IntechOpen

Corn

Production and Human Health in Changing Climate

Edited by Amanullah and Shah Fahad

CORN - PRODUCTION AND HUMAN HEALTH IN CHANGING CLIMATE

Edited by **Amanullah** and **Shah Fahad**

Corn - Production and Human Health in Changing Climate
http://dx.doi.org/10.5772/intechopen.74074
Edited by Amanullah and Shah Fahad

Contributors

Haq Nawaz, Saima Muzaffar, Momna Aslam, Shakeel Ahmad, John Agbo Ogbodo, Samuel E. Anarah5, Abubakar Sani Mashi, Jerry Hatfield, Christian Dold, Arturo Navarro, Andrea Torres, Fernanda Fernandez-Aulis, Carolina Peña, Jacinto Bañuelos Pineda, Carmen Cecilia Gómez Rodiles, Luis Octavio Aguirre López, José Ricardo Cuéllar Pérez, Jean-Paul Chavas, Paul D. Mitchell, Dr. Amanullah

© The Editor(s) and the Author(s) 2018
The rights of the editor(s) and the author(s) have been asserted in accordance with the Copyright, Designs and Patents Act 1988. All rights to the book as a whole are reserved by INTECHOPEN LIMITED. The book as a whole (compilation) cannot be reproduced, distributed or used for commercial or non-commercial purposes without INTECHOPEN LIMITED's written permission. Enquiries concerning the use of the book should be directed to INTECHOPEN LIMITED rights and permissions department (permissions@intechopen.com).
Violations are liable to prosecution under the governing Copyright Law.

Individual chapters of this publication are distributed under the terms of the Creative Commons Attribution 3.0 Unported License which permits commercial use, distribution and reproduction of the individual chapters, provided the original author(s) and source publication are appropriately acknowledged. If so indicated, certain images may not be included under the Creative Commons license. In such cases users will need to obtain permission from the license holder to reproduce the material. More details and guidelines concerning content reuse and adaptation can be foundat http://www.intechopen.com/copyright-policy.html.

Notice

Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

First published in London, United Kingdom, 2018 by IntechOpen
eBook (PDF) Published by IntechOpen, 2019
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, The Shard, 25th floor, 32 London Bridge Street
London, SE19SG – United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Corn - Production and Human Health in Changing Climate
Edited by Amanullah and Shah Fahad

p. cm.

Print ISBN 978-1-78984-155-8

Online ISBN 978-1-78984-156-5

eBook (PDF) ISBN 978-1-83881-767-1

Meet the editors

Dr. Amanullah is currently working as Associate Professor in the Department of Agronomy, the University of Agriculture, Peshawar, Pakistan. He did his PhD in Agronomy at the University of Agriculture, Peshawar and his Post Doctorate from Dryland Agriculture Institute, WTAMU, Canyon, Texas, USA. Dr. Amanullah has published more than 100 papers in impact factor journals. He as published many books. He is the coauthor of three books published by the FAO: Soil and Pulses: Symbiosis for Life (2016), Unlocking the Potential of Soil Organic Carbon (2017), and Soil Pollution: A Hidden Reality (2018). Dr. Amanullah has also edited two books with Intech: Rice—Technology and Production (2017) and Nitrogen in Agriculture—Updates (2018). Dr. Amanullah has been awarded three Research Productivity Awards by the Pakistan Council for Science and Technology, Islamabad, in 2011/2012, 2012/2013, and 2015/2016. Dr. Amanullah represented Pakistan on the FAO Intergovernmental Technical Panel on Soils of Global Soil Partnership (2015–2018).

Dr. Shah Fahad was born in Dargai (Malakand Division), Pakistan. He studied in Pakistan at the Agricultural University, Khyber Pakhtunkhwa, and Quiad-I-Azam University, Islamabad, where he successfully completed two degrees: a BSc (Hons) in Agronomy and an MPhil in Plant Physiology. As a scholar he continued for another degree in Graduate Studies at Huazhong Agricultural University pursuing a PhD in Agronomy, which was achieved with honors in 2015. Mr. Shah Fahad is now doing a Post Doctorate at Huazhong Agricultural University. He is a contributor to many international journals with focuses on global warming and its influence on rice crop attributes in his articles. He is a member of the editorial boards and a critic of seven international journals.

Contents

Preface

Corn or maize (*Zea mays* L.) plays an important role in global food security. The many uses of corn make it a central commodity and a great influence on prices. Because of its worldwide distribution and relatively lower price, corn has a wider range of uses. It is used directly for human consumption, in industrially processed foods, as livestock feed, and in industrial nonfood products such as starches, acids, and alcohols. Recently, there has been interest in using maize for the production of ethanol as a substitute for petroleum-based fuels. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Climate change, however, is a growing concern among corn growers worldwide. Scientists estimate that corn production will need to be increased by 15% per unit area between 2017 and 2037. To increase corn yields, advanced and new production technology needs to be developed and distributed among corn growers. The advanced technology to boost corn yields and counteract climate change is important for food security for the growing global population. Nutritionally, maize seeds contain 60–68% starch and 7–15% protein. Maize oil is widely used as a cooking medium and for manufacturing hydrogenated oil. The oil has the quality of reducing cholesterol in the human blood similar sunflower oil. Corn flour is used as a thickening agent in the preparation of many edibles such as soups, sauces, and custard powder. Integrated nutrients management improves corn growth, leaf area index and light interception, dry matter accumulation and distribution, grain and fodder quality, yield components, grain and biomass yields, harvest index, and shelling percentage, and reduces the problem of food insecurity. Recent studies indicate that the integrated use of chemical and organic N-fertilizers can improve corn growth, increase yield and yield components, improve grain quality, and reduce environmental pollution. Macro- and micronutrients rich organic manures (animal manure, poultry manure, and plant residues, etc. in the form of compost, biochar, and residues) can serve as an effective substitute to costly synthetic fertilizers (urea, ammonium sulfate, nitrate, di-ammonium phosphate, potassium chloride, potassium sulfate, etc.), which not only reduce the cost of production but also environmental pollution, and increases growers' income on a sustainable basis. Integrated nutrients management (combined use of chemical + organic + biofertilizers) in a cereals-based system, especially corn production, is therefore more resilient to climate change.

The purpose of the book *Corn* is to present a comprehensive picture of the importance of corn globally. The book is divided into three parts. The first part deals with corn management practices, the second part is related to the role of corn in human health, and the third part deals with corn's response to climate change. This book is intended to satisfy to the needs of students, researchers, technologists, and policy makers. It comprises eight chapters. We are thankful to all the authors who contributed their valuable chapters to this book. We are also extremely grateful to Ms. Marina Dusevic (Author Service Manager) of InTech for helping us to publish the book in an excellent form in the shortest possible time. We owe our sincere thanks and gratitude to our families whose consistent encouragement and love have been a tremendous impetus for the completion of this book.

Dr. Amanullah
Associate Professor
Department of Agronomy
Faculty of Crop Production Sciences
The University of Agriculture Peshawar
Pakistan

Shah Fahad, PhD
Department of Plant Science and Technology
Huazhong Agricultural University
Wuhan, China

Section 1

Corn Management

Chapter 1

Integrated Nutrient Management in Corn Production: Symbiosis for Food Security and Grower's Income in Arid and Semiarid Climates

Amanullah and Shah Fahad

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.80995

Abstract

Soil fertility and corn productivity is continuously declining due to removal of essential plant nutrients from the soils. The deficiencies of essential plant nutrients, organic matter, and beneficial soil microbes in soils had negative impact on soil fertility, corn productivity, and grower's income, which has increased the problem of food insecurity under arid and semiarid climates. Best management practices including the proper use of plant nutrients increase (1) soil fertility and health, (2) yield per unit area, and (3) grower's income (profitability). Our long-term field experiments on maize crop indicated that a significant increase in yield per unit area occurred with the integrated nutrient management (combined use of chemical fertilizers + organic fertilizers + biofertilizers). The integrated use of major plant nutrients (nitrogen, phosphorus, and potash) along with different organic carbon sources (animal manures and plant residues) plus biofertilizers (beneficial microbes) significantly improves maize growth, yield and yield components, and grower's income.

Keywords: maize, corn, integrated nutrients management, organic fertilizers, chemical fertilizers, bio-fertilizers, yield, grower's income

1. Economic importance of maize

Corn or maize (*Zea mays* L.) is an important cereal crop in the world. It provides staple food to many populations. Maize is the third most important cereal crop in Pakistan after wheat and rice. In Khyber Pakhtunkhwa it ranked second after wheat in its importance [1, 2]. In developing countries, maize is a major source of income to farmers among whom many are poor. Corn is used as animals feed and industrial raw material in the developed countries, while in developing countries mostly used as food for human and feed for animals (http://cornindia.com/importance-and-utilization-of-maize/). Because of its worldwide distribution and relatively lower price, maize has wider range of uses. For example, it is used directly for human consumption, as livestock and poultry feed, and in nonfood products such as starches, acids, and alcohols. Recently, there has been interest in using maize for production of ethanol as a substitute for petroleum-based fuels. Nutritionally, maize seeds contain 60–68% starch and 7–15% protein. The embryo of corn seeds which forms about 12% of the whole grain is the source of protein, fats, and sugars. Yellow maize is the richest source of vitamin A. Maize contains 1.2–5.7% edible oil. Varieties developed particularly for oil production contain as much as 14%. Maize oil is widely used as a cooking medium and for manufacturing of hydrogenated oil. The oil has the quality of reducing cholesterol in the human blood like sunflower oil. Maize acts as a source in the manufacture of starch, syrup, dextrose, oil, gelatin, lactic acid, etc. Corn flour is used as a thickening agent in the preparation of many edibles like soups, sauces, and custard powder. Corn syrup is used as an agent in confectionary units. Corn sugar (dextrose) is used in pharmaceutical formulations and as a sweetening agent in soft drinks, etc. Corn gel on account of its moisture retention character is used as a bonding agent for ice-cream cones and as a dry Dustin agent for baking products (http://cornindia.com/importance-and-utilization-of-maize/). Integrated nutrient management improves corn growth, leaf area index and light interception, dry matter accumulation and distribution, grain and fodder quality, yield components, grain and biomass yields, harvest index, shelling percentage, and grower's income.

2. Maize response to chemical fertilizers (N, P, and K)

Commercial fertilizers are applied to maize crop to improve its growth and yield [1–7]. Maize (cereal) is an exhaustive crop and produces high biomass [7–14] and therefore has a high requirement for nutrients especially nitrogen [15], phosphorus [1, 7, 10, 16], and potassium [2, 14, 17–19].

2.1. Nitrogen management

Nitrogen is an essential nutrient for plant and microbial growth and one of the key limiting nutrients in many natural ecosystems all over the world. In many developing countries, the imbalance use of nitrogen in crop production results in nitrous oxide (N_2O) which is considered much stronger greenhouse gas than carbon dioxide. The integrated use of chemical and organic N fertilizers can improve plant growth, increase yield and yield components and grain quality, and reduce environmental pollution. Nitrogen-rich organic manures (animal manure, poultry manure, plant residues, etc.) can be served as an effective substitute to chemical N fertilizers (urea, ammonium sulfate, nitrate, etc.) to reduce the costs of chemical fertilizers, reduce environmental pollution, and increase grower's income [20]. Increase in N rate and number of split applications at high density improve light interception contributing to the remarkable increase in the crop growth rate and yield [21]. The increase in light interception at high-density plots was due to the increase in leaf area index [17, 22]. The efficient use of nitrogen is also important for increasing grain quality (Amanullah and Shah [13]), partial factor productivity (PFP), and agronomic N use efficiency (NUEA) in maize [23]. Amanullah [24] compared the agronomic N use efficiency (NUEA) and harvest index response of different maize genotypes to different N-fertilizer sources (urea, calcium ammonium nitrate (CAN) and ammonium sulfate (AS)) at various levels (0, 50, 100, 150, and 200 kg ha^{-1}). The results revealed that NUEA had negative relationship with increase in N rate, while harvest index had positive relationship with increase in N rate up to 150 kg ha^{-1}. Both NUEA and harvest index ranked first with the application of AS (AS > CAN > urea). The maize hybrid produced higher NUEA and harvest index than local cultivars (Pioneer-3025 > Jalal > Azam). Khan et al. [15] reported that nitrogen application yielded 41 and 26% more grain than the check (control) in year 1 and year 2, respectively. The hybrid (P-3025) yielded 30 and 24% more grain than the local cultivars in years 1 and 2, respectively. The application of urea at 150 and 200 kg N ha^{-1}, CAN at 100 and 150 kg N ha ha^{-1}, and AS at 50 and 100 kg N ha ha^{-1} was economical in terms of NR in both years ([15]). Seed protein contents in corn increased with the application of higher N rates (150 and 200 kg ha^{-1}) as compared with the lower N rates (50 and 100 kg ha^{-1}), while application of ammonium sulphate increased seed oil contents as compared to urea and CAN [25]. Yield components (number of rows ear^{-1}, seeds row^{-1}, seeds ear^{-1}, ears per 100 plants), and both grain and stover yields in corn increased with higher N rate [5]; ammonium sulfate at the highest rate of 200 kg N ha^{-1} was found beneficial in terms of higher productivity & profitability for hybrid maize [5].

2.2. Phosphorus management

Phosphorus is second to nitrogen in total application to crops yet is used by plants in much lower quantities. Unlike N, soil P readily forms weakly soluble mineral compounds in the soil, thus resulting in poor mobility. The major problems under semiarid condition in Northwest Pakistan are (1) low soil moisture and (2) low soil fertility especially P unavailability ([26–28]). Highest level of 90 kg P ha^{-1} 10 days before sowing (DBS) had marked an increase in ear length, grain weight, grain yield, shelling percentage, and net returns [29]. Among the sources of P-fertilizers, diammonium phosphate (DAP) and single super phosphate (SSP) improved growth, dry matter partitioning, and grain yield than Nitrophos (NP) and control [27]. The highest level of 90 kg P ha^{-1} at 10 DBS increased plant height, number of leaves per plant, mean leaf area, dry weight of leaf, stem and ear as well as biomass yield, and harvest index [28]. Amanullah et al. [26] also reported that application of DAP and SSP resulted in higher partial factor productivity (PFP) (63.58 and 61.92 kg grains kg^{-1} P), agronomic efficiency (AE) (13.01 and 13.71 kg grains kg^{-1} P), and net returns (NR) (Rs. 16,289 and 16,204 ha^{-1}), respectively, as compared with NP with lower PFP (57.16 kg grains kg^{-1} P), AE (8.94 kg grains kg^{-1} P), and NR (Rs. 4472 ha^{-1}). Increase in P rate (90 > 60 > 30 > 0 kg P ha^{-1}) and tillage depth (45 cm) increased maize productivity and profitability [6]. Earlier, Amanullah et al. [28] reported that phosphorus level and its time of application are considered as some of the most important factors affecting crop growth, dry matter accumulation, and harvest index in maize.

2.3. Potassium management

Asif et al. [18] reported that tasseling, silking, and physiological maturity were delayed when potash levels were increased up to 60 kg ha^{-1}, while further increase in K level up to 90 kg ha^{-1}

enhanced tasseling, silking, and maturity. Tasseling, silking, and physiological maturity showed positive relationship with increase in the number of splits. Maximum grain yield was recorded when K was applied at the highest rate of 90 kg ha^{-1}, while minimum grain yield of 1898.8 kg ha^{-1} was recorded when K was not applied. The highest grain yield was recorded in those plots which received 100% of K at sowing time, while the lowest grain yield was recorded when K was applied in three splits, i.e., 33.3% at sowing time, 33.3% at 15 DAE, and 33.3% at 30 DAE. Amanullah et al. [2] reported that potassium fertilizer management is beneficial for improving growth, yield, and yield components of maize under moisture stress condition in semiarid climates. The results confirmed that increasing the rate of soil applied K up to 90 kg P ha^{-1} in two equal splits (50% each at sowing and knee height) improve growth and maize productivity under semiarid climates.

3. Maize response to foliar nutrition

Amanullah et al. [30] studied the response of maize to urea spray (U0 = control, U1 = 2, U2 = 4, U3 = 6, and U4 = 8% urea) at different growth stages (T1 = V9, T2 = V12, T3 = VT, and T4 = R1 stages) assigned to subplots. It was concluded from the study that urea spray at the rate of 6% at V12 stage improves the grain yield and yield components of maize. Foliar application of nitrogen (2%) from different sources (e.g., urea, ammonium sulfate (AS), and calcium ammonium nitrate (CAN)) and its application time (15, 30, 45, and 60 days after emergence (DAE)) were studied on maize. It was concluded from the results that late foliar-N application (urea, CAN, or AS) about 1 week before tasseling up to silking could increase maize productivity in the study area [31]. Amanullah et al. [12] reported that foliar nutrient management not only applies nutrients to the hungry crops, but it could also be beneficial in terms of providing water to the thirsty crops under moisture stress condition. They conducted field experiment to investigate effects of foliar NPK (2% each) applied alone and in various combinations (N, P, K, N + P, N + K, P + K, and N + P + K) and their application time (one split at 30 and 60 days after emergence (DAE) and two equal splits at 30 + 60 DAE) on the growth and yield of maize (*Zea mays* L., cv. Azam) under moisture stress condition. It was concluded from the results that combined foliar application of the three major nutrients (N + P + K) at the rate of 1% each in two equal splits at 30 and 60 DAE increased maize productivity under moisture stress condition. In our recent study (Amanullah et al. [4]), response of dryland maize was investigated to foliar phosphorus (1, 2, and 3% P) and zinc levels (0.1, 0.2, and 0.3% Zn) and their application time (T1 = at boot stage and T2 = at silking stage). It was concluded from this study that the application of 3% foliar P + 0.3% foliar Zn at boot stage improves growth and increases maize productivity and profitability under moisture stress condition in semiarid climates.

4. Maize response to organic matter

Soil organic matter (SOM) is a key indicator of soil health because of its vital functions that affect soil fertility, productivity, and the environment. Soil organic matter plays a key role in supplying plants with the nutrients they require. Organic matter improves soil physical (texture, structure, bulk density, and water-holding capacity), soil chemical (nutrient availability, cation exchange capacity, reduced aluminum toxicity, and allelopathy), and soil biological (nitrogen mineralization bacteria, dinitrogen fixation, mycorrhizae fungi, and microbial biomass) properties. SOM adsorb heavy metals in the soils, which reduce toxicity of these metals to plants and reduce their escape to ground water. SOM also adsorbs herbicides, which may inhibit contamination of surface and groundwater. Furthermore, SOM also functions as a sink to organic carbon and mitigates carbon dioxide escape to the environment. SOM stabilize soil aggregates, making soil easier to cultivate, increasing soil water-holding and buffering capacities, and releasing plant nutrients upon mineralization [32]. Adequate amount of SOM maintains soil quality (health), preserves sustainability of cropping systems, and reduces environmental pollution [33].

4.1. Animal manures

Farhad et al. [34] reported maximum plant height, leaf area index, leaf area, number of leaves plant^{-1}, and transpiration with composted poultry manure. Delayed tasseling resulted in Monsanto-919 with fresh poultry manure at 75% FC, whereas early tasseling resulted in FH-810 with same treatment at 100% field capacity. Ahmad et al. [35] reported that the use of poultry manure at the rate of 2.50 t ha^{-1} with inorganic fertilizer 200–150–125 kg NPK ha^{-1} resulted in higher grain yield due to the enhancement in grains per cob and cobs per m^{-2}. Baloch et al. [36] reported that combined application of manures and inorganic fertilizers significantly increases the growth and yield of maize crop. Amanullah and Khalid [10] Studied the impact of animal manures (poultry, cattle, and sheep manures) on hybrid maize "CS-200." They concluded that application of poultry manure delay phenological development, improve growth, and increase total corn biomass. Amanullah and Khalid [1] reported that the application of poultry manure increased yield and yield components of maize.

4.2. Plant residues

Adejumo et al. [37] reported that application of compost significantly increased maize biomass and decreased lead concentration in soil as compared to control and inorganic fertilizers. It was concluded that compost enhance soil fertility and crop productivity and increase plant resistance to heavy metals. Nziguheba et al. [38] studied the effects of residue incorporation and inorganic fertilizers on nutrient availability and maize yield. Plant residue incorporation increased P uptake and soil P as compared to inorganic fertilizer treatments in 3 years. Schiemenz et al. [39] studied the effectiveness of various types of ashes obtained after burning of different plant biomasses like rape meal, straw, and cereal residues. Ash application increased P uptake and soil P content, and the fertilizing effect of ash was comparable to triple super phosphate (TSP, a chemical fertilizer). Amanullah and Khan [16] studied the impact of compost application times ((30, 15, and 0 days before sowing (DBS)) on maize yield. The results confirmed that compost applied at sowing time significantly increased yield and yield components of maize under semiarid condition. Amanullah et al. [3] reported that application of compost tremendously improved growth and increased yield and yield components of maize when grown alone in mono-cropping or inter-cropped with common bean. The land equivalent ratio (LER) was higher in plots treated with compost than without compost-treated plots.

5. Maize response to biofertilizers (beneficial microbes)

Biofertilizers (beneficial microbes) are known to play many vital roles in soil fertility, crop productivity, and profitability. Beneficial microbes reduce the use of chemical fertilizers and thereby reduce environmental pollution caused by chemical fertilizers. Beneficial microbes reduce cost of production and so increase grower's income and profitability [40]. Our recent publications [1, 10, 16] indicated significant ($P \leq 0.05$) differences in growth, yield components, yield, and harvest index between the seeds treated with PSB (+) and without PSB (−). Amanullah and Khan [16] conducted field trial to study the effects of P levels, compost application times, and seed inoculation with phosphate-solubilizing bacteria (PSB) on the yield and yield components of maize (*Zea mays* L., cv. Azam). Maize seed inoculated with PSB (+) had tremendously increased yield and yield components of maize over PSB-control plots (−). Amanullah and Khalid [10] conducted field experiment to investigate impact of P levels (40, 80, 120, and 160 kg P ha^{-1}) and animal manures (poultry, cattle, and sheep manures) with (+) and without (−) phosphate-solubilizing bacteria (PSB) on phenological development, growth, and biomass yield of hybrid maize "CS-200." The plots with PSB (+) produced significantly taller plants with higher mean single leaf area and leaf area index and produced the highest biomass yield. Amanullah and Khalid [1] conducted a field trial to investigate the impact of the integrated use of different animal manures and phosphorus levels on yield and yield components of hybrid maize (CS-200) with (+) and without (−) phosphate-solubilizing bacteria (PSB). Maize seeds treated with PSB (+) before sowing had produced higher yield and yield components than untreated seeds (−). We concluded from this study that combined application of 160 kg P ha^{-1} + poultry manure + seed treatment with PSB (+) could improve corn productivity and profitability under semiarid condition.

6. Maize response to integrated nutrient management

The basic concept underlying integrated nutrient management (INM) is the maintenance and possible improvement in soil health for sustained crop productivity and sustainability. Amanullah et al. [7] reported that application of 120 kg N ha^{-1} + 2 t compost ha^{-1} under deep tillage system (45 cm) could improve spring maize yield and yield-contributing traits. Amanullah et al. [9] reported that application of the highest level of sulfur at 40 kg S ha^{-1} + N level at 160 kg N ha^{-1} increased maize productivity. Amanullah and Khan [16] reported that compost applied at sowing time + P applied at the two higher rates (75 and 100 kg P ha^{-1}) + PSB (phosphate-solubilizing bacteria) tremendously increased yield and yield components of maize. Application of 120 kg P ha^{-1} + poultry manure along with seed treatment with PSB improved growth and total biomass [10] and increased yield and yield components of maize [1]. According to Iqbal et al. [14], application of K at the highest rate of 90 kg ha^{-1} in two equal splits (50% at sowing +50% at V9 stage) along with cattle dung (5 t ha^{-1}) could improve number and area of leaves, dry matter partitioning, biomass yield, and harvest index under limited irrigation condition. Amanullah [41] reported that integrated use of organic carbon sources, plant nutrients and bio-fertilizers is key to improve field crops productivity under arid and semiarid climates.

7. Conclusions

Soil fertility and corn productivity are continuously declining due to the removal of essential plant nutrients from the soils. The deficiencies of essential plant nutrients, organic matter, and beneficial soil microbes in soils had negative impact on soil fertility, corn productivity, and grower's income that have increased the problem of food insecurity globally. Best management practices including the proper use of plant nutrients increase (1) soil fertility and health, (2) yield per unit area, and (3) grower's income (profitability). Our long-term field experiments on maize crop indicated that a significant increase in yield per unit area occurred with integrated nutrient management (combined use of chemical fertilizers + organic fertilizers + biofertilizers). The integrated use of major plant nutrients (nitrogen, phosphorus, and potash) along with different organic carbon sources (animal manures and plant residues) plus biofertilizers (beneficial microbes) significantly improves maize growth, yield and yield components, and grower's income.

Author details

Amanullah[1]* and Shah Fahad[2]

*Address all correspondence to: amanullah@aup.edu.pk

1 Department of Agronomy, The University of Agriculture, Peshawar, Pakistan

2 Department of Agriculture, The University of Swabi, Pakistan

References

[1] Amanullah, Khalid S. Integrated use of phosphorus, animal manures and biofertilizers improve maize productivity under semiarid condition. In: Larramendy ML, Soloneski S, editors. Organic Fertilizers–From Basic Concepts to Applied Outcomes. Rijeka, Croatia: InTech; 2016. pp. 137-155

[2] Amanullah, Iqbal A, Irfanullah, Hidayat Z. Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. Scientific Reports. 2016a;**6**:34627. DOI: 10.1038/srep34627

[3] Amanullah, Khan F, Muhammad H, Jan AU, Ali G. Land equivalent ratio, growth, yield and yield components response of mono-cropped vs. inter-cropped common bean and maize with and without compost application. Agriculture and Biology Journal of North America. 2016b;**7**(2):40-49

[4] Amanullah, Saleem A, Iqbal A, Fahad S. Foliar phosphorus and zinc application improve growth and productivity of maize (*Zea mays* L.) under moisture stress conditions in semi-arid climates. Journal of Microbial and Biochemical Technology. 2016c;**8**:433-439. DOI: 10.4172/1948-5948.1000321

[5] Amanullah, Iqbal A, Ali A, Fahad S, Parmar B. Nitrogen source and rate management improve maize productivity of smallholders under semiarid climates. Frontiers in Plant Science. 2016d;**7**:1773. DOI: 10.3389/fpls.2016.01773

[6] Amanullah A, Zahid A, Iqbal, Ikramullah. Phosphorus and tillage management for maize under irrigated and dryland conditions. Annals of Plant Sciences. 2016e;**5**(3):1304-1311

[7] Amanullah, Khan I, Jan A, Jan MT, Khalil SK, Shah Z, et al. Compost and nitrogen management influence productivity of spring maize (*Zea mays* L.) under deep and conventional tillage systems in semi-arid regions. Communications in Soil Science and Plant Analysis. 2015a;**46**(12):1566-1578

[8] Amanullah, Khan I. Compost and nitrogen application influence phenology, growth and biomass yield of spring maize under deep and conventional tillage systems. Journal of Soils and Crops. 2017;**27**(1):1-6

[9] Amanullah, Bashir SF, Iqbal A. Interactive effects of nitrogen and sulfur on growth, dry matter partitioning and yield of maize. Pure and Applied Biology. 2015b;**4**(2):164-170

[10] Amanullah, Khalid S. Phenology, growth and biomass yield response of maize (*Zea mays* L.) to integrated use of animal manures and phosphorus application with and without phosphate solubilizing bacteria. Journal of Microbial & Biochemical Technology. 2015;**7**:439-444. DOI: 10.4172/1948-5948.1000251

[11] Amanullah et al. Effects of variable nitrogen source and rate on leaf area index and total dry matter accumulation in maize (*Zea mays* L.) genotypes under calcareous soils. Turkish Journal of Field Crops. 2014a;**19**(2):276-284

[12] Amanullah, Kakar KM, Khan A. Growth and yield response of maize (*Zea mays* L.) to foliar NPK-fertilizers under moisture stress condition. Soil & Environment. 2014b;**33**(2):116-123

[13] Amanullah, Shah P. Timing and rate of nitrogen application influence grain quality and yield in maize planted at high and low densities. Journal of Science and Food Agriculture. 2010;**15**(1):21-29

[14] Iqbal I, Amanullah, Iqbal M. Impact of potassium rates and their application time on dry matter partitioning, biomass and harvest index of maize (*Zea mays*) with and without cattle dung application. The Emirates Journal of Food and Agriculture. 2015;**27**(5):447-453

[15] Khan A, Almas LK, Al-Noaim MI. Nitrogen rates and sources affect yield and profitability of maize in Pakistan. Crop, Forage & Turfgrass Management. 2015;**1**:6. DOI: 10.2134/cftm2014.0021. (American Society of Agronomy)

[16] Amanullah, Khan A. Phosphorus and compost management influence maize (*Zea mays*) productivity under semiarid condition with and without phosphate solubilizing bacteria. Frontiers in Plant Science (Plant Biotic Interactions). 2015;**6**:1083. open access

[17] Amanullah, Asif M, Shah Z, Hassan M. Potassium effects on the yield and yield components of maize in Northwest Pakistan. Annals of Agrarian Science. 2007;**5**(4):13-17

[18] Asif M, Amanullah, Anwar M. Phenology, leaf area and yield of spring maize (cv. azam) as affected by levels and timings of potassium application. World Applied Sciences Journal. 2007;**2**(4):299-303

[19] Khan K. Evaluation of organic sources for improving maize productivity at low and high levels of phosphorus and potassium. Thesis submitted to Department of Agronomy, The University of Agriculture Peshawar, Pakistan; 2016b

[20] Amanullah, Fahad S, editors. Nitrogen in Agriculture-Updates. Rijeka, Croatia: InTech; 2018. (ISBN: 978-953-51-5398-6)

[21] Amanullah, Rahman H, Shah Z, Shah P. Effects of plant density and N on growth dynamics, light interception and yield of maize. Archives of Agronomy and Soil Science. 2008;**54**(4):401-411

[22] Toler JE, Murdock EC, Stapleton GS, Wallace SU. Corn leaf orientation effects on light interception, intra-specific competition, and grain yields. Journal of Production Agriculture. 1999;**12**:396-399

[23] Amanullah. Rate and timing of nitrogen application influence partial factor productivity and agronomic NUE of maize (*Zea mays* L.) planted at low and high densities on calcareous soil in Northwest Pakistan. Journal of Plant Nutrition. 2016;**39**(5):683-690

[24] Amanullah. Source and rate of nitrogen application influence agronomic N-use efficiency and harvest index in maize (*Zea mays* L) genotypes. Maydica. 2014;**59**:80-89

[25] Khan A. Maize (*Zea mays* L.) genotypes differ in phenology, seed weight and quality (protein and oil contents) when applied with variable rates and source of nitrogen. Journal of Plant Biochemistry and Physiology. 2016a;**4**:164. DOI: 10.4172/2329-9029.1000164

[26] Amanullah, Asif M, Almas LK. Agronomic efficiency and profitability of P-fertilizers applied at different planting densities of maize in Northwest Pakistan. Journal of Plant Nutrition. 2012;**35**:331-341

[27] Amanullah, Asif M, Nawab K, Shah Z. Impacts of planting density and P-fertilizer source on the growth analysis of maize. Pakistan Journal of Botany. 2010b;**42**(4):2349-2357

[28] Amanullah, Zakirullah M, Tariq M. Levels and time of phosphorus application influence growth, dry matter partitioning and harvest index in maize. Pakistan Journal of Botany. 2010c;**42**(6):4051-4061

[29] Amanullah, Almas LK, Shah P. Timing and rate of nitrogen application influence profitability of maize planted at low and high densities in Northwest Pakistan. Agronomy Journal. 2010a;**102**:575-579

[30] Amanullah, Yasir M, Khan AZ, Tariq Jan M. Phenology, growth, and grain yield of maize as influenced by foliar applied urea at different growth stages. Journal of Plant Nutrition. 2010d;**33**(1):71-79

[31] Amanullah, Khan AZ, Khan F. Foliar application of nitrogen at different growth stages influence the phenology, growth and yield of maize (*Zea mays* L.). The Journal Soil & Environment. 2013;**32**(2):135-140

[32] Carter MR, Stewart BA. Structure and Organic Matter Storage in Agriculture Soils. Boca Raton, Fl: CRC Press; 1996

[33] Fageria NK. Role of soil organic matter in maintaining sustainability of cropping systems. Communications in Soil Science and Plant Analysis. 2012;**43**(16):2063-2113

[34] Farhad W, Saleem MF, Cheema MA, Hammad HM. Effect of poultry manure on productivity of spring maize (*Zea mays* L.). Journal of Animal and Plant Sciences. 2009;**19**(3): 122-125

[35] Ahmad RD, Habib E, Rehman A. Complementary effects of organic manures on the agronomic traits of spring maize. Crop and Environment. 2012;**3**(1-2):28-31

[36] Baloch PA, Abro BA, Chandio AS, Depar N, Ansari MA. Growth and yield response of maize to integrated use of gliricidia sepium, farm manure and NPK fertilizers. Pakistan Journal of Agriculture. Agricultural Engineering and Veterinary Sciences. 2015;**31**(1):14-23

[37] Adejumo SA, Togun AO, Adediren JA, Ogundiren MB. Effects of compost application on remediation and the growth of maize planted on lead contaminated soil. In: Proceeding of 19th World Congress of Soil Science, Soil Solutions for a Changing World; 1-6 August 2010; Brisbane, Australia; 2010. pp. 99-102

[38] Nziguheba G, Merckx R, Palm CA, Rao MR. Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. Biology and Fertility of Soils. 2000;**32**(4):328-339. DOI: 10.1007/s003740000256

[39] Schiemenz K, Kern J, Paulsen HM, Bachmann S, Eichler-Löbermann B. Phosphorus fertilizing effects of biomass ashes. In: Recycling of Biomass Ashes. Berlin/Heidelberg: Springer; 2011. pp. 17-31

[40] Amanullah. The role of beneficial microbes (biofertilizers) in increasing crop productivity and profitability. EC Agriculture. 2015;**2.6**(2015):504

[41] Amanullah. Integrated use of organic carbon, plant nutrients and bio-fertilizers is key to improve field crops productivity under arid and semiarid climates. In: FAO (2017) Proceedings of the Global Symposium on Soil Organic Carbon. Rome, Italy: Food and Agriculture Organization of the United Nations; 2017. pp. 480-481

Corn Productivity: The Role of Management and Biotechnology

Jean-Paul Chavas and Paul D. Mitchell

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77054

Abstract

The last few decades have seen a rapid increase in corn production, making corn the most important cereal in the world. This evolution is due in large part to rapid productivity growth for corn. Both improved genetics and improved farm management have contributed to large increases in corn yield. The paper reviews how genetics, biotechnology and management have interacted to increase agricultural productivity and reduce farm risk exposure. It documents the stellar performance of corn in terms of productivity growth. It also discusses the recent evolution of corn markets and evaluates the prospects for the future.

