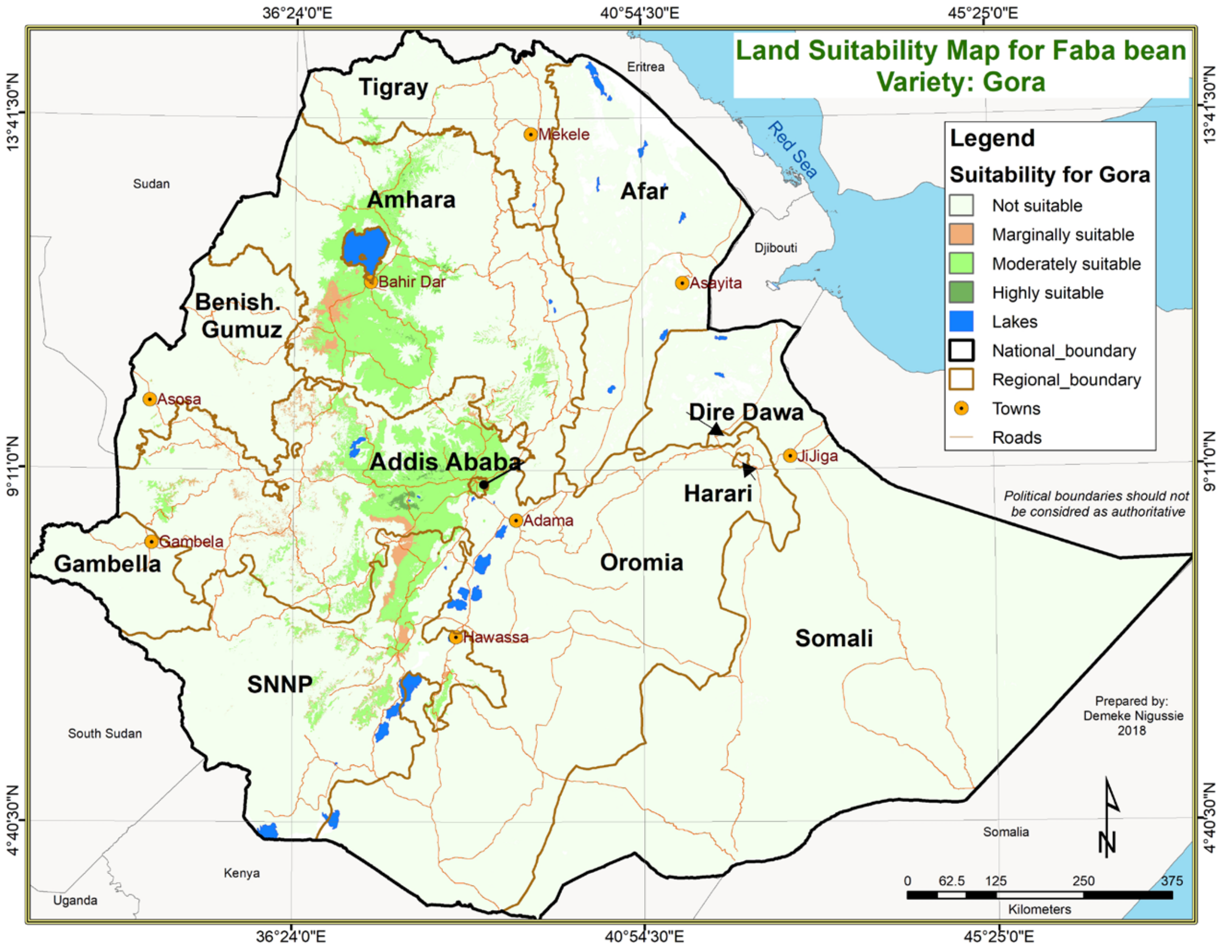


Table 18. Area of land under different suitability for Gora variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	28,916	0.19	3,293,744	21.16	250,416	1.61	11,990,293	77.04
Oromia	74,056	0.23	2,778,712	8.56	340,668	1.05	29,255,977	90.16
SNNP	0	0	1,024,368	9.07	271,180	2.4	9,994,438	88.52
Tigray	4,768	0.09	58,508	1.17	0	0	4,957,382	98.74
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	12,812	0.26	9,560	0.19	4,977,985	99.55
Gambella	0	0	4	0	4	0	2,570,128	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	107,740	0.10	7,168,148	6.34	871,828	0.77	104,870,504	92.79

Figure 16. Land suitability map for faba bean *var*. Moti.

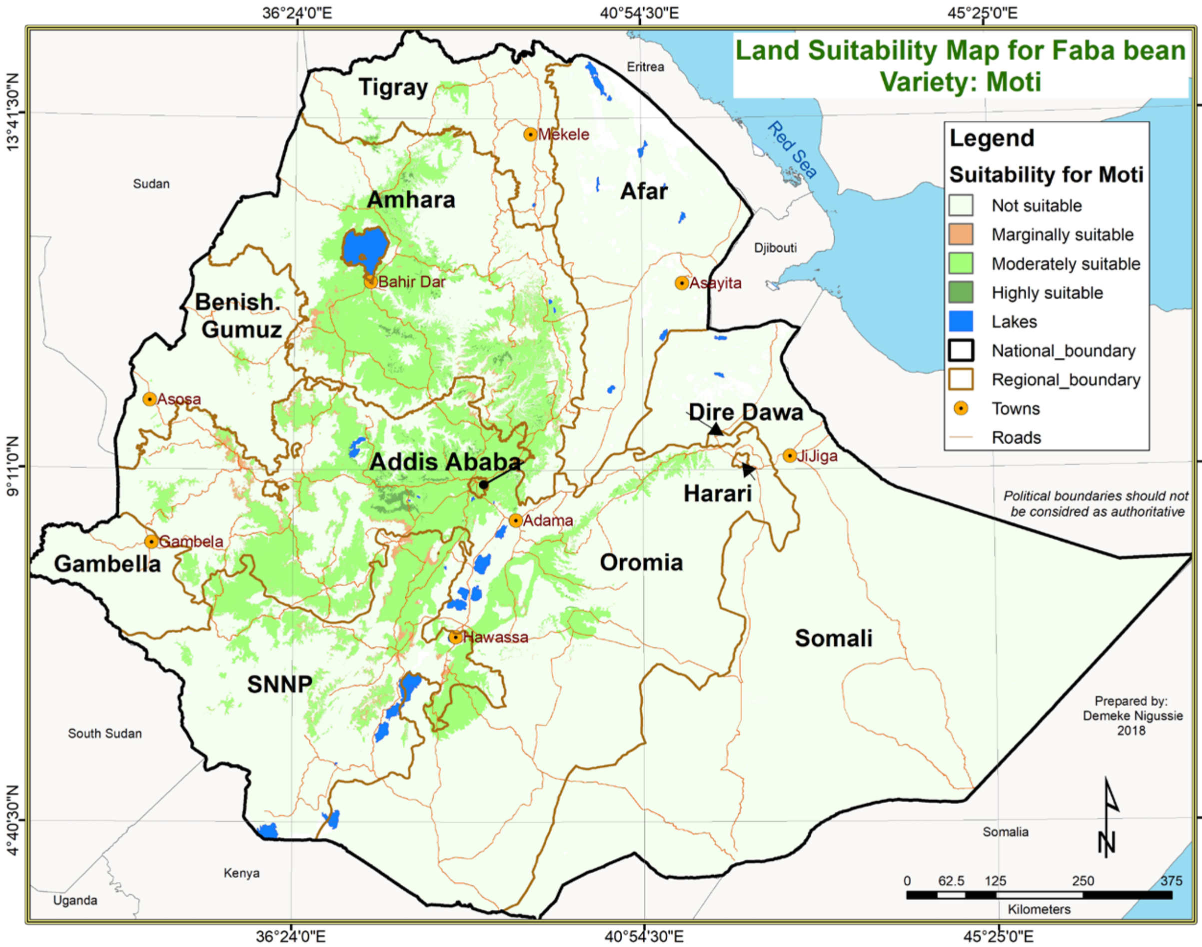


Table 19. Area of land under different suitability for Moti variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	132,888	0.85	5,495,292	35.31	163,120	1.05	9,772,069	62.79
Oromia	184,884	0.57	6,933,696	21.37	292,568	0.9	25,038,265	77.16
SNNP	0	0	2,613,396	23.15	208,688	1.85	8,467,902	75
Tigray	7,888	0.16	150,424	3	412	0.01	4,861,934	96.84
Afar	0	0	36	0	0	0	9,562,300	100
BSG	0	0	91,212	1.82	9,796	0.2	4,899,349	97.98
Gambella	0	0	6,244	0.24	4	0	2,563,888	99.76
Somali	0	0	0	0	0	0	31,561,965	100
Total	325,660	0.29	15,290,300	13.53	674,588	0.60	96,727,672	85.59

Figure 17. Land suitability map for faba bean *var*. Dagm.

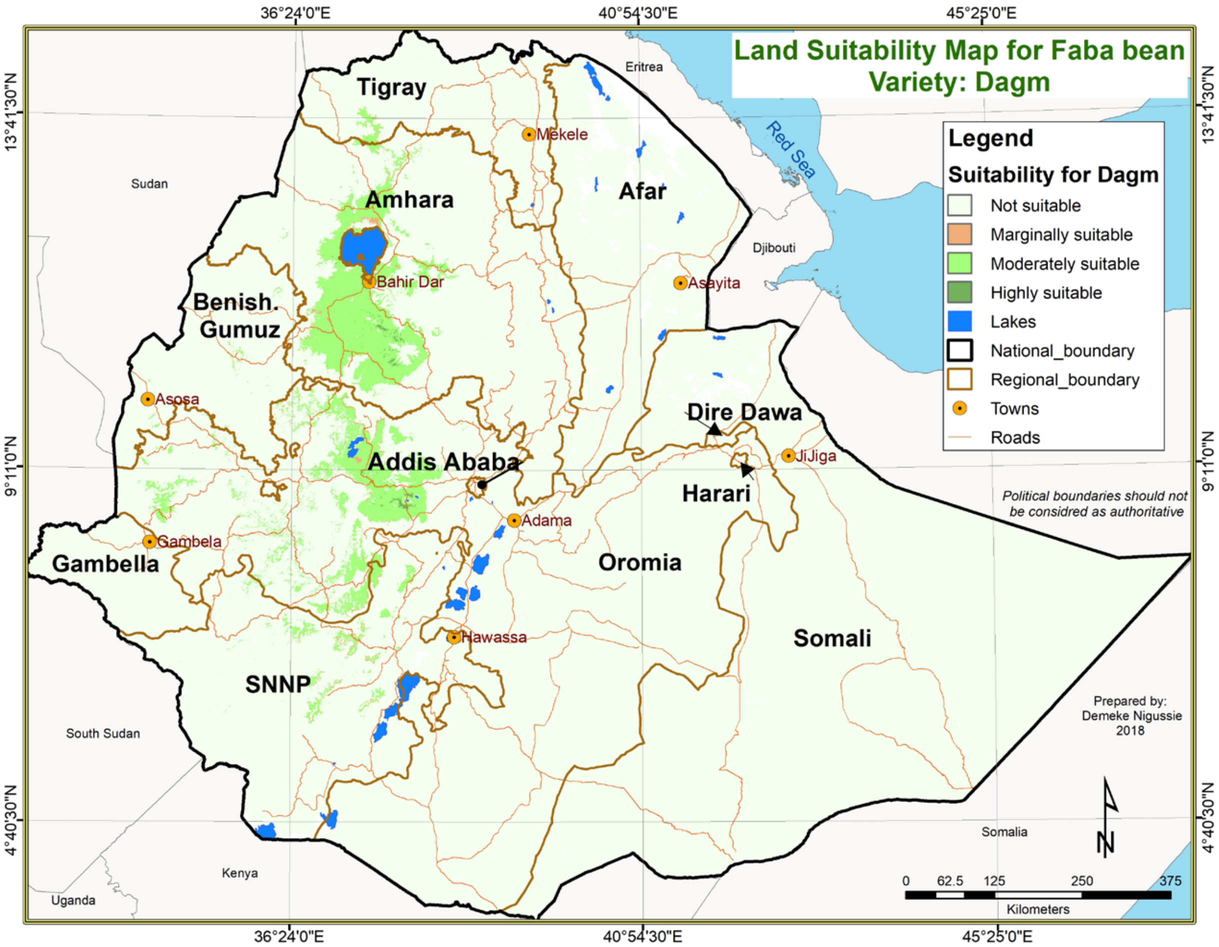


Table 20. Area of land under different suitability for Dagm variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	30,876	0.2	2,380,028	15.29	43,688	0.28	13,108,777	84.23
Oromia	22,776	0.07	1,827,616	5.63	47,568	0.15	30,551,453	94.15
SNNP	48	0	307,896	2.73	41,412	0.37	10,940,630	96.91
Tigray	268	0.01	68,704	1.37	5,220	0.1	4,946,466	98.52
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	25,592	0.51	2,848	0.06	4,971,917	99.43
Gambella	0	0	8	0	0	0	2,570,128	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	53,968	0.05	4,609,844	4.08	140,736	0.12	108,213,672	95.75

Figure 18. Land suitability map for faba bean *var*. Hachalu.

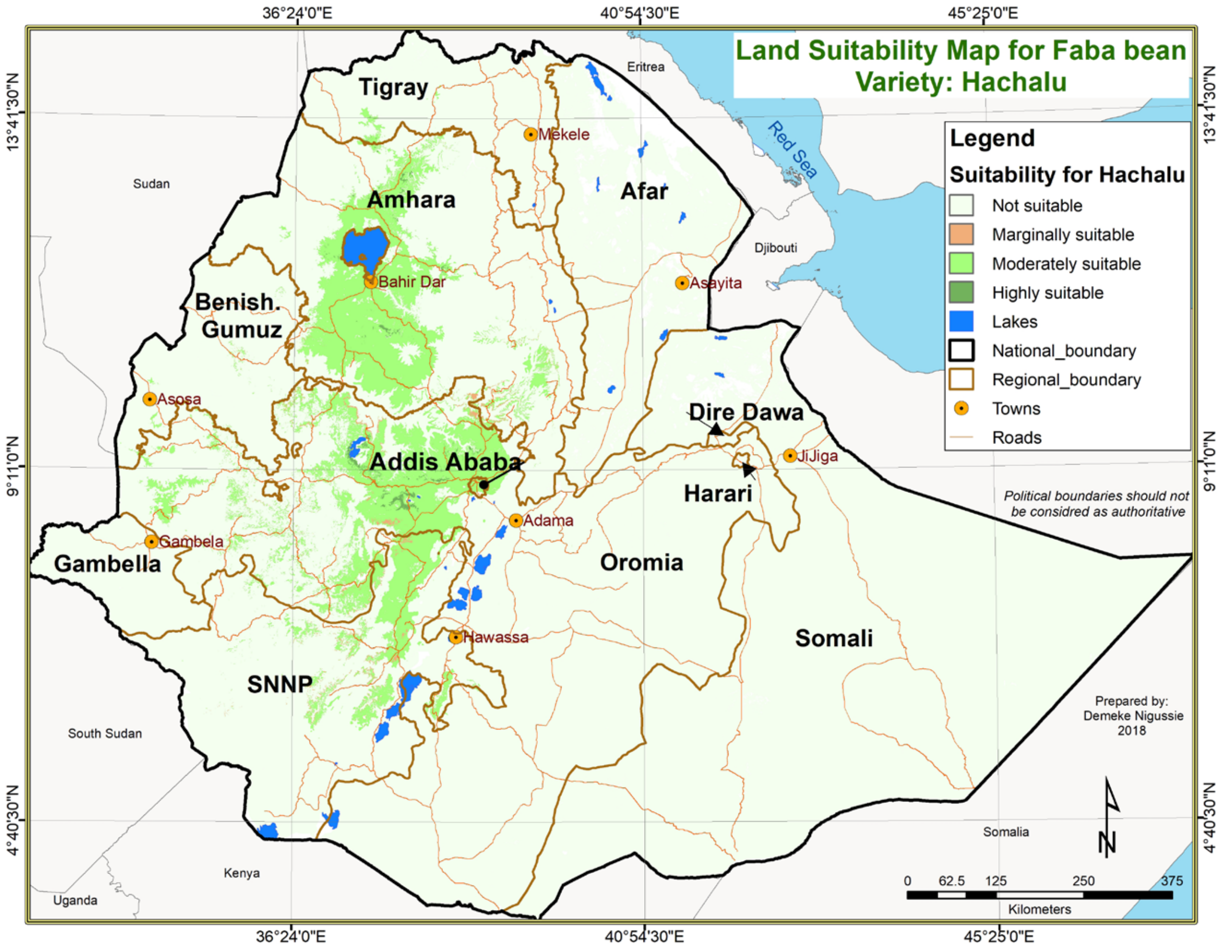


Table 21. Area of land under different suitability for Hachalu variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	37,860	0.24	3,754,940	24.13	28,756	0.18	11,741,813	75.45
Oromia	96,812	0.3	3,619,408	11.15	92,144	0.28	28,641,049	88.26
SNNP	52	0	1,352,132	11.98	75,620	0.67	9,862,182	87.35
Tigray	1,476	0.03	65,208	1.3	84	0	4,953,890	98.67
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	41,608	0.83	1,132	0.02	4,957,617	99.15
Gambella	0	0	96	0	0	0	2,570,040	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	136,200	0.12	8,833,392	7.82	197,736	0.17	103,850,892	91.89

Figure 19. Land suitability map for faba bean *var*. Walki.

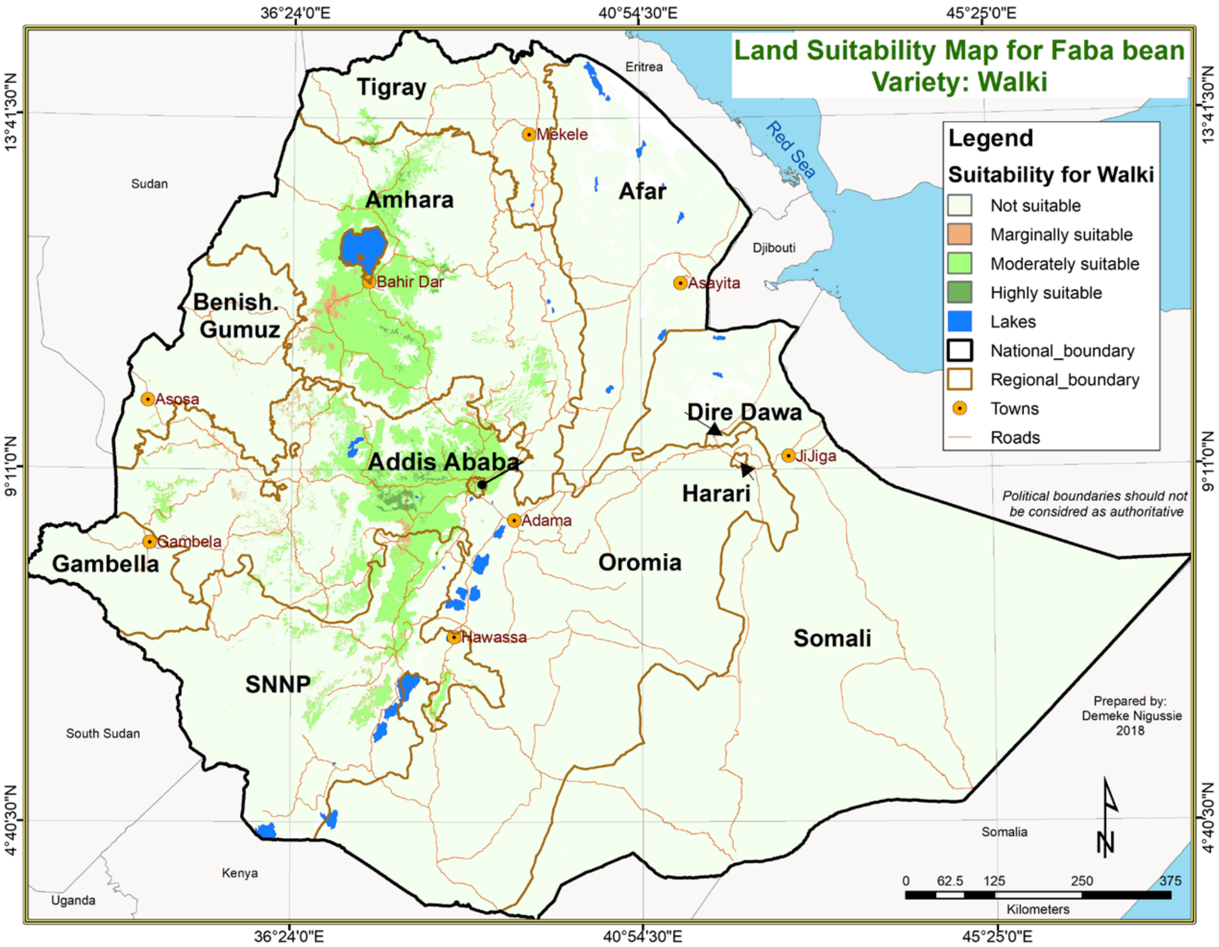


Table 22. Area of land under different suitability for Walki variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	78,228	0.5	3,358,480	21.58	136,368	0.88	11,990,293	77.04
Oromia	178,140	0.55	2,842,356	8.76	172,940	0.53	29,255,977	90.16
SNNP	0	0	1200676	10.63	94,872	0.84	9,994,438	88.52
Tigray	8,516	0.17	54,760	1.09	0	0	4,957,382	98.74
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	17,296	0.35	5,076	0.1	4,977,985	99.55
Gambella	0	0	8	0	0	0	2,570,128	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	264,884	0.23	7,473,576	6.61	409,256	0.36	104,870,504	92.79

The variety level suitability analysis and mapping results for this variety are shown in Figure 19 and Table 22. When compared with the overall (crop level) suitability map of faba bean, the suitable areas of the Walki variety is smaller mostly covering the west-central highlands of Ethiopia including parts of Amhara, Oromia and SNNP regions.

Summary of potential suitability areas and major administrative zones

The major administrative zones listed in the table below are the land areas where highly suitable (S_1) and moderately suitable (S_2) for the faba bean varieties at large (Table 23). For each variety, fifteen zones are listed in decreasing order of suitable area for S^1 and S_2.

Table 23. Land suitability for faba bean varieties.

Varieties	Suitability classes	Area (ha)	Major zones
1. Dosha	S_1	23,672	South West Shewa, West Shewa, West Gojam, East Gojam, South Gonder, Horo Guduru, North Gonder, Western, East Wellega, Metekel, Jimma, Ilubabor, West Wellega, Kelem Wellega, Dawro
	S_2	5,021,556	West Gojam, Jimma, West Shewa, East Gojam, Ilubabor, North Gonder, Horo Guduru, East Wellega, South Gonder, West Wellega, Kelem Wellega, South West Shewa, Dawro, Gamo Gofa, Awi/Agew
2. Gabelcho	S_1	192,836	West Shewa, North Gonder, North Shewa of Oromia Region, South West Shewa, South Gonder, Arsi, South Wollo, West Arsi, Western, East Gojam, North Shewa of Amhara Region, Region 14, West Gojam, Bale, Gurage
	S_2	9,409,608	East Gojam, North Gonder, West Shewa, West Gojam, South Gonder, North Shewa of Oromia Region, South Wollo, North Shewa of Amhara Region, South West Shewa, Guji, Bale, West Arsi, Arsi, East Shewa, North Wollo
3. Gora	S_1	107,740	South West Shewa, North Gonder, South Gonder, East Gojam, Western, North Shewa of Oromia Region, West Gojam, Horo Guduru, South Wollo, North Shewa of Amhara Region, Jimma, Gurage, Awi/Agew, Gamo Gofa
	S_2	7,168,148	West Shewa, West Gojam, North Gonder, East Gojam, North Shewa of Oromia Region, South Gonder, South West Shewa, Jimma, Horo Guduru, Gurage, Awi/Agew, North Shewa of Amhara Region, Gamo Gofa, Hadiya, East Wellega
4. Moti	S_1	325,660	West Shewa, North Gonder, South West Shewa, South Wollo, East Gojam, South Gonder, North Shewa of Oromia Region, North Shewa of Amhara Region, West Gojam, Horo Guduru, Western, Arsi, East Shewa, Bale, West Harerge
	S_2	15,290,300	Jimma, West Gojam, West Shewa, East Gojam, North Gonder, South Wollo, North Shewa of Oromia Region, North Shewa of Amhara Region, Arsi, South Gonder, Ilubabor, Keffa, South West Shewa, East Wellega, Horo Guduru

Varieties	Suitability classes	Area (ha)	Major zones
5. Dagm	S_1	53,968	West Gojam, West Shewa, East Gojam, South West Shewa, South Gonder, North Gonder, Horo Guduru, Western, Jimma, Dawro, East Wellega, Awi/Agew, Kelem Wellega, Ilubabor, Gamo Gofa
	S_2	4,609,844	West Gojam, West Shewa, North Gonder, East Gojam, Jimma, Awi/Agew, Horo Guduru, South Gonder, East Wellega, South West Shewa, Kelem Wellega, Western, Ilubabor, Gamo Gofa, Keffa
6. Hachalu	S_1	136,200	West Shewa, Horo Guduru, North Gonder, South West Shewa, West Gojam, South Gonder, North Shewa of Oromia Region, East Gojam, Western, East Wellega, Jimma, Dawro, North Shewa of Amhara Region, Awi/Agew, Gurage
	S_2	8,833,392	West Gojam, North Gonder, East Gojam, North Shewa of Oromia Region, South Gonder, Jimma, South West Shewa, Awi/Agew, Gurage, Horo Guduru, East Wellega, Gamo Gofa, Hadiya, North Shewa of Amhara Region
7. Walki	S_1	264,884	West Shewa, North Gonder, South West Shewa, South Gonder, East Gojam, North Shewa of Oromia Region, Western, West Gojam, Horo Guduru, North Shewa of Amhara Region, Addis Ababa Region, South Wollo, Jimma, Gurage, Awi/Agew
	S_2	7,473,576	West Gojam, West Shewa, North Gonder, East Gojam, North Shewa of Oromia Region, South Gonder, South West Shewa, Jimma, Horo Guduru, Gurage, Awi/Agew, Hadiya, Gamo Gofa, North Shewa of Amhara Region, East Wellega

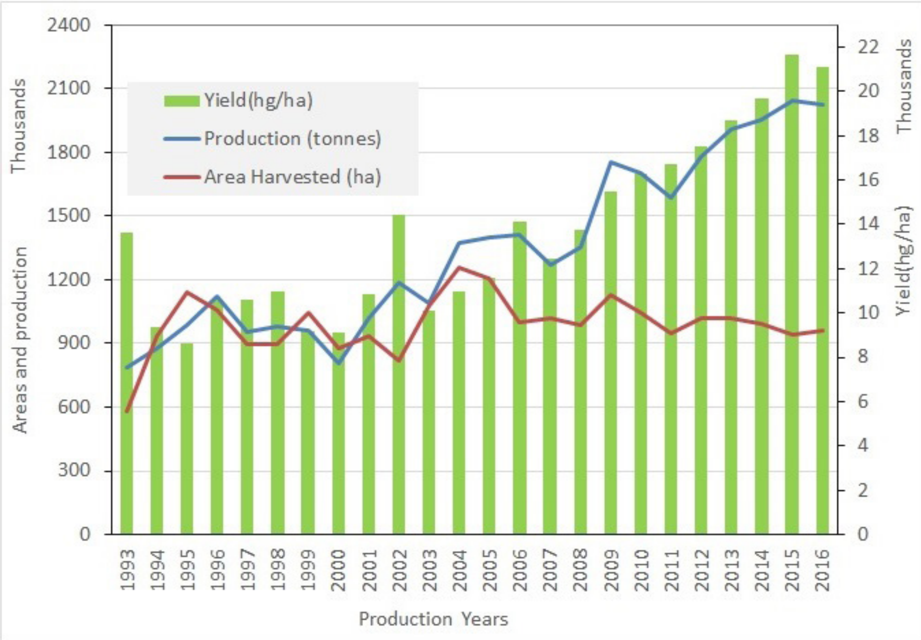
3.4. Malt barley (*Hordeum vulgare* L.)