Keywords: corn, productivity, biotechnology, risk, management

1. Introduction

Corn (*Zea mays*), also called maize or field corn, is the most important cereal in the world, with annual global production exceeding that of wheat and rice. In 2017, corn production accounted for 41% of total grain production in the world [1]. While corn is a staple food in parts of the world, it has many uses, including animal feed, biofuel and sweetener. This chapter provides an overview of the evolving role of corn in agriculture.

Corn was first domesticated in southern Mexico about 9000 years ago [2, 3]. Its closest wild relative is teosinte, a wild grass of Mexico, Guatemala and Honduras. A major puzzle is the great genetic differences between teosinte and corn, indicating how key mutations and human selection contributed to genetic evolution [4]. After the Columbian exchange, corn production spread throughout the world. Corn is a highly productive crop with the ability to exploit available soil nutrients. As a C4 plant, corn has some photosynthetic advantages in capturing solar energy in warm weather compared to C3 crops such as wheat, rice and soybean. Due to its high productivity under various climate conditions, corn is now the largest grain crop in the world [1]. Favorable agro-climatic conditions in the US "Corn Belt" have made the US the largest corn producer. In 2017, corn production in the US accounted for 35% of world corn production [1].

The rise of corn as the most important cereal in the world has been associated with important improvements in its productivity [5]. **Figure 1** illustrates the evolution of the average corn yield on US farms from 1870 to 2017 [6]. **Figure 1** shows that corn productivity was basically stagnant before 1940: during the period 1870–1940, US average corn yields stayed within a narrow range between 20 and 30 bu/acre. (between 1200 and 1900 kg/ha)[1] Starting in 1940, a period of fast and steady rise in corn productivity began and continues to this time. US average corn yield increased from 28.9 bu/acre (1.81 metric tons/ha) in 1940 to 176.6 bu/acre (11.1 metric tons/ha) in 2017 [6]. This amazing achievement means that a given area of land can produce 6.1 times more corn in 2017 than in 1940, which corresponds to an average annual growth rate of 2.35%, reflecting the rapid technological progress sustained over the last seven decades. This achievement raises two questions. First, what are the sources of this growth in corn productivity? Second, is it likely to continue in the future? Below, we discuss the role played by two key drivers of corn productivity: improved genetics and improved management. We also consider the corn market and its evolving prices. Finally,

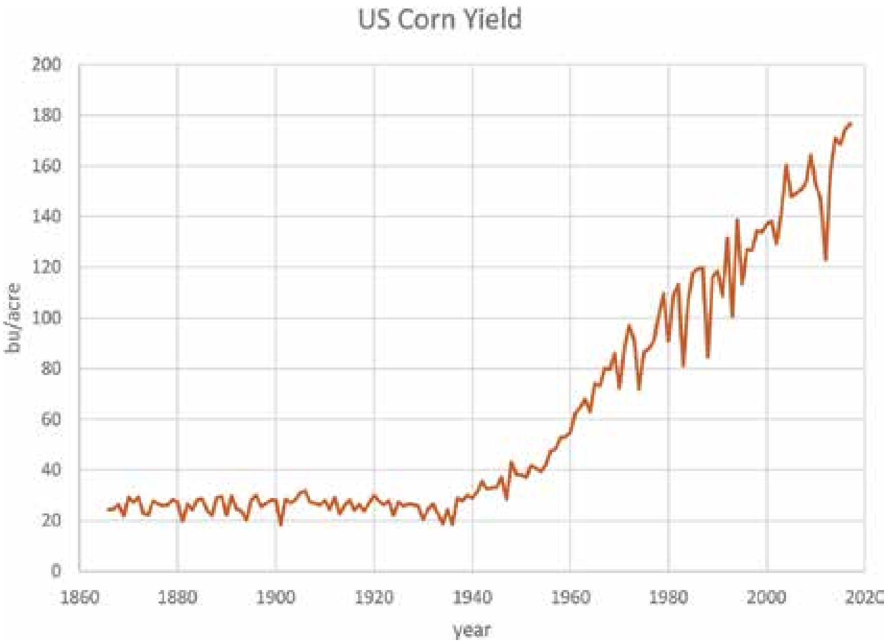


Figure 1. Historical corn yield, US. Source: The corn yield is measured in dollar per bushel, as reported by USDA-NASS [6].

---

[1] 1 bushel of corn equals 25.40 kg and 1 acre of land equals 0.4047 hectare. Thus, 1 bu/acre = 62.77 kg/hectare.

we reflect on what may come next. Some evidence suggests that agricultural productivity growth may be slowing down, raising concerns about our ability to feed a growing world population (e.g., [7]). We ponder these prospects as they apply to corn production.

2. Corn productivity

Genetic selection has been a very important driver of agricultural productivity. The process started some 9000 years ago in Mexico when corn was first "selected" and evolved from its wild ancestor [2]. Over the centuries, accidental mutations and some intentional selections contributed to beneficial changes [3]. But as **Figure 1** indicates, the rate of genetic improvement was very slow before 1940. Genetic selection was then based mostly on traditional breeding methods trying to combine desirable characteristics of each parent into the progeny. Applied to crops, farmers used selective breeding to pass on desirable traits while omitting undesirable ones. The desirable traits included higher yield and better quality as well as improved adaptation to local agro-climatic and ecological conditions. When applied by farmers, the selection intensity was low, generating slow genetic changes.

The early part of the twentieth century saw the rise of modern genetics and its applications to plant breeding. The discovery of hybrid vigor led to the development of hybrid seed corn and rapid improvements in corn productivity [5, 8]. The higher corn yields stimulated the rapid adoption of hybrid seed corn among US farmers [8, 9]. The new corn hybrids also contributed to the development of a seed corn industry that focused on refined genetic selection [10]. The increased intensity of genetic selection contributed to the development of improved varieties that were better at capturing soil nutrients and more resistant to diseases [5]. As **Figure 1** shows, the result has been decades of genetic improvements and rapid and sustained growth in corn yields.

Starting in the 1980s, progress in biotechnology revolutionized genetic selection. The identification of genes and the refinements in gene transfer[2] technologies opened new opportunities for genetic selection. Eventually, this process led to the development of genetically engineered (GE) corn hybrids that, along with the patenting of GE seeds, stimulated the growth of biotechnology in agriculture. The first GE corn hybrids became commercially available in the US in 1996, with US farmers rapidly adopting the technology. In 2017, more than 90% of all corn planted in the US was GE [12]. The rapid adoption of GE corn in the US led to significant productivity improvements [13]. Over the last two decades, the adoption of GE seed in agriculture has proceeded around the world, though at different rates depending on each country's regulations [14].

Two major types of GE traits are currently available in the hybrid seed corn market: those providing insect resistance (IR) (commercially available in corn in 1996) and those providing herbicide tolerance (HT) (commercially available for corn in 1998). Hybrid seed corn contains these traits either singly or combined as stacks or pyramids, so that a single hybrid is both IR to multiple pests and HT to more than one herbicide.

---

[2] We now know that horizontal gene transfers across species are not uncommon and that they played an important role in the evolution of life (e.g., [11]).

In the US, currently available IR traits involve gene transfers from the soil bacterium *Bacillus thuringiensis* (Bt) so that hybrids express insecticidal proteins in their tissues that help control specific insect pests. Bt corn hybrids in the US focus on two pests that have had significant adverse effects on corn yield: European corn borer (*Ostrinia nubilalis*) and corn rootworm, a complex of four closely related species (*Diabrotica* spp.). European corn borer larvae feed on corn plant tissues, including tunneling through corn stalks and ear shanks, which not only disrupts plant functions and so causes direct yield loss, but also causes plant lodging and ear drops, causing additional yield loss. Corn rootworm larvae feed on corn roots, which disrupts water and nutrient uptake by the plant and so causes direct yield loss, and also causes plant lodging. Both pests have historically caused significant damage to corn plants, reduced corn yield and are somewhat difficult to control using conventional insecticides [15].

Bt corn has proven more effective in controlling European corn borer and corn rootworm than conventional insecticides, thus increasing harvested yields. In addition, farmer adoption in the US of Bt corn has reduced the aggregate use of insecticides [16]. The rapid adoption of IR Bt corn in the US reflects that US farmers have obtained significant productivity benefits from this technology [12, 13].

HT corn hybrids simplify herbicide-based weed management by allowing application of herbicides on the crop without causing crop damage. Weed management without HT hybrids is managerially more complicated since several weed species look similar when they are small at the time when farmers must make herbicide decisions, but different species commonly require different herbicides for effective control. The earliest and still most popular HT hybrid is tolerant of the herbicide glyphosate, though other types of HT hybrids have been available. As a broad-spectrum herbicide, glyphosate controls a wide range of weed species, so that farmers do not need to know the specific weed species in their fields and which herbicides provide effective control. As a result, farmers rapidly adopted glyphosate tolerant corn hybrids and glyphosate quickly become the most commonly used corn herbicide, with glyphosate used on approximately 75% of US corn acres since 2008 [17]. In US, farmer adoption of HT hybrids has reduced the aggregate use of herbicides [16]. In addition, HT varieties facilitate farmer adoption of reduced tillage and no-till systems, which not only reduces soil erosion, but also lowers labor and fuel requirements [18]. Features such as these have made GE corn attractive to US farmers, contributing to their rapid adoption [12, 13].

3. The role of management

While improved genetics have contributed greatly to increasing corn productivity over the last 70 years, other factors also played a role. Duvick [5] has noted that corn productivity per plant has not changed much over the last few decades, suggesting that, under favorable conditions, the efficiency of photosynthesis for corn (as a C4 plan) has not improved. If so, what is the source of corn productivity growth? Duvick [5] argued that most of the historical increases in US corn yields are due to increases in plant density. Thus, corn productivity gains have come from the interactions between the plant and its environment, along with improvements in farm management and cultural practices. Over the years, new corn hybrids have been selected to be more resistant to lodging and more tolerant of biotic stress (pest damage, weed competition, disease) and abiotic stress (adverse weather, poor soil conditions). These genetic changes have interacted with improved management practices, including fertilizer use, irrigation, tillage system, weed control, pest management and crop rotation. Fertilizer applications remedy soil nutrient scarcity, as corn yield is very responsive to nitrogen [5]. When available, irrigation alleviates soil water scarcity and drought. Pest and weed populations can be (at least partially) controlled and suppressed by tillage, crop rotations and by the use of pesticides (insecticides and herbicides). Crop rotation had been used by farmers for centuries to reduce pest and weed infestation and to restore soil fertility [19–21].

The hypothesis that management and genetic biotechnology interacted in generating recent corn productivity gains have been investigated by Chavas and Shi [22] and Chavas et al. [23]. They found evidence of the important role of management and of interaction effects between technology and management. First, they documented how biotechnology has been a major driver of improved corn productivity over the last decade. They also explored how the benefit of GE traits can vary with agro-climatic conditions. Second, they showed how GE hybrids provide enhanced control of pest damages, thus reducing exposure to both risk and downside risk (the provability of facing low yields). Reducing risk exposure is a major part of the benefits of GE technology [24]. Importantly these GE benefits can go beyond the farm if the suppression of pest population is regional [25]. Third, Chavas and Shi [22] and Chavas et al. [23] showed how crop rotation and GE technology provide alternative ways to control pest populations, indicating that they behave as substitutes in the corn production process. Fourth, they reported the presence of synergy between biotechnology and plant density as they affect corn productivity. By improving pest control, GE hybrids make it possible to obtain greater productivity from higher plant density, evidence that the observed growth in corn productivity has been the outcome of important synergies between genetics and improved management.

4. Corn markets

In a market economy, technological progress affects producers, consumers and prices. **Figure 2** presents the evolution of US corn prices ($/bu) over the period 1947–2017, reporting both nominal prices and real prices [6]. Real prices are nominal prices adjusted for inflation by dividing by the US Consumer Price Index (CPI), in this case with 1983 normalized to 1. **Figure 2** shows that the nominal price of corn has gone from $1.52/bu ($59.8/metric ton) in 1950 to $3.36/bu ($132.3/metric ton) in 2017, corresponding to an average increase of +1.19% per year. It also shows that the real price of corn has gone from $6.30 to $1.37/bu, corresponding to an average decline of −2.25% per year.[3] This sharp decline in real price means that, holding purchasing power constant, an individual can buy 4.6 times more corn in 2017 than in 1950. This dramatic change mostly arises from productivity gains. Indeed, the rate of change in the real corn price (−2.25% per year) almost perfectly matches the rate of change in yield reported earlier (+2.35% per year).

---

[3] The difference is due to inflation, the average US inflation rate between 1950 and 2017 being +3.44% per year.

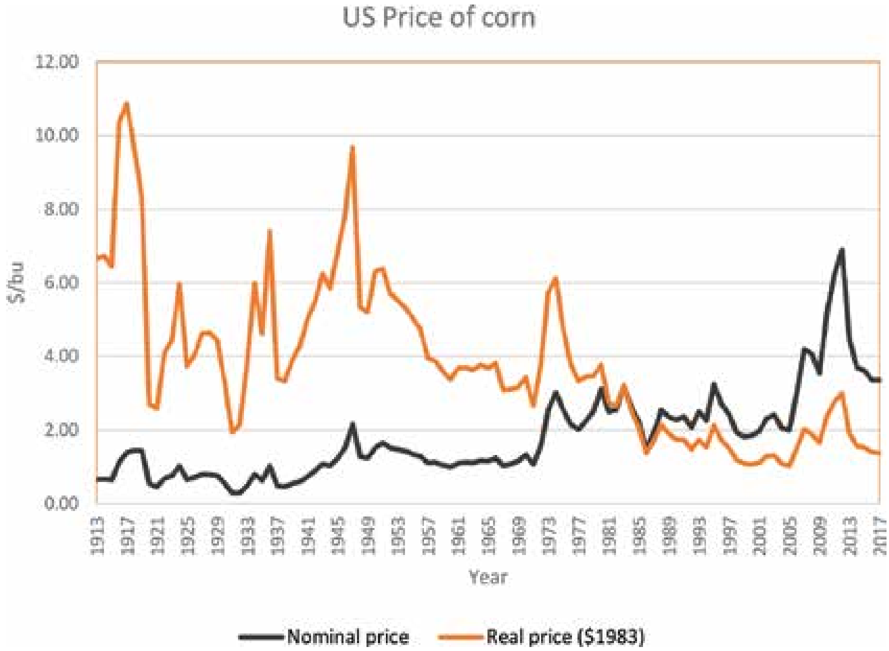


Figure 2. Historical price of corn, US. Source: The nominal corn price is the price received by farmers ($/bu) as reported by USDA-NASS [6]. The real price of corn is the nominal price divided by the consumer price index (*CPI*) as reported by BLS, with $CPI_{1983} = 1$.

In general, technological progress improves the aggregate welfare of society by allowing the production of greater outputs at lower cost (less resource use). But productivity growth can also have important distributional effects. In the corn sector, rapid technological progress has reduced cost and stimulated supply, which in turn has pushed market prices down. As just noted, the observed decrease in real prices reported in **Figure 2** can be attributed in large part to technological progress in the corn industry. It indicates that most of the benefits of productivity gains are actually captured by consumers in the form of expanded quantities produced and lower market prices. As most corn is not directly consumed by people, but used for livestock feed and more recently fuel, these consumer gains arise from lower prices for meat, dairy products, eggs and fuel. But these lower (real) market prices contribute to declining farm revenue.

Interestingly, technological progress in agriculture may not benefit farmers at the aggregate—if the lower output price due to increased productivity generates a decline in revenue that exceeds the reduction in production cost.[4] This process is called the technology treadmill or Cochrane's treadmill after the originator of the theory [27]. Early adopters of new productive technologies benefit by reducing their cost of production, but later adopters will lose if, as supply expands, the output price declines more than the decrease in production costs. The

---

[4] This can take place when the demand is highly price-inelastic, i.e., when the output price decline is "large enough" to imply a substantial decline in revenue that swamps the decrease in cost. This scenario is relevant as the demand for food in general and for corn in particular tends to be highly price-inelastic (e.g., [26]).

treadmill occurs because, even if farmers in aggregate are made worse off by the new technology, farmers individually still have an incentive to adopt the new technology to reduce their cost of production in a race to outrun the decline in real prices [28, 29].

Globally, about 5% of the calories consumed per person come directly from corn, but this demand varies across countries. In much of Latin America, corn is mostly used for direct human consumption. For example, 33% of the calories consumed per person in Mexico come directly from corn.[5] In the US (and many other countries), corn is used mainly as livestock feed, an important input in the production of meat (beef, pork, and poultry), dairy and eggs. As a result, the demand for corn is a derived demand, with meat, dairy and eggs being the final consumer good.

Corn also has other uses such as for making sweeteners and ethanol. Derived demands for these corn products depend in part on government policy. For example, the US has a protectionist policy toward sugar, so sugar import restrictions have increased the domestic price of sugar [30]. The higher US sugar price has stimulated the search for sugar substitutes in the US, including corn sweeteners. This policy increases demand for corn, with more than 5% of US corn production used for sweeteners, and contributes to a higher corn price, which benefits US farmers but costs US consumers [30].

The US ethanol policy has an even larger impact. The rapid development of the US ethanol industry after 2000 is closely associated with government policies supporting the production of biofuel [31]. Ethanol subsidies, restrictions on ethanol imports and mandates for blending ethanol with gasoline have greatly stimulated the production of corn-based ethanol, leading the US ethanol industry to consume almost one third of US corn production. Over the last 15 years, US biofuel policy has greatly stimulated the demand for corn and affected agricultural markets. Roberts and Schlenker [26] estimated that US ethanol policy has increased world food prices by about 30%. This large effect is due to a price-inelastic demand for food and a diversion of land away from producing feed/food toward producing biofuel. In general, farmers have benefited from higher food prices, but the policy has significant distributional consequences, as consumers pay significantly more for food. Using “consumer surplus” as a measure of consumer welfare, Roberts and Schlenker [26] estimated that US ethanol policy contributed to a loss in world consumer welfare of $180 billion per year. The debate about the economics and policy of corn-based biofuel continues [32, 33].

5. Prospects for the future

Over the last several decades, productivity growth in the corn sector has been stellar, which is good news in a world where feeding a growing world population is challenging. There are current concerns that agricultural productivity growth may be slowing down (e.g., [7, 34]). So far, such concerns do not seem to apply to corn, since US average corn yields continue to climb at a steady rate, and Chavas et al. [13] provide evidence that biotechnology has helped

---

[5] These estimates from https://www.nationalgeographic.com/what-the-world-eats/ based on UN FAOSTAT data for 2011.

increase corn productivity growth over the last two decades. Despite these continual productivity gains, challenges still exist, chief among them are resistance and climate change.

The stellar productivity gains from commercially applying biotechnology in corn have focused on improving insect and weed management, which has created selection pressure on many pest species to evolve resistance to control. Even if farmers follow resistance management practices, pests have and will continue to evolve resistance—these practices only slow the rate of resistance evolution, they do not stop it.

Western corn rootworm (*Diabrotica virgifera virgifera*) evolved resistance to rootworm Bt corn within a few years of commercial release [35]. Rootworm Bt hybrids still have value to farmers, but their continued use requires that companies pyramid multiple rootworm traits together and that farmers use additional management practices such as crop rotation and conventional insecticides [36]. Companies have also responded by developing alternative GE traits to manage corn rootworm. Potentially the most promising is RNA interference (RNAi), which uses biotechnology so that crops create double-stranded RNA segments that interfere with transcription of specific segments of RNA found in only the target species [37–39]. The first US commercialization of RNAi in corn received EPA approval in 2017.[6] Also, corn has been genetically engineered to express insecticidal proteins from non-Bt bacteria and shows excellent activity for control of corn rootworm larvae [40].

Weed control in corn (as with many crops) is important, with potential yield losses without control exceeding 50% [41]. Over the last few decades, herbicide resistant weed populations have continued to develop and spread globally [42]. HT seeds do not directly cause the development of herbicide resistant weeds, as herbicide resistant weeds have evolved in regions such as Western Australia where HT crops are not used [42]. Rather, HT crops contribute by encouraging farmers to rely on fewer herbicides modes of action and less tillage, which accelerate the development and spread of resistant weed populations [43, 44]. Problems with herbicide resistant weeds continue to develop and spread globally, which is worrisome because no new herbicide modes of action have become commercially available since the early 1990s and weed populations resistant to multiple modes of action having been documented [45, 46]. How weed control in corn and other crops will evolve over the next few decades to address herbicide resistant weeds and the possible role that GE hybrids and biotechnology will play is unclear. The race between insects and weeds and our ability to develop technologies and management schemes will continue to impact agricultural productivity. Maintaining our lead in this race will require R&D investments and continued innovations in the future.

Climate change presents another challenge for agricultural productivity, with studies documenting impacts on corn yields [47]. Adaptation to climate change is a rising concern [48, 49]. Some regions will gain and some will lose productivity as climate patterns evolve and crop production shifts among regions. US farmers generally see agricultural adaptation to climate change as a private problem. They expect to respond with managerial changes, such as adjusting crops, using irrigation, modifying leases and using crop insurance, while seed companies will breed varieties and hybrids adapted to new climates [50, 51]. Breeding will certainly be important for corn, since hybrids must be adapted to new photoperiods when changing latitudes. Also, seed companies have commercialized drought-resistant corn hybrids, but these and other traits providing yield gains under extreme conditions tend to be quantitative or polygenic and can imply productivity tradeoffs [52–54].

---

[6] Official US EPA news release: https://www.epa.gov/newsreleases/epa-registers-innovative-tool-control-corn-rootworm.

Despite these and other emerging challenges, several promising opportunities exist to continue the productivity gains for corn and agriculture more broadly, among them microbial seed treatments and gene editing techniques. Seed treatments have been used in crop production for some time, fungicides to protect seeds during storage, so that in the US all corn seed (both GE and conventional) uses fungicide seed treatments. More recently, insecticidal seed treatments became widely used in corn production, particularly neonicotinoid seed treatments, to control below-ground and early season insect pests. In the US, more than 90% of corn planted area uses neonicotinoid seed treatment [17, 55]. In addition to insecticidal properties, neonicotinoids have demonstrated plant grower regulator effects in the laboratory and are associated with increased early season vigor in the field [56].

These chemical seed treatments have contributed to observed corn yield productivity, but significant research focus has moved to microbial seed treatments, soil microbes and fungi that increase yields. These seed treatments improve the rhizosphere around crop seedlings and plants through a variety of mechanisms, such as increasing nutrient availability, controlling diseases or nematodes, or supplying plant growth hormones [57]. Though some microbial seed treatments have been commercialized, including for corn, research needs still exist before widespread commercialization and achievement of their potential can occur [58]. An interesting possibility is to engineer microbes or fungi to enhance soil microbes for agricultural use.

A variety of gene editing techniques have recently been developed (e.g., CRISPR/Cas9, TALENs, ZFNs) with agricultural applications only beginning to be realized. The cost of using gene editing techniques is relatively low compared to gene-transfer technology. Also, gene editing is likely to face lower regulatory burden, as it does not require gene transfer across species. Public acceptance exists for therapeutic human health applications and some agricultural applications as well [59, 60]. Applications to crops could include pest and pathogen control, as well as improved tolerance to abiotic stresses such as extreme heat or cold and drought, helping crop production adapt to climate change and increases in extreme weather events. Furthermore, gene editing could include the possibility of increasing the efficiency of photosynthesis in crops. Besides applications to crops directly, gene editing could be applied to other key organisms, such as to engineer soil microbes to develop new or more effective microbial seed treatments. Similarly, gene editing can be used to engineer gene drives in order to introgress select genes into populations in order to suppress or eliminate pest populations or to make herbicide-resistant weed populations susceptible to herbicides [61, 62]. Given the economic importance of corn and its existing research and commercial infrastructure, corn seems likely to be at the frontier of the next wave of such innovations in agriculture.

Author details

Jean-Paul Chavas[1*] and Paul D. Mitchell[1,2]

*Address all correspondence to: jchavas@wisc.edu

1 Department of Agricultural and Applied Economics, University of Wisconsin, Madison, WI, USA

2 Renk Agribusiness Institute, University of Wisconsin, Madison, WI, USA

References

[1] USDA. World Agricultural Supply and Demand Estimates. USDA, Economics, Statistics and Market Information System. WASDE-575, March 8, 2018. Available from: https://www.usda.gov/oce/commodity/wasde/latest.pdf

[2] Matsuoka Y, Vigouroux Y, Goodman MM, Sanchez J, Buckler GE, Doebley J. A single domestication for maize shown by multilocus microsatellite genotyping. Proceedings of the National Academy of Sciences. 2002;**99**:6080-6084

[3] Piperno DR. The origins of plant cultivation and domestication in the new world tropics: Patterns, process, and new developments. Current Anthropology. 2011;**52**:453-470

[4] Hufford MB, Lubinksy P, Pyhäjärvi T, Devengenzo MT, Ellstrand NC, Ross-Ibarra J. The genomic signature of crop-wild introgression in maize. PLoS Genetics. 2013;**9**:e1003477. DOI: 10.1371/journal.pgen.1003477

[5] Duvick D. The contribution of breeding to yield advances in maize. Advances in Agronomy. 2005;**86**:84-145

[6] USDA-NASS. National Agricultural Statistical Service. 2018. Available from: https://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS

[7] Ray DK, Ramankutty N, Mueller ND, West PC, Foley JA. Recent patterns of crop yield growth and stagnation. Nature Communications. 2012;**3**:1293. DOI: 10.1038/ncomms2296

[8] Crow JF. 90 years ago: The beginning of hybrid maize. Genetics. 1998;**148**:923-928

[9] Griliches Z. Hybrid corn: An exploration in the economics of technological change. Econometrica. 1957;**25**:501-522

[10] Troyer AF. Background of U.S. hybrid corn. Crop Science. 1999;**39**:601-626

[11] Simonson AB, Servin JA, Skophammer RG, Herbold CW, Rivera MC, Lake JA. Decoding the genomic tree of life. Proceedings of the National Academy of Sciences. 2005;**102**:6608-6613. DOI: 10.1073/pnas.0501996102

[12] USDA-ERS. Economic Research Service. Washington, DC. 2018. Available from: www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us.aspx#.U9XFj7EvfNg

[13] Chavas JP, Shi G, Nehring R, Stiegert K. The effects of biotechnology on productivity and input demands in U.S. Agriculture. Journal of Agricultural and Applied Economics. 2018 (forthcoming)

[14] Qaim M. The economics of genetically modified crops. Annual Review of Resource Economics. 2009;**1**:665-694

[15] Gray ME, Sappington TW, Miller NJ, Moeser J, Bohn MO. Adaptation and invasiveness of western corn rootworm: Intensifying research on a worsening pest. Annual Review of Entomology. 2009;**54**:303-321. DOI: 10.1146/annurev.ento.54.110807.090434

[16] Perry ED, Ciliberto F, Hennessy DA, Moschini G. Genetically engineered crops and pesticide use in U.S. maize and soybeans. Science Advances. 2016;**2**:e1600850. DOI: 10.1126/sciadv.1600850

[17] Mitchell PD. Methods and assumptions for estimating the impact of neonicotinoid insecticides on pest management practices and costs for U.S. corn, soybean, wheat, cotton and sorghum farmers. In: AgInfomatics Research Report. Madison, WI; 2014. 96 p. Available from: http://aginfomatics.com/index.html

[18] National Academies of Sciences, Engineering, and Medicine. Genetically Engineered Crops: Experiences and Prospects. Washington, DC: The National Academies Press; 2016. DOI: 10.17226/23395

[19] Anderson RL. Are some crops synergistic to following crops? Agronomy Journal. 2005;**97**:7-10

[20] Anderson RL. Corn tolerance to weed interference varies with preceding crop. Weed Technology. 2011;**25**:486-491

[21] Bullock DG. Crop rotation. Critical Reviews in Plant Sciences. 1992;**11**:309-326

[22] Chavas JP, Shi G. An economic analysis of risk, management and agricultural technology. Journal of Agricultural and Resource Economics. 2015;**40**:63-79

[23] Chavas JP, Shi G, Lauer J. The effects of GM technology on maize yield. Crop Science. 2014;**54**:1331-1335

[24] Hurley TM, Mitchell PD, Rice ME. Risk and the value of Bt corn. American Journal of Agricultural Economics. 2004;**86**:345-358

[25] Hutchison WD, Burkness EC, Mitchell PD, Moon RD, Leslie TW, Fleischer SJ, Abrahamson M, Hamilton KL, Steffey KL, Gray ME, Hellmich RL, Kaster LV, Hunt TE, Wright RJ, Pecinovsky K, Rabaey TL, Flood BR, Raun ES. Areawide suppression of European corn borer with Bt maize reaps savings to non-Bt maize growers. Science. 2010;**330**:222-225

[26] Roberts MJ, Schlenker W. Identifying supply and demand elasticities of agricultural commodities: Implications for the US ethanol mandate. American Economic Review. 2013;**103**:2265-2295

[27] Cochrane WW. Farm Prices: Myth and Reality. St. Paul: University of Minnesota Press; 1958

[28] Gabre-Madhin E, Barrett CB, Dorosh P. Technological Change and Price Effects in Agriculture: Conceptual and Comparative Perspectives Discussion Paper. Washington, D.C.: International Food Policy Research Institute; May 2002

[29] Levins RA, Cochrane WW. The treadmill revisited. Land Economics. 1996;**72**:550-553

[30] Beghin JC, El Osta B, Cherlow JR, Mohanty S. The cost of the US sugar program revisited. Contemporary Economic Policy. 2003;**21**:106-116

[31] Tyner WE. The US ethanol and biofuels boom: Its origins, current status, and future prospects. Bioscience. 2008;**58**:646-653

[32] Cui J, Lapan H, Moschini G, Cooper J. Welfare impacts of alternative biofuel and energy policies. American Journal of Agricultural Economics. 2011;**93**:1235-1256

[33] Tao L, Aden A. The economics of current and future biofuels. In: Tomes D, Lakshmanan P, Songstad D, editors. Biofuels. NY: Springer; 2011

[34] Alston JM, Babcock BA, Pardey PG. The shifting patterns of agricultural production and productivity worldwide. In: CARD Books. Ames, IA: Midwest Agribusiness Trace Research and Information Center; Vol. 2. 2010. Available from: https://lib.dr.iastate.edu/card_books/2

[35] Gassmann AJ, Petzold-Maxwell JL, Keweshan RS, Dunbar MW. Field-evolved resistance to Bt maize by western corn rootworm. PLoS One. 2011;**6**(7):e22629

[36] Andow DA, Pueppke SG, Schaafsma AW, Gassman AJ, Sappington TW, Meinke LJ, Mitchell PD, Hurley TM, Hellmich RL, Porter RP. Early detection and mitigation of resistance to Bt maize by western corn rootworm (Coleoptera: Chrysomelidae). Journal of Economic Entomology. 2015;**109**:1-12

[37] Baum JA, Bogaert T, Clinton W, Heck G, Feldmann P, Ilagan O, Johnson S, Plaetinck G, Munyikwa T, Pleau M, Vaughn T, Roberts J. Control of coleopteran insect pests through RNA interference. Nature Biotechnology. 2007;**25**:1322-1326. DOI: 10.1038/nbt1359

[38] Hu X, Richtman N, Zhao J, Duncan K, Niu X, Procyk L, Oneal M, Kernodle B, Steimel J, Crane V, Sandahl G, Ritland J, Howard R, Presnail J, Lu A, Wu G. Discovery of midgut genes for the RNA interference control of corn rootworm. Scientific Reports. 2016;**6**:30542. DOI: 10.1038/srep30542

[39] Niu X, Kassa A, Hu X, Robeson J, McMahon M, Richtman N, Steimel J, Kernodle B, Crane V, Sandahl G, Ritland J, Presnail J, Lu A, Wu G. Control of western corn rootworm (*Diabrotica virgifera virgifera*) reproduction through plant-mediated RNA interference. Scientific Reports. 2017;**7**:12591. DOI: 10.1038/s41598-017-12638-3

[40] Sampson K, Zaitseva J, Stauffer M, Vande Berg B, Guo R, Tomso D, McNulty B, Desai N, Balasubramanian D. Discovery of a novel insecticidal protein from *Chromobacterium piscinae*, with activity against western corn rootworm, *Diabrotica virgifera virgifera*. Journal of Invertebrate Pathology. 2017;**142**:34-43

[41] Soltani N, Dille JA, Burke I, Everman W, VanGessel M, Davis V, Sikkema P. Potential corn yield losses from weeds in North America. Weed Technology. 2016;**30**:979-984

[42] Pannell DJ, Tillie P, Rodríguez-Cerezo E, Ervin D, Frisvold GB. Herbicide resistance: Economic and environmental challenges. AgBioforum. 2016;**19**:136-155

[43] Dong F, Mitchell PD, Davis V, Recker R. Impact of atrazine prohibition on the sustainability of weed management in Wisconsin corn production. Pest Management Science. 2016;**73**. DOI: 10.1002/ps.4298

[44] Norsworthy JK, Ward S, Shaw D, Llewellyn R, Nichols R, Webster T, et al. Reducing the risks of herbicide resistance: Best management practices and recommendations. Weed Science. 2012;**60**(sp1):31-62

[45] Duke S. Why have no new herbicide modes of action appeared in recent years? Pest Management Science. 2012;**68**:505-512

[46] Varanasi VJ, Godar A, Currie R, Dille A, Thompson C, Stahlman P, Jugulam M. Field-evolved resistance to four modes of action of herbicides in a single kochia (*Kochia scoparia* L. Schrad.) population. Pest Management Science. 2015;**71**:1207-1212

[47] Schlenker W, Roberts MJ. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academy of Sciences. 2009;**106**:15594-15598

[48] Nelson GC, Valin H, Sands RD, et al. Climate change effects on agriculture: Economic responses to biophysical shocks. Proceedings of the National Academy of Sciences. 2014;**11**:3274-3279. DOI: 10.1073/pnas.1222465110

[49] Vermeulen SJ, Aggarwal PK, Ainslie A, et al. Options for support to agriculture and food security under climate change. Environmental Science and Policy. 2012;**15**:136-144

[50] Arbuckle JG, Prokopy LS, Haigh T, Hobbs J, Knoot T, Knutson C, Loy A, Mase AS, et al. Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. Climatic Change. 2013;**117**:943-950. DOI: 10.1007/s10584-013-0707-6

[51] Rejesus RM, Mutuc-Hensley M, Mitchell PD, Coble KH, Knight TO. U.S. agricultural producer perceptions of climate change. Journal of Agricultural and Applied Economics. 2013;**45**:701-718

[52] Gaffney J, Schussler J, Löffler C, Cai W, Paszkiewicz S, Messina C, Groeteke J, Keaschall J, Cooper M. Industry-scale evaluation of maize hybrids selected for increased yield in drought-stress conditions of the US corn belt. Crop Science. 2015;**55**:1608-1618

[53] Nemali KS, Bonin C, Dohleman F, Stephens M, Reeves W, Nelson D, Castiglioni P, et al. Physiological responses related to increased grain yield under drought in the first biotechnology-derived drought-tolerant maize. Plant, Cell and Environment. 2015;**38**:1866-1880

[54] Varshney RK, Bansal K, Aggarwal P, Datta S, Craufurd P. Agricultural biotechnology for crop improvement in a variable climate: Hope or hype? Trends in Plant Science. 2011;**16**:363-371

[55] Douglas MR, Tooker JF. Large-scale deployment of seed treatments has driven rapid increase in use of neonicotinoid insecticides and preemptive pest management in U.S. field crops. Environmental Science and Technology. 2013;**49**(2015):5088-5097. DOI: 10.1021/es506141g

[56] Macedo WR, de Camargo e Castro PR. Thiamethoxam: Molecule moderator of growth, metabolism and production of spring wheat. Pesticide Biochemistry and Physiology. 2011;**100**:299-304

[57] Dubey KK, Kumar P. Microbes in crop improvement: Future challenges and perspective. In: Prasad R, Singh Gill S, Tuteja N, editors. Crop Improvement through Microbial Biotechnology. Amsterdam: Elsevier; 2018. pp. 415-425. DOI: 10.1016/B978-0-444-63987-5.00021-9

[58] O'Callaghan M. Microbial inoculation of seed for improved crop performance: Issues and opportunities. Applied Microbiology and Biotechnology. 2016;**100**:5729-5746. DOI: 10.1007/s00253-016-7590-9

[59] Jones MS, Brown Z, Delborne J, Mitchell P, Elsensohn J. U.S. public attitudes and uncertainties about gene drive insects. 2018. In review

[60] Scheufele DA, Xenos MA, Howell EL, Rose KM, Brossard D, Hardy BW. U.S. attitudes on human genome editing. Science. 2017;**357**:553-554. DOI: 10.1126/science.aan3708

[61] Esvelt KM, Smidler AL, Catteruccia F, Church GM. Concerning RNA-guided gene drives for the alteration of wild populations. eLife. 2014;**3**:20131071. DOI: 10.7554/eLife.03401

[62] Mitchell PD, Brown Z, McRoberts N. Economic issues to consider for gene drives. Journal of Responsible Innovation. 2017;**5**:S180-S202. DOI: 10.1080/23299460.2017.1407914

Section 2

Corn and Health

The Maize Contribution in the Human Health

Bañuelos-Pineda Jacinto,
Gómez-Rodiles Carmen Cecilia,
Cuéllar-José Ricardo and Aguirre López Luis Octavio

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78700

Abstract

Maize (*Zea mays*) is a cereal very important around the world and is a fundamental element of the Mexican cuisine. The basis of Mexican traditional food is maize prepared by the process of "nixtamalización" which conserves the properties of the whole grain cereal. The phytochemical profiles of *Z. mays* contain total phenolics, ferulic acid, carotenoids, and flavonoids called anthocyanins. It is generally accepted that anthocyanin food colors do not exert obvious toxicity, teratogenicity, or mutagenicity and, indeed, anthocyanins may inhibit mutagenesis. Nutraceutical properties of phenolic and anthocyanin compounds in the maize that offer antioxidant activities is shown in five types of corn (white, yellow, high carotenoid, blue, and red). Therefore, the consumption of maize or its derivates such as tortillas, tortilla chips, etc., become functional food, with the ability to be used to prevent the incidence of diseases such as cancer, diabetes, obesity, and neurodegenerative disorders. Likewise, a diet that includes corn can be used during the management of these diseases. However, it is necessary to carry out more studies that highlight the efficiency of corn byproduct consumption during these diseases.