Ethiopia is known as center of diversity for barley where the crop has been grown for millennia. Barley grain is used for human food and malt (local or industrial) and the straw for animal feed. It is a versatile crop grown in the highlands. Figure 20 show the trends in area harvested, production and productivity of barley in Ethiopia. According to FAOSTAT (2018), the production area for barley has increased from 578,790 ha in 1993 to 959,273 ha in 2016 and with an increase in production from 787,484 tons to 2,024,922 tons with a productivity increase from 1.36 tons to 2.11 tons ha^{-1}. This shows an increment of 65.7%, 157.1% and 55.1% in area harvested, production and productivity, respectively.

Malt barley seed production © ICARDA

In Ethiopia, the introduction of malt barley and favorable agro-ecology together with flourishing malt factories and breweries, has opened a huge market

Figure 20. Area harvested, production and productivity of barley.



Note: hg is hectogram; one hectogram is equivalent to 100 g. Source: FAOSTAT (2018).

opportunity for smallholder farmers through malt barley production and marketing in the country (ICARDA and EIAR 2016; Mengistu, Kirub and Zegeye 2017). The malt barley demands for these breweries have not yet been met from local production. In 2015, malt barley supplies in Ethiopia met only 35% of demand, with the remaining 65% (63,526 tons of malt) imported. Malt barley production covers only about 150,000 ha (ICARDA and EIAR 2016) and there is greater opportunity to expand production and import substitution in the country.

3.4.1. Crop level land suitability for malt barley

The crop level suitability analyses results for malt barley are shown in Figure 21 and Table 24. Similar to faba bean and chickpea, the crop level suitability analysis results show that the areas of suitability classes are wider than the variety level suitability analysis results, indicated in Figure 21 and Table 24. This is expected because the environmental range boundaries for the different suitability classes' thresholds are defined considering broader ranges of adaptation to encompass the adaptation ranges of most of the varieties currently available.

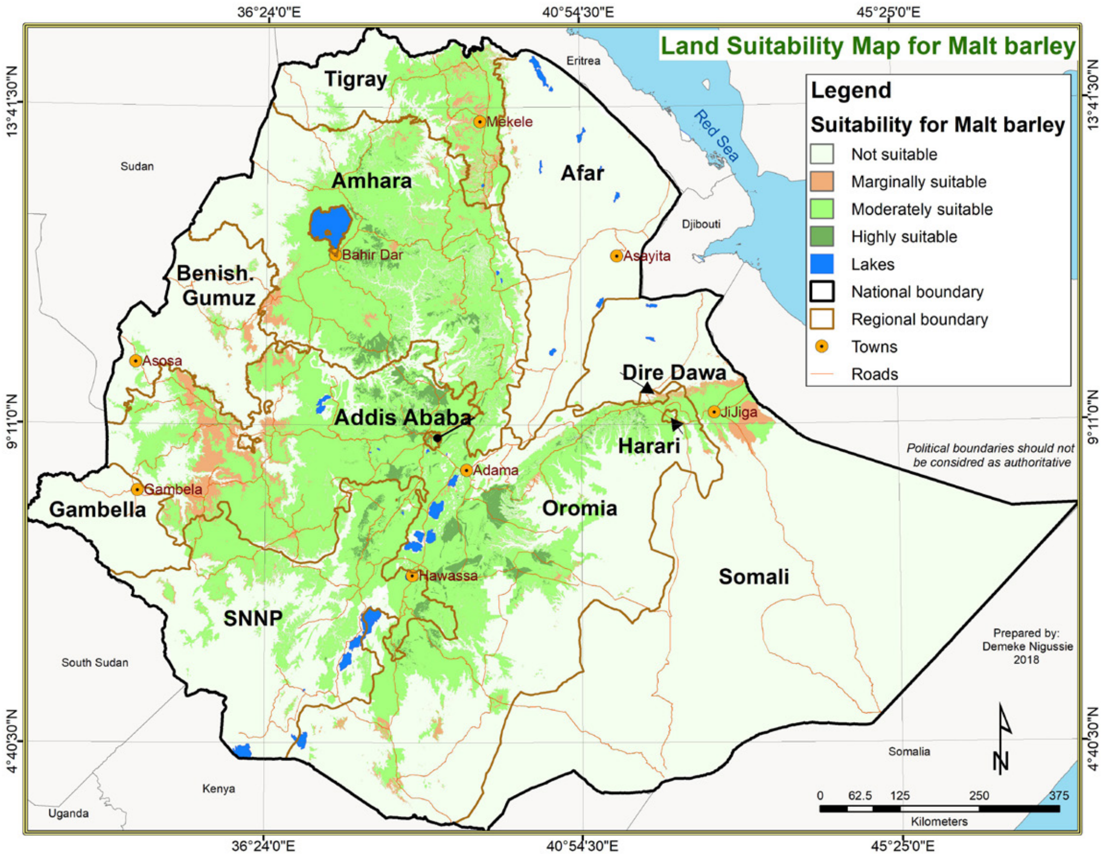
3.4.2. Variety level land suitability for malt barley

Bekoji-1(EH1293/F2-18B-11-1-14-18)

Bekoji-1 is developed and released by KARC in 2010. This variety yields, on average, 3.5-5.0 tons ha^{-1} in research fields under recommended management (MoA 2010). It is resistant to scald and net blotch diseases. Bekoji-1 is a late-maturing variety and therefore performs best in frost-free high altitude areas. In Ethiopia, rainfall amount and length of growing period mostly increase with increasing altitude, and therefore, late-maturing varieties mostly attain their higher productivity in high altitude areas so long as excessive rainfall and terminal frost are avoided. Field observations in high altitudes (above 2700 masl) during the 2015-2017 USAID-ICARDA malt barley scaling project indicated that Bekoji-1 expresses its highest yield potential when planted as soon as effective rainfall sets in late May to mid-June in order to have a frost-free period during grain filling in late September to end of October. Due to its tall plant height, Bekoji-1 has better weed competition characteristics and higher straw yield for animal feed when compared with IBON-174/03.

The variety level suitability analysis and mapping results for this variety are shown in Figure 22 and Table 25. The results show that the suitable areas for this variety are very small compared with the crop level suitability shown in Figure 21 and Table 24. The suitable lands are concentrated in Arsi, North and West Shewa administrative zones with some scattered suitable lands in Amhara and SNNP regional states.

Figure 21. Land suitability map of malt barley.



Source: Nigussie (2016, unpublished).

Table 24. Area of land under different suitability classes for malt barley by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	551,060	3.56	9,133,240	58.99	327,852	2.12	5,455,560	35.23
Oromia	1,141,840	3.82	13,964,520	46.67	1,449,416	4.84	13,352,112	44.62
SNNP	202,712	1.91	4,439,224	41.72	65,496	0.62	5,933,940	55.77
Tigray	1,588	0.03	2,199,640	44.4	346,360	6.99	2,394,940	48.34
Afar	56	0	89,908	1.07	48,828	0.58	8,222,108	97.45
BSG	0	0	252,512	5.01	127,336	2.53	4,640,468	92.15
Gambella	0	0	72,124	2.41	20,020	0.67	2,887,268	96.48
Somali	0	0	632,948	1.82	356,132	1.02	33,741,164	96.93
Total	1,897,256	1.68	30,784,116	27.24	2,741,440	2.43	76,627,560	67.80

Source: Nigussie (2016, unpublished).

Figure 22. Land suitability map for malt barley *var*. Bekoji-1.

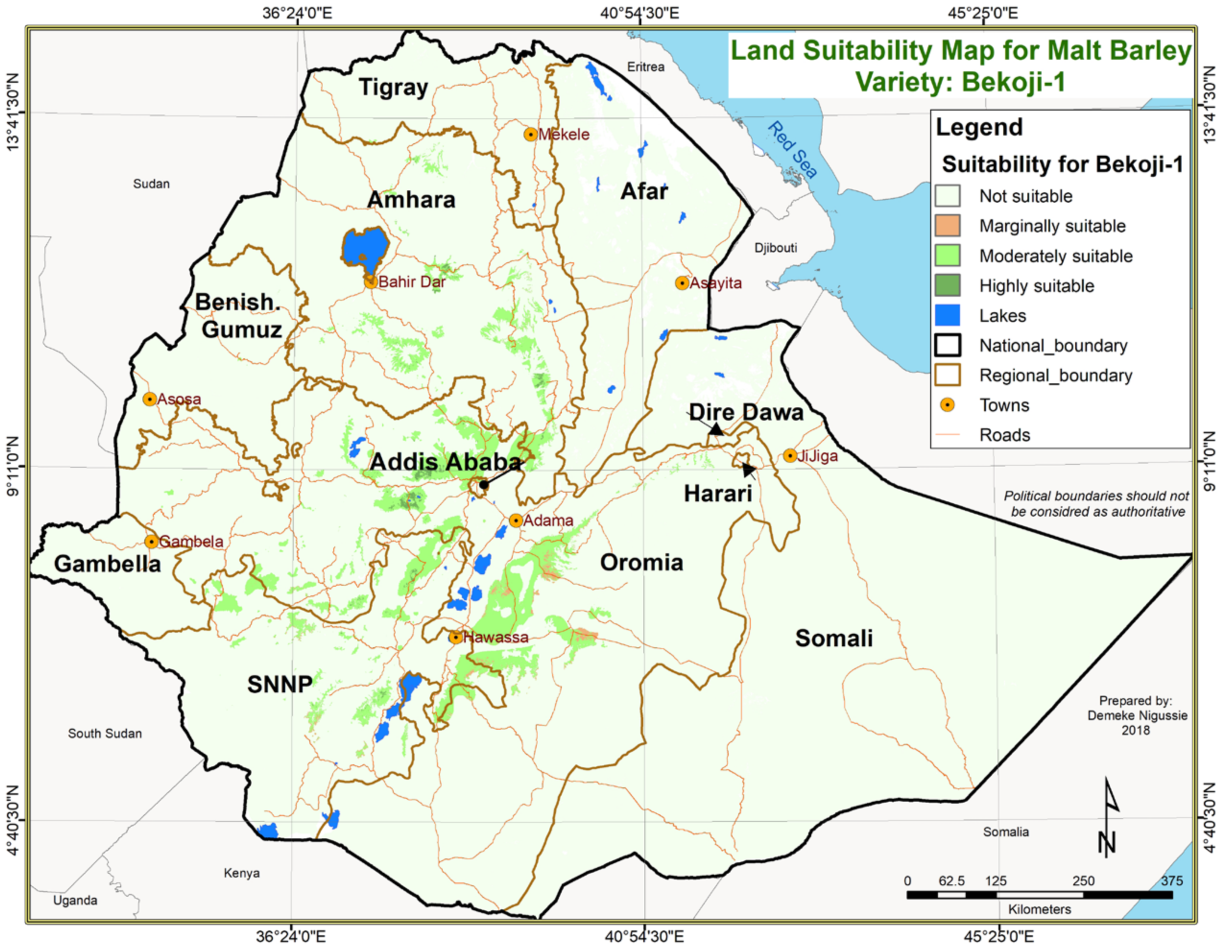


Table 25. Area of land under different suitability for Bekoji-1 variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	35,240	0.23	860,992	5.53	3,892	0.03	14,663,245	94.22
Oromia	75,392	0.23	2,513,736	7.75	128,084	0.39	29,732,201	91.63
SNNP	14,700	0.13	961,160	8.51	31,268	0.28	10,282,858	91.08
Tigray	0	0	3,400	0.07	0	0	5,017,258	99.93
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	2,668	0.05	0	0	4,997,689	99.95
Gambella	0	0	88	0	0	0	2,570,048	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	125,332	0.11	4,342,044	3.84	163,244	0.14	108,387,600	95.90

EH-1847/F4.2P.5.2 (Bea/IBON 64/91)

EH-1847 is a malt barley germplasm introduced from ICARDA and released by HARC in 2011. This variety yields, on average, 3.5-4.4 tons ha^{-1} in research fields under recommended management (MoA 2011). According to field observations during the 2015-2017 ICARDA-USAID malt barley scaling project, EH-1847 was found to be resistant to scald, which is the predominant barley disease in the highlands. EH-1847 is also a late-maturing and tall variety like Bekoji-1 and Holker but with better weed competition and a higher straw yield for animal feed.

The variety level suitability analysis and mapping results for this variety are shown in Figure 23 and Table 26. The results for this variety also show that the suitable areas are very small compared with the crop level suitability shown in Figure 21 and Table 24. The suitable areas are concentrated in Arsi, North and West Shewa administrative zones, with some scattered suitable lands in Amhara and SNNP regional states.

Grace

Grace is a malt barley variety introduced by the private sector (Heineken Brewery), which was tested for adaptation and released by HARC of EIAR in 2013. This variety yields, on average, 2.0-4.5 tons ha^{-1} in research fields under recommended management (MoA 2013). The variety is resistant to net blotch but shows some level of susceptibility to scald disease. Grace is an early maturing variety and was suitable for mid-altitude areas since scald increases with increasing altitude.

The variety level suitability analysis and mapping results for this variety are shown in Figure 24 and Table 27. Although it is smaller than the crop level suitability shown in Figure 21 and Table 24, the suitability analysis results for this variety show that it ranks first and second for the moderately suitable and highly suitable areas, respectively, when compared with other varieties released by NARS and included in this work. It ranks first with the combined area of highly and moderately suitable areas showing its dominance in mid-altitude areas where much of land is available in the country (land area at mid-altitudes is by far larger than that in the high altitudes in Ethiopia).