Keywords: maize, nutraceutics, antioxidants, chronic diseases, functional foods

1. Introduction

Corn is by far the cereal most commonly consumed by the people and cultures of the American continent: ancient civilizations, such as the Olmec and the Teotihuacan in Mesoamerica and the Quechuas in the Andean region of South America, developed around this plant [1].

Pre-Columbian natives deified this plant due to its relevance in their lives; the sacred book of the Quiche, the Popol Vuh, even tries to explain the origin of man by narrating how corn was given to mankind by the gods Paxil and Cayalan [2].

Corn is a monocotyledonous plant cultivated widely around the world and has constituted itself in one very common staple food. Corn and its wild variant, teosinte, belongs to the Poaceae family, of the Maydeas tribe; species of the *Tripsacum* genus are wild variants of corn, also originating in the American continent, but without any direct trade value. This family also includes important agricultural crops, such as wheat, rice, sorghum, barley, and sugar cane. Based on the characteristics of the ear or male inflorescence, the *Zea* genus divides into two sections, luxurians and annuals [3].

In Latin America, corn is a staple food product, and so it is the crop of greatest production, and it is also used as a dietary input for livestock, and for the industrial production of large numbers of products; that is why, from a nutritional, economic, political, and social point of view, it is the most important agricultural product. Generally, the diet of a people develops a collective memory and transcends mere food consumption, expressing socioeconomic relations and revealing acts deeply rooted in cultural symbolism [4, 5].

Corn as food has been found in archeological ruins and manuscripts such as the Florentine or the Mendoza Codices, wherein it has been possible to elucidate that corn represented on the main components of the Mesoamerican diet since the Middle Preclassic (1200–400 BC) [4–6]. Archeological remains also show the use and consumption of other plants important during that period; however, ancient settlers developed a preference for corn and it kept growing in popularity.

In pre-Hispanic times, the production of flours, pinole, and the ancient equivalent to modern "popcorn" stood out [7]. Currently, corn is widely consumed in of tortillas, arepas, toasts, tamales, snacks, corncobs, and in other various forms. When it comes to tortilla, it is now known that it not ancient as previously thought, but it was already prevalent in Mesoamerican diet by the time the Spaniards arrived at the continent. Today, the tortilla is considered as the basis of Mexican people's diet, directly related to its survival for over 3500 years [8]. The richness of indigenous cuisine based on corn was recorded in the reliable testimonies of conquistadors and chroniclers alike, from Hernán Cortés and Bernal Díaz del Castillo to Bernardino de Sahagún, all of them providing evidence of the high cultural development of ancient Mexicans, as well as of the rich diversity of corn, already noticeable back in those days. The miscegenation resulting from the Spanish Conquest had in gastronomy one of its main manifestations, enriching pre-Hispanic diet with elements from Spanish/Arab cuisine, and the other way around, too. However, the indigenous element dominated in this "food miscegenation," as can be seen in the fact that corn remains a fundamental ingredient and one of the main sources of energy in nowadays Latin American diet. An example of this can be seen in the fact that the average Mexican today obtains 1022 kilocalories and 26.3 g of protein from corn daily, which may represent 50% of an adult's daily intake, based on a diet of 2000 kilocalories with 56 g of protein [9].

2. Corn as healthy food

In recent years, cereal consumption has been linked to the reduction of chronic-degenerative diseases such as cancer, obesity, type 2 diabetes, cardiovascular and metabolic problems, and even symptoms associated with neurodegenerative problems. These health benefits have been attributed to the vast variety and high concentration of nutraceutical molecules present in cereals. Strictly speaking, these molecules cannot be considered as nutritional elements in themselves, but as bioactive components that can interact with biological systems from various cellular mechanisms, allowing optimal maintenance of the body's physiological functions, thus preventing the occurrence of diseases [10].

The confusion that usually arises when talking about concepts such as "nutrients," "nutraceuticals," "functional foods," and "nutritional supplements" should be noted. Clarifying these terms becomes relevant if one takes into account that the different qualities of the elements included in these categories can directly impact on their consumption. The term "nutrients" refers to the elements of a diet that can be absorbed by the body and incorporated into different physiological systems, allowing for basic functions to occur. For example, lipids and carbohydrates are known as the source of metabolic energy, as constituents of the cell membrane and as hormonal precursors; in its turn, the integration of proteins into the organism is used as an element of cellular structural reconstitution and integration into enzymatic systems. Also, vitamins and minerals allow for osmotic maintenance to occur, participate in nerve and muscle functioning, and can act as enzymatic cofactors. On the other hand, the term nutraceutical refers to the consumption of substances contained in food, able to promote beneficial effects on health without having direct participation in the basic processes of the different systems. The functional food concept encompasses natural or processed food products that contain biologically active compounds, which may or may not be nutrients. Together, these molecules must have the capacity to promote health benefits, preventing or aiding in the treatment of chronic diseases, in nontoxic quantities that can be included in a daily diet [11]. As an example of the above, the consumption of fish that provide omega fatty acids can be mentioned; also, the consumption of fruits and vegetables rich in minerals, vitamins, and dietary fiber, as well as other foods added with biologically active substances such as antioxidants and probiotics [12].

In recent times, cereals such as corn have been acknowledged as functional foods, as they are an important source of calories, as well as proteins, peptides, carbohydrates, fibers, and antioxidants with a nutraceutical function. The nutritional contribution of corn to the world population is undeniable, partly because of the great versatility of its kernels to produce food. Corn for consumption is mainly processed by three methods: dry milling, wet milling, and alkaline cooking (nixtamalization), and it is through these processes that the raw material for the production of different products is generated. Corn can be consumed in nixtamalized products such as tortillas and chips, in prepared beverages such as chicha morada, atole, tejuino, or pozol, in dishes such as polenta, pozole, or tamales, and all of these are merely a fraction of the many byproducts derived from this cereal. The flexibility with which this plant can be exploited should be emphasized, since its contribution to health keeping and improvement is not limited only to the kernel or its byproducts [13]; other anatomical parts of the plant such as stigmata, cobs, and leaf sheaths have proven to be an important source of nutraceutical molecules, as will be seen later in this chapter.

Corn kernels consist mainly of fiber, ranging from 61 to 86%, depending on the variety of the plant. Approximately 99% of the fiber is found in the endosperm and consists of starch (approximately 73% of the total weight), and the rest of resistant starch. The kernel also contains non-starch polysaccharides such as cellulose, hemicellulose, and, to a lesser extent, lignin (approximately 10% of the total weight), located mainly in the brand. Protein follows; depending on the variety of corn, it can range from 6 to 12%, calculated on the dry basis, while lipids represent around 3–6%. Out of these, between 81 and 85% is stored in the germ. Other phytochemical elements can also be found in pigmented and yellow varieties, in the form of secondary metabolites, phenolic compounds, and carotenoids for the most part. A very wide range of phenolic content exists among corn varieties, which has been assessed by the quantification of total polyphenols under the Folin–Ciocalteu reagent method, reporting amounts of 1756 mg of gallic acid equivalent/100 g of sample for a variety of purple corn with Andean genotype [14] and 266 mg gallic acid equivalent/100 g of sample for varieties of purple corn with Mexican genotype [15]. When it comes to Mexican white corn, amounts of 260 mg of gallic acid equivalent/100 g of sample have been reported; likewise, it is likely that corn types with a high profile of carotenoids contain a higher concentration of phenolic compounds, reporting 320 mg of gallic acid equivalent/100 g of sample [15]. It should be noted that yellow corn varieties have reported the highest carotenoid content, with an average dry base concentration of 13 μg of β-carotene equivalent/100 g of sample [16], although red varieties also synthesize carotenoids.

These elements act as nutraceuticals depending on their bioavailability, molecular structure, physicochemical characteristics, and their physiological effects, as well as on the properties acquired or lost after the different food byproducts have been processed.

3. Nutraceutical properties of corn

The kernel of corn contains proteins that have been classified into four groups in relation to their solubility. The most water-soluble proteins fall into the category of albumins, while proteins soluble in saline solutions are known as globulins. Proteins soluble in alcoholic solutions make up the group of prolamins or zeins, and proteins unable to be solubilized in any of the previous solutions form the group of glutelins. In view of this, the disposition and location of these proteins have a differential characteristic. For example, albumins and globulins are located mainly in the germ, while prolamins and glutelins can be found predominantly in the endosperm. In relation to their concentration, proteins are distributed unevenly in the corn kernel; 40% of the proteins are concentrated in zeins, followed by the glutelins, with 30%, and globulins and albumins together representing less than 5%. Of these, approximately 60% of the proteins are concentrated in the endosperm and are prolamins, with α-zein being the most abundant in corn, reaching up to 75% of the total prolamins [17]. Due to the water insolubility of corn proteins, its potential health benefits are limited; however, late technological advances have allowed to obtain peptides by hydrolysis in order to improve their bioavailability [18].

Once ingested, corn proteins are hydrolyzed by the activity of gastrointestinal enzymes such as pepsin, trypsin, and chymotrypsin. In vitro, this process can be carried out by the addition of enzymes, or by acidification or fermentation. Nonetheless, in vitro hydrolysis processes have shown some drawbacks, for example, when using acids, controlling the process can be complicated and some amino acids can be lost; also, protein hydrolysis turns out to be inefficient under the process of fermentation. As of late, enzymatic digestion has been chosen for in vitro isolation of bioactive peptides, which has proven to be a more efficient process. From two-amino acid peptides to 30-amino acid polypeptides can be isolated by means of these processes. Hydrophobic amino acids can be counted among peptides with bioactive capacity, structured with a positive charge and a proline in their C-terminal end [19]. On the other hand, dipeptides and tripeptides have greater resistance to the degradation of stomach, pancreatic, and intestinal proteases and peptidases, and larger peptides (six amino acids and larger) have a higher biological activity outside the intestine [20].

Studies have shown that bioactive peptides can have beneficial effects on health, mainly as antihypertensive, anticholesterolemic, antioxidant, anti-inflammatory, anticarcinogenic, antimicrobial, and others, due to their immunomodulatory properties. Likewise, it has been reported that they can help decrease the effects associated with high alcohol consumption. A large number of bioactive peptides have been obtained by means of the hydrolysis of zeins proteins, for example, the tripeptide lysine-proline-proline, and from the γ-zein protein, the valine-histidine-leucine-proline-proline-proline polypeptide, whereas the tripeptide proline-arginine-proline, which has also shown a biological functional activity, has been isolated from the α-zeins protein, as well as MBP-1 peptides from the corn kernel. Successful efforts have been made to isolate other peptides from corn gluten meal, such as Cys-Ser-Gln-Ala-Pro-Leu-Ala or Tyr-Pro-Lys-Leu-Ala-Pro-Asn-Glu. Overall, it has been observed that a large number of peptides can be isolated from the different components of corn, although their possible biological activity is still undergoing further research, as it is still necessary to carry out studies that help find the mechanisms from which these peptides can exert their biological activity.

As for the total fiber contained in corn, resistant starch is a type of non-digestible fiber, as it is highly resistant to the activity of digestive enzymes. The presence of resistant starch seems to be directly related to the percentage of amylose content. In normal corn, the presence of 34% of amylose is related to 0.8% of resistant starch, while high-amylose corn starch, the recorded presence of 83% amylose results in 39% resistant starch [21, 22]. However, resistant starch can be metabolized by the microbiota of the large intestine through fermentation and this in turn results in small chains of fatty acids [23]. Both the starch and the resistant starch contained in corn kernels have grown in relevance due to their possible function as regulators of body weight, thus a possible natural alternative for the treatment of obesity. On the other hand, these elements have also been linked to liver protection and the prevention of type 2 diabetes [24, 25].

In turn, phenolic compounds are a group of molecules whose chemical structure is made up of several hydroxyl groups linked to an aromatic group. When two or more rings are conjugated, a polyphenolic structure is generated; depending on the number of aromatic rings and the structural elements that bind them together, thousands of polyphenols have been identified. The polyphenols synthesized in corn can be classified into three groups according to their concentration and their contribution to human health; this way, we can speak of non-anthocyanin flavonoids, phenolic acids, and anthocyanin flavonoids. The group of non-anthocyanin flavonoids includes flavonols (rutin, isoquercetin, flavonol, morin, kaempferol, and quercetin) and flavonones (naringenin and hesperetin) [26], while the phenolic acids found in corn are protocatechuic acid, vanillic acid, syringic acid, trihydroxybenzoic acid, caffeic acid, chlorogenic acid, and p-hydroxyphenylacetic acid. Ferulic acid and p-coumaric acid are the compounds with more concentrates in corn, particularly in pigmented varieties [27, 28]. Total ferulic acid content detected in kernels of white varieties with Mexican genotype has been reported as 124,053 mg of ferulic acid equivalent/100 g of sample, while pigmented varieties such as blue or red corn have reported 129,985 and 130,297 mg of ferulic acid/100 g sample, respectively [15].

The food industry has exploited the varieties of yellow and white corn for a long time now; however, the use of pigmented varieties has gained more and more strength in the food sector recently, not only as a possible source of natural edible pigments but also for its properties as a functional food. Among the most common colors, red, blue, and black can be found. This pigmentation is conferred by anthocyanins. Anthocyanins are a group of natural pigments soluble in water, widely distributed in the different tissues of the plant. Anthocyanins are responsible for conferring shades ranging from red to blue and purple. Functionally, anthocyanins protect the plant from damage by radiation, partake in the defense against pathogens and/or predators, and in reproductive functions as pollinator attractants; likewise, they regulate the synthesis of growth factors such as auxin. In corn kernels, anthocyanins are stored mainly in the aleurone layer; it is also possible to find these molecules in the pericarp, or in both structures. Even native non-pigmented varieties, pure lines, and hybrids have some pigmented tissue in the roots of the seedling or anthers [29–31]. In pigmented corn, the content of anthocyanins can be evaluated as low, medium, and high, with values that range between 5.9 and 3045 mg of cyanidin-3-glucocide equivalent/100 g of sample, while values reported in white or yellow corn varieties range from 0.9 to 1.2 mg of cyanidin-3-glucocide equivalent/100 g [32, 33]. It is also possible to find anthocyanins in other tissues such as cobs and leaf sheaths, but the concentration in these structures is not precisely defined. Some studies have been found concentrations ranging from 430 to 11,700 mg of cyanidin-3-glucocide equivalent/100 g of sample for the cob [33], whereas for the leaf sheaths, it has been possible to extract up to 17,7900 mg of cyanidin-3-glucide equivalent/100 g of sample [34]. It should be noted that cyanidin and its derivates are more abundant in pigmented corn varieties [35].

Carotenoids are natural pigments in corn and other plants, responsible for conferring colorations ranging from yellow to orange. Carotenoids participate in functions such as photosynthesis due to their ability to absorb light from different spectra and transfer energy to chlorophyll. The carotenoids have a skeleton made up of 40 carbons of isopropene units. These structures can be cycled in one or both terminations, having several levels of hydrogenation or can have oxygenated functional groups and, according to this, can be classified into carotenes, which are tetrapenoid hydrocarbons, consisting solely of carbon and hydrogen atoms, and xanthophylls or oxo-carotenoids, structures that contain at least one oxygen. Yellow corns contain lutein, zeaxanthin, β-cryptoxanthin, and β-carotenes [36, 37]. Carotenoid concentration can vary widely depending on genotypes and external characteristics. For example, the blue variety of the Mexican genotype has concentrations of 0.18 μg of β-carotene equivalent/g of sample [38], while the yellow variety of the Canadian genotype has concentrations of up to 60 μg of xanthophylls equivalent/g of sample [39]. Carotenoids are found mainly in the germ, followed by the aleurone and the endosperm. Generally, by decreasing lipoperoxidation, carotenoids can act as antioxidant agents in lipid environments.

Tissues such as stigmata, cobs, stems, and leaf sheaths of corn can be an important source of anthocyanins, ferulic acid, and some other substances that may help improve health; even when those are not products fit for human consumption, they could be processed to obtain extracts with a potential nutraceutical use. As of today, there is scientific evidence of the use of stigmata for the treatment of conditions such as kidney disorders, hypertension, and some neurodegenerative diseases. Some of the bioactive compounds that can be isolated from these tissues are terpenoids, steroids, saccharides, cerebrosides, flavonoids such as flavonones and anthocyanins, and lignan [40, 41].

3.1. Antioxidant properties of corn

Reactive oxygen species (ROS) are a group of molecules derived from oxygen that are characterized by their high reactivity and a short life span. The reactivity of these molecules is due to the presence of two unpaired electrons in the outermost electron layer. Among the molecules included in the ROS group are the superoxide free radical (O_2^-), the hydroxyl radical (OH^-), and the hydrogen peroxide (H_2O_2). ROS can be generated by endogenous, extracellular, and intracellular mechanisms. The main source of ROS is the mitochondria during the cellular respiration process, followed by cellular metabolism processes, whereas exogenous production of ROS arises from smoking, ultraviolet radiation, ionizing radiation, drug consumption, and the presence of toxins. The damage generated by ROS is due to their reductive property, and if not properly regulated, they can alter cell integrity due to the peroxidation of lipids and proteins of the cell membrane, being able to even damage the structure of DNA.

Oxidative stress is generated by excess ROS, linked to cell damage associated with chronic-degenerative diseases such as cancer, chronic inflammation, cardiovascular diseases, neurodegenerative problems, and metabolic dysfunction. The process of cellular oxidation is regulated by antioxidant mechanisms, which delay or prevent the formation of ROS. Antioxidant protection is achieved through the correct balance between pro-oxidants and endogenous and/or exogenous antioxidants. Cells have an endogenous system of enzymes such as superoxide dismutase (SOD), catalases (CAT), glutathione peroxidase (GPx), quinone reductase (QR), and glutathione reductase (GR), which function as ROS stabilizers [42]. Compounds with antioxidant activity can be introduced in the body through diet, and corn is one important source of such compounds.

Fruits, vegetables, and seeds in general contain a great diversity of antioxidants that can act for the benefit of health more efficiently than some synthetic antioxidants. Recent studies have shown that the consumption of cereals can provide a greater antioxidant activity [2600–3500 μmol of Trolox equivalent (TE)/100 g] compared to some fruits (1200 μmol of TE/100 g) or vegetables (450 μmol of TE/100 g). Carotenoids, bioactive peptides, and flavonoids such as corn anthocyanins can act as antioxidant agents by lowering ROS levels, or by activating endogenous antioxidant systems that reduce cell damage. The antioxidant activity of nutraceuticals in corn is different; for example, when assessing the antioxidant activity of the carotenoids of Croatian genotype corn through the ABTS technique, values of

0.767 μmol of TE/g of sample were reported [34], whereas the total extracts of Italian genotype corn have reported antioxidant activity of 29 μmol of TE/g of sample [43]. These data suggest that carotenoids only contribute approximately 5% of the total antioxidant activity, while the phenolic fraction has the highest antioxidant activity. It should be noted that the antioxidant activity of carotenoids depends on their concentration, their distribution in the kernel, and the type of carotenoid, as studies have found activity values of 71 μmol of TE/g of sample in extracts of aleurone and 66.2 μmol of TE/g of sample in the endosperm. Other studies measured the antioxidant activity of the carotenoids contained in corn tortillas with the β-carotene/linoleate bleaching method, showing that the nixtamalization process can improve the antioxidant activity of carotenoids. In tortillas made of Mexican genotype corn of red or blue varieties, a decrease in whitening of approximately 27% has been reported, while in unprocessed kernels, the value reported was 15%. A value of 25% has been reported for white corn tortillas and 12% for raw kernels [38].

When comparing the antioxidant activity of phenolic compounds of pigmented corn and the polyphenols of blue berries, it was shown that corn has a greater antioxidant capacity and greater reaction kinetics [14]. When evaluating the antioxidant capacity in phenolic compounds of the blue, red, white, yellow, and high carotenoid corn varieties by the peroxyl radical scavenging capacity assay (PSC), an activity of 41–49 μmol of vitamin C equivalent/100 g of sample was reported [15]. This fact has proven that the higher the phenolic content, the greater the antioxidant activity, not only in kernels, but this quality is also maintained in byproducts elaborated by the nixtamalization process, such as the tortilla. However, unlike carotenoids, corn phenolic compounds are affected by production processes such as nixtamalization, which causes a decrease in their nutraceutical properties. For example, in Mexican phenotype corn kernels of the blue variety, a concentration of 343 mg of gallic acid equivalent/100 g of sample has been reported, while in products such as tortillas made with this same kernel, 201 mg of gallic acid equivalent/100 g of sample has been found. Antioxidant capacity can be expressed as the inhibition of ABTS cation formation; this way, it was determined that the antioxidant activity of the kernel is approximately 63%, while for the tortilla, it was 44%. The antioxidant activity of corn is not only limited to inhibiting the formation of ROS, it can also regulate cellular enzymatic elements for the defense against oxidative stress. It has been shown that corn components can increase the activity of the QR enzyme [44]. Only some of the phenolic compounds contained in corn have biological activity; for example, phenolic acids have only been able to recognize the nutraceutical capacity of compounds such as ferulic acid, protocatechuic acid, and p-coumaric acid [45].

Researchers from the University of Florida quantified and characterized the content of phenolic compounds in commercial genotype corn kernels of white varieties and of two blue varieties, one of Mexican genotype and the other North American, and reported a higher content of phenols in white corn, mainly ferulic acid, protocatechuic acid, and p-coumaric acid, while in blue corn, there were no traces of these acids. However, they found high concentrations of anthocyanins in the Mexican genotype, followed by the North American genotype. In addition, the antioxidant capacity of the three varieties was evaluated, demonstrating that the Mexican genotype has a greater capacity to inhibit the formation of ROS [46]. In this sense and due to their structural composition, the compounds contained in corn with a greater antioxidant activity are the flavonoids, the anthocyanins being those that inhibit, to a greater extent, the formation of ROS, in a concentration-dependent manner. In addition to kernels, other tissues such as stigmata, leaf sheaths, and cobs, particularly those of pigmented varieties, stand out as potential sources for anthocyanins, showing a high antioxidant activity.

Another group of compounds that can be found in corn is that of bioactive peptides, exogenous antioxidants that can act as scavengers of free radicals, inhibitors of ROS formation, and promoters of the activation of endogenous antioxidant systems. It has been shown that from the peptide fraction of corn gluten, only the sequences of Gly-Leu-Leu-Leu-Pro-His and Tyr-Phe-Cys-Leu-Thr can exert their antioxidant activity through the reduction of the amount of ROS and regulate the activity of enzymes such as SDO, CAT, and GR [42]. Some peptides synthesized from corn gluten meal can decrease the formation of the O_2^- radical by acting as electron donors. In spite of the scientific evidence demonstrating the antioxidant activity of corn bioactive peptides, it is still necessary to carry out further studies in biological models to explain their interaction in the organism. From the above, it can be concluded that corn and its byproducts not only represent a food source with a high nutritional value but also that, due to its anthocyanin, polyphenol, and peptide content, they contribute to the correct functioning and homeostatic maintenance of the organism. Moreover, due to its antioxidant properties, it can be used as an alternative to prevent the oxidative damage caused by stress and the subsequent negative effects associated with it.

3.2. Corn and metabolism

Obesity is currently a multifactorial etiology, chronic course disease, which involves genetic, environmental, and lifestyle aspects. Obesity is defined as the abnormal or excessive accumulation of fat harmful to health. One of the parameters that must be evaluated in order to determine if a person has obesity is the body mass index (BMI). Thus, a person with a BMI equal to or greater than 30 is considered obese. In recent years, obesity has been acknowledged as a global public health problem: an estimated 1900 million adults are overweight, and 600 million are obese [47]. Research carried out in rodents has shown that anthocyanins contained in purple corn can improve insulin resistance induced by a high-fat diet. For example, the cyanidin 3-glucoside present in purple corn may suppress the transcription of mRNA for the synthesis of enzymes involved in the production of fatty acids and triglycerides and reduce the sterol, a regulatory element that binds to the mRNA level of the protein-1 in white adipose tissue. The downregulation of protein-1 may contribute to the accumulation of triglycerides in white adipose tissue. These data, reported in 2003 by researchers from the University of Doshisha in Japan, have established the biochemical and nutritional bases for the use of cyanidin and anthocyanins in purple corn, as a functional food factor able to provide benefits for the prevention of obesity and diabetes [48]. Components of bioactive foods, such as resistant corn starch with a high content of amylose type 2 and sodium butyrate, reduce obesity in rodents [24].

Recently, an integral version has been used in a study carried out on humans, demonstrating greater postprandial satiety [49]. In addition, in vitro studies have shown a potential anti-obesity effect of purple corn stigmata in multiple stages of the adipocyte life cycle. The potential effects of high concentrations of purple corn stigmata extracts may inhibit adipocyte proliferation and adipogenesis, as well as induce lipolysis and apoptosis [50]. Another bioactive compound present in corn is maysin; the use of maysin in some studies has shown that it is a potent beneficial functional ingredient for health and a therapeutic agent in the prevention or treatment of obesity [51]. Menopause is a stage in which the production of estrogen is reduced, promoting the increase of body fat, and is a risk factor that contributes to obesity in older women. On the other hand, it is known that the modification of the gastrointestinal microbiota can reduce obesity by controlling energy expenditure. Therefore, adding prebiotics to the diet can contribute to the modification of the intestinal microbial flora, thus reducing obesity. Accordingly, the high-amylose type 2 resistant starch of corn can be used as a prebiotic, as has been proven in studies performed in ovariectomized rats. These studies showed that the bacterial levels increased with the addition of resistant starch of high corn amylose to the diet of the animals. In addition, the weight gain caused by the lack of estrogen was attenuated [52]. The consumption of fermentable corn fiber is recommended for postmenopausal women.

Diabetes is one of the most severe chronic metabolic diseases with great impact on the health of the population; the complications that this pathology entails are serious, fatal, and disabling, in such a way that it significantly affects the socioeconomic level of a country. According to the International Diabetes Federation, worldwide, 425 million people have been reported with diabetes during the year 2017, and the failure to intervene in time is expected to increase this figure to 693 million by 2045, while in Latin America, the number of people with diabetes could reach between 25 and 40 million by the year 2030 [53]. It has been demonstrated that a diet with purple corn rich in anthocyanins can be useful in the prevention of obesity and diabetes in mice, since the alterations induced by a high-fat diet (hyperglycemia, hyperinsulinemia, and hyperleptinemia) were normalized in the group that consumed purple corn in addition to its conventional diet [48]. It was also observed that the diet added with purple corn can suppress the transcription of genes involved in the synthesis of fatty acids and triglycerides. Other studies have shown that the consumption of resistant starch contained in corn improves insulin sensitivity in humans [52], and several studies in animals have documented a reduction of glucose concentration and a change of blood lipid profile due to the consumption of resistant starch [54]. It has also been observed that anthocyanin consumption (1 g/day) in non-hypertensive diabetic patients is effective in reducing triglyceride levels, increasing HDL cholesterol and optimizing glucose control; ferulic acid seems to be responsible for these antidiabetic properties.

Diabetic nephropathy is one of the main complications in diabetes and is mainly caused by chronic renal failure, which is growing in prevalence. This disease is characterized by a microvascular injury that causes glomerular hyperfiltration, renal damage, and an increase in urinary albumin excretion, finally inducing a glomerular dysfunction with renal failure. The consumption of feruloylated oligosaccharides, derived from the esterification of ferulic acid or oligosaccharides, impacts common physiological functions and has been shown to be effective in the regulation of serum insulin levels, and, although not as effective as ferulic acid, this esterified compound can slow down weight loss in diabetic rats [45]. In addition, purple corn extract rich in anthocyanins has been used as a therapeutic agent focused on the regulation of the abnormal angiogenesis that occurs in diabetic nephropathy, which can lead to renal failure. This is mediated by the decrease in receptor 2 activity for vascular endothelial growth factor after consumption of purple corn, tested in diabetic mice [55]. It has also been reported that purple corn extract can have antidiabetic effects through the protection of the β cells of the pancreas, favoring the secretion of insulin and the activation of the AMPK pathway in diabetic mice. The extract also causes increased phosphorylation by AmpC-activated kinase protein (AmpK), decreases the activity of phosphoenolpyruvate carboxykinase (PEPCK), decreases the transcriptional activity of genes for glucose 6-phosphatase in the liver, and increases the expression of the glucose transporter 4 (GLUT4) in skeletal muscle [56].

Another complication of diabetes is the formation of cataracts in the eye, caused by an optical dysfunction in the lens. Researchers from the KhonKaen University in Thailand conducted a study with rat enucleated lenses, which were incubated in artificial water humor containing 55 mM glucose with various concentrations of *Zea mays* L. (purple waxy corn), and found that the extract is capable of protecting against diabetic cataract in a dose-dependent way, probably due to the reduction of oxidative stress, while with high doses of corn extract, an effect is exerted through the inhibition of aldose reductase, which limits the speed in the polyol pathway (sorbitol). However, it is necessary to conduct studies with in vivo models that support these findings [57]. Raw extracts of flavonoids contained in corn stigmata have been used in models of diabetic mice reporting a decrease in body weight, glycemia, and antidiabetic capacity, in addition to the reduction in the levels of total cholesterol, of triglycerides, of low-density lipoproteins and an increase in the levels of high-density lipoproteins, suggesting an anti-hyperlipidemic effect [58]. Therefore, corn is proposed as a nutraceutical food, with a potential therapeutic effect to improve the alterations associated with diabetes. The diversity of corn byproducts, such as tortillas, pozol (thick, cocoa- and corn-based drink of Mesoamerican origin that is consumed in southern Mexico), chicha (unfermented drink made with purple corn, flavored with pineapple peels, consumed in Peru), etc., contains a large amount of antioxidant hydrophilic phenolic compounds that are beneficial for the control and maintenance of intermediate metabolism, so they can be considered an alternative for the prevention or treatment of diseases associated with metabolic alterations.

3.3. Corn and cancer

Cancer is among the leading causes of death in the world, resulting from the interaction between genetic factors and external physical factors, such as ultraviolet and ionizing radiation, chemical carcinogens such as asbestos and tobacco smoke, and biological carcinogens (some viral, bacterial, or parasitic infections). The consumption of pigmented corn, like purple, red, and blue varieties, has been shown to have anti-mutagenic properties due to anthocyanin content. Since 2001, research has been carried out to demonstrate the antineoplastic effects of corn anthocyanins, finding that it prevents carcinogenesis due to exposure to 2-amino-1-methyl-6-phenylimidazo pyridine (a free radical belonging to the nitrosamines group) [59]. Purple corn, in addition, has been shown to have chemopreventive properties in in vitro models of prostate cancer and in transgenic rats [60]. Also, maysin, one of the most abundant flavones in stigmata, can inhibit the growth of PC-3 cancer cells by stimulating apoptotic cell death dependent on the mitochondria [61]. These results suggest that maysin is a strong nutraceutical that can be used for the treatment of prostate cancer in humans who are resistant to chemotherapy, and more recently the non-amylaceous peptide polysaccharide of corn was isolated and characterized, and after a series of tests, it showed anticancer properties by blocking metastasis mediated by galectin-3 [62].

In 2015, Mexican researchers conducted a study with extracts of phenolic acids and blue corn anthocyanins, measuring their anticancer properties in breast, liver, colon, and prostate cancer cell lines; results indicated an antiproliferative effect in all cell lines, in which malonyl glucoside cyanidin was the anthocyanin with the greatest reduction in cell viability [28]. It has also been shown that the bioactive peptides of corn exert antitumor activity through key mechanisms such as (a) the induction of apoptosis mediated through specific proteases or caspases; strategies to overcome tumor resistance to apoptotic pathways include the activation of pro-apoptotic receptors, the restoration of p53 activity, the modulation of caspases, and the inhibition of the proteasome; (b) blocking the intermediate generation of tumors by regulating cellular mechanisms associated with cell proliferation and survival, or biosynthetic pathways that control cell growth; and (c) regulation of immune system functions, increasing the expression of antigens associated with the tumor (antigenicity) in cancer cells, activating the tumor cells for them to release warning signals that stimulate the immune response (immunogenicity), or increasing the predisposition of the tumor cells to be recognized and neutralized by the immune system (susceptibility) by means of autophagy and apoptosis [63]. The possible therapeutic use of corn peptide is still limited, since the bioavailability of these molecules depends on their capacity to remain active and intact elements during the digestive process, and the probability of reaching the general circulation to exert their physiological effects. Even so, some evidence supports the use of corn peptides as nutraceutical molecules with therapeutic capacity against a wide range of diseases related to oxidative damage, including cancer. The peptides contained in corn represent an important alternative due to their anticancer potential, but it is necessary to carry out more studies in patients, thus ensuring their therapeutic efficacy.

3.4. Corn and the nervous system

In addition to the nutritional benefits that corn consumption can bring, recent efforts have been made to evaluate its possible health benefits, especially on the nervous system. It is well recognized that a poor diet can contribute to the etiology of chronic diseases such as heart disease, cancer, and others. In view of this, aging should be considered as the main risk factor for chronic and/or chronic-degenerative diseases, among which are disabling disorders associated with cognitive and memory impairment, and dementia, all of them having a lasting impact on family life, as well as high costs for public health institutions [64]. In this sense, the consumption of bioactive nutrients contained in a diet rich in vitamins and polyphenols, and low in saturated fat content, can be a viable alternative for the preservation and/or delay of damage to the brain, since these elements can modify and preserve the state of health of the nervous system through the modulation of biochemical and biological processes [65].

A proper diet includes fruits, vegetables, grains, cereals, and other plants that can have beneficial effects on health, preventing the development of various diseases, thanks to the presence of bioactive components such as flavonols, flavones, catechins, flavonones, anthocyanidins, procyanidin B, among others [65]. Therefore, recently, special importance has been granted to the consumption of foods rich in these substances, among which purple corn (*Z. mays* L.)

stands out, being an important source of anthocyanins, which is the natural pigment distributed widely in the plant that confers its characteristic color, also containing other polyphenols (non-anthocyanin flavonoids and phenolic acids) distributed through the plant, for example, in the ear and seeds, cyanidin-3-glucoside, pelargonidin-3-glucoside, peonidin-3-glucoside, and its malonated counterparts can be found. Many biological activities have been attributed to these anthocyanins, so it is considered that corn and its byproducts that contain them have an intrinsic capacity to prevent cognitive deterioration and memory decline [66, 67].

3.4.1. Corn and Alzheimer's

Alzheimer's disease (AD) is a highly prevalent neurodegenerative disease, affecting approximately 10% of the population over 65 years of age, and it has been estimated that by the year 2050, only in the United States of North America, this disease will affect about 14 million people, with an expected incidence close to one million people per year [68], and it has been estimated that the global prevalence of AD will increase to 1 per 85 people in 2050 [69]. AD is the most common cause of dementia, conceived as a syndrome—a group of symptoms—that have been attributed to numerous causes, although the most characteristics are deficits in memory, language, and problem-solving capacity, together with other cognitive disorders that affect the performance of those who suffer from it and their ability to carry out daily activities [70].

The pathophysiology of AD is characterized by the formation of extracellular deposits of beta-amyloid peptide and the hyperphosphorylation of skeletons of intracellular tau proteins. Extensive research has been carried out with the aim of identifying the etiology of AD, although the specific mechanisms that cause neurodegenerative damage have not been well established yet. However, this disease is attributed to multiple factors, including the hypothesis of damage caused by oxidative stress on DNA, RNA, lipid peroxidation, and protein oxidation, responsible for the cognitive deterioration characteristic of the disease [71]. Studies carried out in patients diagnosed with AD have shown a decrease in antioxidant concentration in plasma, as well as an increase in the concentration of metabolites associated with the oxidation of lipids and proteins (distinctive markers of oxidative stress). It should be noted that this oxidative damage in the brain is implied in the toxicity induced by the β-amyloid fibrillar peptide (Aβ) [72].

Therefore, in recent years, the efforts of a large number of researchers in the world have focused on the search for natural alternatives that contribute to the prevention of neurodegenerative diseases such as Alzheimer's. Among the bioactive components with important biological activity, it has been reported that polyphenols (natural compounds present in fruits and vegetables) have the capacity to act as neuroprotective elements, although the ways in which they can perform this activity are still being studied. A series of studies are being carried out aimed at extracting molecules such as polyphenols for their potential use for preventive and/or therapeutic purposes, from different sources of fruits and vegetables, among which pigmented corn of the yellow, purple, brown, green, and blue varieties stand out [35]. Polyphenols exert biological action in the prevention of AD, due to their intrinsic capacity as reducing agents, and indirectly promote protection by activating endogenous defense systems, and by modulating cell-signaling processes related to the activation of the nuclear factor kappa B (NF-κB), of the protein-1 (AP-1)DNA binding activator, of the synthesis of glutathione, of the phosphatidylinositide-3 (PI3)-protein kinase B (Akt)pathway, of mitogen activated by protein kinase

(MAPK)(regulation of extracellular signaling protein kinase (ERK), of c-Jun N-terminal kinase (JNK) and P38), and also related to the translocation of erythroid nuclear factor 2 (Nrf2) [73].

Corn polyphenols, particularly flavonoids, can also modulate the neuronal signaling cascade activated by aging, acting on the ERK/CREB pathway involved in synaptic plasticity and long-term potentiation, improving learning and memory capacity in humans and animals [73]. They have also shown modulatory effects on the signaling pathway of kinases such as calcium calmodulin kinase II (CaMKII) and ERK, which control the activation of CREB (cAMP response element-binding) and increase the expression of brain-derived neurotrophic factor (BDNF) and nerve growth factor (NGF) at brain level [64]. As a matter of fact, it has been experimentally proven that polyphenols exert a protective effect on the hippocampus, preserving and promoting learning strategies and visuospatial memory in middle-aged rodents through the restoration of the mRNA levels of CaMKII, and the increase in the expression of hippocampal NGF [67]. Due to the above, the consumption of foods rich in molecules with biological potential, such as those present in corn, represents a nutritional alternative that can also help prevent the cognitive deterioration and dementia associated with age. However, it is still necessary to carry out studies that help prove their biological effectiveness in in vivo systems, and especially in the human population vulnerable to the development of neurodegenerative diseases.

4. Conclusions

Corn is a cereal with excellent nutritional qualities due to its resistant fiber, carotenoids, and polyphenols content. Moreover, the possibility of obtaining peptides with a great biological activity also contributes to nutraceutical qualities to corn. Regarding this, pigmented corn also contains anthocyanins, natural pigments that, in addition to their antioxidant properties, can modulate intracellular signals in different tissues of the organism. All the above makes corn a functional food to prevent the incidence of diseases such as cancer, diabetes, obesity, and neurodegenerative disorders. Likewise, a diet that includes corn can be implemented during the treatment of these diseases. However, it remains necessary to carry out more studies that highlight the efficiency of corn byproduct consumption during the incidence of such diseases.

Conflict of interest

The authors declare that there is no conflict of interest.

Author details

Bañuelos-Pineda Jacinto, Gómez-Rodiles Carmen Cecilia*, Cuéllar-José Ricardo and
Aguirre López Luis Octavio

*Address all correspondence to: carmen.grodiles@academicos.udg.mx

Universidad de Guadalajara, Guadalajara, Mexico

References

[1] Doebley J. The genetics of maize evolution. Annual Review of Genetics. 2004;**38**:37-59

[2] Vela E. Popol Vuh: el libro sagrado de los mayas. Arqueología mexicana. 2007;**15**(88):42-50. Available from: http://arqueologiamexicana.mx/mexico-antiguo/el-popol-vuh-el-libro-sagrado-de-los-mayas [Accessed: Apr 18, 2018]

[3] Paliwal RL. El maíz en los trópicos: Mejoramiento y producción [Internet]. Food and Agriculture Organization. 2001. p. 392. Avalibable from:https://curlacavunah.files.wordpress.com/2010/04/el-maiz-en-los-tropicos.pdf [Accessed: 2018-04-18]

[4] Doebley J, Iltis HH. Taxonomy of Zea (Gramineae). I. A subgeneric classification with key to taxa. American Journal of Botany. 1980;**67**(6):982-993. DOI: 10.1002/j.1537-2197.1980.tb07730.x

[5] Fernández-Suárez R, Morales-Chávez LA, Gálvez-Mariscal A. Importancia de los-maícesnativos de México en la dietanacional: Una revisión indispensable. Revista Fitotecnia Mexicana [Internet]. 2013;**36**(Suppl):275-283. Available from: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-73802013000500004&lng=es

[6] Taube KA. The maize tamale in classic Maya diet, epigraphy, and art. American Antiquity. 1989;**54**:31-51. DOI: 10.2307/281330

[7] Mera-Ovando LM. Aspectossocioeconómicos y culturales. In: Kato TA, Mapes C, Mera LM, Serratos JA, Bye RA, editors. Origen y Diversificación del Maíz: Una Revisión Analítica. Universidad Nacional Autónoma de México, Comisión Nacional para el Uso y Conocimiento de la Biodiversidad. Editorial Impresora Apolo. 2009. pp. 33-42. ISBN: 978-607-02-0684-9

[8] Paredes-López O, Guevara-Lara F, Bello-Pérez LA. La nixtamalización y el valor nutritivo del maíz. Vol. 92-93. Ciencias: Universidad Nacional Autónoma de México; 2009. pp. 60-70. Available from: 0187-6376revci@hp.fciencias.unam.mx

[9] Rocío F-S, Morales-Chávez LA, Gálvez-Mariscal A. Importancia de los maícesnativos de México en la dieta nacional: Una revisión indispensable. Revista Fitotecnia Mexicana.2013;**36**:275-283

[10] Chaturvedi N, Sharma P, Shukla K, Singh R, Yadav S. Cereals nutraceuticals, health ennoblement and diseases obviation: A comprehensive review. Journal of Applied Pharaceutical Science. 2011;**1**:6-12

[11] Díaz-Gómez JL, Castorena-Torres F, Preciado-Ortiz RE, García-Lara S. Anti-cancer activity of maize bioactive peptides. Frontiers in Chemistry. 2017;**5**:44. DOI: 10.3389/fchem.2017.00044

[12] Cadaval A, Artiach-Escauriaza B, Garín-Barrutia U, Pérez-Rodrigo C, Aranceta J, Serra L. Alimentos funcionales Para una alimentación más saludable. Sociedad Española de Nutrición Comunitaria (SENC). 2005. pp. 7-48. Available from: http://www.piaschile.cl/wp-content/uploads/2015/04/Alimentos-funcionales-para-una-alimentaci%C3%B3nmas-saludable.pdf

[13] Castañeda-Sánchez A. Propiedades nutricionales y antioxidantes del maíz azul (*Zea mays* L.). Temas Selectos de Ingeniería de Alimentos. 2011;**5**(2):75-83. Available from: http://www.udlap.mx/WP/tsia/files/No5-Vol-2/TSIA-5%282%29-Castaneda-Sanchez-2011.pdf

[14] Cevallos-Casals BA, Cisneros-Zevallos L. Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweetpotato. Journal of Agricultural and Food Chemestry. 2003;**51**:3313-3319. DOI: 10.1021/jf034109c

[15] De la Parra C, Serna-Saldivar SO, Liu RH. Effect of processing on the phytochemical profiles and antioxidant activity of corn for production of masa, tortillas, and tortilla chips. Journal of Agricultrual and Food Chemestry. 2007;**55**:4177-4183

[16] Panfili G, Fratianni A, Irano M. Normal phase high-performance liquid 527 chromatography method for the determination of tocopherols and tocotrienols in cereals. Journal of Agricultural and Food Chemistry. 2003;**51**:3940-3944. DOI: 10.1021/jf030009v

[17] Momany FA, Sessa DJ, Lawton JW, Selling GW, Hamaker SA, Willett JL. Structural characterization of a-Zein. Journal of Agricultural and Food Chemestry. 2006;**54**:543-547. DOI: 10.1021/jf058135h

[18] Liu XL, Zheng XQ, Song ZL, Liu XF, Kopparapu NK, Wang XJ, Zheng YJ. Preparation of enzymatic pretreated corn gluten meal hydrolysate and in vivo evaluation of its antioxidant activity. Journal of Functional Foods. 2015;**18**:1147-1157

[19] Orona-Tamayo D, Valverde MM, Paredes-López O. Bioactive peptides from selected latinamerican food crops–A nutraceutical and molecular approach. Critical Reviews in Food Science and Nutrition. 2018;**1**:1-27. DOI: 10.1080/10408398.2018.1434480

[20] Maestri E, Marmiroli M, Marmiroli N. Bioactive peptides in plant-derived foodstuffs. Journal of Proteomics. 2016;**147**:140-155. DOI: 10.1016/j.jprot.2016.03.048

[21] Jin D, Xiao-lan L, Xi-qun Z, Xiao-Jie W, Jun-fang H. Preparation of antioxidative corn protein hydrolysates, purification and evaluation of three novel corn antioxidant peptides Food Chemistry. 2016;**204**:427-436. DOI: 10.1016/j.foodchem.2016.02.119

[22] Jongfeng A, Jay-Lin J. Macronutrients in corn and human nutrition. Comprehensive Reviews in Food Science and Food Safety. 2016;**15**(3):581-598. DOI: 10.1111/1541-4337.12192

[23] Higgins JA. Resistant starch: Metabolic effects and potential health benefits. Journal of AOAC International. 2004;**87**:761-768

[24] Keenan MJ, Zhou J, McCutcheon KL, Raggio AM, Bateman HG, Todd E, Jones CK, Tulley RT, Melton S, Martin RJ, Hegsted M. Effects of resistant starch, a non-digestible fermentable fiber, on reducing body fat. Obesity (Silver Spring). 2006;**14**:1523-1534. DOI: 10.1038/oby.2006.176

[25] Nishimura N, Tanabe H, Sasaki Y, Makita Y, Ohata M, Yokoyama S, Asano M, Yamamoto T, Kiriyama S. Pectin and high-amylose maize starch increase caecal hydrogen production and relieve hepatic ischaemia-reperfusion injury in rats. The British Journal of Nutrition. 2012;**107**(4):485-492. DOI: 10.1017/S0007114511003229. Epub 2011 Jul 15

[26] Lao F, Sigurdson GT, Giusti MM. Health benefits of purple corn (*Zea mays* L.) phenolic compounds. Comprehensive Reviews in Food Science and Food Safety. 2017;**16**(2):234-246

[27] Zilic S, Serpen A, Akıllıogˇlu G, Go¨kmen V, Vancˇetovic´ J. Phenolic compounds, carotenoids, anthocyanins, and antioxidant capacity of colored maize (*Zea mays* L.) kernels. Journal of Agricultural and Food Chemistry. 2012;**60**(5):1224-1231. DOI: 10.1021/jf204367z [Epub Jan 26, 2012]

[28] Urias-Lugo DA, Heredia JB, Muy-Rangel MD, Valdez-Torres JB, Serna-Sald′ıvar SO, Guti′errez-Uribe JA. Anthocyanins and phenolic acids of hybrid and native blue maize (*Zea mays* L.) extracts and their antiproliferative activity in mammary (MCF7), liver (HepG2), colon (Caco2 and HT29) and prostate (PC3) cancer cells. Plant Foods for Human Nutrition. 2015;**70**(2):193-199. DOI: 10.1007/s11130-015-0479-4

[29] Salinas Y, Bustos F, Hernández M, Pakza R, Vázquez JL. Efecto de la nixtamalización sobre las antocianinas del grano de maíces pigmentados. Agrociencia. 2003;**37**(6):617-628 Available from: http://www.redalyc.org/articulo.oa?id=30237607

[30] Agatia G, Azzarella G, Pollastri S, Tattini M. Flavonoids as antioxidants in plants: Location and functional significance. Plant Science. 2012;**196**:67-76. DOI: 10.1016/j.plantsci.2012.07.014

[31] Petroni K, Pilu R, Tonell C. Anthocyanins in corn: A wealth of genes for human health. Planta. 2014;**240**:901-911. DOI: 10.1007/s00425-014-2131-1

[32] Aburto EA, Wong RB, Chávez TIP, Hoyos BMJ, Cárdenas F, Cervantes LJ. La nixtamalización y su efecto en el contenido de antocianinas de maíces pigmentados, una revisión. Revista Fitotecnia Mexicana. 2013;**36**(4):429-437 Available from: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-73802013000400009

[33] Lao F, Giusti MM. Quantification of purple corn (*Zea mays* L.) anthocyanins using spectrophotometric and HPLC approaches: Method comparison and correlation. Food Analytical Methods. 2015;**9**(5):1367-1380. DOI: 10.1007/s12161-015-0318-0

[34] Li CY, Kim HW, Won SR, Min KJ, Park JY, Ahn MS, Rhee HI. Corn husk as a potential source of anthocyanins. Journal of Agricultura Food Chemistry. 2008;**56**:11413-11416. DOI: 10.1021/jf802201c

[35] Aoki H, Kuze N, Kato Y, Gen SE. Anthocyanins isolated from purple corn (*Zea mays* L.). Foods and Food Ingredients Journal of Japan. 2002:41-45

[36] Kristina K, Grbeša D. Carotenoid content and antioxidant activity of hexane extracts from selected Croatian corn hybrids. Food Chemistry. 2015;**167**:402-408. DOI: 10.1016/j.foodchem.2014.07.002

[37] Hulshof PJ, Kosmeijer-Schuil T, West CE, Hollman PC. Quick screening of maize kernels for provitamin A content. Journal of Food Composition and Analysis. 2007;**20**(8):655-661. Available from: http://www.scielo.br/scielo.php?script=sci_nlinks&ref=000098&pid=S0103-90162014000600006000015&lng=en

[38] Mendoza-Díaz S, Ortiz-Valerio Mdel C, Castaño-Tostado E, Figueroa-Cárdenas Jde D, Reynoso-Camacho R, Ramos-Gómez M, Campos-Vega R, Loarca-Piña G. Antioxidant capacity and antimutagenic activity of anthocyanin and carotenoid extracts from nixtamalized pigmented Creole maize races (*Zea mays* L.). Plant Foods for Human Nutrition. Dec 2012;**67**(4):442-449. DOI: 10.1007/s11130-012-0326-9

[39] Masisi K, Diehl-Jones WL, Gordon J, Chapman D, Moghadasian MH, Beta T. Carotenoids of aleurone, germ, and endosperm fractions of barley, corn and wheat differentially inhibit oxidative stress. Journal of Agricultural and Food Chemistry. 2015;**63**(10):2715-2724. DOI: 10.1021/jf5058606 [Epub Mar 3, 2015]

[40] Jung YJ, Park JH, Cho JG, Seo KH, Lee DS, Kim YC, Kang HC, Song MC, Baek NI. Lignan and flavonoids from the stems of *Zea mays* and their anti-inflammatory and neuroprotective activities. Archives of Pharmaceutical Research. 2015;**38**(2):178-185. DOI: 10.1007/s12272-014-0387-4 [Epub Apr 19, 2014]

[41] Žilić S, Janković M, Basić Z, Vančetović J, Maksimović V. Antioxidant activity, phenolic profile, chlorophyll and mineral matter content of corn silk (Zea mays L): Comparison with medicinal herbs. Comparison with medicinal herbs. Journal of Cereal Science. 2016;**69**:363-370. DOI: 10.1016/j.jcs.2016.05.003

[42] Wang L, Ding L, Yu Z, Zhang T, Ma S1, Liu J.Intracellular ROS scavenging and antioxidant enzyme regulating capacities of corn gluten meal-derived antioxidant peptides in HepG2 cells. Foodservice Research International. 2016;**90**:33-41. DOI: 10.1016/j.foodres.2016.10.023 [Epub Oct 15, 2016]

[43] Alfieri M, Hidalgo A, Berardo N, Redaelli R. Carotenoid composition and heterotic effect in selected Italian maize germplasm. Journal of Cereal Science. 2014;**59**(2):181-188. DOI: 10.1016/j.jcs.2013.12.010

[44] Lopez-Martinez LX, Parkin KL, Garcia HS. Phase II-inducing, polyphenols content and antioxidant capacity of corn (*Zea mays* L.) from phenotypes of white, blue, red and purple colors processed into masa and tortillas. Plant Foods for Human Nutrition. 2011; **66**(1):41-47. DOI: 10.1007/s11130-011-0210-z

[45] Huang J, Wang X, Tao G, Song Y, Ho C, Zheng J, Ou S. Feruloylated oligosaccharides from maize bran alleviate the symptoms of diabetes in streptozotocin-induced type 2 diabetic rats. Food & Function. Mar 1, 2018;**9**(3):1779-1789. DOI: 10.1039/c7fo01825h

[46] Del Pozo-Insfran D, Brenes CH, Serna-Saldivar SO, Stephen T. Polyphenolic and antioxidant content of white and blue corn (*Zea mays* L.) products. Research International. 2006;**39**(6):696-703. DOI: 10.1016/j.foodres.2006.01.014

[47] World Health Organization. Obesity and Overweight [Internet]. Fact sheet, 311. 2016

[48] Tsuda T, Horio F, Uchida K, Aoki H, Osawa T. Dietary Cyanidin 3-O-D-glucoside-rich purple corn color prevents obesity and ameliorates hyperglycemia in mice. The Journal of Nutrition. 2003;**133**(7):2125-2130. DOI: 10.1093/jn/133.7.2125

[49] Anderson GH, Cho CE, Akhavan T, Mollard RC, Luhovyy BL, Finocchiaro ET. Relation between estimates of cornstarch digestibility by the Englyst in vitro method and glycemic

response, subjective appetite, and short-term food intake in young men. The American Journal of Clinical Nutrition. 2010;**91**:932-939. DOI: 10.3945/ajcn.2009.28443

[50] Chaiittianana R, Sutthanutb K, Rattanathongkomc A. Purple corn silk: A potential anti-obesity agent with inhibition onadipogenesis and induction on lipolysis and apoptosis in adipocytes. Journal of Ethnopharmacology. 2017;**201**:9-16. DOI: 10.1016/j.jep.2017.02.044

[51] Lee WC, Seoa YJ, Kimb S-L, Leea J, Choi WJ, Park YI. Corn silk maysin ameliorates obesity in vitro and in vivo via suppressionof lipogenesis, differentiation, and function of adipocytes. Biomedicine and Pharmacotherapy. 2017;**93**:267-275. DOI: 10.1016/j.biopha.2017.06.039

[52] Keenan MJ, Zhou J, Hegsted M, Pelkman C, Durham HA, Coulon DB, Martin RJ. Role of resistant starch in improving gut health, adiposity, and insulin resistance. Advancen in Nutrition. 2015;**6**:198-205. DOI: 10.3945/an.114.007419

[53] Cho, Nam Han et al. Epidemiología de la diabetes. In: 2017, Diabetes Atlas Federation International Diabetes Octava edición [Internet]. 2017. pp. 6-7. Available from: www.idf.org/diabetesatlas

[54] Zhou Z, Wang F, Ren X, Wang Y, Blanchard C. Resistant starch manipulated hyperglycemia/hyperlipidemia and related genes expression in diabetic rats. International Journal of Biological Macromolecules. 2015;**75**:316-321. DOI: 10.1016/j.ijbiomac.2015.01.052

[55] Kang M-K, Lim SS, Lee J-Y, Yeo KM, Kang Y-H. Anthocyanin-rich purple corn extract inhibit diabetes-associated glomerular angiogenesis. PLoS One. 2013;**8**(11):e79823. DOI: 10.1371/journal.pone.0079823

[56] Huang B, Wang Z, Park JH, Ryu OH, Choi MK, Lee JY, Kang YH, Lim SS. Anti-diabetic effect of purple corn extraction C57BL/KsJdb/dbmice. Nutrition Research and Practice. Feb 2015;**9**(1):22-29. DOI: 10.4162/nrp.2015.9.1.22 [Epub Jan 28, 2015]

[57] Thiraphatthanavong P, Wattanathorn J, Muchimapura S, Thukham-mee W, Lertrat K, Suriharn B. The combined extract of purple waxy corn and ginger prevents cataractogenesis and retinopathy in streptozotocin-diabetic rats. Oxidative Medicine and Cellular Longevity. 2014;**2014**:11 p. DOI: 10.1155/2014/789406

[58] Zhang Y, Wu L, Ma Z, Cheng J, Liu J. Anti-diabetic, anti-oxidant and anti-Hyperlipidemic activities of flavonoids from corn silk on STZ-induced diabetic mice. Molecules. 2015;**21**(1):E7. DOI: 10.3390/molecules21010007

[59] Hagiwara A, Miyashita K, Nakanishi T, Sano M, Tamano S, Kadota T, Koda T, Nakamura M, Imaida K, Ito N, Shirai T. Pronounced inhibition by a natural anthocyanin, purple corn color, of 2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine (PhIP)-associated colorectal carcinogenesis in male F344 rats pretreated with 1,2-dimethylhydrazine. Cancer Letters. 2001;**171**:17-25. DOI: 10.1016/S0304-3835(01)00510-9

[60] Long N, Suzuki S, Sato S, Naiki-Ito A, Sakatani K, Shirai T, Takahashi S. Purple corn color inhibition of prostate carcinogenesis by targeting cell growth pathways. Cancer Science. 2013;**104**:298-303. DOI: 10.1111/cas.12078

[61] Lee J, Lee S, Kim SL, Choi JW, Seo JY, Choi DJ, Park YI. Corn silk maysin induces apoptotic cell death in PC-3 prostate cancer cells via mitochondria-dependent pathway. Life Sciences 2014;**119**(1-2):47-55. DOI: 10.1016/j.lfs.2014.10.012 [Epub Oct 30, 2014]

[62] Jayaram S, Kapoor S, Dharmesh SM. Pectic polysaccharide from corn (*Zea mays* L.) effectively inhibited multi-step mediated cancer cell growth and metastasis. Chemico-Biological Interactions. 2015;**235**:63-75. DOI: 10.1016/j.cbi.2015.04.008

[63] Díaz-Gómez JL, Castorena-Torres F, Preciado-Ortiz RE, García-Lara S.Anti-cancer activity of maize bioactive peptides. Frontiers in Chemistry. Jun 21, 2017;**5**:44. DOI: 10.3389/fchem.2017.00044 (eCollection 2017)

[64] Abate G, Marziano M, Rungratanawanich W, Memo M, Uberti D. Nutrition and ageing: Focusing on Alzheimer's disease. Oxidative Medicine and Cellular Longevity. 2017;**2017**:7039816. DOI: 10.1155/2017/7039816 [Epub Jan 12, 2017]

[65] Ramos-Escudero F, Muñoz AM, Alvarado-Ortíz C, Alvarado A, Yánez JA. Purplecorn (*Zea mays* L.) phenolic compounds profile and its assessment as an agent against oxidative stress in isolated mouse organs. Journal of Medicinal Food. 2012;**15**(2):206-215. DOI: 10.1089/jmf.2010.0342

[66] Choi DY, Lee YJ, Hong JT, Lee HJ. Antioxidant properties of natural polyphenols and their therapeutic potentials for Alzheimer's disease. Brainresearch Bulletin. 2012;**87**(2-3):144-153. DOI: 10.1016/j.brainresbull.2011.11.014

[67] Aguirre-López LO, Chávez-Servia JL, Gómez-Rodiles CC, Beltrán-Ramírez JR, Bañuelos-Pineda J. Blue corn tortillas: Effects on learning and spatial memory in rats. Plant Foods for Human Nutrition. Dec 2017;**72**(4):448-450. DOI: 10.1007/s11130-017-0642-1

[68] Sadik K, Wilcock G. The increasing burden of Alzheimer disease. Alzheimer Disease and Associated Disorders. 2003;**17**(3):S75-S79

[69] Brookmeyer R, Johnson E, Ziegler-Graham K, Arrighi HM. Fore casting the global burden of Alzheimer's disease. Alzheimer's & Dementia. 2007;**3**:186-191. DOI: 10.1016/j.jalz.2007.04.381

[70] Alzheimer's Association. 2017 Alzheimer's disease facts and figures. Alzheimer's & Dementia. 2017;**13**(4):325-373 Available from: https://www.alz.org/documents_custom/2017-facts-and-figures.pdf

[71] Markesbery WR, Lovell MA. Damagetolipids, proteins, DNA, and RNA in mild cognitive impairment. Archives of Neurology. 2007;**64**:954-956. DOI: 10.1001/archneur.64.7.954

[72] Sonnen JA, Breitner JC, Lovell MA, Markesbery WR, Quinn JF, Montine TJ. Free radical-mediated damage to brain in Alzheimer's disease and its transgenic mouse models. Free Radical Biology and Medicine. 2008;**45**:219-230. DOI: 10.1016/j.freeradbiomed.2008.04.022

[73] Han X, Shen T, Lou H. Dietary polyphenols and their biological significance. International Journal of Molecular Sciences. 2007;**8**(9):950-988. DOI: 10.3390/i8090950

Chapter 4

Phytochemical Composition: Antioxidant Potential and Biological Activities of Corn

Haq Nawaz, Saima Muzaffar, Momna Aslam and
Shakeel Ahmad

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79648

Abstract

Corn seeds are used as a nutritional source for humans, and the stem and leaves are utilized as fodder for cattle throughout the world. Corn silk and corn cob are usually discarded as waste. This chapter highlights the nutritional as well as medicinal importance of various parts of corn plant. All parts of corn plant are good source of a variety of bioactive phytochemical compounds which possess antioxidant potential. The principal phytochemicals present in corn seed and corn silk include polyphenols, phenolic acids, flavonoids, anthocyanins, glycosides, carotenoids, and polysaccharides of biological importance, reducing compounds and some water-soluble vitamins. The presence of these phytochemicals makes corn a medicinal plant which shows various biological activities particularly the antioxidant, antimicrobial, antidiabetic, anti-obesity, antiproliferative, hepatoprotective, cardioprotective, and renal-protective activities. On the account of its high antioxidant potential, all parts of corn plant can be used for the management of oxidative stress and the treatment of various diseases.

Keywords: corn, *Zea mays*, maize, phytochemical composition, antioxidant potential, biological activities

1. Introduction

Corn (*Zea mays* L.), which belongs to the family Poaceae (Gramineae), is the principle cereal crop around the world following wheat and rice. Its annual production reaches almost 780 million metric tons, of which the larger producers are the USA, China, Brazil, and India. It is an annual herbaceous plant having 2–20 feet high stalk. The genus *Zea* comprises five species

Z. diploperennis, Z. luxurians, Z. nicaraguensis, Z. perennis, and Z. mays. Zea mays is the only cultivated species, while others are wild grasses [1–4].

The corn plant is classified as:

Kingdom	Plantae
Family	Poaceae
Subfamily	Panicoideae
Genus	*Zea*
Species	*mays*
Synonyms	Maize, corn, mealie

Various parts of corn such as grains, leaves, corn silk, stalk, and inflorescence are commonly used as food for humans, feedstuff for animals, fuel for small industries, and potential ingredient of homemade remedies [3, 5]. Corn seeds are served as food in Asian countries including China, Korea, Taiwan, Vietnam, Laos, Myanmar, Thailand, India, and Pakistan [6]. The unripe seeds of sweet corn are eaten raw or cooked, while the mature seeds are dried and ground to make flour that is used in various food preparations. The major products of wet and dry milling of corn seeds are used to make breakfast cereals, snacks, and tortillas, while the coproducts are used as animal feed. The maize flour has been found to enhance the nutritional and functional quality of food materials when used in the form of blend with other cereal flours [7, 8]. Corn kernel is also used to obtain ethanol as a fuel [9]. Oil obtained from seeds is edible and is used in the preparation of various food products. A semidrying oil obtained from seeds has many industrial uses like manufacturing of linoleum, paints, varnishes, and soaps.