Holker

Holker is a malt barley variety introduced and maintained by HARC of EIAR (ex. Institute of Agricultural Research) in 1979. This variety yields an average of 2.4-3.1 tons ha^{-1} in research fields under recommended management (NSIA, 1998). Holker is an old and late maturing variety, with lower yields than Bekoji-1 and EH-1847, which are recent releases to replace it. Being a tall variety, Holker provides comparable straw yield to that of Bekoji-1 and EH-1847. Disease resistance of Holker was comparable to EH-1847 but IBON-174/03 was reported to be the best (Aynewa et al. 2013).

The variety level suitability analysis and mapping results for this variety are shown in Figure 25 and Table 28. The suitability analysis results for this variety also show that the suitable areas are very small when compared with the crop level suitability shown in Figure 21 and Table 24. The suitable areas are concentrated in Arsi, North and West Shewa administrative zones, with some scattered suitable lands in Amhara and SNNP regional states.

IBON 74/03

IBON 174/03 is a malt barley germplasm introduced from ICARDA and released by HARC in 2012. This variety yields an average of 3.0-5.7 tons ha^{-1} in research fields under recommended management (MoA 2012). Although malt barley is more susceptible to waterlogging and requires well-drained soil for higher yield and malt quality than food barley, field observations indicated that IBON 174/03 is relatively tolerant to transient soil saturation caused by excessive rainfall at the vegetative stage. It is tolerant to scald and resistant to leaf blotch.

IBON 174/03 is also an early maturing variety escaping terminal stresses such as moisture deficit and relatively higher temperature in mid altitude areas, and frost damage in high altitude areas of 2700-3200 masl. It is gaining wider acceptance by smallholder farmers and malt factories for its early maturity, wider adaptability, high grain yield potential, acceptable plant height for outcompeting weeds and production of higher animal feed, low grain protein content, and large bolded seed for high flour yield (for home consumption). Therefore, IBON-174/03 is fast replacing the widely grown old variety, Holker, which was released in 1979.

The variety level suitability analysis and mapping results for this variety are shown in Figure 26 and Table 29. This variety has the largest highly suitable lands compared with other varieties included here though it ranks third, following Grace and Sabini, for moderately suitable lands.

Figure 23. Land suitability map for malt barley *var*. EH-1847.

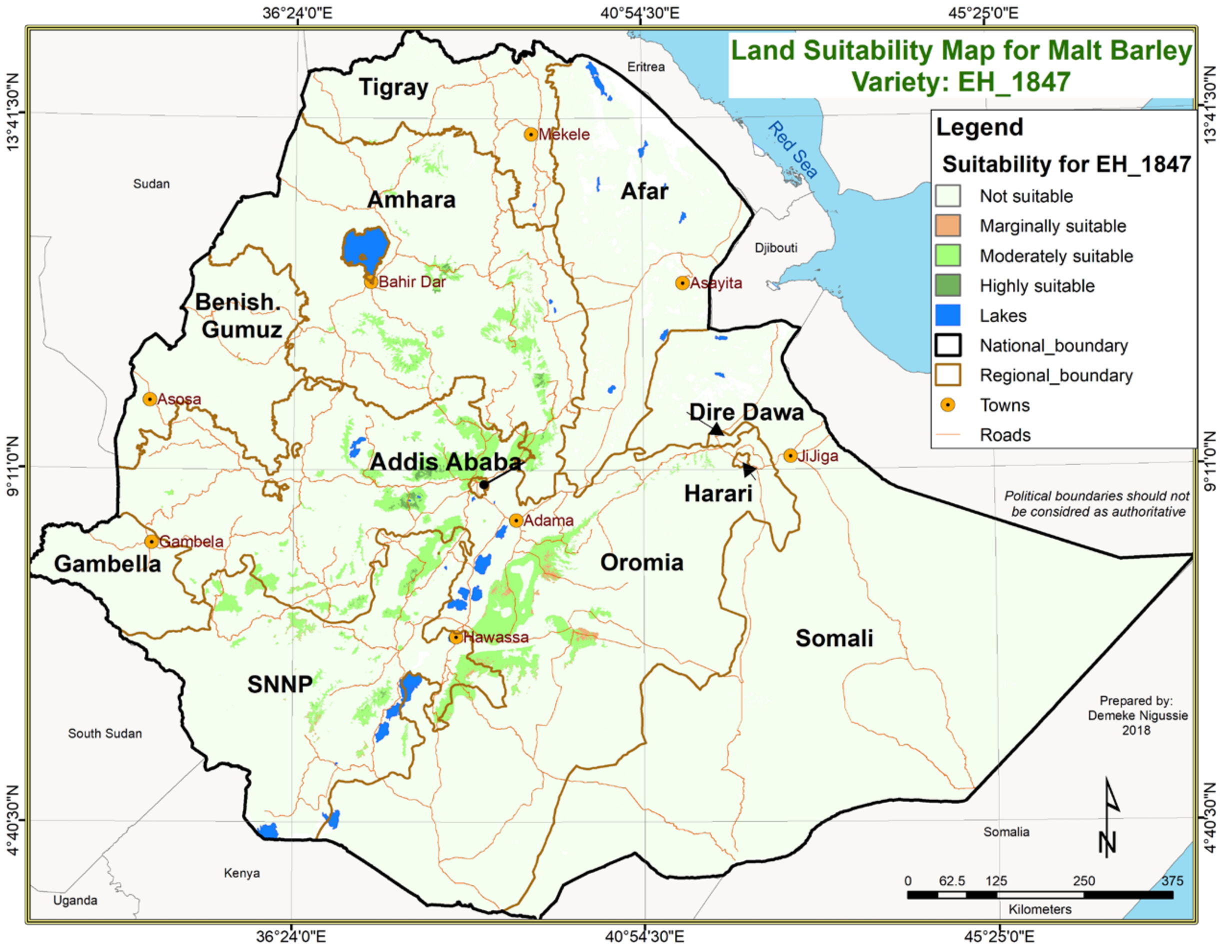


Table 26. Area of land under different suitability for EH-1847 variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	35,280	0.23	860,068	5.53	4,776	0.03	14,663,245	94.22
Oromia	74,780	0.23	2,510,864	7.74	131,136	0.4	29,732,633	91.63
SNNP	13,944	0.12	953,844	8.45	38,348	0.34	10,283,850	91.09
Tigray	0	0	3,400	0.07	0	0	5,017,258	99.93
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	2,668	0.05	0	0	4,997,689	99.95
Gambella	0	0	88	0	0	0	2,570,048	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	124,004	0.11	4,330,932	3.83	174,260	0.15	108,389,024	95.90

Figure 24. Land suitability map for malt barley *var*. Grace.

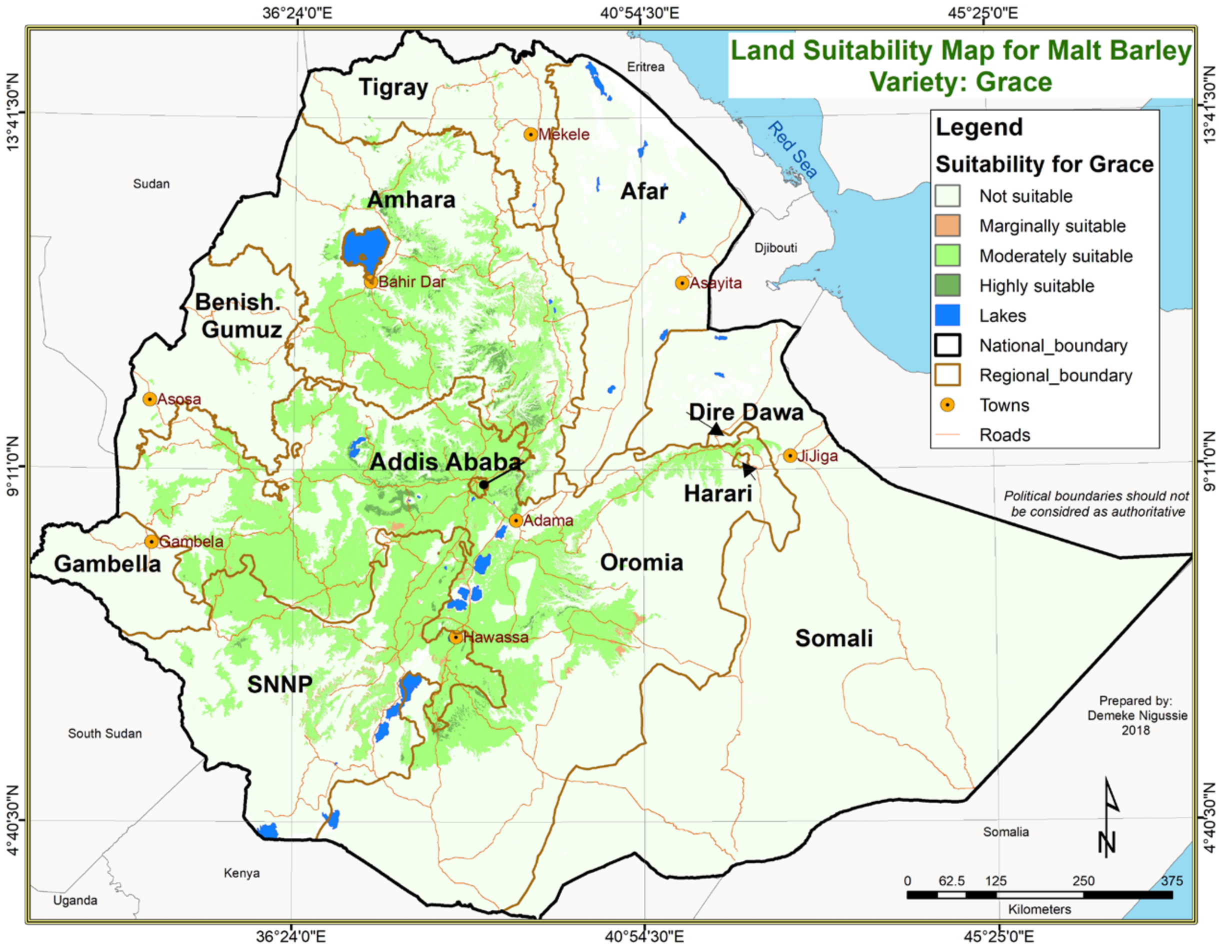


Table 27. Area of land under different suitability for Grace variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	360,748	2.32	4,943,524	31.76	17,128	0.11	10,241,969	65.81
Oromia	359,520	1.11	11,363,196	35.02	163,200	0.5	20,563,497	63.37
SNNP	48,388	0.43	4,155,640	36.81	121,596	1.08	6,964,362	61.69
Tigray	6,640	0.13	45,428	0.9	0	0	4,968,590	98.96
Afar	0	0	108	0	0	0	9,562,228	100
BSG	16	0	108,048	2.16	1,072	0.02	4,891,221	97.82
Gambella	0	0	13,364	0.52	0	0	2,556,772	99.48
Somali	0	0	19,456	0.06	276	0	31,542,233	99.94
Total	775,312	0.69	20,648,764	18.27	303,272	0.27	91,290,872	80.78

Figure 25. Land suitability map for malt barley *var*. Holker.

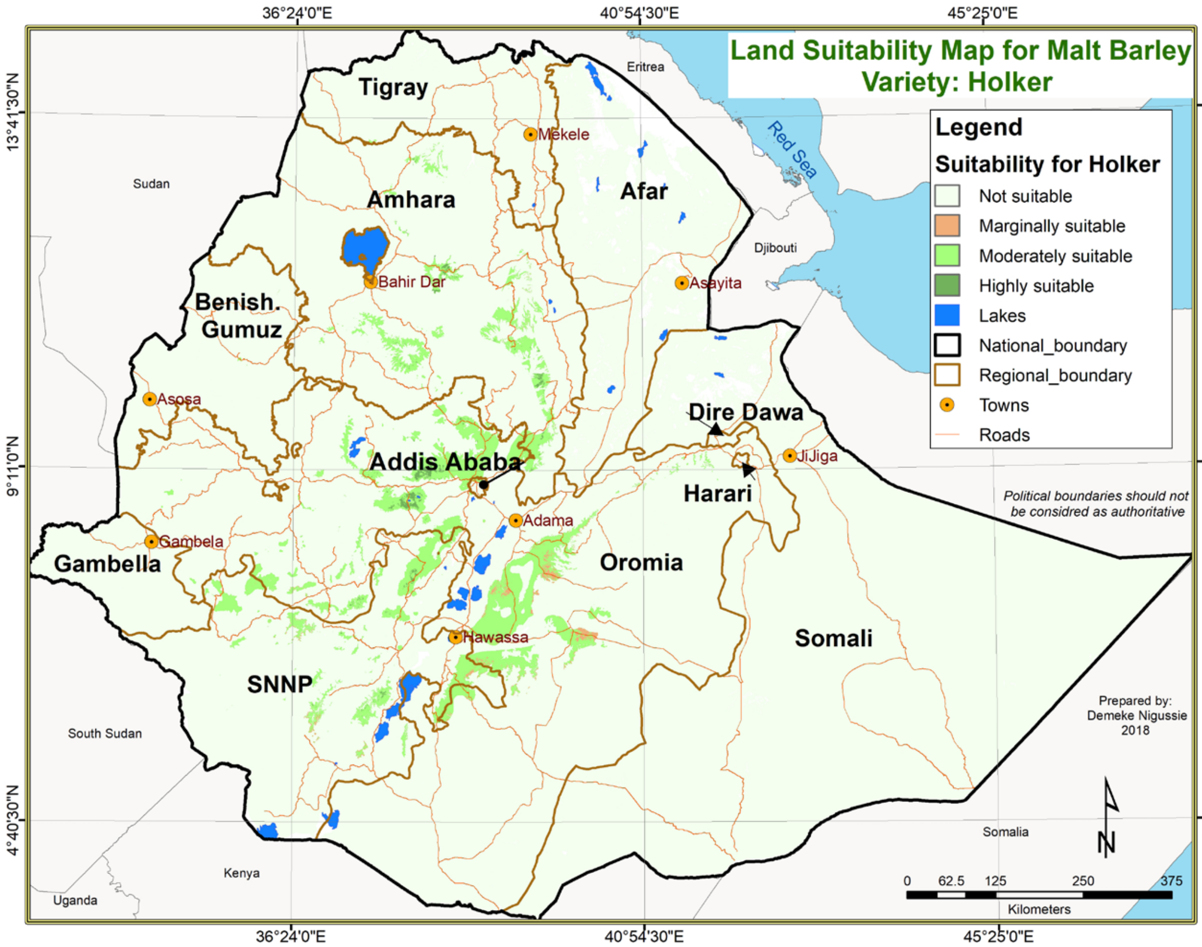


Table 28. Area of land under different suitability for Holker variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	35,172	0.23	861,060	5.53	3,892	0.03	14,663,245	94.22
Oromia	75,484	0.23	2,514,372	7.75	127,356	0.39	29,732,201	91.63
SNNP	14,700	0.13	961,168	8.51	31,260	0.28	10,282,858	91.08
Tigray	0	0	3,400	0.07	0	0	5,017,258	99.93
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	2,668	0.05	0	0	4,997,689	99.95
Gambella	0	0	88	0	0	0	2,570,048	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	125,356	0.11	4,342,756	3.84	162,508	0.14	108,387,600	95.90

Figure 26. Land suitability map for malt barley *var*. IBON-174/03.