The edible part of corn is covered by long, silky, and colored (yellowish to reddish) hairlike structures known as corn silk. Corn silk, due to its high medicinal value, has been traditionally used as herbal remedies for the treatment of various diseases [6]. It has been reported to be used in the treatment of hypercholesterolemia, urinary infections, and associated diseases [10]. Corn silk is also used as an important ingredient in development of various drugs [11]. It has been found to be nontoxic and is safe for human consumption [12, 13]. In Asia, it is used in tea as a healthy and medical drink [14]. Corn silk powder can also be used as food additive and flavoring agent as it does not change the taste; rather, it enhances the content and physical characteristics of meals like beef patties [15, 16]. Pith of the stem of corn plant is used to make corn syrup [17], the spathes are used in making papers, straw hats, and baskets, and dried cobs are used as fuel [3].

2. Nutritional composition

Corn, due to its high nutritional quality, is a permanent global crop used to fulfill the nutritional requirements of humans and cattle [3]. Corn is rich in nutritional compounds such as carbohydrates, proteins, vitamins, and minerals including calcium, magnesium, potassium, and sodium salts [3]. Corn seeds contain sugars (16.39–21.20 g/100 g dw), protein (11.46–12.70 g/100 g dw), and crude oil (5.73–6.21 g/100 g dw) [18]. Corn silk contains moisture (9.65–10.4%), protein (9.42–17.6%), fat (0.29–4.74%), ash (1.2–3.91%), dietary fiber (7.34%), and carbohydrates (65.5–74.3%), and good composition of vitamins and minerals as sodium, potassium (28, 1360 mg/100 g dw, respectively), calcium, magnesium, iron, zinc, manganese, and copper (0.1869, 0.1939, 0.005, 0.0165, 0.0109, and 0.0073 mg/g fw, respectively) [3, 19, 20]. The processed corn silk contains significant amounts of crude fiber (13%), crude protein (13%), and carbohydrates (69%). Being low in crude fat content, corn silk can be preferably used in the preparation of fat-free food formulations [21].

3. Phytochemical composition

Phytochemicals are the non-nutritional bioactive compounds found in various parts of plants. In plants these compounds perform vital functions particularly protection from predators and harsh environmental conditions. These compounds are also important in pharmaceutical and medicinal field due to their antioxidant, antimicrobial, and other biological properties. Flavonoids are the bioactive phytochemical compounds which make the plant resistant to the attack of microbes and insects and also protect the animals against various diseases [22–24]. Flavonoids possess strong antioxidant activity and free radical-scavenging capacity and inhibit protein glycation [23, 25, 26]. The anthocyanins have been found to protect against ischemic reperfusion injury in rats [27]. These have been also found to show antioxidant and antiradical activities which are further associated with certain health-promoting activities such as anticancer, anti-inflammatory, anti-obesity, antidiabetic, cardioprotective, and hepatoprotective activities [28–30]. Tannins are polyphenolic compounds which show several biological activities such as anti-inflammatory, antioxidant, free radical-scavenging, and antimutagenic activities [31, 32].

Various parts of corn plant such as silk, seed, stem, leaves, and roots are good sources of bioactive phytochemical compounds such as phenolic acids, flavonoids, steroids, alkaloids, carotenoids, tannins, saponins, anthocyanins, and other phenolic compounds [6, 28, 33, 34]. Corn seeds contain polyphenols, phenolic acids, flavonoids, anthocyanins, carotenoids, vitamins, sugars, polysaccharides, and other phytochemicals of medicinal importance [35, 36]. Corn silk contains a number of bioactive phytochemical compounds including phenols, polyphenols, phenolic acids, flavonoids, flavone glycosides, anthocyanins, carotenoids, terpenoids, alkaloids, steroids, luteins, tannins, saponins, volatile oils, vitamins, some sugars, and polysaccharides (**Table 1**) [6, 11, 22]. The corn silk flavonoids have been also reported to reduce the oxidative stress and show anti-fatigue activity in mice [37, 38]. The content of the major phytochemical compounds found in various parts of corn are summarized in **Table 2**.

Corn part	**Class of phytochemicals**	**Phytochemical components**	**Reference**
Corn silk	Polyphenols	Tannins, saponins, flavonoids, alkaloids, steroids, cardiac glycosides, allantoins, anthocyanins, hesperidin, and resins	[19]
	Phenolic acids	Para-aminobenzoic acid (PABA), vanillic acid, p-coumaric acid, chlorogenic acid, protocatechuic acid, caffeic acid, ferulic acid, maizenic acid, hydroxycinnamic acid ester, and 3-O-caffeoylquinic acid	[20]
	Flavonoids	Catechin, protocatechin, quercetin, rutin, flavone, 3-hydroxyl, 4-hydroxy, 5-hydroxy, and 7-hydroxy flavones and isoflavones. 2-O-α-L-rhamnosyl-6-C-3-deoxyglucosyle-3-methoxy luteolin and 6,4-dihydroxy-3-methoxyflavone-7-O-glucoside.	[11, 36, 73–76] [20, 34, 77]
		Isoorientin-2-2-*O*-α-L-rhamnoside, cardiac glycosides	
		Luteolins: 2″-O-α-L-rhamnosyl-6-C-quinovosylluteolin, 2″-O-α-L-rhamnosyl-6-C-fucosylluteolin, and 2″-O-α-L-rhamnosyl-6-C-fucosyl-3′-methoxyluteolin, 2″-O-α-L-rhamnosyl-6-C-3″-deoxyglucosyl-3′ methoxyluteolin, 2″-O-α-L-rhamnosyl-6-C-(6-deoxyxylo-hexos-4-ulosyl)-luteolin, 2″-O-α -L-rhamnosyl-6-C-(6-deoxy-xylo-hexos-4-ulosyl)-luteolin-3′-methylether, kaempferol	
		Maysins: Rhamnosyl-6-C-(4-ketofucosyl)-5, 7, 3′4′-tetrahydroxyflavone, ax-5′-methane-3′-methoxymaysin, ax-4″-OH-3′-methoxymaysin, 6,4′-dihydroxy-3′-methoxyflavone-7-O-glucosides, 7,4′-dihydroxy-3′-methoxyflavone-2″-O-α-L-rhamnosyl-6-C-fucoside	
	Carotenoids	β-Carotene, zeaxanthin	
	Sterols	Phytosterols like stigmasterol, beta-sitosterol	
	Tannins	Gallotannins, phlobatannins	
	Volatile compounds	Menthol, carvacrol, thymol, eugenol, neo-iso-3-thujanol, *cis*-sabinene hydrate, 6,11-oxidoacor-4-ene, citronellol, *trans*-pinocamphone, *cis*-sabinene hydrate, *cis*-R-terpineol, and neo-iso-3-thujanol	[78]
	Vitamins	Vitamin C, vitamin K, vitamin E	[79]
	Sugars	Dextrose, xylose	
	Miscellaneous compounds	Polysaccharides (galactan), geraniol, limonene, terpenoids, α-terpineol, citronellol, trans-pinocamphone, formononetin, apigenin, pelargonidin, anthraquinones, hordenine, xanthoproteins,	[6, 23, 25, 34–36, 49, 55, 70, 74, 75, 78, 80]
Corn seeds	Polyphenols	Tannins, saponins, rutin, allantoins, quercetin, isoquercetin, morin, naringenin, kaempferol	
	Phenolic acids	Gallic acid, chlorogenic acid, syringic acid, hydroxycinnamic acid derivatives, ferulic acid, 7-hydroxy-2-indolinone-3-acetic acid, caffeic acid	[35]
	Flavonoids	Anthocyanins, quercetin, and catechin	[81]
	Carotenoids	Carotenes including lutein, cyclosadol, β-cryptoxanthin, zeaxanthin, α- and β-carotene, α and β-cryptoxanthin	[82]
	Anthocyanins	Cyanogenic glycosides including pelargonidin-3-glucoside, cyanidin-3-glucoside, and peonidin-3-glucoside	[36]
	Vitamins	Vitamin E (tocopherols), vitamin B (biotin, riboflavin, pantothenic acid, folic acid, niacin, pyridoxine, thiamine), vitamin C	[83]
	Miscellaneous compounds	Polysaccharide, sugars, proteins, inositols, resins, hexaphosphoric and maizenic acid, esters of indole-3-acetic acid, d-glucose hydroxyl-2-indolinone-3-acetic acid, N-coumaryltryptamine, N-feruloyltryptamine, 6-methoxybenzoazoline, oxalic acids, essential fatty acids, and choline	[28, 30, 35, 78, 82]

Corn part	Class of phytochemicals	Phytochemical components	Reference
Corn stem	Phenolic compounds	Methyl (E)-p-cumarate, methyl (Z)-p-cumarate, methyl ferulate, and 1,3-O-diferuloyl glycerol	[84]
	Lignan	Tetrahydro-4,6-bis(4-hydroxy-3-methoxyphenyl)-1H,3H-furo[3,4-c]furan-1-one	[81]
	Flavonoids	Tricin, salcolin A, and salcolin B	[81]
	Anthocyanins	Cyanidin-3-glucoside, pelargonidin-3-glucoside, and peonidin-3-glucoside	[27, 29, 67]
Corn root and shoot	Polyphenols, flavonoids, and others	Flavonoids, terpenoids, alkaloids, tannins, phlobatannins, saponins	[85]

Table 1. Bioactive phytochemical components in various parts of corn.

Corn part	Extracting solvent	TPC	TFC	TAC	TCC	References
Corn silk	Water	1.5 mg GAE/g extract	2–7 μg/ml extract			[86]
		35.34–64.22 mg GAE/g extract	2.31–7.55 mg CE/g extract			[79, 87]
		42.71 μg TAE/g extract				[88]
		256.36–272 mg GAE/100 g dw	4.1–38.01 mg CE/g dw			[87, 89],
	Hot water	68.61 mg GAE/g	72.74 mg QE/g	0.02 mg CGE/g		[21]
	Methanol	101.99–175.8 mg GAE/g dw	0.66–9.26 mg CE/g dw			[87, 90]
		40.38 μg TAE/g extract		0.017–0.023 g CGE/100 g dw.		[18, 88]
		272.81 mg GAE/100 g dw				[89]
	Methanol acidified with 1% citric acid	69.01–85.49 mg GAE/100 g of fw		78.90–408.54 mg CGE/100 g fw		[91]
	Ethanol	164.1 μg GAE/g dw	69.4 μg RE/g dw			[34]
		1756 mg chlorogenic acid/100 g dw		1779 mg CGE/100 g dw.		[92]
		86.26–143.58 mg GAE/g extract	14.66–26.63 mg CAE/g extract			[79, 93]
		80.8–117.1 μg GAE/g dw	30.1–88.8 μg RE/g dw	0.4–72.9 μg CGE/g dw		[57, 41]
		93.43 mg GAE/g dw	65.58 mg RE/g dw			[87, 90],
		34029.37 ± 1926.61 mg /kg dw	211.05 ± 3.73 mg/kg dw		11.3 mg/kg dw	[94]
	Aqueous acetone	2093–4447 81 mg GAE/100 g dw	1840–3644 mg CE/100 g dw	1.49 mg CGE/100 g dw		[20],
	Ethyl acetate	6.70 mg GAE/g extract	8.40 mg CE/g extract			[90]

Corn part	Extracting solvent	TPC	TFC	TAC	TCC	References
Corn kernel	Methanol	115.4–175.5 mg GAE/100 g dw			6.7 μg/g fw, 9.7 μg/g dw	[95]
	Methanol acidified with citric acid	17.67–23.97 and 2.1 mg GAE/g fw, 2.8 mg GAE/g dw		16.53–45.84 mg CGE/100 g fw, 0.3 mg CGE/g fw, 0.4 mg CGE/g dw		[61, 91]
	Methanol acidified with HCl		178–515 mg NE /100 g dw	0–90 mg CGE /100 g dw		[95]
	Ethanol	223–467 mg GAE /100 g dw			16–564 μg/100 g dw	[82]
	Ethanol acidified with citric acid	287.3 ± 0.03 mg GAE/100 g fw		70.50 mg CGE /100 g		[41]
		20.06–24.97 mg GAE/100 g fw		25.8–133.26 mg CGE/100 g fw		[61, 91]
		353 ± 53 mg GAE/100 g dw	270 ± 62 mg NE /100 g of dw	30 ± 26 mg CGE /100 g dw	135 ± 119 μg/100 g dw	[95]
	Aqueous alcohol	215.8–3400 53 mg GAE/100 g dw		1.54–850.9 mg CGE/100 g dw		[96]
Corn cob	Methanol			129–1166 mg/100 g dw		[67]
	Methanol acidified with citric acid	15.43–64.02 mg GAE/100 g fw		17.87–115.97 mg CGE/100 g fw		[91]
	Various polarity solvents	79.61–92.64 mg GAE/g extract, 0.86 g GAE/100 g	14.41 mg CAE/g extract, 1.56 g QE/100 g, 0.46 g QE/100 g		0.85–1.18 g BCE/100 g	[93, 97]
Corn leaves	Various polarity solvents	4.94–1.75 g GAE/100 g	17.68 g QE/100 g		3.73–44.91 g BCE/100 g	[97]
Corn shoot	Water	69 μg GAE/g extract				[85]
	Ethanol	31.32 μg GAE/g extract				[85]
Corn root	Water	9.98 μg GAE/g extract				[85]
Corn husk	Various polarity solvents	1.62–14.77 g GAE/100 g	1.48–2.05 g QE/100 g		0.45–3.63 g BCE/100 g	[97]

GAE, gallic acid equivalent; RE, rutin equivalent; TFC, total flavonoid content; TPC, total phenolic content; TAC, total anthocyanin content; CGE, cyanidin-3-glucoside equivalents; fw, fresh weight; CE, catechin equivalent; TCC, total carotenoid contents; QE, quercetin equivalent; BCE, β-carotene equivalent; dw, dry weight; NE, naringin equivalent; TAE, tannic acid equivalent.

Table 2. Phytochemical composition of extracts from various parts of corn.

4. Antioxidant potential

The pharmaceutical and medicinal significance of medicinal plants is usually based on their antioxidant phytochemical composition. Antioxidants are the substances which have the ability to prevent the oxidation reactions in living and nonliving systems. They possess hydrogen-donating ability due to which they reduce other species and are themselves oxidized. These substances perform their action by reducing the reactive oxygen or nitrogen species or metals in their oxidized forms. These substances have the ability to terminate the free radical chain reactions occurring in the living system. Owing to their antiradical and reducing properties, the antioxidant phytochemicals play a key role in the preparation of pharmaceutical formulations against various diseases. The diversity in the phytochemical quality and high content of bioactive antioxidant phytochemicals make corn a valuable candidate for pharmaceutical application. Among various parts of corn, the corn silk is a rich source of antioxidant compounds and possesses strong antioxidant potential. The antioxidant properties of various parts of corn studied in terms of total antioxidant activity, ferric reducing, iron chelating, copper-reducing properties, and free radical-scavenging capacities are presented in **Tables 3–5**. The corn extracts have been also reported to improve the antioxidant status of various organs by affecting the activity of antioxidant enzymes [38].

Corn part	Extracting solvent	TAOA	β-CABC	References
Corn silk	Water	73–44.19%		[87]
	Methanol		66.05%	[87]
	Ethanol	5.61–9.98 mg $FeSO_4$/g dw	52.92%	[87]
	Ethyl acetate	2.15–2.735 mg GAE/g dw	38.65%, 26.33%	[87, 89]
Corn seed	Methanol acidified with citric acid	1827.5–2429.3 μmol TE/100 g dw, 61.15%, 3.1 μmol TE/g fw, 3.8 μmol TE/g dw, 17.9–32.19%		[61, 82, 91]
	Methanol acidified with HCl	18–100 μmol AAE/100 g		[95]
	Ethanol acidified with citric acid	22.95% TE		[41]
Corn cob	Methanol	0.3–10.2 μmol/g dw		[67]
	Methanol acidified with citric acid	31.10%		[91]
Corn husk	Methanol acidified with citric acid	11.85%		[91]

TAOA, total antioxidant activity; β-CABC, β-carotene-bleaching capacity; GAE, gallic acid equivalent; TE, Trolox equivalent; AAE, ascorbic acid equivalent; fw, fresh weight; dw, dry weight.

Table 3. Total antioxidant activity and β-carotene-bleaching capacity of extracts from various parts of corn.

Corn part	**Extracting solvent**	**FRAP**	***CRC***	**References**
Corn silk	Water	35.01%		[87]
	Methanol	56.41%		[87]
	Ethanol	51.16%, 38.90–65.46%		[87, 93]
	Ethyl acetate	27.21%		[87]
Corn kernel	Methanol	6.4–12.7 37 μM TE/g dw		[95]
	Methanol acidified with citric acid	0.09 μmol Fe(II) E/g fw 0.10 μmol Fe(II)/g dw 13.1–26.1 μM TE/g		[61, 82, 98]
	Methanol acidified with HCl	9 ± 2 mmol TE/100 g dw		[95]
Corn cob	Various polarity solvents	35.81–41.39%	EC$_{50}$ (218.1–735.0 μg/ml)	[93, 97]
Corn leaves	Various polarity solvents		EC$_{50}$ (152.3–248.8 μg/ml)	[97]
Corn husk	Various polarity solvents		EC$_{50}$ (205.7–723.4 μg/ml)	[97]

FRAP, ferric-reducing antioxidant power; *CRC*, cupric-reducing capacity; EC$_{50}$, effective concentration required for 50% inhibition; TE, Trolox equivalent.

Table 4. Metal-reducing capacity of extracts from various parts of corn.

Corn part	**Extracting solvent**	**DPPH**	**ABTS**	**References**
Corn silk	Water	63.5%		[89]
		IC$_{50}$ (195.21 μg/ml)		[99]
	Methanol	81.7%		[89]
	Methanol	IC$_{50}$ (0.10–0.18 mg/ml)		[18]
	Methanol	41–76%		[19]
	Methanol	IC$_{50}$ (140.89 μg/ml)		[99]
		81.7–71.5%		[89]
	Ethanol	84%, 68–75.6%		[78]
		68.4–75.6%		[57]
		IC$_{50}$ (140.89 μg/ml)		[87]
	Ethanol	IC$_{50}$ (143.55 μg/ml)		[99]
	Ethanol-water	92.6% with IC$_{50}$ (0.56 mg/ml)		[6]
	Ethyl acetate	IC$_{50}$ (411.69 μg/ml)		[99]
Corn seed	Methanol	IC$_{50}$ (66.3–79.8 μg/ml) IC$_{50}$ (52–177 mg/ml)	IC$_{50}$ (219–799 μg/ml)	[40, 98]
	Methanol acidified with citric acid	13.15%, 28.7% fw, 34.2% dw, 10.48–13.46%		[61, 91]
	Methanol acidified with HCl		5–14 μM TE/g dw 11 ± 2 mmol TE/100 g dw	[95],
	Ethanol acidified with citric acid	49.2 μM ET/g		[41]

Corn part	Extracting solvent	DPPH	ABTS	References
Corn cob	Methanol	4–22 μmol/g dw		[67]
	Methanol acidified with citric acid	21.01%		[91]
	Various polarity solvents	IC$_{50}$ (11.8–154.4 μg/ml)		[97]
Corn husk	Methanol acidified with citric acid	10.25%		[91]
	Various polarity solvents	IC$_{50}$ (34.1–170.9 μg/ml)		[97]
Corn leaves	Various polarity solvents	IC$_{50}$ (9–78 μg/ml)		[97]

DPPH, 2,2-diphenyl-1-picrylhydrazyl radical-scavenging ability; IC$_{50}$, inhibitory concentration required for 50% inhibition; ABTS, azino-bis-tetrazolium sulfate.

Table 5. Free radical-scavenging capacity of extracts from various parts of corn.

5. Biological activities

Epidemiological studies have demonstrated a relationship between the consumption of food with high quantities of phenolic compounds and a reduction in the risks of chronic and degenerative diseases, such as cancers and cardiovascular disease. Corn seed possesses antidiabetic, antioxidant, antiproliferative, and anti-cataractogenic activities [18, 39–41].

Corn part	Extracting solvent	Activity	Reference
Corn silk	Water	Diuretic and kaliuretic activity with reduced glomerular function, anti-hepatocarcinomic, antiadipogenic, antiobesitic, antihyperglycemic, antidiabetic, lipid lowering, hematinic, anti-inflammatory, and analgesic activity	[43, 55, 59, 99, 100]
	Hot water	Antioxidant activity and inhibition of IgE antibody formation in mice	[48, 101]
	Methanol	Antioxidant, antimicrobial, anti-hyperthyroidism, inhibition of lipid peroxidation, immunomodulatory activity by enhancing the innate immunity, lipid lowering, and cardioprotective activity	[19, 47, 49, 102, 103]
	Ethanol	Inhibition of tumor necrosis factor-α and adhesion of leukocytes to cell surface, activation of human peroxisome proliferator activator receptors, induction of antioxidant enzymes, and reduction of oxidative stress, antioxidant and free radical-scavenging, urease inhibitory, anti-hyperlipidemic, and diuretic activity	[34, 38, 44, 46, 50, 76, 104]
	Aqueous alcohol	Anti-fatigue, hepatoprotective, and renal protective activity in terms of inhibition of lipid peroxidation	[10, 37, 105–108]
	Aqueous acetone	Antioxidant activity	[20]
	Various polarity solvents	Antioxidant activity in terms of free radical-scavenging, metal-reducing and beta-carotene-bleaching capacities and antimicrobial activity	[24, 87, 109]
	Corn silk powder	Antioxidant and immunostimulatory activity in fish	[110]

Corn part	Extracting solvent	Activity	Reference
Corn seed	Methanol	Antioxidant activity in terms of free radical-scavenging and metal-reducing capacity	[18, 40]
	Aqueous alcohol	Antioxidant and anti-cataractogenic activity against diabetic cataract	[39]
Corn stem	Methanol	Anti-inflammatory, neuroprotective, hepatoprotective, and antioxidant	[81, 84]
Corn husk	Ethanol	Nephroprotective activity by dose-dependent increase antioxidant enzymes in diabetic rat	[111]

Table 6. Biological activities of extracts from various parts of corn.

Corn silk has been traditionally used for the treatment of several ailments due to various pharmacological activities exhibited by its extracts. It has been found to possess antioxidant, antidiabetic, antiproliferative, antimutagenic, anticoagulant, antifungal, antiadipogenic, anti-obesitic, antihypertensive, antihyperlipidemic, antilithiatic, antibiotic, antibacterial, antiseptic, anti-inflammatory, antidepressant, and anti-fatigue activities [6, 11, 34, 38, 42, 43]. It has been also reported to possess antihyperglycemic, antihyperlipidemic, diuretic, neuroprotective, hepatoprotective, and uricosuric activities [44, 45]. Corn silk has been investigated to activate the receptors for the binding of human peroxisome proliferator activators used in the treatment of diabetes [46]. Its methanolic extract has been found to be effective in thyroid dysfunction [47]. Corn silk extracts contain certain bioactive compounds which show immunomodulation activity [33, 48, 49]. Corn silk extracts have been also found to be effective in inhibition of tumor necrosis factor-α and adhesion of leukocytes to cell surface and induction of nitric oxide synthase and cyclooxygenase in macrophages [50–52]. The chemically modified corn silk polysaccharides have been reported to show antioxidant and amylase inhibitory activities [14]. Recently, the studies have shown that corn silk has no cytotoxic effect, but the excessive use of corn silk may be cardiotoxic particularly in patients with compromised cardiac health [4]. The biological activities of various extracts of different parts of corn are presented in **Table 6**.

6. Medicinal importance

Corn seed kernel is commonly used as nutritional purpose, but owing to its good phytochemical composition and biological properties, it has great medicinal value. The toxicological assessment of corn at various doses against various clinical parameters has proven it clinically nontoxic and can be used for nutritional and medicinal purposes [53]. Anthocyanins in purple waxy corn have been reported to be effective against diabetic cataract [39]. Corn silk is usually discarded as waste and not used for nutritional purpose. However, it has a great medicinal importance due to the presence of valuable bioactive phytochemical compounds. It has been traditionally used as an effective herbal remedy for the treatment of hyperglycemia, diabetes, obesity, hypercholesterolemia, hyperthyroidism, rheumatism, arthritis, gout, tumors, hepatitis, heart problems, jaundice, malaria, inflammation, asthma prostatitis, cystitis, nephritis, kidney stones, bed wetting, renal conditions, and other kidney-related diseases. Corn silk is also known to be urine laxative, antihypertensive, and immune enhancer. Corn silk tea has been used as diuretic for the treatment of urinal irritation. In combination with other herbs, corn silk has been found to be effective against mumps or inflammation of the bladder. It has been also reported to be useful in gonorrhea, acute and chronic cystitis, and bladder irritation due to uric acid and phosphate gravel [11, 14, 37, 38, 42–44, 46, 47, 51, 54–59]. Recently, corn silk polysaccharides have been suggested to be a good choice as functional food or medicine for the treatment of type 2 diabetes mellitus due to its hypoglycemic activity [60].

7. Factors affecting the phytochemical profile and antioxidant potential of corn

There are several factors which have been reported to affect the phytochemical quality and antioxidant potential of various parts of corn. The phytochemical composition and antioxidant profile of maize have been observed to be different in different varieties and at various stages of maturity [18, 61–63]. The phytochemical content of corn silk has been found to be enhanced by treatment with red algae [64]. The location, climatic, water stress, irrigation method, and plant density significantly affect the growth, metabolism, and physiological characteristics of corn plant [65–67]. The spraying of salicylic acid and collection period have been found to increase the growth rate and phytochemical content of corn silk [68]. The fermentation of corn samples has been found to result in an increase in carotenoid and ascorbic acid content with a slight decrease in antioxidant activity [69]. The germination conditions between light and dark periods have been also found to affect the morphological structures, biochemical and phytochemical composition, and antioxidant activity of corn sprouts [70]. The storage conditions, processing techniques, and cooking methods have been also found to affect the phytochemical content and free radical-scavenging activity of maize [21, 71]. Recently, studies in our laboratory have shown that high-dose gamma irradiation results in a decrease in antioxidant properties of corn flour [72].

8. Conclusion

All parts of corn plant are good sources of phytochemical compounds which possess antioxidant potential. Corn seed have a valuable role in human nutrition, while corn silk has a great medicinal importance due the presence of a variety of bioactive phytochemical compounds. The principal phytochemicals present in corn silk include polyphenols, phenolic acids, flavonoids, anthocyanins, glycosides, carotenoids, and some water-soluble vitamins. The presence of these phytochemicals makes corn a medicinal plant which shows various biological activities particularly the antioxidant activity. On the account of its high antioxidant potential, all parts of corn plant can be used for the management of oxidative stress and the treatment of various diseases.

Conflict of interest

I confirm that there are no conflicts of interest.

Author details

Haq Nawaz[1]*, Saima Muzaffar[2], Momna Aslam[1] and Shakeel Ahmad[3]

*Address all correspondence to: haqnawaz@bzu.edu.pk

1 Department of Biochemistry, Bahauddin Zakariya University, Multan, Pakistan

2 Department of Chemistry, University of Education, Vehari, Pakistan

3 Department of Agronomy, Faculty of Agriculture, Bahauddin Zakariya University, Multan, Pakistan

References

[1] Vaughan JG, Geissler CA. The New Oxford Book of Food Plants. Oxford: Oxford University Press; 1997. ISBN 0-19-854825-7

[2] Purohit SS, Sharma AK, Prajapati ND, Kumar T. A Handbook of Medicinal Plants: A Complete Source Book. 2nd ed. Jodhpur, India: Agrobios; 2009. pp. 352-353

[3] Nuss ET, Tanumihardjo SA. Maize: A paramount staple crop in the context of global nutrition. Comprehensive Reviews in Food Science and Food Safety. 2010;**9**:417-436

[4] Ishak WRW, Ali SM. Assessment of Malaysian cornsilk bioactive compounds and its cytotoxicity test on brine shrimp (*Artemia salina*). Health (N Y). 2016;**7**:124-138

[5] Naqvi S, Ramessar K, Farré G, Sabalza M, Miralpeix B, Twyman RM, et al. High-value products from transgenic maize. Biotechnology Advances. 2011;**29**:40-53

[6] Ebrahimzadeh MA, Pourmorad F, Hafezi S. Antioxidant activities of Iranian corn silk. Turkish Journal of Biology. 2008;**32**:43-49

[7] Shad MA, Nawaz H, Noor M, Ahmad HB, Hussain M, Choudhry MA. Functional properties of maize flour and its blends with wheat flour: optimization of preparation conditions by response surface methodology. Pakistan Journal of Botany. 2013;**45**:2027-2035

[8] Nawaz H, Shad MA, Mehmood R, Rehman T, Munir H. Comparative evaluation of functional properties of some commonly used cereal and legume flours and their blends. International Journal of Food and Allied Sciences. 2015;**1**:67-73

[9] Voca N, Varga B, Kricka T, Curic D, Jurisic V, Matin A. Progress in ethanol production from corn kernel by applying cooking pre-treatment. Bioresource Technology. 2009; **100**:2712-2718

[10] Karami M, Shokerzadeh M, Naghshvar F, Ala S, Fezbakhsh R, Nosrati A, et al. Comparison the renal protective activity of corn silk and Feijoa extracts by using insitu rat renal perfusion system. Iranian Journal of Toxicology. 2014;**8**(25)

[11] Hasanudin K, Hashim P, Mustafa S. Corn silk (*Stigma maydis*) in healthcare: A phytochemical and pharmacological review. Molecules. 2012;**17**:9697-9715

[12] Wang C, Zhang T, Liu J, Lu S, Zhang C, Wang E, et al. Subchronic toxicity study of corn silk with rats. Journal of Ethnopharmacology. 2011;**137**:36-43

[13] Gwendlin V, Induja TA, Manoj J, Shivasamy MS. Recent trends in effective utilization of by-product of corn. Indian Journal of Science. 2015;**22**:18-26

[14] Chen S, Chen H, Tian J, Wang Y, Xing L, Wang J. Chemical modification, antioxidant and α-amylase inhibitory activities of corn silk polysaccharides. Carbohydrate Polymers. 2013;**98**:428-437

[15] Rosli W, Nurhanan AR, Solihah MA, Mohsin SSJ. Cornsilk improves nutrient content and physical characteristics of beef patties. Sains Malays. 2011;**40**:155-161

[16] Aukkanit N, Kemngoen T, Ponharn N. Utilization of corn silk in low fat meatballs and its characteristics. Procedia—Social and Behavioral Sciences. 2015;**197**:1403-1410

[17] Ebrahimzadeh MA, Pourmorad F, Bekhradnia AR. Iron chelating activity, phenol and flavonoid content of some medicinal plants from Iran. African Journal of Biotechnology. 2008;**7**(18):3188-3192

[18] Nawaz H, Shad MA, Batool Z. Inter-varietal variation in biochemical, phytochemical and antioxidant composition of maize (*Zea mays* L.) grains. Food Science and Technology Research. 2013;**19**:1133-1140

[19] Emmanuel SA, Olajide O, Abubakar S, Akiode SO, Etuk-Udo G. Chemical evaluation, free radical scavenging activities and antimicrobial evaluation of the methanolic extracts of corn silk (*Zea mays*). Journal of Advances in Medical and Pharmaceutical Sciences. 2016;**9**:1-8

[20] Jana ŽS, Janković M, Basić Z, Vančetović J, Maksimović V. Antioxidant activity, phenolic profile, chlorophyll and mineral matter content of corn silk (*Zea mays* L): Comparison with medicinal herbs. Journal of Cereal Science. 2016;**69**:363-370

[21] Cabrera SG, Perez IFR, Aguilar LJL, Caringal MC, Dado AG, Evangelista DM. Determination of properties of selected fresh and processed medicinal plants. Asia Pacific Journal of Multidisciplinary Research. 2015;**3**

[22] Guevara P, Perez-Amador MC, Zuniga B, Snook M. Flavones in corn silks & resistance to insect attacks. Phyton. 2000;**69**:151-156

[23] Silva MM, Santos MR, Caroço G, Rocha R, Justino G, Mira L. Structure-antioxidant activity relationships of flavonoids: A re-examination. Free Radical Research. 2002;**36**:1219-1227

[24] Nessa F, Ismail Z, Mohamed N. Antimicrobial activities of extracts and flavonoid glycosides of corn silk (*Zea mays* L). International Journal of Biotechnology for Wellness Industries. 2012;**1**:115-120

[25] Matsuda H, Wang T, Managi H, Yoshikawa M. Structural requirements of flavonoids for inhibition of protein glycation and radical scavenging activities. Bioorganic & Medicinal Chemistry. 2003;**11**:5317-5323

[26] Wu C-H, Yen G-C. Inhibitory effect of naturally occurring flavonoids on the formation of advanced glycation endproducts. Journal of Agricultural and Food Chemistry. 2005;**53**:3167-3173

[27] Toufektsian M-C, De Lorgeril M, Nagy N, Salen P, Donati MB, Giordano L, et al. Chronic dietary intake of plant-derived anthocyanins protects the rat heart against ischemia-reperfusion injury. The Journal of Nutrition. 2008;**138**:747-752

[28] Wang L-S, Stoner GD. Anthocyanins and their role in cancer prevention. Cancer Letters. 2008;**269**:281-290

[29] He J, Giusti MM. Anthocyanins: Natural colorants with health-promoting properties. Annual Review of Food Science and Technology. 2010;**1**:163-187

[30] Abdel-Aal EM. Anthocyanin-pigmented grain products. In: Advances in Cereal Science: Implications to Food Processing and Health Promotion. Washington DC, USA: ACS Publications; 2011. pp. 77-109

[31] Kaur S, Grover IS, Singh M, Kaur S. Antimutagenicity of hydrolyzable tannins from *Terminalia chebula* in *Salmonella typhimurium*. Mutation Research. Genetic Toxicology and Environmental Mutagenesis. 1998;**419**:169-179

[32] Kong J-M, Chia L-S, Goh N-K, Chia T-F, Brouillard R. Analysis and biological activities of anthocyanins. Phytochemistry. 2003;**64**:923-933

[33] Luhong T, Xiaolin D, Lifen Y, Weier G, Furong Y. Bio-active substances from corn silk corn silk polysaccharide (CSPS) and its immunological enhancing function. Journal of Wuxi University of Light Industry. 1995;**4**

[34] Liu J, Wang C, Wang Z, Zhang C, Lu S, Liu J. The antioxidant and free-radical scavenging activities of extract and fractions from corn silk (*Zea mays* L.) and related flavone glycosides. Food Chemistry. 2011;**126**:261-269

[35] Lewer P, Bandurski RS. Occurrence and metabolism of 7-hydroxy-2-indolinone-3-acetic acid in *Zea mays*. Phytochemistry. 1987;**26**:1247-1250

[36] Yang Z, Zhai W. Identification and antioxidant activity of anthocyanins extracted from the seed and cob of purple corn (*Zea mays* L.). Innovative Food Science & Emerging Technologies. 2010;**11**:169-176

[37] Hu Q-L, Zhang L-J, Li Y-N, Ding Y-J, Li F-L. Purification and anti-fatigue activity of flavonoids from corn silk. International Journal of. Physical Sciences. 2010;**5**:321-326

[38] Hu QL, Deng ZH. Protective effects of flavonoids from corn silk on oxidative stress induced by exhaustive exercise in mice. African Journal of Biotechnology. 2011;**10**:3163-3167

[39] Thiraphatthanavong P, Wattanathorn J, Muchimapura S, Thukham-Mee W, Wannanon P, Tong-Un T, et al. Preventive effect of *Zea mays* L. (purple waxy corn) on experimental diabetic cataract. BioMed Research International. 2014;**2014**:1-8

[40] Ganie AH, Yousuf PY, Ahad A, Pandey R, Ahmad S, Aref IM, et al. Quantification of phenolic acids and antioxidant potential of inbred, hybrid and composite cultivars of maize under different nitrogen regimes. Journal of Environmental Biology. 2016;**37**:1273

[41] Herrera-Sotero MY, Cruz-Hernández CD, Trujillo-Carretero C, Rodríguez-Dorantes M, García-Galindo HS, Chávez-Servia JL, et al. Antioxidant and antiproliferative activity of blue corn and tortilla from native maize. Chemistry Central Journal. 2017;**11**:110

[42] Grases F, March JG, Ramis M, Costa-Bauzá A. The influence of *Zea mays* on urinary risk factors for kidney stones in rats. Phytotherapy Research. 1993;**7**:146-149

[43] Min O-J, Sharma BR, Park C-M, Rhyu D-Y. Effect of myadis stigma water extract on adipogenesis and blood glucose in 3T3-L1 adipocytes and db/db mice. Korean Journal of Pharmacognosy. 2011**42**:201-208

[44] Cáceres A, Girón LM, Martínez AM. Diuretic activity of plants used for the treatment of urinary ailments in Guatemala. Journal of Ethnopharmacology. 1987;**19**:233-245

[45] Chen G, Wang H, Zhang X, Yang S-T. Nutraceuticals and functional foods in the management of hyperlipidemia. Critical Reviews in Food Science and Nutrition. 2014;**54**:1180-1201

[46] Rau O, Wurglics M, Dingermann T, Abdel-Tawab M, Schubert-Zsilavecz M. Screening of herbal extracts for activation of the human peroxisome proliferator-activated receptor. Pharmazie. 2006;**61**:952-956

[47] Bhaigyabati T, Ramya J, Usha K. Effect of methanolic extract of sweet corn silk on experimentally induced hyperthyroidism in Swiss albino rats. International Research Journal of Pharmacy. 2012;**3**:241-245

[48] Namba T, Xu H, Kadota S, Hattori M, Takahashi T, Kojima Y. Inhibition of IgE formation in mice by glycoproteins from corn silk. Phytotherapy Research. 1993;**7**:227-230

[49] Lee J, Kim S-L, Lee S, Chung MJ, Park YI. Immunostimulating activity of maysin isolated from corn silk in murine RAW 264.7 macrophages. BMB Reports. 2014;**47**:382

[50] Habtemariam S. Extract of corn silk (Stigma of *Zea mays*) inhibits tumour necrosis factor-α-and bacterial lipopolysaccharide-induced cell adhesion and ICAM-1 expression. Planta Medica. 1998;**64**:314-318

[51] Kim KA, Choi S-K, Choi H-S. Corn silk induces nitric oxide synthase in murine macrophages. Experimental & Molecular Medicine. 2004;**36**:545

[52] Kim KA, Shin H-H, Choi SK, Choi H-S. Corn silk induced cyclooxygenase-2 in murine macrophages. Bioscience, Biotechnology, and Biochemistry. 2005;**69**:1848-1853

[53] Sabiu S, O'Neill FH, Ashafa AOT. Toxicopathological evaluation of a 28-day repeated dose administration of *Zea mays* L. (Poaceae), Stigma maydis aqueous extract on key metabolic markers of Wistar rats. Transactions of the Royal Society of South Africa. 2017;**72**:225-233

[54] Barter P, Gotto AM, LaRosa JC, Maroni J, Szarek M, Grundy SM, et al. HDL cholesterol, very low levels of LDL cholesterol, and cardiovascular events. The New England Journal of Medicine. 2007;**357**:1301-1310

[55] Zhao W, Yin Y, Yu Z, Liu J, Chen F. Comparison of anti-diabetic effects of polysaccharides from corn silk on normal and hyperglycemia rats. International Journal of Biological Macromolecules. 2012;**50**:1133-1137

[56] Nessa HA, Muchtar H. Efek Diuretik dan Daya Larut Batu Ginjal Dari Ekstrak Etanol Rambut Jagung (*Zea mays* L.). Pros Semin Nas Perkemb Terkini Sains Farm Dan Klin III Sumat Utara Fak Farm Univ Andalas; 2013

[57] Sarepoua E, Tangwongchai R, Suriharn B, Lertrat K. Relationships between phytochemicals and antioxidant activity in corn silk. International Food Research Journal. 2013;**20**:2073

[58] Sukandar EY, Sigit JI, Adiwibowo LF. Study of kidney repair mechanisms of corn silk (*Zea mays* L. Hair)-Binahong. International Journal of Pharmacology. 2013;**9**:12-23

[59] Yang J, Li X, Xue Y, Wang N, Liu W. Anti-hepatoma activity and mechanism of corn silk polysaccharides in H22 tumor-bearing mice. International Journal of Biological Macromolecules. 2014;**64**:276-280

[60] Pan Y, Wang C, Chen Z, Li W, Yuan G, Chen H. Physicochemical properties and anti-diabetic effects of a polysaccharide from corn silk in high-fat diet and streptozotocin-induced diabetic mice. Carbohydrate Polymers. 2017;**164**:370-378

[61] Khampas S, Lertrat K, Lomthaisong K, Suriharn B. Variability in phytochemicals and antioxidant activity in corn at immaturity and physiological maturity stages. International Food Research Journal. 2013;**20**:3149

[62] Tian J, Chen H, Chen S, Xing L, Wang Y, Wang J. Comparative studies on the constituents, antioxidant and anticancer activities of extracts from different varieties of corn silk. Food & Function. 2013;**4**:1526-1534

[63] Sarepoua E, Tangwongchai R, Suriharn B, Lertrat K. Influence of variety and harvest maturity on phytochemical content in corn silk. Food Chemistry. 2015;**169**:424-429

[64] Al-Saman MA, Farfour SA, Hamouda RA. Effects of some red algae on antioxidant and phytochemical contents of maize (*Zea mays* L.) plants. International Journal of Agriculture Sciences. 2015;**5**:393-398

[65] Bahadori A, Mobasser HR, Ganjali HR. Influence of water stress and plant density on some characteristics in corn. Biological Forum – An International Journal. Research Trend. 2015;**7**:673

[66] Ghanati F, Mohamadalikhani S, Soleimani M, Afzalzadeh R, Hajnorouzi A. Change of growth pattern, metabolism, and quality and quantity of maize plants after irrigation with magnetically treated water. Electromagnetic Biology and Medicine. 2015;**34**:211-215

[67] Khampas S, Lertrat K, Lomthaisong K, Simla S, Suriharn B. Effect of location, genotype and their interactions for anthocyanins and antioxidant activities of purple waxy corn cobs. Turkish Journal of Field Crops. 2015;**20**:15-23

[68] MH A-M. Effect of spraying salicylic acid and collection dates of corn silk (*Zea mays* L.) on growth, yield and content of some antioxidant compounds. Journal of Global Pharma Technology. 2017;**9**:98-103

[69] Oladeji BS, Akanbi CT, Gbadamosi SO. Effects of fermentation on antioxidant properties of flours of a normal endosperm and quality protein maize varieties. Journal of Food Measurement and Characterization. 2017;**11**:1148-1158

[70] Xiang N, Guo X, Liu F, Li Q, Hu J, Brennan CS. Effect of light-and dark-germination on the phenolic biosynthesis, phytochemical profiles, and antioxidant activities in sweet corn (*Zea mays* L.) sprouts. International Journal of Molecular Sciences. 2017;**18**:1246

[71] Song J, Liu C, Li D, Meng L. Effect of cooking methods on total phenolic and carotenoid amounts and dpph radical scavenging activity of fresh and frozen sweet corn (*Zea mays*) kernels. Czech Journal of Food Sciences. 2013;**31**(6):607-612

[72] Nawaz H, Shad MA, Rehman T, Ramzan A. Influence of high-dose gamma radiation and particle size on antioxidant properties of maize (*Zea mays* L.) flour. Brazilian Journal of Pharmaceutical Sciences. 2016;**52**:771-780

[73] Liu RH. Potential synergy of phytochemicals in cancer prevention: mechanism of action. The Journal of Nutrition. 2004;**134**:3479S-3485S

[74] Yu TT, Lu XX, Lian XJ, Zhang YQ. Composition analysis of flavonoids from corn silk with thin-layer chromatography and ultraviolet spectrophotometry. Food Science. 2008;**29**:477-481

[75] Ren S-C, Liu Z-L, Ding X-L. Isolation and identification of two novel flavone glycosides from corn silk (*Stigma maydis*). Journal of Medicinal Plants Research. 2009;**3**:1009-1015

[76] Ismael RH, Ahmed SA, Mahmoud SS. Detection of rutin, kaepferol, and quercetin based crude from corn silk and studying their effects on the inhibition of pure urease enzyme and urease of *Klebsiella* species. International Journal of Current Microbiology and Applied Sciences. 2017;**6**:2676-2685

[77] Snook ME, Widstrom NW, Wiseman BR, Byrne PF, Harwood JS, Costello CE. New C-4″-hydroxy derivatives of maysin and 3′-methoxymaysin isolated from corn silks (*Zea mays*). Journal of Agricultural and Food Chemistry. 1995;**43**:2740-2745

[78] El-Ghorab A, El-Massry KF, Shibamoto T. Chemical composition of the volatile extract and antioxidant activities of the volatile and nonvolatile extracts of Egyptian corn silk (*Zea mays* L.). Journal of Agricultural and Food Chemistry. 2007;**55**:9124-9127

[79] Rahman NA, Wan Rosli WI. Nutritional compositions and antioxidative capacity of the silk obtained from immature and mature corn. Journal of King Saud University – Science. 2014;**26**:119-127

[80] Xie L, Yu Y, Mao J, Liu H, Hu JG, Li T, et al. Evaluation of biosynthesis, accumulation and antioxidant activity of Vitamin E in sweet corn (*Zea mays* L.) during kernel development. International Journal of Molecular Sciences. 2017;**18**:2780

[81] Jung Y-J, Park J-H, Cho J-G, Seo K-H, Lee D-S, Kim Y-C, et al. Lignan and flavonoids from the stems of *Zea mays* and their anti-inflammatory and neuroprotective activities. Archives of Pharmacal Research. 2015;**38**:178-185

[82] Bacchetti T, Masciangelo S, Micheletti A, Ferretti G. Carotenoids, phenolic compounds and antioxidant capacity of five local Italian corn (*Zea mays* L.) kernels. Journal of Nutrition & Food Sciences. 2013;**3**:1

[83] Edelman M, Colt M. Nutrient value of leaf vs. seed. Frontiers in Chemistry. 2016;**4**:1-5 Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4954856/

[84] Jung Y-J, Park J-H, Seo K-H, Shrestha S, Lee D-S, Kim Y-C, et al. Phenolic compounds from the stems of *Zea mays* and their pharmacological activity. Journal of Korean Society for Applied Biological Chemistry. 2014;**57**:379-385

[85] Ahmed HM. Phytochemical screening, total phenolic content and phytotoxic activity of corn (*Zea mays*) extracts against some indicator species. Natural Product Research. 2018;**32**:714-718

[86] Li P, Lapčík L, Lapčíková B, Kalytchuk S. Physico-chemical study of flavonoids from different matureness corn silk material. Potravinarstvo Slovak Journal of Food Sciences. 2018;**12**:347-354

[87] Nurhanan AR, WR WI. Evaluation of polyphenol content and antioxidant activities of some selected organic and aqueous extracts of cornsilk (*Zea mays* hairs). Journal of Medical and Bioengineering. 2012;**1**:48-51

[88] Solihah MA, Rosli WW, Nurhanan AR. Phytochemicals screening and total phenolic content of Malaysian *Zea mays* hair extracts. International Food Research Journal. 2012;**19**:1533

[89] Muda RJ, Nurhanan AR, Rosli W, Mohsin S. Total polyphenol content and free radical scavenging activity of cornsilk (*Zea mays* hairs). Sains Malays. 2012;**41**:1217-1221

[90] Singh NK, Sahu AN, Singh SK. Free radical scavenging and hepatoprotective activities of standardized methanolic extract of Maydis stigma. 2009

[91] Simla S, Boontang S, Harakotr B. Anthocyanin content, total phenolic content, and anti-radical capacity in different ear components of purple waxy corn at two maturation stages. Australian Journal of Crop Science. 2016;**10**:675

[92] Cevallos-Casals BA, Cisneros-Zevallos L. Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweetpotato. Journal of Agricultural and Food Chemistry. 2003;**51**:3313-3319

[93] Ho YM, Wan Amir Nizam WA, Wan Rosli W. Antioxidative activities and polyphenolic content of different varieties of malaysian young corn ear and cornsilk. SAINS Malays. 2016;**45**:195-200

[94] Laeliocattleya RA, Prasiddha IJ, Estiasih T, Maligan JM, Muchlisyiyah J. The potential of bioactive compounds from corn silk (*Zea mays* L.) that result from gradual fractionation using organic solvents for the use as a natural sunscreen. Jurnal of Teknologi Pertanian. 2014;**15**(3):175-184

[95] Ku KM, Kim HS, Kim SK, Kang Y-H. Correlation analysis between antioxidant activity and phytochemicals in Korean colored corns using principal component analysis. The Journal of Agricultural Science. 2014;**6**:1

[96] Lopez-Martinez LX, Oliart-Ros RM, Valerio-Alfaro G, Lee C-H, Parkin KL, Garcia HS. Antioxidant activity, phenolic compounds and anthocyanins content of eighteen strains of Mexican maize. LWT-Food Science and Technology. 2009;**42**:1187-1192

[97] Fidrianny I, Eriani Wulandari RH. In Vitro Antioxidant Activity of Different Organs Extracts of Corn Grown in Cimahi-West Java-Indonesia

[98] Ramos-Escudero F, Muñoz AM, Alvarado-Ortíz C, Alvarado A, Yánez JA. Purple corn (*Zea mays* L.) phenolic compounds profile and its assessment as an agent against oxidative stress in isolated mouse organs. Journal of Medicinal Food. 2012;**15**:206-215

[99] Adedapo AA, Babarinsa OS, Ogunshe AAO, Oyagbemi AA, Omobowale TO, Adedapo AD. Evaluation of some biological activities of the extracts of corn silk and leaves. Tropical Veterinarian. 2013;**31**:12-32

[100] Velazquez DVO, Xavier HS, Batista JEM, de Castro-Chaves C. *Zea mays* L. extracts modify glomerular function and potassium urinary excretion in conscious rats. Phytomedicine. 2005;**12**:363-369

[101] Kılıç C, Can Z, Yılmaz A, Yıldız S, Turna H. Antioxidant properties of some herbal teas (green tea, senna, corn silk, rosemary) brewed at different temperatures. International Journal of Secondary Metabolite. 2017;**4**:142-148

[102] Maksimović ZA, Kovačević N. Preliminary assay on the antioxidative activity of Maydis stigma extracts. Fitoterapia. 2003;**74**:144-147

[103] Ozuruoke DF, Olaniyan MF, Temitope F. Changes in plasma level of LDH, CKMB and lipid profile in rabbits administered with corn silk extract. American Journal of Biomedical Sciences. 2016;**8**

[104] Wu J, Ye M, Wang Z. Extraction, purification and anti-hyperlipidemic activities of total flavonoids from corn silk. Pakistan Journal of Zoology. 2017;**49**

[105] Karami M, Saeidnia S, Naghshvar F. The hepatoprotective effects of corn silk against dose-induced injury of ecstasy (MDMA) using isolated rat liver perfusion system. Iranian Journal of Toxicology. 2013;**7**:808-815

[106] Karami M, Saeed Nia S, Ebrahimzadeh MA, Amali Amiri M, Karami N. Study of therapeutic and histopathologic effects of corn silk's aqueous and metanolic extract against dosage induced by MDMA in isolated rat liver perfusion system. ISMJ. 2014;**17**:21-32

[107] Karami M, Shokerzadeh M, Naghshvar F, Ala S, Fezbakhsh R, Nosrati A, et al. The renal protective effects of corn silk and feijoa by using in situ rat renal system. Iran Journal of Toxicology. 2014;**8**:1060-1067

[108] Zhao H, Zhang Y, Liu Z, Chen J, Zhang S, Yang X, et al. Acute toxicity and anti-fatigue activity of polysaccharide-rich extract from corn silk. Biomedicine & Pharmacotherapy. 2017;**90**:686-693

[109] Morshed S, Islam SS. Antimicrobial activity and phytochemical properties of corn (*Zea mays* L.) silk. SKUAST Journal of Research. 2015;**17**:8-14

[110] Catap ES, Jimenez MRR, Tumbali MPB. Immunostimulatory and anti-oxidative properties of corn silk from *Zea mays* L. in Nile tilapia, *Oreochromis niloticus*. International Journal of Fisheries and Aquaculture. 2015;**7**:30-36

[111] Okokon JE, Nyong ME, Essien GE, Nyong E. Nephroprotective activity of husk extract and fractions of *Zea mays* against alloxan-induced oxidative stress in diabetic rats. Journal of Basic Pharmacology and Toxicology. 2017;**1**:1-10

Chapter 5

Bioactive Compounds in Pigmented Maize

Arturo Navarro, Andrea Torres,
Fernanda Fernández-Aulis and Carolina Peña

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78340

Abstract

Mexico is the center of origin of maize where there is a great variety of pigmented corns with health benefits. These properties are attributed to their high content of phenolic compounds. The most studied compounds are anthocyanins that no matter the variety of corn are mainly six: cyanidin, pelargonidin and peonidin-3-glucoside and their malonated derivatives. Among the pigmented corns, the purple has the most concentration of anthocyanins, these are found in the whole plant but in more quantity in the silk. The health benefits attach to anthocyanins are principally anti-obesity agent and anticancer activity. Regarding the phenolic acids reported in the pigmented corn plant, the most abundant acid in kernel is ferulic acid, in cob is syringic acid while in the silk is chlorogenic acid. This variation, in the phenolic acid profiles according to the organ, indicates the biological function that each of them plays in the plant; meanwhile in humans, they have important antioxidant effects. Flavonoids are the group less studied of bioactive compounds in pigmented corns; however, the concentrations of these compounds are high especially in purple silk; inside the flavonoids described are morin, kaempferol, naringin, maysin, rutin, quercetin and hyperoside; with antioxidant effects, as neuroprotective, apoptosis induction and others.

Keywords: pigmented corn, anthocyanins, flavonoids, phenolic acids

1. Introduction

The oldest macroremains unambiguously identified as maize (*Zea mays*) were retrieved from preceramic strata of dry caves in two states of Mexico: Puebla (Tehuacan Valley) and Tamaulipas (Ocampo Caves). These were found with microremains of pepper (*Capsicum*) and squash (*Cucurbit asp)* and other species used by humans. Archeological strata, suggesting a rough date for this foods around 9000–7000 B.P. [1]. In different myths, leyends and codices prehispanics civilizations Olmecas, Mayan and Mexican showing the prominent position of corn. For example, one myth the Mexica gods of corn: Tell us that corn was created after the goddess Centéotl sank into the ground to make vegetables to feed the people. It was in the wake of that event that cotton, huazantle, chia, sweet potato and corn began to grow from the ground. The Mexican Indians called corn as "the plant of the gods" [2].

At this time, corn (*Zea mays*) is the most important cereal that is produced in the world, the white and yellow corns are more used, the world production of maize was 987 million metric tons (MMT) and the United States of America (USA) is the largest producer and Mexico is the sixth producing country [3].

In the world, corn is generally used for animal feed and biofuels. In Mexico, this cereal is used for making foods; maize grains are consumed fresh (elotes and esquites, boiled grains) or processed in the form of dough or cornmeal for the preparation of some foods: dishes (tortillas), corn flakes (salads and sweets totopos), starch (atoles and pinole), tamale dough (tamales), fermented foods (pozol and atoles), boiled or steamed corn (pozole), soups (chilaquiles), bakery products and another foods. Some foods and grains of maizes are depicted in **Figure 1**.

The colorful corns are less common while the white and yellow are the most popular. All parts such as silk, cob, leaves, husk and kernel of corns have been used by people at remote time to Mesoamerican civilization, the pigment corns referred to as blue, red or purple corn are botanically the same species white and yellow. This cereal was used in the preparation to color foods and beverages. The interest on pigmented (blue, red and purple) corn is due to the bioactive compounds; these are anthocyanins, *p*-hydroxycinnamic acids, flavonoids and to minor proportion carotenoids, phytoesterols, vitamin E, lignans, policosanols and xylans. The purpose of this chapter is to provide an overview of bioactive compounds and of the

Figure 1. Food products elaborated with pigmented corn.

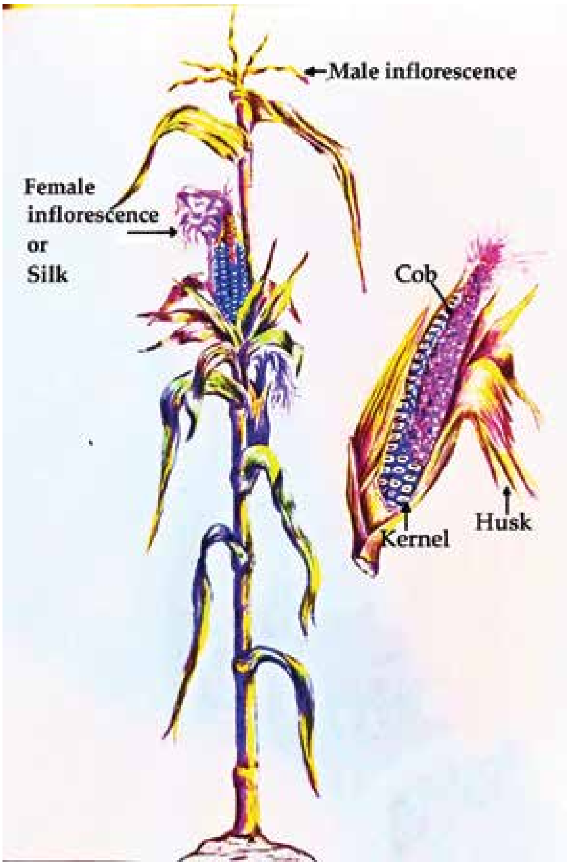


Figure 2. Organs of the corn plant. Painting by Esteban Torres 2018.

biological activity of the purple, red and blue corns in all parts of the plant including pericarp of the grain (kernel), silk (seda), inflorescence (espiga), husk (totomoxtle) and corn cobs (olote). The plant parts typical to corn are shown in **Figure 2**.

2. Anthocyanin in pigmented corn

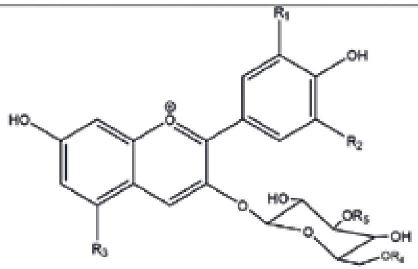
Anthocyanins are the largest group of phenolic pigments responsible for the pink, red, purple and blue corns which is the cereal with most anthocyanin content [4]. For that reason, the pigmented corn has caught attention in research and production. There is a great diversity in types of corn including sweet corn, popcorn, pod corn, flint corn, flour corn, waxy corn and dent corn; everyone is able to have different variety of color as shown in **Figure 3**, which give us opportunity to get a great source of anthocyanins using the whole plant because, according with the variety of corn, the silk, corn husk and corn cob could have more anthocyanins than kernel, as we will see in later section.

Figure 3. Purple corn and Cacahuacintle corn with purple cornhusk and corn cob.

2.1. Anthocyanin in pigmented corn kernel

Anthocyanin in corn is found in kernel, cob, husk, silk, leaves and stem [5, 6]. In terms of anthocyanins, kernel is the most studied and anthocyanins are found in pericarp and aleurone layer. Pericarp can be transparent, orange, red or brown while aleurone layer can be transparent, red or purple [7]. Currently, researches in corn are focused on major production of anthocyanins, so there are some strategies to find new and better source of pigmented corns. One of them is the study of Mexican maize due to an excellent source for the production of anthocyanins because there are more than 60 native races of corn that have been little studied. However, Mendoza had studied the anthocyanins content in different corn lines and found corns with higher anthocyanins [8]. Other strategy is hybrid corn which is also studied; nevertheless, the anthocyanins content is not better than other pigmented native corns.

The later research about anthocyanin characterization shows a similar profile include cyanidin-3-glucoside and cyanidin-3-(6″malonyl) glucoside as the main anthocyanins. **Figure 4** shows anthocyanins found in pigmented corn. However, the variety of colors on pigmented corns is due to the difference on the concentration of each anthocyanin depending on genetics [9]. Peonidin-3-glucoside and pelargonidin-3-glucoside and their derivatives are the anthocyanins that have major variability and a major concentration of pelargonidin-3-(6″malonyl) glucoside are found in red corn [10] while blue corn has neither pelargonidin-3-glucoside nor peonidin-3-glucoside as purple corn has [11], moreover blue corn has more cyanidin-3-(6″ malonyl)glucoside than purple corn; however, its total concentration is much less than purple corn as shown in **Table 1** [9].



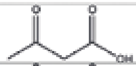
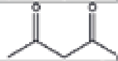
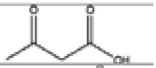
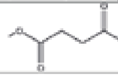
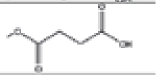
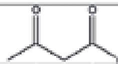
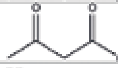
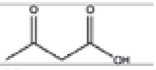
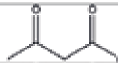
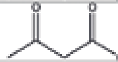
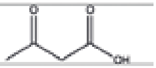
Anthocyanin	R1	R2	R3	R4	R5
Cyanidin-3-glucoside	OH	H	H	H	H
Cyanidin-3,5-diglucoside	OH	H	Glucose	H	H
Cyanidin-3-(6"malonyl)glucoside	OH	H	H		H
Cyanidin-3-(3",6"dimalonyl)glucoside	OH	H	H		
Cyanidin-(disuccinyl)glucoside	OH	H	H		
Pelargonidin-3-glucoside	H	H	H	H	H
Pelargonidin-3,5-diglucoside	H	H	Glucose	H	H
Pelargonidin-3-(6"malonyl)glucoside	H	H	H		H
Pelargonidin-3-(dimalonyl)glucoside	H	H	H		
Peonidin-3-glucoside	OCH_3	H	H	H	H
Peonidin-3-(6"malonyl)glucoside	OCH_3	H	H		H
Peonidin-3-(dimalonyl)glucoside	OCH_3	H	H		
Delphinidin-3-glucoside	OH	OH	H	H	H

Figure 4. Structure of anthocyanin found in pigmented corn.

2.2. Anthocyanin in pigmented corn cob

Cob is considered as a by-product from the corn and represents the 20.6–26.2% of the plant and it is used as animal feed. However, it has a chemical high value due to their high anthocyanin concentration and other phenolic compounds. Purple corn cob anthocyanin concentration is 3–3900 mg/100 g according to the last years' review (**Table 2**). Differences are due to corn variety and also, but in a lesser way, extraction method. Anthocyanin composition in cob is similar to the kernel, finding the six main anthocyanins, and identification has made by HPLS-MS [15, 40].

2.3. Anthocyanin in pigmented corn silk

Corn silk can be yellow, green or purple depending on the corn variety. Silk is used in local community as medicinal herbs; however, it does not take advantage and is considered a waste [34].

Part of the corn	Corn phenotype	Anthocyanin	Ref.
Kernel	Purple corn^{2}	Cy-3-glu (45.8%)^{2}, (45.8%)^{3}, (47.3%)^{4} (73.62%)^{6}	[11]^{4}, [12]^{2}, [13]^{3}
	Purple corn bran^{3}	Pg-3-gluc (2.0%)^{2} (3.3%)^{3}, (4.7%)^{4} (15.50%)^{6}	
	Purple corn pericarp^{6}	Pn-3-gluc (9.3%)^{2}, (4.,1%)^{3}, (11.9%)^{4} (10.88%)^{6}	
		Cy-3-malonylglu (17.2%)^{2}, (11.9%)^{4}	
		Pg-3-malonylglu (2.4%)^{2}, (2.1%)^{4}	
		Pn-3-malonylglu (3.1%)^{2}, (6.0%)^{4}	
		Condensed form (16.8%)^{2}, (11.2%)^{4}	
	Purple corn V1-V9^{1} Purple corn^{2,3,9} Purple Hybrid (WenveiiR5 R11)^{5}	Condensed forms^{1}; Cy-3-glu^{1,2,3,5,6}, Pg-3-gluc^{1,2,6,9}; Pn-3-gluc^{1,2,5,6,9}; Cy-3-malonylglu^{1,2,3,5}; Pg-3-malonylglu^{1,2,3,5}; Cy-3-dimalonylglu^{1}; Pn-3-malonylglu^{1,2,3}; Pg-3-dimalonylglu^{1,2}; Pn-3-dimalonylglu^{1}	[9]^{5}, [10]^{1}, [12]^{2}, [14]^{6}, [15]^{9}
	Red hybrid corn (Wenwei2 R6 x LH287 R8)^{5}	Cy-3-glu^{5}; Pn-3-gluc^{5}; Cy-3-malonylglu^{5}	[9]^{5}
	Blue corn	Cy-3-glu (24.4%)^{7} (61.50%)^{8}	[11]^{7}, [16]^{8}
		Pg-3-glu (13.88%)^{8}	
		Pn-3-glu (3.39%)^{8}	
		Cy-3-malonylglu (56.6%)^{7}	
		Pg-3-malonylglu (9.1%)^{7}	
		Pn-3-malonylglu (10.4%)^{7}	
		Cy-3-succinylglu (3.62%)^{8}	
		Cy-3-disuccinylglu (4.56%)^{8}	
	Blue hybrid corn (Lfy blue RI)^{5}	Cy-3-glu^{5}; Cy-3-malonylglu^{5}; Pn-3-malonylglu^{5}	[9]^{5}
Germ	Purple corn sprouts	Direct condensed	[17]
		(Epi)catechin-Cy/Pg-3,5 diglu	
		(Epi)catechin (4-8)-Cy/Pn/Pg 3,5 diglu	
		(Epi)catechin (4-8)-Cy 3-malonylglu-5 glu	
		Cy- 3,5 diglu	
		Cy/Pg/Dp/Pn 3-glu	
		Cy 3-malonylhexoside	
		Cy/Pg/Pn 3-(6″-malonylglu)	
		Pn-3-(6″-malonylhexoside)	
		Cy/Pg/Pn 3-(3″,6″-dimalonylhexoside)	
Cob	Purple corn^{9} Purple corn (Peru)^{10}	Cy-3-glu$^{9, 10}$; Cy-3-malonylglu$^{9, 10}$; Pn-3-glu$^{9, 10}$; Pn-3-malonylglu$^{9, 10}$; Pg-3-glu$^{9, 10}$; Pg-3-malonylglu$^{9, 10}$	[15]^{9}, [18]^{10}
	Purple corn (Peru)	Cy-3-glu (75.28%)	[14]
		Pn-3-glu (8.55%)	
		Pg-3-glu (16.16%)	

Part of the corn	Corn phenotype	Anthocyanin	Ref.
Husk	Purple corn	Cy-3-glu (11.7%)^{11} (39.8%)^{12} Cy-3-malonylglu (29.0%)^{11} (8.4%)^{12} Pg-3-malonylglu (11.0%)^{12} Cy-3-succinylglu (20.8%)^{12} Cy-3-glu monomalonate (1.0%)^{11} Pg-3-glu (~1.5%)^{11} (2.0%)^{12} Cy-3-malonylglu (6.3%)^{11} Pn-3-glu (0.9%)^{11} Cy-3-glu dimalonate (3.9%)^{11} Cy-3-dimalonylglu (35%)^{11} Pn-3-malonylglu (2.0%)^{11} Pg-3-dimalonylglu (1.5%)^{11} Pn-3-dimalonylglu (1.4%)^{11}	[19]^{11}, [20]^{12}
Silk	Purple corn	Cy-3-glu Cy-3-malonylglu Pg-3-glu Pn-3-glu	[21]

Superscript indicates the correlation of the concentration of anthocyanins with its reference.

Table 1. Composition of Anthocyanins found in pigmented corn plant.