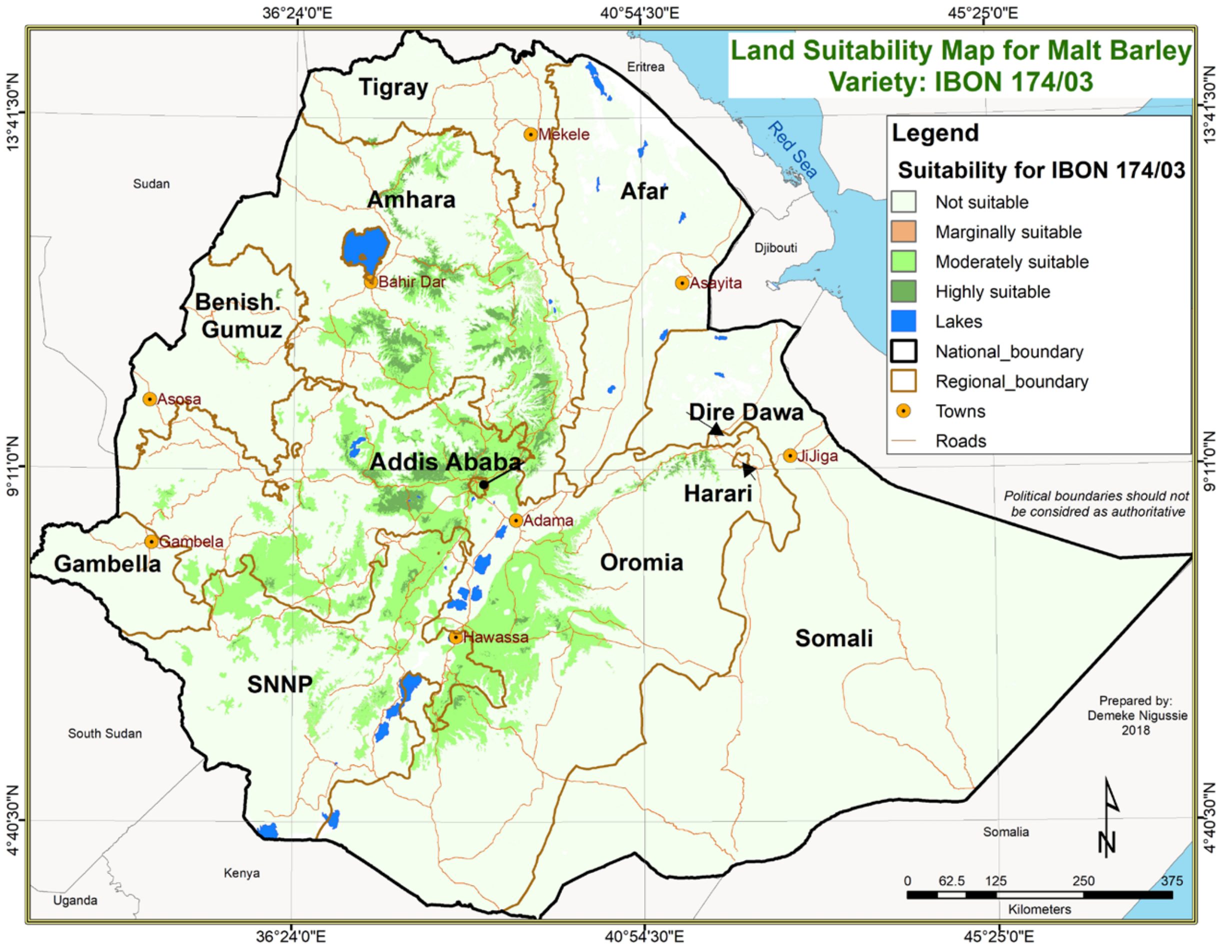


Table 29. Area of land under different suitability for IBON-174/03 variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	845,712	5.43	2,888,004	18.56	4,120	0.03	11,825,533	75.98
Oromia	738,680	2.28	6,108,104	18.82	17,440	0.05	25,585,189	78.85
SNNP	78,508	0.7	2,551,312	22.6	11,232	0.1	8,648,934	76.61
Tigray	8,044	0.16	3,608	0.07	0	0	5,009,006	99.77
Afar	0	0	0	0	0	0	9,562,336	100
BSG	6,444	0.13	33,160	0.66	0	0	4,960,753	99.21
Gambella	0	0	3,968	0.15	0	0	2,566,168	99.85
Somali	0	0	0	0	0	0	31,561,965	100
Total	1,677,388	1.48	11,588,156	10.25	32,792	0.03	99,719,884	88.23

The suitable lands for this variety are still lower than that of the crop level suitability area shown in Figure 21.

Sabini

Sabini is a malt barley variety developed and released by KARC in 2012. This variety yields, on average, 2.5-4.9 tons ha^{-1} in research fields under recommended management (MoA 2012). The variety is early maturing but is susceptible to scald in the highlands. Sabini has better malt quality than other varieties but is inferior to Holker, and its susceptibility to scald is tolerable since the effect on yield and malt quality is negligible as observed during the 2015-2017 USAID-ICARDA malt barley scaling project. Its early maturity makes it fit for production in higher altitudes where frost is a serious yield-reducing factor in comparison to scald. Its relatively short height, compared to tall varieties such as Holker and Bekokji-1, means it needs early weed control.

The variety level suitability analysis and mapping results for this variety are shown in Figure 27 and Table 30. When compared with other varieties included in this work, though it is still less than the crop level suitability, the suitability area for Sabini ranks third in the combined area of highly and moderately suitable areas.

Summary of potential suitable areas and major administrative zones

The major administrative zones listed in Table 31 are the land areas where highly suitable (S_1) and moderately suitable (S_2) areas occupy large proportions for the malt barley varieties analyzed in this work. For each variety, fifteen zones are listed in decreasing order of suitable area for S_1 and S_2.

Figure 27. Land suitability map for malt barley *var*. Sabini.

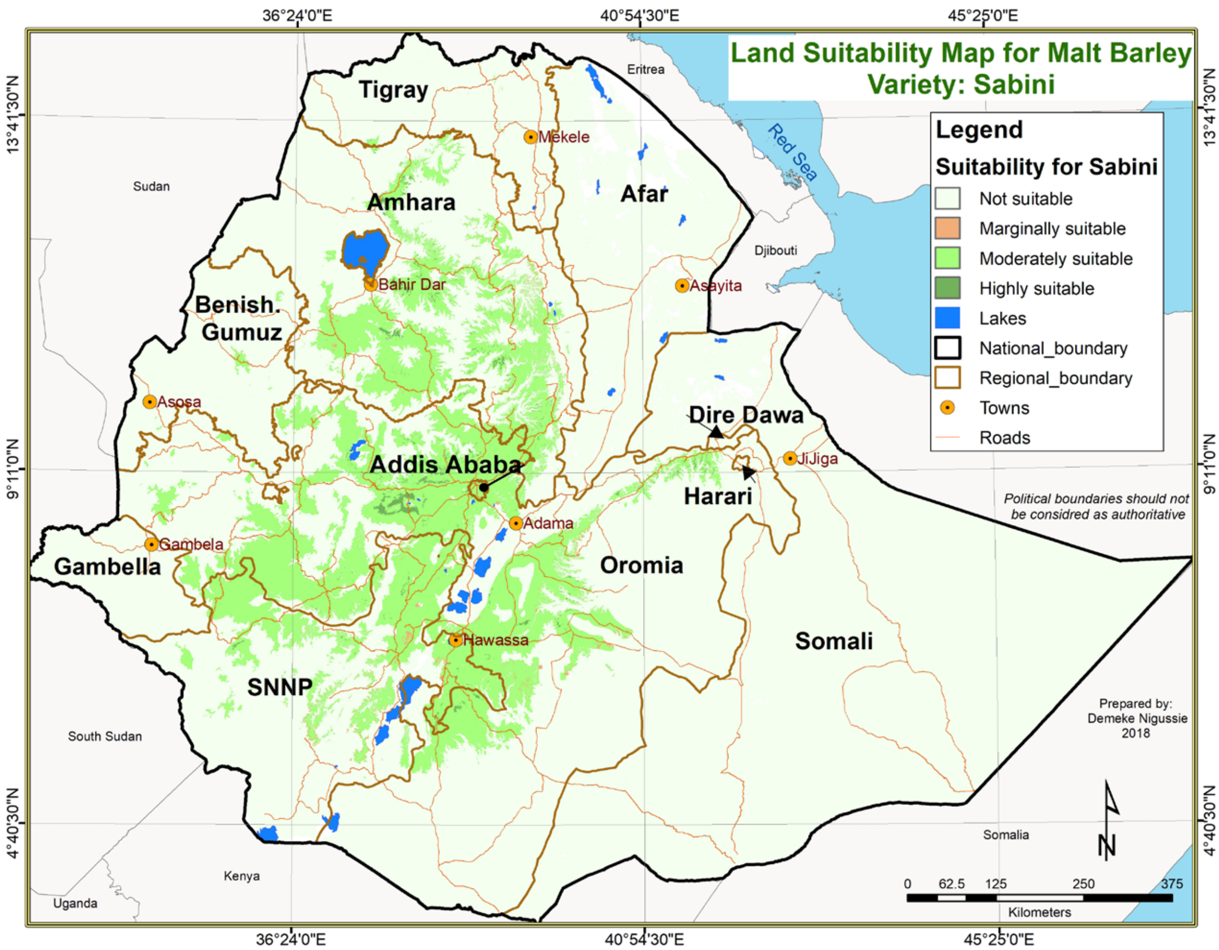


Table 30. Area of land under different suitability for Sabini variety by regional states.

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Amhara	101,588	0.65	4,236,844	27.22	36,812	0.24	11,188,125	71.89
Oromia	185,216	0.57	8,581,572	26.45	71,856	0.22	23,610,769	72.76
SNNP	19,840	0.18	3,450,676	30.56	79,660	0.71	7,739,810	68.55
Tigray	1,308	0.03	21,696	0.43	16	0	4,997,638	99.54
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	60,236	1.2	1,596	0.03	4,938,525	98.76
Gambella	0	0	7,308	0.28	0	0	2,562,828	99.72
Somali	0	0	16	0	8	0	31,561,941	100
Total	307,952	0.27	16,358,348	14.47	189,948	0.17	96,161,972	85.09

Table 31. Land suitability for malt barley varieties.

Varieties	Suitability classes	Area (ha)	Major administrative zones
1. Bekoji-1	S_1	125,332	West Shewa, South Wollo, North Shewa of Amhara Region, North Gonder, South Gonder, Guji, South West Shewa, Horo Guduru, East Shewa, Arsi, West Gojam, East Gojam, North Shewa of Oromia Region, West Arsi, Borena
	S_2	4,342,044	Jimma, Arsi, Ilubabor, West Shewa, Bale, West Arsi, East Gojam, North Shewa of Oromia Region, West Gojam, South Wollo, Keffa, South Gonder, Guji, East Wellega, North Shewa of Amhara Region
2. EH-1847	S_1	124,004	West Shewa, North Shewa of Amhara Region, South West Shewa, South Gonder, Gamo Gofa, Gurage, East Gojam, North Shewa of Oromia Region, Selti, Jimma, North Gonder, South Wollo, Hadiya, South Omo, Dawro
	S_2	4,330,932	Arsi, West Arsi, West Shewa, North Shewa of Oromia Region, North Shewa of Amhara Region, South Wollo, Jimma, Bale, Gurage, Gamo Gofa, East Gojam, Keffa, Sidama, South West Shewa, Guji

Varieties	Suitability classes	Area (ha)	Major administrative zones
3. Grace	S_1	775,312	West Shewa, South Wollo, North Shewa of Amhara Region, North Gonder, South Gonder, Guji, South West Shewa, Horo Guduru, East Shewa, Arsi, West Gojam, East Gojam, North Shewa of Oromia Region, West Arsi, Borena
	S_2	20,648,764	Jimma, Arsi, Ilubabor, West Shewa, Bale, West Arsi, East Gojam, North Shewa of Oromia Region, West Gojam, South Wollo, Keffa, South Gonder, Guji, East Wellega, North Shewa of Amhara Region
4. Holker	S_1	125,356	West Shewa, South West Shewa, North Shewa of Amhara Region, South Gonder, Gamo Gofa, Gurage, Jimma, East Gojam, Selti, North Shewa of Oromia Region, North Gonder, South Wollo, Hadiya, South Omo, Dawro
	S_2	4,342,756	Arsi, West Arsi, West Shewa, North Shewa of Oromia Region, North Shewa of Amhara Region, South Wollo, Jimma, Bale, Gurage, Gamo Gofa, East Gojam, Keffa, Sidama, South West Shewa, Guji
5. IBON 174/03	S_1	1,677,388	West Shewa, North Shewa of Amhara Region, South Gonder, South Wollo, East Gojam, North Shewa of Oromia Region, West Gojam, North Gonder, South West Shewa, East Harerge, Jimma, Horo Guduru, Arsi, Guji, Gurage
	S_2	11,588,156	Arsi, Jimma, West Arsi, North Shewa of Oromia Region, South Wollo, East Gojam, North Shewa of Amhara Region, West Shewa, Keffa, Bale, Guji, Sidama, South West Shewa, Ilubabor, North Wollo
6. Sabini	S_1	307,952	West Shewa, South West Shewa, South Gonder, North Gonder, South Wollo, East Harerge, Arsi, North Shewa of Amhara Region, West Gojam, Guji, East Gojam, North Shewa of Oromia Region, Gedio, Bale, West Harerge
	S_2	16,358,348	Jimma, Arsi, West Shewa, West Arsi, East Gojam, North Shewa of Oromia Region, South Wollo, North Shewa of Amhara Region, Ilubabor, Keffa, South Gonder, Guji, South West Shewa, Bale, Sidama

3.5. Summary of variety level suitability analysis

This work is a national level and broad scale suitability analysis without considering irrigation potentials and socio-economic aspects. With all its limitations, the following are some summaries of the variety level suitability analysis for chickpea, faba bean and malt barley:

1. Amhara, Oromia, SNNP and Tigray remain the major regions with suitable areas for production of available varieties of chickpea, faba bean and malt barley compared to Afar, Benishangul Gumuz, Gambella, and Somali regions. However, the highly suitable areas are limited compared to moderately suitable areas, which are higher across the regions.
2. In general, areas of the highly and moderately suitable lands for most varieties considered in this analysis are smaller than the areas of crop level suitability. This difference is expected since the crop level environmental range boundaries for the suitability class thresholds are defined to encompass the adaptation ranges of available varieties.
3. For chickpea varieties considered in this analysis, the highly suitable areas are much larger than the

current estimated area under chickpea production in the country. Some of the chickpea varieties such as Kasech and Arerti have close to 2.3 million ha each of highly suitable areas which is more than the estimated highly suitable areas for chickpea crop itself (1.81 million ha). Arerti variety, followed by Teketay and Mastewal, have broader adaptation compared to other varieties. Amhara has more highly suitable areas whereas Oromia has more moderately suitable areas than other regions. Oromia region has more land of moderately suitable area for Arerti and Teketay chickpea varieties with the respective regional share of up to 40.05% and 38.59%.

4. For the faba bean varieties considered in this analysis, the highly suitable areas of each variety were found to be smaller than the current estimated area under faba bean production in the country. Likewise, both highly suitable areas and moderately suitable areas for faba bean varieties are less than the crop suitability levels for respective categories. However, Moti followed by Gabelcho, Hacahlu and Walki have broader adaptation. For most faba bean varieties analyzed, Oromia has more highly suitable areas whereas Amhara has more moderately suitable areas than other regions. Amhara region has the highest moderately suitable areas for Gabelcho, Moti and Gora accounting for 31.5, 35.3, and 21.16%, respectively, in the respective region.
5. For the malt barley varieties considered in this analysis, the highly suitable areas were found to be much smaller than the current estimated area under barley production in the country and crop level suitability with the exception of one variety. IBON has the highest overall highly suitable area of 1.7 million ha which is close to the crop suitability level followed by Grace with 0.8 million ha. Oromia has more highly suitable and moderately suitable areas than other regions. Oromia region has the highest moderately suitable area for malt barley of which Grace, Sabini and IBON has a share of up to 35.02%, 26.45% and 18.82%, respectively.
6. The suitability analysis results show that the currently available improved varieties of chickpea, faba bean and malt barley can be targeted for scaling out in the identified land suitability classes in Ethiopia with some caution.

4. Conclusions and recommendations

4.1. Conclusions

Although this work is a broad scale nationwide suitability analysis, which is only based on biophysical factors, it is intended to serve as a guide for agricultural research and development related policy and decision-making at broad scale (national level). One of the constraints that limit the quality of these suitability analyses and mapping is the lack of fine-resolution geospatial data on biophysical and socioeconomic factors. The quality and scale of this work is dependent on the quality of geospatial data and information of environmental requirements of the different varieties included in this analysis. Hence, it should be noted that the outputs may not directly be used for applications that demand finer resolutions (e.g. at farm scale). Cognizant of this, information on environmental variables and weights (thresholds) used in land suitability mapping are provided in Annexes 1-4 to support individual decision-making on how to use the products.

The results of this multiple criteria land suitability analysis for crop varieties can be used to help policymakers in land-use planning and decision-making in a way that ensures land resources are used in the most productive and sustainable way and to resolve mismatches between current land use and land suitability for crop varieties.

4.2. Recommendations

It is recommended to undertake site-specific analysis and to map the key parameters at higher spatial details to better understand the granularity and level of scaling-up of the specific crop technology for targeting location specific recommendation at farm to farming systems level. The analysis in this study does not exclude the areas occupied by non-agricultural areas such as forests, woodlands, towns (except Addis Ababa, Dire Dawa and Harari) and other non-cropland uses. It also does not accounted the updated cropland currently under active cultivation. Hence, the suitability maps can further be refined by using updated land use database and masking out areas outside of the actual arable lands. In this type of analysis, scales of geospatial data, such as land forms, land use, soils and climate information, are the major constraints which need to be addressed for refining suitability maps to present context and actual arable areas at much finer spatial scales. Data on performance of crop varieties across a range of representative environments are very scanty and need future attention. The organizations that are involved in improving soil, land use/land cover, and climate information at national level need to produce high-resolution consistent information that could be used for site-specific spatial and simulation modelling for agricultural application. Furthermore, researchers involved in crop improvements also need to be able to use these suitability analysis results as a general guide in their research targeting decisions and feedback on performance of the crops for further refinement.

It is also suggested that researchers need to develop, update and have detailed documents elaborating information on environmental requirements for the different crops and varieties for suitability analysis, mapping and simulation modelling based on recent research findings, particularly when new varieties are released. We also recommend to leverage recent advances in Earth Observation, Bigdata and ICTs for demand-driven decision system support for targeting site-specific intervention and smart farming for building resilient agroecosystems.

References

AAFC (Agricultural and Agri-Food Canada). 2004. Chickpeas: Situation and Outlook, *Bi-Weekly Bulletin* 19 (13): 1-4

Aynewa, Y., T. Dessalegn and W. Bayu .2013. Participatory evaluation of malt barley genotypes (*Hordeum vulgare* L.) genotypes for yield and other agronomic traits at northwest Ethiopia. *Wudpecker Journal of Agricultural Research* 2(8): 218-222

Bekele, D., et al. 2015. Genetic progresses achieved in Ethiopian chickpea (*Cicer arietinum* L.) breeding program based on grain yield and seed size, 119-134. *In*: (Korbu, L., T. Damte and A. Fikre (eds.). Harnessing Chickpea Value Chain for Nutrition Security and Commercializing of smallholder Agriculture in Africa. 30 January –1 February 2014. Debre Zeit, Ethiopia.

Biradar, C.M., et al. 2009. A global map of rainfed cropland areas (GMRCA) at the end of last millennium using remote sensing. *International Journal of Applied Earth Observation and Geoinformation*, 11: 114–129.

Collis, S. N., and J. D. Corbett. 1999. Africa Maize Research Atlas (V.2). Mexico, D.F.: CIMMYT. C.D)

CSA (Central Statistical Agency). 2016. Agricultural Sample Surveys 2015/2016 (2008 E.C.): Report on area, production of major crops. Addis Ababa, Ethiopia: Ministry of Finance and Economic Development (MoFED).

CSA 2015a. Agricultural Sample Survey 2014/2015 (2007 E.C.), Addis Ababa, EMFED.

CSA. 2015b. Key findings of the 2014/2015 (2007 E.C.): Agricultural Sample Surveys, Addis Ababa, Ethiopia: MoFED.

EIAR (Ethiopian Institute of Agricultural Research). 2017. Pulses Research Strategy (2016-2030). Addis Ababa, Ethiopia: Ethiopian Agricultural Transformation Agency.

Elsheikh, F., and R. Abdalla. 2016. Physical Land Suitability Assessment Based on FAO Framework. *IOSR Journal of Engineering* 12 (6): 36-44.

Ermias, T., and T. Addisu. 2013. Integrated management of chocolate spot (*Botrytis fabae* Sard.) of faba bean (Vicia faba L.) at highlands of Bale, southeastern Ethiopia. *Research Journal of Agricultural and Environmental Management* 2(1): 11-14.

FAO (Food and Agricultural Organization). 2019. FAOSTAT Database. Accessed on 10 May 2019 from http://www.fao.org/faostat/en/#data/QC

FAO. 1993. Guidelines for Land-Use Planning. FAO Development Series 1. FAO, Rome, Italy

FAO. 1984. Land Evaluation: Part Three. Crop Environmental Requirements. Assistance to Land Use Planning. Addis Ababa, Ethiopia: Ministry of Agriculture.

FAO. 1976. Framework for Land Evaluation. Rome, Italy.

Gaur, P.M., et al. 2007. Breeding Achievements,391-416. In Chickpea Breeding and management (Yadav, S.S., R. B. Reden, W. Chen and B. Sharma (eds.). Wallingford, UK: CABI (Centre for Agriculture and Bioscience International).

Gobel, W. and N. Thomas. 1999. Ethiopian Agricultural Research Organization (EARO) Information Technologies Study: A Concept for Climate and Crop Modeling and Geo-Informatics. Revised Version. Addis Ababa, Ethiopia : EARO.

IBC (Institute of Biodiversity Conservation). 2007. Country Report on the State of PGRFA to FAO. Addis Ababa, Ethiopia

ISRIC (International Soil Reference Information Center). 2015. www.soilgrids.org, Accessed on 07.02.2016

Jarvis, A., H. I. Reuter, A. Nelson, E. Guevara. 2008. Hole-filled SRTM for the Globe Version 4, available from the

CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org accessed on May 2016).
Jones, R., P. Audi, B. Shiferaw and E. Gwata. 2006. Production and Marketing of *Kabuli* Chickpea Seeds in Ethiopia: Experiences from Ada District. Submitted to the project for Improving Productivity and Market Success (IPMS) of Ethiopian Farmers. Regional Office for Eastern and Southern Africa , ICRISAT.
Löw, F., et al. 2018. Regional-scale monitoring of cropland intensity and productivity with multi-source satellite image time series. *GIScience & Remote Sensing*, 55:4, 539-567.
Mengistu, F., A. Kirub and F. Zegeye. 2017. *Retrospect and Prospects of Ethiopian Agricultural Research*. Addis Ababa, Ethiopia: EIAR (Ethiopian Institute of Agricultural Research).
MoA (Ministry of Agriculture). 2014. Crop Variety Register Issue No. 17, Addis Ababa, Ethiopia
MoA. 2013. Crop Variety Register Issue *No. 16*, Addis Ababa, Ethiopia
MoA. 2012. Crop Variety Register Issue *No. 15*, Addis Ababa, Ethiopia
MoA. 2011. Crop Variety Register Issue *No. 14*, Addis Ababa, Ethiopia
MoA. 2010. Crop Variety Register Issue *No. 13*, Addis Ababa, Ethiopia.
MoARD (Ministry of Agriculture and Rural Development). 2004. *Crop Variety Register Issue No.7*, Addis Ababa, Ethiopia
MoARD. 2009. Crop Variety Register. Issue No.12, Addis Ababa, Ethiopia
MoARD. 2008. Crop Variety Register. Issue No.11, Addis Ababa, Ethiopia
MoARD. 2007. Crop Variety Register. Issue No.10, Addis Ababa, Ethiopia
MoARD. 2006. Crop Variety Register. Issue No.9, Addis Ababa, Ethiopia
Mokarram, M., K. Rangzan, A. Moezzi, and J. Baninemeh. 2010. Land suitability evaluation for wheat cultivation by fuzzy theory approach as compared with parametric method. *The international archives of the photogrammetry, remote sensing and spatial information sciences - ISPRS Archives*, 38 (2): 140-145.
NAIA (National Agricultural Inputs Authority). 2003. Crop Variety Register Issue No.5, Addis Ababa, Ethiopia.
Nigussie, D. 2018. GIS-based land suitability mapping for legume crops technology targeting and scaling-up. *Ethiopian Journal of Agricultural Science* 6 (1): 179-198.
Nigussie, D. 2016. National level land suitability analysis for selected crops of Ethiopia. EIAR, Addis Ababa, Ethiopia. Unpublished manuscript
Nigussie, D. 2014. Land Suitability Atlas for Selected Crops of Ethiopia. Addis Ababa, Ethiopia: EIAR.
NSIA (National Seed Industry Agency). 1998. Crop Variety Register, Issue No. 01, Addis Ababa, Ethiopia
Perveen, M.F., et al. 2007. Crop-land suitability analysis using a multicriteria evaluation and GIS approach. University of California, Berkeley, USA: ISDE (International Symposium on Digital Earth).
Pettapiece, W. W. eds. 1995. Land Suitability Rating System for Agricultural Crops: 1. Spring-seeded Small Grains. AIWG (Agronomic Interpretations Working Group) technical report. Ottawa: CLBRR (Centre for Land and Biological Resources Research, Agricultural and Agri-Food Canada).
Saaty, R. W. 1987. The Analytic Hierarchy Process—what it is and how it is used. *Mathematical Modelling*, 9 (3-5): 161-176.
Singha, C. and K. C. Swai. 2016. Land suitability evaluation criteria for agricultural crop selection: A review. *Agricultural Reviews*, 37 (2): 125-132.
Soil Resources, Management and Conservation Service. 1993. Guidelines for Land-Use Planning. FAO Development Series 1. Rome, Italy: FAO (Food and Agricultural Organization).
Sys. C., et al. 1993. Land Evaluation Part III, Crop Requirements. Agricultural Publication No. 7, Brussels, Belgium.
Tafere, M., D. Tadesse and D. Yigzaw. 2012. Participatory varietal selection of faba bean (*Vicia faba* L.) for yield and yield components in Dabat district, Ethiopia. *Wudpecker Journal of Agricultural Research* 1 (7): 270-274
WBISPP (Woody Biomass Inventory and Strategic Planning Project). 2004. Woody Biomass Inventory and Strategic Planning Project database. Addis Ababa, Ethiopia: MoA.
Yirga, C., Y. A. Yigezu, A. Aw-Hassen. 2015. Tracking Adoption and Diffusion of Improved Chickpea Varieties: Comparison of Approach. Research Report, Addis Ababa, Ethiopia: EIAR