Part of corn	Maize phenotype	Extraction method	Anthocyanins content (mg/100 g)	Ref.
Maceration				
Kernel	Purple/Blue (*Zea mays var. saccharata*)	Heat water 60 min	878.9/26.2	[22]
Kernel	Purple Corn	2% formic acid, 2 h 40:1 liquid-to-solid 3 extractions	473	[11]
Kernel	Purple (AREQ-084)	Alcoholic extraction (Methanol or ethanol) with acid (85:15 v/v) 1–3 extractions	310	[23]
	Purple (*Zea mays* L., cv Zihei)		55.8	[15]
	Purple (AREQ-516540TL)		850	[24]
	Purple (EP24)		153	[25]
	Purple (race Conico)		97–426	[26]
	Purple corn		1600	[27]
	Purple (KKU-WX)		74.5	[28]
	Purple corn (ZM01-ZM22)		0.8–111.7	[29]
Kernel	Red corn (ZM01-ZM22)	Methanol acid	0.8–33.4	[29]

Part of corn	Maize phenotype	Extraction method	Anthocyanins content (mg/100 g)	Ref.
Kernel	Pink (ZM01-ZM22)	Methanol acid	0.3–1.4	[29]
	Pink (EP24)		0.018	[25]
Kernel	Blue pericarp	Alcoholic extraction (Methanol or ethanol) with acid (85:15 v/v) One to three extractions	39	[11]
	Blue (ZM01-ZM22)		7.3–7.4	[29]
	Blue (race Chalqueño)		64.6	[30]
	Blue (race Conico)		89.2	[30]
	Blue hybrid corn		73.0–105.2	[30]
	Blue hybrid corn		27.39–78.28	[31]
Cob	Red/Purple waxy corn **1.** KKU-WX111031 **2.** KKU-OP **3.** hybrid **4.** commercial	Methanol-1% citric acid (80:20 v/v) Mixed 24 h, 4°C	**1.** 34/37 **2.** 116/179 **3.** 17/189 **4.** 27/336	[5]
Cob	Purple waxy corn (red to black)	Methanol Shaken for 2 h 1:10 Two extractions	202–1423	[32]
Cob	Purple hybrid corn (KPSC 901)	Conventional heating	3660	[33]
		Microwave	3970	
		Ultrasound	3830	
		Ohmic heating	3280	
Husk	Purple corn husk	0.1 N HCl 6 h, room temperature	3500	[19]
Husk	Red/Purple waxy corn **1.** KKU-WX111031 **2.** KKU-OP **3.** hybrid **4.** commercial	Methanol-1% citric acid (80:20 v/v) Mixed 24 h, 4°C	**1.** 5/3 **2.** 34/130 **3.** 48/494 **4.** 5/213	[5]
Silk	Purple (ZPEXP)/Pink (ZP341) Purple hybrid (PWC1-5)	Methanol acidified with 1 N (85:15 v/v) Shaking by 30 min 70°C, 1.5 h	193/1.49 0.44–2.38	[34, 35]
Silk	Purple corn	Ethanol 50% Ratio 1:1 w/v 5 min	970	[21]

Part of corn	Maize phenotype	Extraction method	Anthocyanins content (mg/100 g)	Ref.
Silk	Red/Purple waxy corn **1.** KKU-WX111031 **2.** KKU-OP **3.** hybrid **4.** commercial	Methanol-1% citric acid (80:20 v/v) Mixed 24 h, 4°C	**1.** 78/478 **2.** 408/419 **3.** 289/456 **4.** 249/500	[5]
Germinated	Purple corn (PMW-581)		240	[17]
Foliar	Purple corn (Jingzi No. 1)	Ethanol 60% with citric acid 1% 60°C, 120 min	1780	[36]
Ultrasound assisted extraction				
Kernel	Purple corn	96% ethanol and 1.5 N HCl (85:15) 1:25/80 solid-to solvent 15 min Two extractions	10–300 (kernel) 70–3700 (pericarp)	[8]
Kernel	Purple corn bran	400 W	362	[13]
Cob	Dried cob of purple waxy	65°C, 35 min 1:20 solid-solvent ratio	2.4	[37]
Supercritical fluid technology				
Kernel	Purple corn pericarp (Peru)	50°C, 400 bar Supercritical CO2→Ethanol→H_2O	1060	[14]
Kernel	Purple waxy corn (*Zea mays* L. var. ceratina)	Subcritical solvent extraction method Water-ethanol 1:3 Sample-to-solvent ratio 1:20)	99	[38]
Cob	Purple waxy corn (*Zea mays* L. var. ceratina) Peru	Subcritical solvent extraction method Water-ethanol 1:1 Sample-to-solvent ratio 1:20)	1240–1270	[14, 38]
Silk	Purple waxy corn (*Zea mays* L. var. ceratina)	Subcritical solvent extraction method Water-ethanol 1:1 Sample-to-solvent ratio 1:30)	1550	[38]
Kernel	Purple waxy corn *Zea mays L. ceratina*	High-pressure processing 700 MPa (30–45 min)	116	[39]

Table 2. Anthocyanins extraction methods and concentration.

But silk has a great potential to obtain phenolic compound, among them, anthocyanins. Research of silk is about its quantification and characterization of anthocyanins and results showed that has the highest anthocyanins concentration of the whole plant [41].

2.4. Anthocyanin in pigmented corn husk

Husk is the least studied part of the corn; there is limited research about their anthocyanin composition; however, they had a high concentration of anthocyanins depending on corn variety [20]. Most recent reports show a deeper studied of the type of anthocyanins in purple husk which has more anthocyanin diacylated [19] but there is other report that found cyaniding-3-succinylglucoside instead of diacylated anthocyanin [20]. For that reason, more research is needed; due to the low information, it is not possible to ensure that corn husk composition is different from other parts.

2.5. Extraction methods and characterization of anthocyanins in pigmented corn

Extraction of anthocyanin is made with methanol solvent acid and the method most used is ultrasound-assisted extraction that shows better efficiency, although, microwave-assisted extraction, ohmic heating extraction and supercritical solvent extraction are also used. Liquid chromatography techniques are the most used in anthocyanin identification. **Table 2** shows the extraction methods used until 2018 and the anthocyanin content.

2.6. Biological activity of pigmented corn anthocyanins

Structural anthocyanins have conjugation that provides stabilization of free radicals. Antioxidant activity is plenty reported in pigmented corn. Additionally, anthocyanin extract of pigmented corn has been used in *in vitro* and *in vivo* assays, **Table 3** shows some of the activities studied where anti-obesity is the most recurrent.

Extract of anthocyanin	**Biological activity**		**Ref.**
Red corn	Inhibition proliferation of colorectal cancer cell	*In vitro* Cell lines	[42]
Purple corn	Inhibition proliferation of colorectal cancer cell	*In vitro* Cell lines	[42]
Purple corn (hybrid maize) kernel	Cardioprotective activity	In vitro	[43]
Purple maize flour	Reduce visceral adiposity index, total body fat mass, systolic blood pressure, total cholesterol and plasma triglycerides. Improve glucose tolerance, liver and cardiovascular structure and function	*In vivo* In rats diet	[44]
Purple corn pericarp	Adipogenesis, inflammation and insulin resistance in adipocytes	*In vitro*	[45]
Purple waxy corn cob	Neuroprotective and memory enhancing effect		[46]
Purple corn silk (*Zea mays* L. var. ceratina)	Anti-obesity agent		[21]
Blue tortillas	Learning capability	In rats diet	[47]

Table 3. Biological activity found in purple corn.

2.7. Applications of pigmented corn anthocyanins

Purple corn is used traditionally to make tortillas, atole, chips, popcorn and other type of food products. However, chemical studies of these food products are limited. Food industry is more interested in elaboration of products with a major quality and bioactive compounds content; in consequence, the development of new products with purple corn have been the most studied. Some of the developed products are presented in **Table 4**, where the main purpose was to find the best process to keep the major anthocyanins concentration.

Additionally, the anthocyanins are used to make photosensitizers from different colored parts of the corn including cob, husk and silk.

Furthermore, due to the low stability of anthocyanins, there are some studies related to this topic. The stability of anthocyanins has been improved using intermolecular copigmentation with gallic ferulic, caffeic acids, and results show that those acids do not protect the anthocyanins only have a hypochromic effect. There is a better protection by self-association. Other strategy is the encapsulated of anthocyanins in alginate-pectin hydrogel [49] and the spray-dried purple corn found that 5% of maltodextrin, 150°C and water are the best condition to obtain a soluble product with the major anthocyanin concentration [50]. Haggard in 2018 also found that beverage with more pelargonidin-3-glucoside concentration has a major half-life [10].

Corn phenotype	Use	Ref.
Purple corn	Beverage	[12]
Blue popping corn and dark-red popping corn (*Zea mays* L. spp. Everta)	Bakery (cookies) with higher phenolic content	[4, 35]
Purple corn (husk, cob and silk)	Photosensitizers	[48]

Table 4. Use of anthocyanins found in pigmented corn.

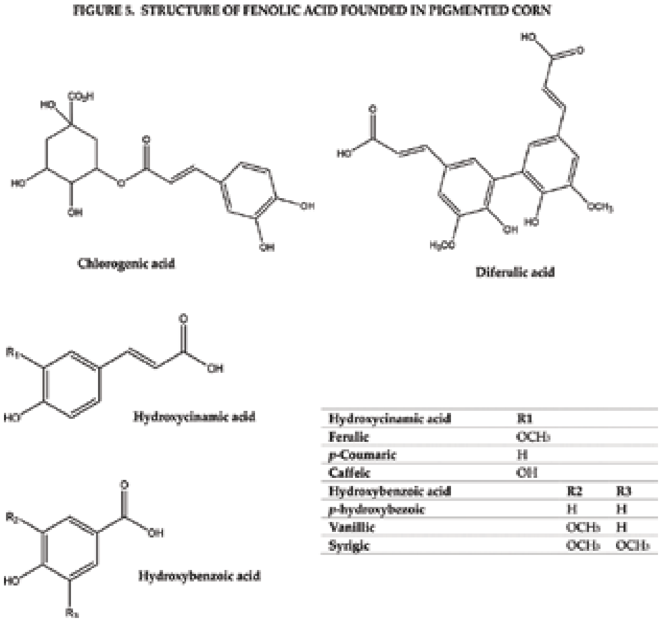
3. Phenolic acids in pigmented corn

Pigmented corns are good source of phenolic acids; mainly hydroxycinnamic acids but also hydroxybenzoic and chlorogenic acids. These compounds are distributed in whole plant. **Table 4** shows the main phenolic acids found in different parts of the plant reported in the literature (**Figure 5**).

In white, yellow and pigmented maize, ferulic acid is the most abundant phenolic acid. There are reports that in white and yellow corn it can be found in the forms of dimers, trimers and tetramers [51]. Other authors have reported 1.94 mg/100 g [52] of free diferulic acid in blue Mexican corn which is the most abundant in that variety (**Table 5**).

3.1. Phenolic acid in pigmented corn kernel

Free ferulic acid concentration in a variety of pigmented kernel is similar among Mexican and Khao Niew Dum varieties (2.02–3.99 mg/100 g) [24, 52]; however, Peruvian variety has the highest concentration with 5.50 mg/100 g [53].



Hydroxycinamic acid	R1		
Ferulic	OCH3		
p-Coumaric	H		
Caffeic	OH		
Hydroxybenzoic acid		R2	R3
p-hydroxybezoic		H	H
Vanillic		OCH3	H
Syrigic		OCH3	OCH3

Figure 5. Phenolic acids structures in pigmented corn.

Corn part	Phenolic acid	Pigmented corn phenotype	Content (mg/100 g)	Ref.
Kernel	Ferulic acid	Peruvian purple (INIA-GOI)	5.52	[53]
		Mexican pigmented Pigmentados	1.97–2.02	[24]
		Blue-Queretaro (Mexico)	1.94	[52]
		Purple corn variety Khao Niew Dum	2.3	[54]
Kernel	*p*-Coumaric acid	Blue-Queretaro (Mexico)	0.512	[52]
		Purple corn variety Khao Niew Dum	1.1	[54]
Kernel	Diferulic acid	Blue-Queretaro (Mexico)	1.9	[52]
Kernel	Caffeic acid	Peruvian purple (INIA-GOI)	3.81	[53]
		Purple corn variety Khao Niew Dum	0.29	[54]
Kernel	*p*-Hydroxybenzoic acid	Purple corn variety Khao Niew Dum	0.18	[54]
Kernel	Vanillic acid	Purple corn variety Khao Niew Dum	0.98	[54]
Kernel	Chlorogenic acid	Peruvian purple (INIA-GOI)	1.05	[53]
Silk		Silk from Thai purple corn	25.64	[21]
Cob	Syringic acid	Purple corn cob from four phenotypes of Thai corn	31–202.78	[32]

Table 5. Free phenolic acid concentration in different phenotypes of pigmented corns.

Also, there are reports that evaluate ferulic concentration among different Mexican corn phenotypes pigmented white and yellow and there are no statistically significant differences. The concentration is between 140 and 160 mg and 94–98% are bounded in cell wall and the rest is free [24]. In the cell wall, ferulic acid plays an important role because it is cross-linked through photochemical reactions or coupling reactions catalyzed by peroxidases with the polysaccharides present in the grains, thus improving the rigidity in the cell wall of corn [51].

Other acids found in pigmented maize kernel are as follows: *p*-coumaric, caffeic, vanillic, chlorogenic and hydroxybenzoic acids, however concentrations are different according to the variety. In purple maize variety Khao Niew Dum, the next acid apart of the ferulic acid are *p*-coumaric, vanillic, caffeic and *p*-hydroxybenzoic acid [54]; while in INIA-GUI purple corn from Peru, the acid with major concentration after ferulic acid is the caffeic acid and cholorogenic acid [53]. The difference in concentration could depend on different factors as genetic, environmental, ripening, light-UV exposure and insect and pathogens attack [51].

3.2. Phenolic acid in pigmented corn cob

Research about pigmented corn cob is low; nevertheless, they have concentrations of important phenolic acids. The most abundant phenolic acid in cob from four pigmented corn phenotypes is syringic acid (31–202.78 mg/100 g) [32], followed by ferulic acid (7.34–10.73 mg/100 g) and in minors amounts vanillic acid (1.42–7.05 mg/100 g) and hydroxybenzoic acid (0.73–7.05 mg/100 g).

3.3. Phenolic acid in pigmented corn silk

Other organ from maize plant which has been studied due to their higher concentration of phenolic acids, in particular chlorogenic acids, is the stigma, commonly called silk. Some authors highlight that silk from purple corn have 25.64 mg/100 g of chlorogenic acid [21] and other studies highlight that from 25 days after emergence from four phenotypes of corn (purple, green, pink and yellow) they have 21.2–29.3 mg/100 g of 3-caffeoylquinic acid, and 5 days after emergence 923.7–1840.8 mg/100 g [37], also other three chlorogenic acids where studied: 4-caffeoylquinic acid (186.9–362.1 mg/100 g), 5-caffeoylquinic acid (74.4–86.5 mg/100 g) and *p*-coumaroylquinic acid (43.4–90.9 mg/100 g). Purple and green silk has the major concentration of chlorogenic acids.

3.4. Extraction methods and characterization of phenolic acids in pigmented corn

As already mentioned, most of the phenolic acids in the corn kernel are bound to the cell wall and a minimum amount are free form; for this reason, the way to extract them to identify and quantify them is not simple and is diverse: some authors point to the extraction of free phenolic acids, making an extraction with 80% methanol and centrifuging [31]; while the solid of the methanol extraction was carried out by a basic hydrolysis (with NaOH) with a water bath at 80°C for 30 min, and in this way the acids bound to the cell wall are obtained. Other authors report successive extraction methods for the recovery of free and bound phenolic acids; first for the free acids, they performed an extraction with 80% ethanol using a high-performance disperser, then the residue was assisted by adding an enzyme cocktail (pectinases, amylases and cellulases). To the residue of this, they made a thermal hydrolysis doing another extraction with methanol and 70°C. Finally, to the solid residue of this extraction, they added NaOH to carry out a basic hydrolysis [55].

In the case of phenolic acids present in corn silk, they only report extractions with organic solvents; for example, performing a direct extraction of the silk, using 95% methanol, centrifuging and using the supernatant for quantification and characterization [35]; other studies use 50% ethanol [21]. In the same way, for the case of the phenolic acids of the cob where they describe a simple extraction using methanol and centrifugation [32].

To carry out the characterization and quantification of each of the phenolic acids perform chromatography techniques: such as HPLC and HPLC-MS [52–55].

3.5. Biological activity of pigmented corn phenolic acids

The phenolic acids present in the pigmented corns are of great importance due to the biological effects on human health [56], such as anticancer properties, antimutagenic, anti-inflammatory and cardiovascular diseases [56]. **Table 6** shows the biological properties of each of the phenolic acids present in the pigmented corn plant.

The biological activity that most report is as antioxidant, with phenolic acids having the capacity to reduce the free radical formation and elimination of ROS, inhibition and repair of lesions caused by the oxidation and degradation of other molecules and biomolecules [57].

Phenolic acid	Biological activity	Ref.
Ferulic acid	Potential antioxidant	[24, 52]
	Anticancer properties	[57]
	Against cardiovascular diseases	[56]
Coumaric acid	Reduction of blood glucose	[21]
Diferulic acid	Potential antioxidant Allelopathic effects	[52]
Caffeic acid	Immunostimulatory properties	[58]
p-Hydroxybenzoic acid	Immunostimulatory properties	[58]
Vanillic acid	Reduction of blood glucose	[21]
Chlorogenic acid	Potential antioxidant	[58]
	Reduce visceral adiposity index	[21, 35]
Syringic acid	Effect against cerebral ischemia Antihypertensive	[32]

Table 6. Phenolic acids present in pigmented maize and their biological properties.

The effect of antioxidant activity on corn from Bajio and Morelos (Mexico) has been evaluated; wherein the amount of free and bound phenols was measured; concluding that the antioxidant activity increases three times more in the extractions with basic hydrolysis. Therefore, antioxidant increase is attributed to phenolic acids linked mainly to phenolic acid [31]. In other studies, they reported that one-third of the antioxidant activity of the phenolic fraction in Mexican pigmented corn is given by ferulic acid [24]. They have also described the antioxidant activity between phenolic compounds, reporting that the highest antioxidant activity is generally presented by hydroxycinnamic acids, with ferulic acid presenting the highest and hydroxybenzoic acids less activity. In the case of purple and pink corn silk [35], high antioxidant activity is attributed mainly to chlorogenic acids, these activities being so high that they could be compared with other medicinal plants such as *Mentha piperita* and *Salvia officinalis*.

4. Flavonoids in pigmented corn

Other import group of the bioactive compounds that contain the pigmented corns are of flavonoids; with>4000 compounds, these molecules are most abundant polyphenols present in plant foods. They are characterized by a 15-carbon skeleton, organized as C6-C3-C6, with different substitutions making up the different subclasses. The major groups of the flavonoids of nutritional interest are the flavonols or catechins [59].

The most common chemical structures of flavonoids in corn are shown in **Figure 6**, and the composition of flavonoids in different parts of is presented in **Table 7**.

4.1. Flavonoids in pigmented corn kernel

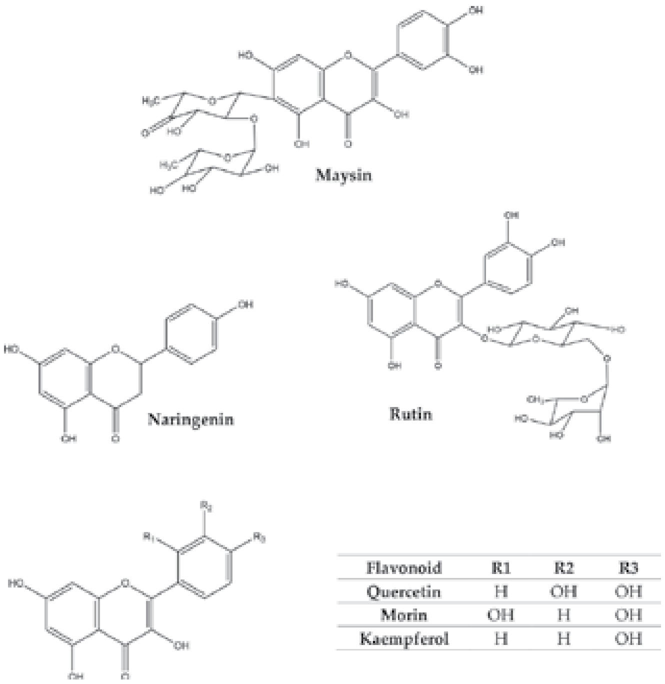
Peruvian purple corn has kaempferol and morin as major flavonoids in kernel (**Table 8**), the concentration is 202–224 mg/100 g [53] which represent almost the total flavonoids (**Table 9**); after kaempferol and morin the naringenin glucoside and in minor amount rutin and quercetin. Meanwhile, Serbian pigmented corn phenotypes [35] report a lower total flavonoid concentration with 19.90–33.75 mg/100 g.

4.2. Flavonoids in pigmented corn silk

Flavonoids are the main bioactive compounds in pigmented corn silk [35] as shown in **Table 9**. Some authors reports until 3644.9 mg/100 g in Serbian purple corn and Mexican pigmented corn reports 797.1 a 2602.4 mg/100 g [61]. Among the flavonoids identified and quantified in pigmented corn silk is the maysin with 12.6–17.1 mg/100 g [35], quercetin (1.58 mg/100 g) and narigenin glucoside (6.45 mg/100) [21].

4.3. Flavonoids in pigmented corn pollen

Other organ of pigmented corn (blue, red and red dark) which represent higher concentration of total flavonoids is pollen (916.36–1087.69 mg/100 g) **Table 9**. The flavonoids identified are (**Table 8**) hyperoside, rutin and quercetin [60].



Flavonoid	R1	R2	R3
Quercetin	H	OH	OH
Morin	OH	H	OH
Kaempferol	H	H	OH

Figure 6. Flavonoids structures in pigmented corn.

Flavonoid	Part of corn	Pigmented corn phenotype	Total flavonoid content (mg/100 g)	Ref.
Quercetin	Silk	Thai purple corn silk	20.26	[21]
	Pollen	Red corn	0.111	[60]
		Blue corn	0.569	
		Dark red corn	0.145	
	Kernel	Peruvian purple corn	1.58	[53]
Naringenin glucoside	Silk	Thai purple corn silk	6.45	[21]
	Kernel	Peruvian purple corn	14.8	[53]
Maysin	Silk	Serbian purple corn	17.1	[35]
		Serbien pink corn	12.6	
Rutin	Pollen	Red corn	0.186	[60]
		Blue corn	0.013	
		Dark red corn	0.010	
	Kernel	Peruvian purple corn	2.74	[53]
Hyperoside	Pollen	Red corn	0.897	[60]
		Blue corn	0.655	
		Dark red corn	0.537	
Kaempferol	Kernel	Peruvian purple corn	224.0	[53]
Morin	Kernel	Peruvian purple corn	202.0	[53]

Table 7. Flavonoid concentration in different parts of pigmented corn.

Parts of the corn	Pigmented corn phenotype	Total flavonoid concentration (mg/100 g)	Ref.
Silk	Serbian purple corn	3644.9	[35]
	Serbian pink corn	3594.2	
	Mexican red corn	2602.4	[61]
	Mexican dark red corn	797.1	
	Mexican white-purple corn	809.5	
Pollen	Red corn	1087.69	[60]
	Blue corn	916.36	
	Dark-red corn	1056.21	
Kernel	Peruvian purple corn	261–266	[53]
	Red	26.76	[62]
	Dark red	27.05	
	Red-yellow	26.84	
	Light blue	33.75	
	Dark blue	30.74	
	Multicolor	19.90	
Corn	Peruvian purple corn	187	[14]
Pericarp	Peruvian purple corn	4200	[14]

Table 8. Total flavonoid concentration in different parts of pigmented corn.

4.4. Extraction methods and characterization of flavonoids in pigmented corn

Flavonoid extraction methods in pigmented corn are made using simple extraction using organic solvents (methanol, ethanol and water in different proportions), centrifuge and using aqueous solution for analysis [21, 35, 53, 60].

Characterization and quantification of each one is made by chromatography techniques as HPLC and HPLC-MS [21, 53].

Flavonoids	Biological activity	Ref.
Quercetine	Apoptosis induction	[18]
	Adiposites lipolysis	
	Antioxidant activity	[56]
Naringenin glucoside	Antioxidant activity	[50]
Maysin	Neuroprotector	[31]
Rutin	Antioxidant activity	[56]
Hyperoside	Antioxidant activity	[56]
Kaempferol	Antioxidant activity	[50]
Morin	Antioxidant activity	[50]

Table 9. Biological activity of maizes flavonoids.

4.5. Biological activity of pigmented corn flavonoids

The most important biological activities of flavonoids in pigmented corns that are reported in the last 10 years are presented in **Table 9**.

Flavonoids of pigmented corns have been studied mainly for their antioxidant and neuroprotection activities. Corn flavonoids have also been reported, which can act as inductors of apoptosis and lipolysis of adipocytes.

5. Conclusions

Pigmented corns and its parts is a food that can be beneficial to the human because of the presence of phytochemicals and biological activities that are present. The studies of pigmented corns have been increased year after year, and they showed that the coloration blue, purple, pink and red is given by anthocyanins. Also, they have a large amount of phenolic acids and flavonoids. These compounds are present in the whole plant (kernel, cob, husk, silk), and their concentration is different depending on the organ.

The most abundant anthocyanins in corn plant are cyanidin-3-glucoside, cyanidin-3- (6″-malonyl) glucoside, peonidin-3-glucoside, peonidin-3- (6″-malonyl) glucoside, pelargonidin-3-glucoside and pelargonidin-3-(6″malonyl) glucoside and the coloration of each corn is depending on the concentration and profile of these.

With reference to phenolic acids, the representatives are ferulic acid in the kernel, syringic acid in the cob and chlorogenic acid in the silk. Finally, the flavonoids are morin, kaempferol, naringin, maysin, rutin, quercetin and hyperoside; the concentrations of these compounds are high especially in purple silk. Each of these compounds has a biological activity, so in the case of anthocyanins is its anti-cancer activity, cardioprotective and anti-obesity activity; according to phenolic acids, the ferulic acid is a potential antioxidant and provides anticancer properties, and in general, flavonoids have antioxidant activity.

Therefore, pigmented corns are important for the development of new functional food products from the grain and for obtaining natural colorants and antioxidants from the other parts of the plant.

Acknowledgements

This chapter was supported by the PAPIIT-IT202318.

Author details

Arturo Navarro[1]*, Andrea Torres[1], Fernanda Fernández-Aulis[1] and Carolina Peña[2]

*Address all correspondence to: arturono@unam.mx

1 Facultad de Química, UNAM, CDMX, Mexico

2 Tecnologico de Veracruz, Mexico

References

[1] Kraft KH, Brown CH, Nabhan GP, Luedeling E, Ruiz JDJL, Coppens d'Eeckenbrugge G, Hijmans RJ, Gepts P. Multiple lines of evidence for the origin of domesticated chili pepper, *Capsicum annuum*, in Mexico. Proceedings of the National Academy of Sciences. 2014;**111**(17):6165-6170

[2] Cardoza y Aragón L. Artes de México. Número 79. Corazón de Maíz. 2006:11-17

[3] Rouf Shah T, Prasad K, Kumar P. Maize-a potential source of human nutrition and health: A review. Cogent Food & Agriculture. 2016;**2**(1):1-9

[4] Žilić S, Kocadağlı T, Vančetović J, Gökmen V. Effects of baking conditions and dough formulations on phenolic compound stability, antioxidant capacity and color of cookies made from anthocyanin-rich corn flour. LWT- Food Science and Technology. 2016;**65**:597-603

[5] Simla S, Boontang S, Harakotr B. Anthocyanin content, total phenolic content, and antiradical capacity in different ear components of purple waxy corn at two maturation stages. Australian Journal of Crop Science. 2016;**10**(5):675-682

[6] Moreno YS, Salinas CG, Coutiño B, Vidal VA. Variabilidad en contenido y tipos de antocianinas en granos de color azul/morado de poblaciones mexicanas de maíz. Revista Fitotecnia Mexicana. 2013;**36**:285-294

[7] Warner LM. Handbook of Anthocyanins. Food Sources, Chemical Applications and Health Benefits. New York: Nova Science Publishers; pp. 476, 2015

[8] Mendoza-Mendoza CG, del C. Mendoza-Castillo M, Delgado-Alvarado A, Castillo-González F, Kato-Yamakake T, Cruz-Izquierdo S. Antocianinas totales y parámetros de color en líneas de maíz morado. Revista Fitotecnia Mexicana. 2017;**40**(4):471-479

[9] Collison A, Yang L, Dykes L, Murray S, Awika JM. Influence of genetic background on anthocyanin and copigment composition and behavior during thermoalkaline processing of maize. Journal of Agricultural and Food Chemistry. 2015;**63**(22):5528-5538

[10] Haggard S, Luna-Vital D, West L, Juvik JA, Chatham L, Paulsmeyer M, Gonzalez de Mejia E. Comparison of chemical, color stability, and phenolic composition from pericarp of nine colored corn unique varieties in a beverage model. Food Research International. 2018;**105**:286-297

[11] Li Q, Somavat P, Singh V, Chatham L, Gonzalez de Mejia E. A comparative study of anthocyanin distribution in purple and blue corn coproducts from three conventional fractionation processes. Food Chemistry. 2017;**231**:332-339

[12] Luna-Vital D, Cortez R, Ongkowijoyo P, Gonzalez de Mejia E. Protection of color and chemical degradation of anthocyanin from purple corn (*Zea mays* L.) by zinc ions and alginate through chemical interaction in a beverage model. Food Research International. 2018;**105**:169-177

[13] Chen L, Yang M, Mou H, Kong Q. Ultrasound-assisted extraction and characterization of anthocyanins from purple corn bran. Journal of Food Processing and Preservation. 2017;**42**(1):1-7

[14] Monroy YM, Rodrigues RAF, Sartoratto A, Cabral FA. Extraction of bioactive compounds from cob and pericarp of purple corn (*Zea mays* L.) by sequential extraction in fixed bed extractor using supercritical CO2, ethanol, and water as solvents. Journal of Supercritical Fluids. 2016;**107**:250-259

[15] Yang Z, Zhai W. Identification and antioxidant activity of anthocyanins extracted from the seed and cob of purple corn (*Zea mays* L.). Innovative Food Science & Emerging Technologies. 2010;**11**(1):169-176

[16] Nankar AN, Dungan B, Paz N, Sudasinghe N, Schaub T, Holguin FO, Pratt RC. Quantitative and qualitative evaluation of kernel anthocyanins from southwestern United States blue corn. Journal of the Science of Food and Agriculture. 2016;**96**(13):4542-4552

[17] Paucar-Menacho LM, Martínez-Villaluenga C, Dueñas M, Frias J, Peñas E. Optimization of germination time and temperature to maximize the content of bioactive compounds and the antioxidant activity of purple corn (*Zea mays* L.) by response surface methodology. LWT- Food Science and Technology. 2017;**76**:236-244

[18] Lao F, Giusti MM. Extraction of purple corn (*Zea mays* L.) cob pigments and phenolic compounds using food-friendly solvents. Journal of Cereal Science. 2018;**80**:87-93

[19] Deineka VI, Sidorov AN, Deineka LA. Determination of purple corn husk anthocyanins. Journal of Analytical Chemistry. 2016;**71**(11):1145-1150

[20] Chung-Ying L, Hee-Woong K, Se-Ra W, Hwang-Kee M, Ki-Jin P, Jong-Yeol P, Mun-Seob A, Hae-Ik R. Corn husk as a potential source of anthocyanins. Journal of Agricultural and Food Chemistry. 2008;**56**:11413-11416

[21] Chaiittianan R, Sutthanut K, Rattanathongkom A. Purple corn silk: A potential anti-obesity agent with inhibition on adipogenesis and induction on lipolysis and apoptosis in adipocytes. Journal of Ethnopharmacology. 2017;**201**:9-16

[22] Somavat P, Kumar D, Singh V. Techno-economic feasibility analysis of blue and purple corn processing for anthocyanin extraction and ethanol production using modified dry grind process. Industrial Crops and Products. 2018;**115**:78-87

[23] Gálvez Ranilla L, Christopher A, Sarkar D, Shetty K, Chirinos R, Campos D. Phenolic composition and evaluation of the antimicrobial activity of free and bound phenolic fractions from a Peruvian purple corn (*Zea mays* L.) accession. Journal of Food Science. 2017;**82**(12):2968-2976

[24] Lopez-Martinez LX, Oliart-Ros RM, Valerio-Alfaro G, Lee CH, Parkin KL, Garcia HS. Antioxidant activity, phenolic compounds and anthocyanins content of eighteen strains of Mexican maize. LWT- Food Science and Technology. 2009;**42**(6):1187-1192

[25] Rodríguez VM, Soengas P, Landa A, Ordás A, Revilla P. Effects of selection for color intensity on antioxidant capacity in maize (*Zea mays* L.). Euphytica. 2013;**193**(3):339-345

[26] García-Tejeda YV, Salinas-Moreno Y, Martínez-Bustos F, Martnez-Bustos F. Acetylation of normal and waxy maize starches as encapsulating agents for maize anthocyanins microencapsulation. Food and Bioproducts Processing. 2014;**94**:717-726

[27] Petroni K, Pilu R, Tonelli C. Anthocyanins in corn: A wealth of genes for human health. Planta. 2014;**240**(5):901-911

[28] Harakotr B, Suriharn B, Tangwongchai R, Scott MP, Lertrat K. Anthocyanins and antioxidant activity in coloured waxy corn at different maturation stages. Journal of Functional Foods. Jul. 2014;**9**(1):109-118

[29] Ryu SH, Werth L, Nelson S, Scheerens JC, Pratt RC. Variation of kernel anthocyanin and carotenoid pigment content in USA/Mexico borderland land races of maize. Economic Botany. 2013;**67**(2):98-109

[30] Urias-Lugo DA, Heredia JB, Serna-Saldivar SO, Muy-Rangel MD, Valdez-Torres JB. Total phenolics, total anthocyanins and antioxidant capacity of native and elite blue maize hybrids (*Zea mays* L.). CyTA Journal of Food. 2015;**13**(3):336-339