Annexes

Annex 1. Environmental information used in land suitability mapping of chickpea varieties

1.1. Desi types

1.1.1. Mastewal

	S_1	S_2	S_3	N
Altitude (masl)	2,200-2,600	2,600-2,800 1,800-2,200	2,800-2,900 1,200-1,800	>2,900 <1,200
LGP (days)	130-150	150-160 120-130	160-170 90-120	>170 <90
pH	6.7-7.5	5.5-6.7 7.5-8	5-5.5 8-8.5	<5 >8.5
Rainfall (during growing period)	900-1,000	1,000-1,100 700-900	1,100-1,200 600-700	>1,200 <600
Temperature (°C)	18-20	16-18 20-22	14-16 22-24	<14 >24
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, G-Gleysols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, V-Vertisols, T-Andosols	A-Acrisols, E-Rendzinas, J-Fluvisols	Q-Arenosols, I-Lithosols, R-Regosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	0-8	8-16	16-30	>30

1.1.2 Naatolii

	S_1	S_2	S_3	N
Altitude (masl)	2.200-2,700	2,700-2,800 1,800-2,200	2,800-2,900 1,200-1,800	>2,900 <1,200
LGP (days)	130-150	150-160 120-130	160-170 90-120	>170 <90
pH	6.7-7.5	5.5-6.7 7.5-8	5-5.5 8-8.5	<5 >8.5
Rainfall (during growing period)	900-1,000	1,000-1,100 700-900	1,100-1,200 600-700	>1,200 <600
Temperature (°C)	18-20	16-18 20-22	14-16 22-4	<14 >24
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, G-Gleysols, H-Phaeozems, L-Luvisols, N-Nitosols,	C-Chernozems, O-Histosols, V-Vertisols, T-Andosols	A-Acrisols, E-Rendzinas, J-Fluvisols,	Q-Arenosols, I-Lithosols, R-Regosols, Z-Solonchaks, X-Xerosols Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	0-8	8-16	16-30	>30

1.1.3 Teketay

	S_1	S_2	S_3	N
Altitude (masl)	1,800-2,600	2,600-2,800 1,500-1,800	2,800-2,900 1,200-1,500	>2,900 -<1,200
LGP (days)	120-140	140-150 100-110	150-160 90-100	>160 <90
pH	6.7-7.5	5.5-6.7 7.5-8	5-5.5 8-8.5	<5 >8.5
Rainfall (during growing period)	800-900	900-1,000 700-800	1,000-1,100 600-700	>1,100 <600
Temperature (°C)	18-20	16-18 20-22	14-16 22-24	<14 >24
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, G-Gleysols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, V-Vertisols, T-Andosols	A-Acrisols, E-Rendzinas, J-Fluvisols,	Q-Arenosols, I-Lithosols, R-Regosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	0-8	8-16	16-30	>30

1.2. Kabuli types

1.2.1. Arerti

	S_1	S_2	S_3	N
Altitude (masl)	1,800-2,600	2,600-2,700 1400-1800	2700-2800 1200-1400	>2800 <1200
LGP (days)	120-150	150-160 100-120	160-170 90-100	>170 <90
pH	6.7-7.5	5.5-6.7 7.5-8	5-5.5 8-8.5	<5 >8.5
Rainfall (during growing period)	800-1,000	1,000-1,200 700-800	1,200-1,400 600-700	>1,400 <600
Temperature (°C)	18-20	16-18 20-22	14-16 22-24	<14 >24
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, G-Gleysols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, V-Vertisols, T-Andosols	A-Acrisols, E-Rendzinas, J-Fluvisols	Q-Arenosols, I-Lithosols, R-Regosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	0-8	8-16	16-30	>30

1.2.2. Habru

	S_1	S_2	S_3	N
Altitude (masl)	1,800-2,500	2,500-2,700 1,400-1,800	2,700-2,800 1,200-1,400	>2,800 <1,200
LGP (days)	120-150	150-160 100-120	160-170 90-100	>170 <90
pH	6.7-7.5	5.5-6.7 7.5-8	5-5.5 8-8.5	<5 >8.5
Rainfall (during growing period)	800-1,000	1,000-1,200 700-800	1,200-1,400 600-700	>1,400 <600
Temperature (°C)	18-20	16-18 20-22	14-16 22-24	<14 >24
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, G-Gleysols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, V-Vertisols, T-Andosols	A-Acrisols, E-Rendzinas, J-Fluvisols	Q-Arenosols, I-Lithosols, R-Regosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	0-8	8-16	16-30	>30

1.2.3. Kasech

	S_1	S_2	S_3	N
Altitude (masl)	1,700-2,400	2,400-2,600 1,500-1,700	2,600-2,800 1,200-1,500	>2,800 -<1,200
LGP (days)	120-140	140-150 100-110	150-160 90-100	>160 <90
pH	6.7-7.5	5.5-6.7 7.5-8	5-5.5 8-8.5	<5 >8.5
Rainfall (during growing period)	700-800	800-900 600-700	900-1000 550-600	>1,000 >8.5
Temperature (°C)	20-22	18-20 22-23	16-18 23-25	<16 >25
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained, imperfectly drained	Poor
Soil type	B-Cambisols, G-Gleysols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, V-Vertisols, T-Andosols	A-Acrisols, E-Rendzinas, J-Fluvisols	Q-Arenosols, I-Lithosols, R-Regosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	0-8	8-16	16-30	>30

1.2.4. Yelbey

	S_1	S_2	S_3	N
Altitude (masl)	1,700-2,400	2,400-2,600 1,500-1,700	2,600-2,800 1,200-1,500	>2,800 -<1,200
LGP (days)	120-140	140-150 100-120	150-160 90-100	>160 <90
pH	6.7-7.5	5.5-6.7 7.5-8	5-5.5 8-8.5	<5 >8.5
Rainfall (during growing period)	800-900	900-1,000 700-800	1,000-1,100 600-700	>1,100 <600
Temperature (°C)	20-22	18-20 22-23	16-18 23-25	<16 >25
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, G-Gleysols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, V-Vertisols, T-Andosols	A-Acrisols, E-Rendzinas, J-Fluvisols	Q-Arenosols, I-Lithosols, R-Regosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	0-8	8-16	16-30	>30

Annex 2. Environmental information used in land suitability mapping of faba bean varieties

2.1. Dosha

	S_1	S_2	S_3	N
Altitude (masl)	2,500-2,800	2,000-2,500 2,800-3,000	1,800-2,000 3,000-3,100	<1,800 >3,100
LGP (days)	145-170	130-145 170-180	110-130 180-190	<110 >190
pH	6.5-7.5	7.5-8 6-6.5	8-8.4 5-6	->8.4 <5.0
Rainfall (during growing period)	1,200-1,400	1,000-1,200 1,400-1,500	900-1,000 1,500-1,600	<900 >1,600-
Temperature (°C)	13-16	16-20 11-13	20-22 10-11	>22 <10
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, E-Rendzinas, G-Gleysols, J-Fluvisols, T-Andosols	A-Acrisols, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, X-Xerosols, Y-Yermosols, Z-Solonchaks
Soil texture	Clay loam, Loam	Sandy loam	Clay	Sand
Slope (%)	0-8	8-16	16-30	>30

2.2. Gabelcho

	S_1	S_2	S_3	N
Altitude (masl)	2,400-2,800	2,000-2,400 2,800-3,000	1,700-2,000 3,000-3,100	<1,700 >3,100
LGP (days)	140-170	120-140 170-180	110-120 180-190	<110 >190
pH	6.5-7.5	7.5-8 6-6.5	8-8.4 5-6	>8.4 <5.0
Rainfall (during growing period)	1,200-1,400	1,000-1,200 1,400-1,500	800-1,000 1,500-1,600	<800 >1,600
Temperature (°C)	13-16	16-19 11-13	19-23 10-11	>23 <10
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained, Moderately well drained	Excessively drained, Imperfectly drained	Poor
Soil type	B-Cambisols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, E-Rendzinas, G-Gleysols, J-Fluvisols, T-Andosols	A-Acrisols, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, X-Xerosols, Y-Yermosols, Z-Solonchaks
Soil texture	Clay loam, Loam	Sandy loam	Clay	Sand
Slope (%)	0-8	8-16	16 -30	>30

2.3. Gora

	S_1	S_2	S_3	N
Altitude (masl)	2,400-2,800	2,000-2,400 2,800-3,000	1,800-2,000 3,000-3,100	<1,800 >3,100
LGP (days)	140-160	110-140 160-170	100-110 170-180	<100 >180
pH	6.5-7.5	7.5-8 6-6.5	8-8.4 5-6	>8.4 <5.0
Rainfall (during growing period)	1,000-1,200	900-1,000 1,200-1,300	800-900 1,300-1,400	<800 >1,400
Temperature (°C)	13-16	16-19 11-13	19-23 10-11	>23 <10
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained, moderately well drained	Excessively drained, imperfectly drained	Poor
Soil type	B-Cambisols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, E-Rendzinas, G-Gleysols, J-Fluvisols, T-Andosols	A-Acrisols, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, X-Xerosols, Y-Yermosols, Z-Solonchaks
Soil texture	Clay loam, Loam	Sandy loam	Clay	Sand
Slope (%)	0-8	8-16	16-30	>30

2.4. Moti

	S_1	S_2	S_3	N
Altitude (masl)	2,200-2,600	1,900-2,200 2,600-2,800	1,800-1,900 2,800-3,100	<1,800 >3,100
LGP (days)	120-150	100-120 150-170	90-100 170-180	<90 <180
pH	6.5-7.5	7.5-8 6-6.5	8-8.4 5-6	>8.4 <5.0
Rainfall (during growing period)	1,000-1,200	900-1,000 1,200-1,400	700-900 1,400-1,500	<700 >1,500
Temperature (°C)	14-18	18-20 12-14	20-23 10-12	>23 <10
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, E-Rendzinas, G-Gleysols, J-Fluvisols, T-Andosols	A-Acrisols, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, X-Xerosols, Y-Yermosols, Z-Solonchaks
Soil texture	Clay loam, Loam	Sandy loam	Clay	Sand
Slope (%)	0-8	8-16	16 -20	>30

2.5. Dagm

	S_1	S_2	S_3	N
Altitude (masl)	2,500-2,800	2,000-2,500 2,800-3,000	1,800-2,000 3,000-3,100	<1,800 >3,100
LGP (days)	145-170	130-145 170-180	110-130 180-190	<110 >190
pH	6.5-7.5	7.5-8 6-6.5	8-8.5 5.5-6	>8.5 <5.5
Rainfall (during growing period)	1,200-1,400	1,000-1,200 1,400-1,500	900-1,000 1,500-1,600	<900 >1,600
Temperature (°C)	13-16	16-20 11-13	20-22 10-11	>22 <10
Soil depth (cm)	>100	80-100	50-80	<50
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, E-Rendzinas, G-Gleysols, J-Fluvisols, T-Andosols, V-Vertisols	A-Acrisols	I-Lithosols, R-Regosols, Q-Arenosols, X-Xerosols, Y-Yermosols, Z-Solonchaks
Soil texture	Clay loam, Loam	Sandy loam	Clay	Sand
Slope (%)	0-8	8-16	16 -30	>30

2.6. Hachalu

	S_1	S_2	S_3	N
Altitude (masl)	2,200-2,700	1,900-2,200 2,700-3,000	1,700-1,900 3,000-3,100	<1,700 >3,100
LGP (days)	135-165	120-135 165-175	100-120 175-185	<100 >185
pH	6.5-7.5	7.5-8 6-6.5	8-8.4 5.5-6	>8.4 <5.5
Rainfall (during growing period)	1,200-1,400	1,000-1,200 1,400-1,500	800-1,000 1,500-1,600	<800 >1,600
Temperature (°C)	14-16	16-19 12-14	19-23 10-12	>23 <10
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, E-Rendzinas, G-Gleysols, J-Fluvisols, T-Andosols, V-Vertisols	A-Acrisols	I-Lithosols, R-Regosols, Q-Arenosols, X-Xerosols, Y-Yermosols, Z-Solonchaks
Soil texture	Clay loam, Loam	Sandy loam	Clay	Sand
Slope (%)	0-8	8-16	16-30	>30

2.7. Walki

	S_1	S_2	S_3	N
Altitude (masl)	2,300-2,700	2,000-2,300 2,700-3,000	1,800-2,000 3,000-3,100	<1,800 >3,100
LGP (days)	130-160	110-130 160-170	100-110 170-180	<100 >180
pH	6.5-7.5	7.5-8 6-6.5	8-8.5 5.5-6	->8.5 <5.5
Rainfall (during growing period)	1,000-1,200	900-1,000 1,200-1,300	800-900 1,300-1,400	<800 >1,400
Temperature (°C)	13-17	17-19 12-13	19-23 10-12	>23 <10
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, H-Phaeozems, L-Luvisols, N-Nitosols	C-Chernozems, O-Histosols, E-Rendzinas, G-Gleysols, J-Fluvisols, T-Andosols, V-Vertisols	A-Acrisols	I-Lithosols, R-Regosols, Q-Arenosols, X-Xerosols, Y-Yermosols, Z-Solonchaks
Soil texture	Clay loam, Loam	Sandy loam	Clay	Sand
Slope (%)	0-8	8-16	16 -30	>30

Annex 3. Environmental information used in land suitability mapping of malt barley varieties

3.1. Bekoji-1

	S_1	S_2	S_3	N
Altitude (masl)	2,600-3,000	2,400-2,600 3,000-3,100	2,000-2,400 3,100-3,200	<2,000 >3,200
LGP (days)	150-180	140-150 180-190	120-140 190-200	<120 >200
pH	6-7.5	7.5-8 5-6	8-8.5 4.5-5	>8.5 <4.5
Rainfall (during growing period)	900-1,400	800-900 1,400-1,500	600-800 1,500-1,600	<600 >1,600
Temperature (°C)	11-13	13-15 10-11	15-17 9-10	>17 <9
Soil depth (cm)	>80	60-80 60-80	40-60 40-60	<40
Drainage	Well drained	Somewhat excessively drained, moderately well drained	Excessively drained, imperfectly drained	Poor
Soil type	B-Cambisols, L-Luvisols, N-Nitosols, H-Phaeozems	C-Chernozems, O-Histosols, J-Fluvisols, G-Gleysols, T-Andosols	A-Acrisols, E-Rendzinas, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	2-15	15-25	1-2 25-30	<1 >30

3.2. EH-1847

	S_1	S_2	S_3	N
Altitude (masl)	2,600-3,000	2,400-2,600 3,000-3,100	2,000-2,400 3,100-3,200	<2,000 >3,200
LGP (days)	150-180	140-150 180-190	120-140 190-200	<120 >200
pH	6-7.5	7.5-8 5-6	8-8.5 4.5-5	>8.5 <4.5
Rainfall (during growing period)	900-1,400	800-900 1,400-1,500	600-800 1,500-1,600	<600 >1,600
Temperature (°C)	11-13	13-15 10-11	15-17 9-10	>17 <9
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained,	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, L-Luvisols, N-Nitosols, H-Phaeozems	C-Chernozems, O-Histosols, J-Fluvisols, G-Gleysols, T-Andosols	A-Acrisols, E-Rendzinas, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	2-15	15 -25	1-2 25-30	<1 >30

3.3. Grace

	S_1	S_2	S_3	N
Altitude (masl)	2,000-2,400	1,800-2,000 2,400-2,800	1,500-1,800 2,800-2,900	<1,500 >2,900
LGP (days)	110-125	100-110 125-160	90-100 160-170	<90 >170
pH	6-7.5	7.5-8 5-6	8-8.5 4.5-5	>8.5 <4.5
Rainfall (during growing period)	900-1,400	700-900 1,400-1,500	500-700 1,500-1,600	<500 >1,600
Temperature (°C)	15-17	17-19 13-15	19-21 12-13	>21 12
Soil depth (cm)	>80	60-80 60-80	40-60 40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, L-Luvisols, N-Nitosols, H-Phaeozems	C-Chernozems, O-Histosols, J-Fluvisols, G-Gleysols, T-Andosols	A-Acrisols, E-Rendzinas, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	2-15	15 -25	1-2 25-30	<1 >30

3.4. Holker

	S_1	S_2	S_3	N
Altitude (masl)	2,600-3,000	2,400-2,600 3,000-3,100	2,000-2,400 3,100-3,200	<2,000 >3,200
LGP (days)	150-180	140-150 180-190	120-140 190-200	<120 >200
pH	6-7.5	7.5-8 5-6	8-8.5 4.5-5	>8.5 4.5-
Rainfall (during growing period)	900-1400	800-900 1,400-1,500	600-800 1,500-1,600	<600 >1,600
Temperature (°C)	11-13	13-15 10-11	15-17 9-10	>17 <9
Soil depth (cm)	>80	60-80 60-80	40-60 40-60	<40
Drainage	Well drained	Somewhat excessively drained, moderately well drained	Excessively drained, imperfectly drained	Poor
Soil type	B-Cambisols, L-Luvisols, N-Nitosols, H-Phaeozems	C-Chernozems, O-Histosols, J-Fluvisols, G-Gleysols, T-Andosols	A-Acrisols, E-Rendzinas, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	2-15	15 -25	1-2 25-30	<1 >30

3.5. IBON-174/03

	S_1	S_2	S_3	N
Altitude (masl)	2,400-3,000	2,000-2,400 3,000-3,200	1,800-2,000 3,200-3,500	<1,800 >3,500
LGP (days)	130-180	110-130 180-190	100-110 190-200	<100 >200
pH	6-7.5	7.5-8 5-6	8-8.5 4.5-5	>8.5 <4.5
Rainfall (during growing period)	900-1600	700-900 1,600-1,700	500-700 1,700-1,800	<500 >1,800
Temperature (°C)	12-16	16-18 10-12	18-19 8-10	>19 <8
Soil depth (cm)	>80	60-80 60-80	40-60 40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, L-Luvisols, N-Nitosols, H-Phaeozems	C-Chernozems, O-Histosols, J-Fluvisols, G-Gleysols, T-Andosols	A-Acrisols, E-Rendzinas, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	2-15	15 -25	1-2 25-30	<1 >30

3.6. Sabini

	S_1	S_2	S_3	N
Altitude (masl)	2,300-2,600	2,000-2,300 2,600-2,800	1,700-2,000 2,800-3,100	<1,700 >3,100
LGP (days)	120-140	110-120 140-175	100-110 175-190	<100 >190
pH	6-7.5	7.5-8 5-6	8-8.5 4.5-5	>8.5 <4.5
Rainfall (during growing period)	900-1,400	700-900 1,400-1,500	500-700 1,500-1,600	<500 >1,600
Temperature (°C)	14-16	16-17 13-14	17-20 11-13	>20 <11
Soil depth (cm)	>80	60-80	40-60	<40
Drainage	Well drained	Somewhat excessively drained; moderately well drained	Excessively drained; imperfectly drained	Poor
Soil type	B-Cambisols, L-Luvisols, N-Nitosols, H-Phaeozems	C-Chernozems, O-Histosols, J-Fluvisols, G-Gleysols, T-Andosols	A-Acrisols, E-Rendzinas, V-Vertisols	I-Lithosols, R-Regosols, Q-Arenosols, Z-Solonchaks, X-Xerosols, Y-Yermosols
Soil texture	Loam, Silt loam, Sandy clay loam	Clay loam, Silty clay loam	Sandy loam, Sandy clay, Silt, Silty clay, Clay	Sand, Loamy sand
Slope (%)	2-15	15 -25	1-2 25-30	<1 >30

Annex 4. List of chickpea, faba bean and malt barley varieties used for suitability mappings

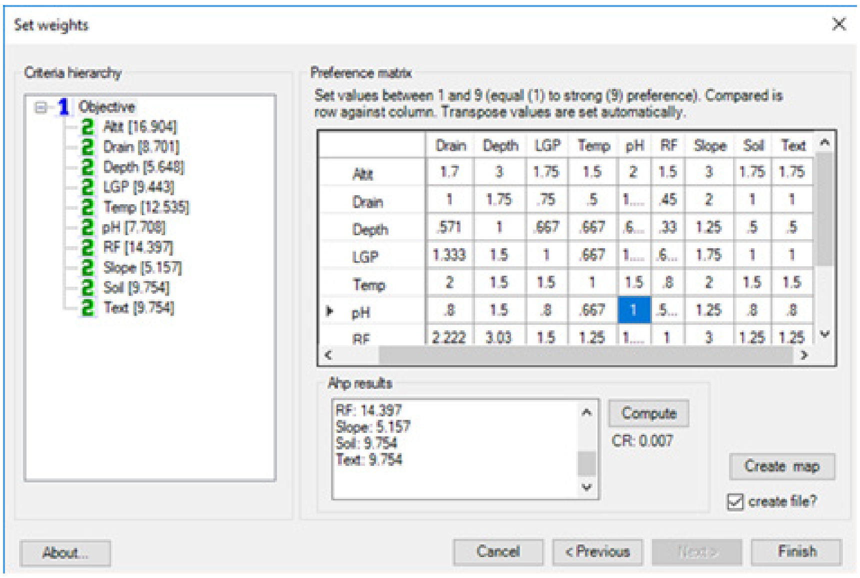
Crop	Origin	Breeder/ Maintainer Institution	Year of release	Pedigree
1. Chickpea				
Arerti	ICARDA	DZARC	1999/2000	FLIP-89-84c
Habru	ICARDA	DZARC	2004	FLIP 88-42c
Kasech	ICARDA	SARC	2011	FLIP-95-31C
Yelbey	ICRISAT	SARC	2006	ICCV-14808
Mastewal	ICRISAT	DBARC	2006	ICRISAT 1993/94, GW517 X ICCV 37 X ICC 12271
Naatolii	ICRISAT	DZARC	2007	ICCX-910112-6
Teketay	ICRISAT	DZARC	2013	CJG-74xICCL-83105
2. Faba bean				
Gora	ICARDA	KARC	2013	EH91026-8-2 X BPL44-1
Walki	ICARDA	HARC	2008	ILB4615 x Bulga 70
Moti	ICARDA	HARC	2006	ILB-4432 x kuse-2-27-33
Gabelcho	ICARDA	HARC	2006	ILB4726 X 75TA26026-1-2
Dosha	Ethiopia	HARC	2008	Landrace collection
Hachalu	ICARDA	HARC	2010	EH00102-4-1
Dagm	Ethiopia	DBARC		Landrace collection
3. Malt barley				
IBON 174/03	ICARDA	HARC	2012	ATCO/COMINO//ALELI/S/ESCOBA/3/MOLA/ SHYRI//CBSS98Y00600T-A0Y-OM3Y-OM
Bekoji-1	ICARDA	KARC	2010	EH1293/F2-18B-11-1-14-18
EH 1847	ICARDA	HARC	2012	EH 1847/F4.2P5.2(Bea/obon64/91)
Sabini	Kenya	KARC	2011	NA
Holker	Kenya	HARC	1979	EH8B/F4 x E.L.7.L
Grace	Germany Heineken*	HARC	2013	NA

Note: * Introduced for adaptation testing and release by Heineken.

Annex 5. Relative values and weights of environmental information

5.1. Pairwise comparison matrix of environmental information relative values and weights used in land suitability mapping of factor/malt barley, chickpea and faba bean (Dosha, Gabelcho, Gora & Moti) varieties, based on experts' group evaluation

	Alti-tude	Drain-age	Soil depth	LGP	Temper-ature	pH	Rainfall	Slope	Soil type	Tex-ture
Altitude	1	1.7	3	1.75	1.5	2	1.5	3	1.75	1.75
Drain-age	.588	1	1.75	.75	.5	1.25	.45	2	1	1
Soil depth	.333	.571	1	.667	.667	.667	.33	1.25	.5	.5
LGP	.571	1.333	1.5	1	.667	1.25	.667	1.75	1	1
Temper-ature	.667	2	1.5	1.5	1	1.5	.8	2	1.5	1.5
pH	.5	.8	1.5	.8	.667	1	.571	1.25	.8	.8
Rainfall	.667	2.222	3.03	1.5	1.25	1.75	1	3	1.25	1.25
Slope	.333	.5	.8	.571	.5	.8	.333	1	.5	.5
Soil type	.571	1	2	1	.667	1.25	.8	2	1	1
Texture	.571	1	2	1	.667	1.25	.8	2	1	1
Criteria weights	16.904	8.701	5.648	9.443	12.535	7.708	14.397	5.157	9.754	9.754



5.2. Pairwise comparison matrix of environmental information relative values and weights used in land suitability mapping of Hachalu, Walki and Dagm faba bean varieties (based on experts' group evaluation)

	Altitude	Drainage	Soil depth	LGP	Temperature	pH	Rainfall	Slope	Soil type	Texture
Altitude	1	.667	2.5	1.75	1.5	2	1.5	3	.8	1.75
Drainage	1.5	1	1.75	1.5	1.15	1.75	1	2	.667	1
Soil depth	.4	.571	1	.667	.667	.667	.33	1.25	.4	.5
LGP	.571	.667	1.5	1	.667	1.25	.667	1.75	.8	1
Temperature	.667	.87	1.5	1.5	1	1.5	.8	2	.87	1.5
pH	.5	.571	1.5	.8	.667	1	.571	1.25	.571	.8
Rainfall	.667	1	3.03	1.5	1.25	1.75	1	3	1	1.25
Slope	.333	.5	.8	.571	.5	.8	.333	1	.333	.5
Soil type	1.25	1.5	2.5	1.25	1.15	1.75	1	3	1	1.15
Texture	.571	1	2	1	.667	1.25	.8	2	.87	1
Criteria weights	14.254	12.15	5.611	8.637	10.84	7.207	12.971	4.948	13.682	9.7

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is a non-profit, CGIAR Research Center that focusses on delivering innovative solutions for sustainable agricultural development in the non-tropical dry areas of the developing world. We provide innovative, science-based solutions to improve the livelihoods and resilience of resource-poor smallholder farmers. We do this through strategic partnerships, linking research to development, and capacity development, and by taking into account gender equality and the role of youth in transforming the non-tropical dry areas.
www.icarda.org

CGIAR is a global research partnership for a food-secure future. CGIAR science is dedicated to reducing poverty, enhancing food and nutrition security, and improving natural resources and ecosystem services. Its research is carried out by 15 CGIAR centers in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations and the private sector.
www.cgiar.org