[31] Urias-Peraldí M, Gutiérrez-Uribe JA, Preciado-Ortiz RE, Cruz-Morales AS, Serna-Saldívar SO, García-Lara S. Nutraceutical profiles of improved blue maize (*Zea mays*) hybrids for subtropical regions. Field Crops Research. 2013;**141**:69-76

[32] Kapcum N, Uriyapongson J, Alli I, Phimphilai S. Anthocyanins, phenolic compounds and antioxidant activities in colored corn cob and colored rice bran. International Food Research Journal. 2016;**23**(6):2347-2356

[33] Piyapanrungrueang W, Chantrapornchai W, Haruthaithanasan V, Sukatta U, Aekatasanawan C. Comparison of anthocyanin extraction methods from high anthocyanin purple corn cob hybrid: KPSC 901, and quality of the extract powder. Journal of Food Processing & Preservation. 2016;**40**(5):1125-1133

[34] Sarepoua E, Tangwongchai R, Suriharn B, Lertrat K. Influence of variety and harvest maturity on phytochemical content in corn silk. Food Chemistry. 2015;**169**:424-429

[35] Žilić S, Janković M, Basić Z, Vančetović J, Maksimović V. Antioxidant activity, phenolic profile, chlorophyll and mineral matter content of corn silk (*Zea mays* L): Comparison with medicinal herbs. Journal of Cereal Science. 2016;**69**:363-370

[36] Gu X, Cai W, Fan Y, Ma Y, Zhao X, Zhang C. Estimating foliar anthocyanin content of purple corn via hyperspectral model. Food Science & Nutrition. 2018:1-7

[37] Muangrat R, Pongsirikul I, Blanco PH. Ultrasound assisted extraction of anthocyanins and total phenolic compounds from dried cob of purple waxy corn using response surface methodology. Journal of Food Processing & Preservation. 2018;**42**(2):1-11

[38] Muangrat R, Williams PT, Saengcharoenrat P. Subcritical solvent extraction of total anthocyanins from dried purple waxy corn: Influence of process conditions. Journal of Food Processing & Preservation. 2017;**41**(6)

[39] Saikaew K, Lertrat K, Meenune M, Tangwongchai R. Effect of high-pressure processing on colour, phytochemical contents and antioxidant activities of purple waxy corn (*Zea mays* L. var. ceratina) kernels. Food Chemistry. 2018;**243**:328-337

[40] Yang Z, Zhai W. Optimization of microwave-assisted extraction of anthocyanins from purple corn (*Zea mays* L.) cob and identification with HPLC–MS. Innovative Food Science & Emerging Technologies. Jul. 2010;**11**(3):470-476

[41] Sarepoua E, Tangwongchai R, Suriharn B, Lertrat K. Relationships between phytochemicals and antioxidant activity in corn silk. International Food Research Journal. 2013;**20**(5):2073-2079

[42] Mazewski C, Liang K, Gonzalez de Mejia E. Inhibitory potential of anthocyanin-rich purple and red corn extracts on human colorectal cancer cell proliferation in vitro. Journal of Functional Foods. 2017;**34**:254-265

[43] Petroni K, Trinei M, Fornari M, Calvenzani V, Marinelli A, Micheli LA, Pilu R, Matros A, Mock HP, Tonelli C, Giorgio M. Dietary cyanidin 3-glucoside from purple corn ameliorates doxorubicin-induced cardiotoxicity in mice. Nutrition, Metabolism, and Cardiovascular Diseases. 2017;**27**(5):462-469

[44] Bhaswant M, Shafie SR, Mathai ML, Mouatt P, Brown L. Anthocyanins in chokeberry and purple maize attenuate diet-induced metabolic syndrome in rats. Nutrition. 2017; **41**:24-31

[45] Luna-Vital D, Weiss M, Gonzalez de Mejia E. Anthocyanins from purple corn ameliorated tumor necrosis factor-α-induced inflammation and insulin resistance in 3T3-L1 adipocytes via activation of insulin signaling and enhanced GLUT4 translocation. Molecular Nutrition & Food Research. 2017;**61**(12):1-13

[46] Kirisattayakul W, Wattanathorn J, Iamsaard S, Jittiwat J, Suriharn B, Lertrat K. Neuroprotective and memory-enhancing effect of the combined extract of purple waxy corn cob and pandan in ovariectomized rats. Oxidative Medicine and Cellular Longevity. 2017;**2017**

[47] Aguirre López LO, Chávez Servia JL, Gómez Rodiles CC, Beltrán Ramírez JR, Bañuelos Pineda J. Blue corn tortillas: Effects on learning and spatial memory in rats. Plant Foods for Human Nutrition. 2017;**72**(4):448-450

[48] Phinjaturus K, Maiaugree W, Suriharn B, Pimanpaeng S, Amornkitbamrung V, Swatsitang K. Dye-sensitized solar cells based on purple corn sensitizers. Applied Surface Science. 2016;**380**:101-107

[49] Guo J, Monica Giusti M, Kaletunç G. Encapsulation of purple corn and blueberry extracts in alginate-pectin hydrogel particles: Impact of processing and storage parameters on encapsulation efficiency. Food Research International. 2018;**107**:414-422

[50] Lao F, Giusti MM. The effect of pigment matrix, temperature and amount of carrier on the yield and final color properties of spray dried purple corn (*Zea mays* L.) cob anthocyanin powders. Food Chemistry. 2017;**227**:376-382

[51] Bento-Silva A, Vaz Patto MC, do Rosário Bronze M. Relevance, structure and analysis of ferulic acid in maize cell walls. Food Chemistry. 2018;**246**:360-378

[52] Urias-Lugo DA, Heredia JB, Muy-Rangel MD, Valdez-Torres JB, Serna-Saldívar SO, Gutiérrez-Uribe JA. Anthocyanins and phenolic acids of hybrid and native blue maize (*Zea mays* L.) extracts and their antiproliferative activity in mammary (MCF7), liver (HepG2), colon (Caco2 and HT29) and prostate (PC3) cancer cells. Plant Foods for Human Nutrition. 2015;**70**(2):193-199

[53] Ramos-Escudero F, Muñoz AM, Alvarado-Ortíz C, Alvarado Á, Yáñez JA. Purple corn (*Zea mays* L.) phenolic compounds profile and its assessment as an agent against oxidative stress in isolated mouse organs. Journal of Medicinal Food. 2012;**15**(2):206-215

[54] Harakotr B, Suriharn B, Tangwongchai R, Scott MP, Lertrat K. Anthocyanin, phenolics and antioxidant activity changes in purple waxy corn as affected by traditional cooking. Food Chemistry. 2014;**164**:510-517

[55] Cuevas Montilla E, Hillebrand S, Antezana A, Winterhalter P. Soluble and bound phenolic compounds in different Bolivian purple corn (*Zea mays* L.) cultivars. Journal of Agricultural and Food Chemistry. 2011;**59**(13):7068-7074

[56] Lao F, Sigurdson GT, Giusti MM. Health benefits of purple corn (*Zea mays* L.) phenolic compounds. Comprehensive Reviews in Food Science and Food Safety. 2017;**16**(2):234-246

[57] de Oliveira Silva E, Batista R. Ferulic acid and naturally occurring compounds bearing a feruloyl moiety: A review on their structures, occurrence, and potential health benefits. Comprehensive Reviews in Food Science and Food Safety. 2017;**16**(4):580-616

[58] Pandey R, Singh A, Maurya S, Singh UP, Singh M. Phenolic acids in different preparations of maize (*Zea mays*) and their role in human health. International Journal of Current Microbiology and Applied Sciences. 2013;**2**(6):84-92

[59] Birt D, Jeffery E. Flavonoids 1. Advances in Nutrition. 2013;**4**(1):576-577

[60] Žilić S, Vanc J, Jankovic M, Maksimovic V. Chemical composition, bioactive compounds, antioxidant capacity and stability of floral maize (*Zea mays* L) pollen. Journal of Functional Foods. 2014;**10**:65-74

[61] Mendoza-lópez ML, Alvarado-díaz CS, Pérez-vega SB, Leal-ramos MY, Gutiérrez-méndez N, Alvarado-díaz CS, Pérez-vega SB, Gutiérrez-méndez N. Compositional and free radical scavenging properti es of *Zea mays* female inflorescences (maize silks) from Mexican maize landraces inflorescences (maize silks) from Mexican maize landraces. CyTA Journal of Food. 2018;**16**(1):96-104

[62] Žilić S, Serpen A, Akillioğlu G, Gökmen V, Vančetović J. Phenolic compounds, carotenoids, anthocyanins, and antioxidant capacity of colored maize (*Zea mays* L.) kernels. Journal of Agricultural and Food Chemistry. 2012;**60**(5):1224-1231

Section 3

Corn and Climate Change

Chapter 6

Climate Change Impacts on Corn Phenology and Productivity

Jerry L. Hatfield and Christian Dold

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.76933

Abstract

Global climate is changing and will impact future production of all food and feed crops. Corn is no exception and to ensure a future supply we must begin to understand how climate impacts both the phenological development of corn and the productivity. Temperature and precipitation are the two climate factors that will have a major benefit on corn phenology and productivity. The warming climate will accelerate the phenological development because the number of thermal units required for leaf appearance is relatively constant in the vegetative stage. Productivity of corn is reduced when extreme temperature events occur during pollination and is further exaggerated when there are water deficits at pollination. During the grain-filling period, warm temperatures above the upper threshold cause a reduction in yield. Model estimates suggest that for every 1°C increase in temperature there is nearly a 10% yield reduction. To meet world demand, new adaptation practices are needed to provide water to the growing crop and avoid extreme temperature events during the growing season. Climate change will continue to affect corn production and understanding these effects will help determine where future production areas exist and innovative adaptation practices to benefit yield stability could be utilized.

Keywords: agroclimatic indices, simulation models, G × E × M interactions

1. Introduction

Corn (*Zea mays* L.) is grown throughout the world and as such is subject to a wide variety of climates and potential scenarios of climate change. Production area continues to increase in response to the increased demand for corn grain and the production per unit area (yield) has continued to increase due to enhanced technology (**Figure 1**). What is imperative to stability

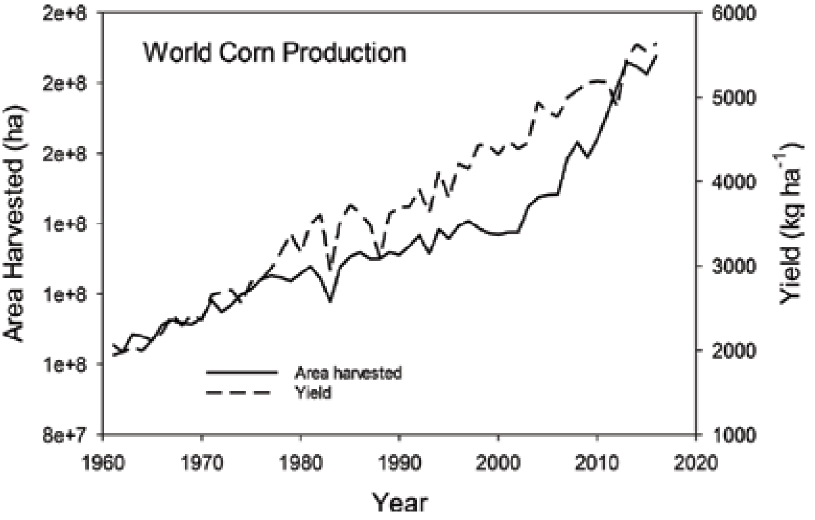


Figure 1. World corn yield and area harvested since 1960 (data obtained from FAO stat, http://www.fao.org/faostat/en, downloaded March 8, 2018).

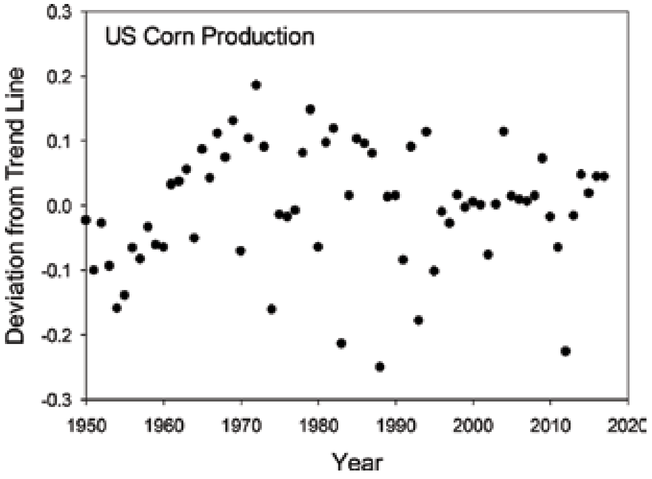


Figure 2. Deviations from the yield trend line for corn production in the United States from 1950 to 2017. (data obtained from the National Agricultural Statistics Service, www.nass.usda.gov, accessed March 8, 2018).

and increases in future production is understanding how climate change will impact this trend in corn production and the areas of the world where corn is produced. Corn is a grain crop with both food and feed uses and variation in production at the local scale can have major impact on local economies and local food supplies as well as world food security.

The trend line for corn yield has shown a steady increase and a small amount of variation among the years; however, at the local scale is where the impacts of seasonal weather and trends in climate become more noticeable. Across the United States, there have been large deviations from the trend line in years in which weather events have caused yield reductions

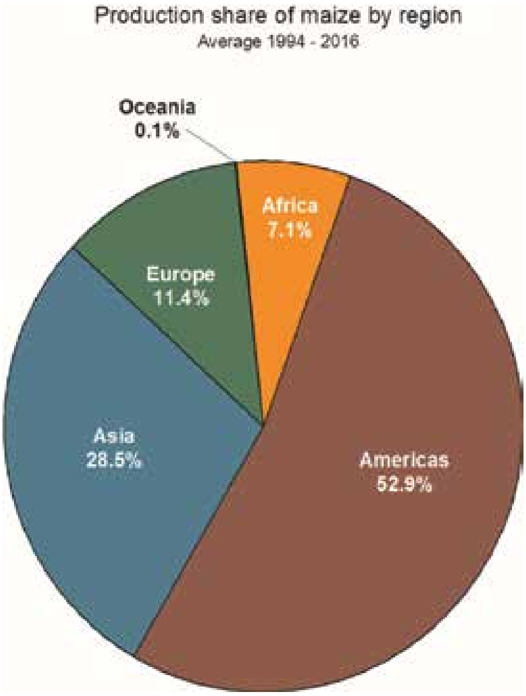


Figure 3. World corn production by region. (data from FAOSTAT, downloaded March 15, 2018).

(**Figure 2**). Throughout this chapter, we will focus on the impacts of climate on corn phenology and production to provide an understanding of the potential for adaptation strategies. In this chapter we will focus on three components critical to corn production: the changing climate, impact of climate on corn phenology and phenological models, and impact of climate on corn productivity.

The production regions for corn show the dominant areas in the Americas followed by Asia accounted for 81% of the world's corn production (**Figure 3**). Climate impacts in the Americas and China will dominate the effects on future corn production.

2. Projections of climate change

Projections of climate change are a result of a combined set of simulation models using various scenarios of changes in carbon dioxide (CO_2) concentrations and the associated forcing functions [1]. The current CO_2 concentrations are at nearly 400 ppm in 2018 and are projected to increase to a range of 794–1142 ppm by 2100 without any abatement scenarios [1]. The result of these efforts can be summarized as [1, 2]:

1. Global mean temperatures will continue to increase throughout the twenty-first century if CO_2 concentrations continue to increase and under the highest emission scenario would range from 2.6 to 4.8°C.

2. These temperatures changes will not be uniform across regions with increases over land surfaces being larger than over the oceans.
3. As the global temperatures increase there will be more hot extremes and fewer cold extremes at both daily and seasonal time scales.
4. Precipitation will increase with increases in global mean surface temperature and could increase 1 to 3% $°C^{-1}$; however, there will be substantial spatial variation in these changes.
5. The water holding capacity of air increases by 7% $°C^{-1}$. The air can take up more water, and water vapor inclines. That leads to higher intensity of precipitation, i.e. higher amount of rainfall per rain event.
6. Annual surface evaporation will increase as the temperatures increases; however, over land, evaporation will be linked to precipitation.

These factors will affect corn growth and productivity and this chapter is directed toward showing how these changes in climate will potentially affect corn production in the future. A general summary of climate impacts on crops was prepared by Hatfield et al. [3] and reveal for corn that temperature and precipitation are the two critical factors. Since corn is a C4 plant, the response to increasing CO_2 will be minimal. Leakey et al. [4] found that leaf photosynthetic response was 3% to a doubling of CO_2 concentrations while total biomass and grain yield increased by 4%. They did observe that leaf stomatal conductance was decreased by 34% under these same experiments. These differences in physiological activity due to increased CO_2 are small compared to C3 species and will not the most evident response to the changing climate. Therefore, in this chapter we will focus on temperature and precipitation impacts on corn.

3. Phenology of corn

The phenology of corn has been described as the appearance of leaves or leaf collars during the vegetative stage and accumulation of material in the grain during the reproductive stage. The developmental stages of corn has been recently described by Abendroth et al. [5] and similar guidelines are used to quantify the phenological stage of corn during the growth cycle. What is important for assessing the effect of climate on corn is to explore what role climate variables have on corn phenology. The most critical variable in phenological development is temperature and each plant has a specific range of temperatures for growth as defined as the upper and lower limit (threshold) and an optimum [3]. For corn during the vegetative stage this has been identified as 8 to 38°C with an optimum of 34°C [6, 7] while the range for the reproductive stage is 8–30°C [8]. Typically, the lower temperature limit in growth models has assumed to be 10°C. Survival of pollen are sensitive to temperature, e.g., temperatures exceeding 35°C have been proven detrimental to pollen viability [9, 10]. There is a strong interaction of temperature with vapor pressure deficit and the viability in the time of movement from the tassel to the silk has been shown to decrease with decreasing moisture content [11]. These results would suggest that as the temperature increases and vapor pressure deficit increases that disruption of the pollination process could become more likely especially with the potential for more extreme temperature events. Quantifying the impact of episodes of temperature extremes on pollen viability and the disruption of reproductive processes will become more important with the projection that extreme temperature events will increase under climate change (Tebabldi et al. [12]). These temperature ranges and the potential for extreme events will become important for corn growth and production because of the projection that temperatures will increase in the future.

The relationship of corn phenology to temperature has been described through the use of growing degree days with a growing degree day (GDD) calculated as $(\mathrm{T}_{\mathrm{max}} + \mathrm{T}_{\mathrm{min}})/2 - \mathrm{T}_{\mathrm{base}}$, where $\mathrm{T}_{\mathrm{max}}$ is the maximum daily temperature, $\mathrm{T}_{\mathrm{min}}$ is the daily minimum temperature and $\mathrm{T}_{\mathrm{base}}$ is the temperature at which growth stops. Kumudini et al. [13] evaluated eight different thermal models for the estimation of corn phenological development. These thermal models were classified into empirical linear typical of the GDD model first shown by Gilmore and Rogers [14] with the most robust model having a $\mathrm{T}_{\mathrm{base}}$ of 10°C and an optimum of 30°C. Another class of thermal models is the empirical nonlinear model described by Brown and Bootsma [15] where the following relationships were used to estimate crop heat units (CHU): if $T_{\mathrm{min}} < 4.4^\circ\mathrm{C}$ then $T_{\mathrm{min}} = 4.4^\circ\mathrm{C}$ to derive $\mathrm{CHU}_{\mathrm{min}} = 1.8(T_{\mathrm{min}} - 4.4^\circ\mathrm{C})$; if $T_{\mathrm{max}} < 10^\circ\mathrm{C}$ then $T_{\mathrm{max}} = 10^\circ\mathrm{C}$; to derive $\mathrm{CHU}_{\mathrm{max}} = 3.33(T_{\mathrm{max}} - 10^\circ\mathrm{C}) - 0.084(T_{\mathrm{max}} - 10^\circ\mathrm{C})^2$ and $\mathrm{CHU} = (\mathrm{CHU}_{\mathrm{max}} + \mathrm{CHU}_{\mathrm{min}})/2$. Stewart et al. [16] used a non-linear empirical model and separated the vegetative and reproductive stages of growth with different functions. The third class of thermal models can be classified as the process-based models similar to the thermal functions used in Agricultural Production Systems sIMulator (APSIM) as described by Wilson et al. [17] which are based on estimates of air temperature at 3 hour intervals throughout the day and given as: if $\mathrm{T} < 0^\circ\mathrm{C}$ then $\mathrm{T} = 0^\circ\mathrm{C}$ and if $\mathrm{T} > 44^\circ\mathrm{C}$ then $\mathrm{T} = 44^\circ\mathrm{C}$ and calculated for different temperature ranges as $0^\circ\mathrm{C} = < T < 10^\circ\mathrm{C}$: $\mathrm{IR} = T(10/18^\circ\mathrm{C})$; $18^\circ\mathrm{C} = < T < 34^\circ\mathrm{C}$: $\mathrm{IR} = T - 8^\circ\mathrm{C}$; and $34^\circ\mathrm{C} = < T < 44^\circ\mathrm{C}$: $\mathrm{IR} = 26^\circ\mathrm{C} - (T - 34^\circ\mathrm{C})2.6$ and thermal units are given as $\sum(\mathrm{IR}/8)$, where IR = instantaneous rates or measurements. In comparing these different approaches, Kumudini et al. [13] found that the precision in terms of goodness of fit was calendar days < empirical linear < process-based < empirical non-linear.

An application of the GDD approach was developed by Neild and Richman [18] where they combined thermal units with precipitation in an agroclimatic index to determine where different corn hybrids could be grown around the world. Currently, this type of model has been replaced with simulation models similar to APSIM [19] to determine climate impacts on corn growth and production. If the thermal units per leaf appearance rate is constant for the vegetative stage of growth then as the temperature increases there will be a more rapid accumulation of leaves in the crop. This effect as observed by Hatfield [20] and Hatfield and Prueger [21] for corn grown under climatic normal (1980–2010) for Ames, Iowa and normal +4°C temperatures throughout the complete growing season for three different corn hybrids. There was no difference in the total number of leaf collars and cumulative leaf area between temperature regimes; however, there was a large difference in yield with the higher temperatures greatly reducing grain yield (**Figure 4**). Analysis revealed there was no difference in the GDD's for leaf collar appearance between the two temperature regimes suggesting that as temperatures increase there will be a more rapid rate of advancement in the phenological

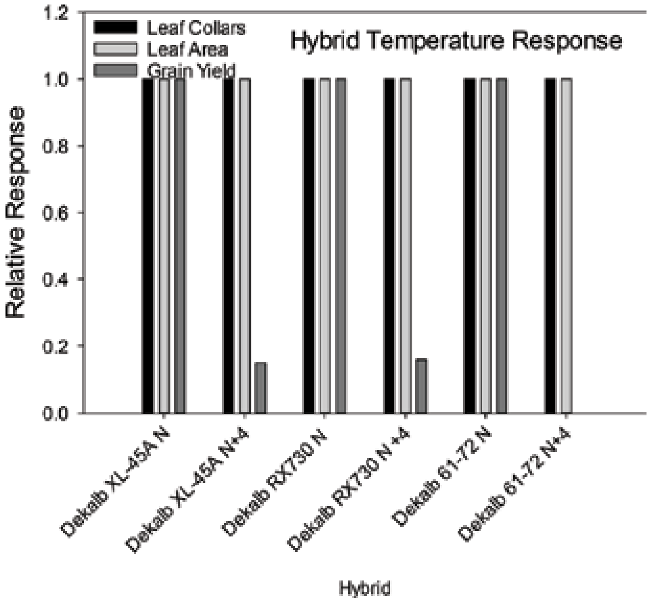


Figure 4. Differences in total leaf collars, cumulative leaf area, and grain yield of three corn hybrids grown under normal Ames, Iowa temperatures and normal +4°C temperatures. (data redrawn from [20]).

development with no effect on the size of the corn plant at the end of the vegetative stage. There was a large difference in grain yield between temperature regimes with a faster rate of maturity with a subsequent reduction in grain production.

4. Corn productivity in response to climate

Corn productivity relative to climate is a function of both temperature and precipitation. Effects of increased temperatures have shown a large degree of variation with projections of reduced production by less than 5% with temperature increases of 1°C [3] to over 50% with 4°C increases [22]. Productivity of corn is affected by temperatures exceeding 35° C during pollination due to dehydration of the pollen [3]. Controlled environment studies have confirmed the effect of high temperatures on corn with temperatures greater than or equal to 3°C above normal temperatures showing maize yield reductions of over 50% in grain yield [20, 21]. They observed an increased rate of phenology with increased temperatures; however, the largest effect on productivity was attributed to the increase in minimum temperatures during the grain-filling period. Field studies on corn have shown under field conditions yield reductions from 13 to 88% due to increased temperature 6°C above normal temperatures [23]. The negative effects of high temperatures during the grain-filling period were attributed to pollen survivability and the efficiency of the grain-filling process. Increasing temperatures likely to be experienced under climate change demonstrate several negative effects plant growth and phenology. Lizaso et al. [24] recorded a reduction of corn yield under field and controlled conditions owing to reduced pollen viability as impacted by increased temperatures. A critical knowledge gap under future climate scenarios will be to evaluate the interaction of high temperature and increased humidity on pollen survivability and the efficiency of the pollination process. Lobell and Field [25] found maize yields decreased 8.3% per 1°C rise without any additional effect due to water stress which was confirmed by Mishra and Cherkauer [26] for Midwest corn grain yields. Challinor et al. [27] compiled a meta-analysis of over 1700 published simulations for wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and corn. They found that without implementing adaptation strategies there would be a loss in yield in both temperate and tropical regions with only 2°C of warming. They also found that adaptation practices could increase simulated yields by 7–15% with this same temperature increase; however, the practices were more effective in wheat and rice than for corn. There was consensus among the simulation models that yield decreases were be greater in the second half of the century with the greater declines in the tropical areas compared to the temperate regions. They estimated that corn yields would decrease by nearly 15% in temperate regions with a 4°C increase and no adaptation but showed no decrease with adaptation practices [27].

Temperature and precipitation interact to affect corn productivity. Short-term water deficits and drought reduce growth and grain yield and are often the largest cause of crop losses. In the United States, drought was related to 41% of crop losses, while excess water was attributed to 16% of the yield loss [28]. Drought stress during the early and middle reproductive stages affected grain yields and these phenological stages were found to be the most sensitive to water stress [29]. Increases in spring precipitation can cause yield reductions due to aeration stress caused by flooded soils; however, drought stress remained the primary factor linked with reduced grain production [29]. In rainfed environments where corn is primarily grown, temperature and precipitation changes under climate change will negatively impact grain production and these interactions need to be more fully understood. In an analysis of wheat production in Europe, Semenov et al. [30], stated that understanding of the effects of higher temperatures and drought stresses during the booting and flowering periods would potentially lead to adaptation practices with the potential to reduce losses in grain numbers and grain weight. With both short-term water stress and drought as major factors affecting grain yield, improved water availability through more extensive root system and changes in root architecture would benefit yield stability [31]. The excess soil moisture in the root zone will require improved soil structure to facilitate gas exchange between the root system and the atmosphere [32]. The impact of precipitation is a combination of the precipitation amount and the soil water holding capacity. This was illustrated in an analysis by Egli and Hatfield [33] where they found average county level corn yields were a function of the soils ability to supply water.

Evaluation of corn yield response to climate is complex because of the interactions of the impacts of temperature and precipitation. To provide a more robust framework for evaluating yield response the utilization of the yield gap as the difference between potential yield and actual yield has been utilized ([34]; van Bussel et al. [35]). This concept has been discussed and utilized for several decades but recently has been extended to create a yield gap atlas for the world. The yield gap approach allows for a quantitative assessment of the ability of the crop to achieve its potential yield and the inability of closing the yield gap can often be ascribed to climatic stress. Potential yield has been defined as "the yield of a cultivar when grown in environments to which it is adapted; with nutrients and water not limiting; and with pests, diseases, weeds, and other stresses effectively controlled" [36]. Potential yield (Y_P) is an expression of the ability of a crop canopy to convert solar radiation into dry matter with no stress during the growth cycle and radiation use efficiency can be used as a measure of this efficiency [37]. The goal of agronomic science is the evaluate practices and increasing the farmer yield (Y_F) may prove to be more fruitful than increasing potential yield (Y_P) ([38]; Lobell et al. [39]. Utilizing the yield gap approach provides a framework for evaluating the factors which affect crop yields and the phenological stage which these factors are having the most significant impact during the growing season. These studies are not simple analyses, because of the interactions of multiple factors affecting yield, and Sinclair and Ruffy [40] argue that nitrogen and water limit crop yield more than plant genetics and should be considered as the primary factors limiting yield. Understanding the yield gap requires being able to quantify both potential and actual yield and comparison among studies is often limited by the lack of consistent data and to advance our understanding of yield gaps will require standardized method for yield comparisons [41]. Fischer et al. [41] introduced attainable yield (Y_A) as a metric between Y_F and Y_P defined as the yield achieved by a producer under near optimum weather and management inputs. Hatfield et al. [42] utilized this approach on county level corn yields in the Midwest United States and defined the attainable yield as the years with the highest yield in the long-term record as illustrated in **Figure 5**. The values for attainable yield are derived by statistically fitting a line through the frontier of the yield observations and then computing the yield gap as the difference between the attainable and actual observed yield for each year. In this analysis, data from 1950 through the present are used because this represents

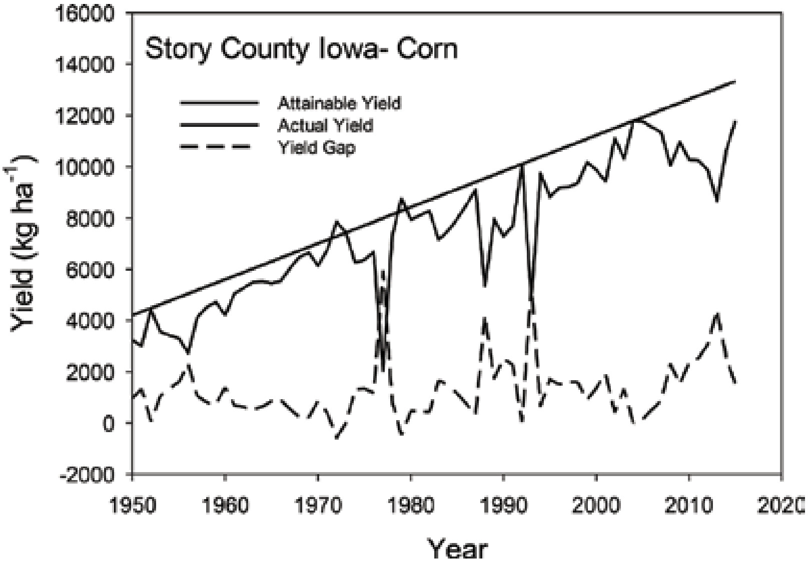


Figure 5. Yield gap analysis for Story County, Iowa, USA using attainable yields derived from annual production values. (data obtained from the National Agricultural Statistics Service, www.nass.usda.gov, accessed March 8, 2018).

the period of time with corn hybrids and enhanced production technology. This approach has been used for different crops and regions of the world to obtain yield gaps.

Hatfield et al. [42] utilized the yield gap approach for the Midwestern US to quantify the effects of climate variability on corn production and found three dominant climatic factors related to the yield gap. These were July maximum temperatures, August minimum temperatures, and July–August total precipitation. Yield gaps increased when July maximum temperatures exceeded 32°C, August minimum temperatures exceeded 20°C, and July–August precipitation totals decreased below 150 mm. The physiological reasons for these variables are related to the disruption of pollination (July temperatures), increased rate of senescence and reduced efficiency of grain-fill (August minimum temperatures), and water deficits during a period of the year with high crop water requirements (July–August precipitation). These relationships were observed for each county in the Midwest and utilized to project the impact of future climate change on the yield gap on corn production. They found that with the trends in temperature for the summer in the Midwest US that yield gaps would exceed 50% by the year 2075 in the southern portion of the Corn Belt. There were some counties in the Midwest in which excess moisture in the spring was related to the yield gap but these relationships were not robust enough for use in projections of future climates. The yield gap framework provides a robust method for assessing the impact of climate on yield variation over time and when combined with efforts similar to those used by Challinor et al. [27] could be used to quantify the impact of adaptation practices.

5. Agroclimatic indices to define corn production regions

Corn is produced around the world and within these areas there may be shifts in production areas due to the changing climate. Green et al. [43] have quantified the changes in the US Corn Belt and provided a geographic analysis to depict these shifts in distribution. Development and utilization of agroclimatic indices has value in being able to assess these shifts because they are related to temperature and precipitation. Neild and Richman [18] were among the first to use the GDD concept to define potential differences among corn hybrids. Development of tools to define where crops can be produced is critical to understand crop distribution and productivity [44]. Estimation of crop distribution within arable areas is necessary to determine whether a species can thrive in an agroclimatic zone and will become more critical with the projected increases in temperature. Zomer et al. [45] extended this concept to demonstrate how climate zones could be used to evaluate technologies that would enhance the ability of management practices to offset the impacts of climate change on crop production. There have continued to be advances in the development of agroclimatic indices to evaluate the suitability of a location for a particular crop since Neild and Richman [18]. Siddons et al. [46] cautioned that development of robust agroclimatic indices requires observations collected over long time periods and extensive observations from experimental locations. There has been an evolution in agroclimatic indices to include more factors affecting plant growth and development to derive values that characterize the environment and the potential for crop production. Typical factors are: average daily minimum temperatures below 0°C; daily mean temperature to estimate crop development rates; average daily maximum temperature above 35°C to estimate exposure to heat stress, especially during pollination; average daily soil water availability (precipitation–reference evapotranspiration (ET)); and length of specific phenological periods to estimate the effects of changing phenological development on biomass accumulation and crop yield [47]. They found a positive relationship between productivity and their suitability index [47]. This approach is a refinement of the effort by Neild and Richman [18] and incorporated more factors to more link crop physiological responses with phenological development.

Agroclimatic zones are a combination of factors affecting plant growth to evaluate the potential for grain or forage crop production (e.g., [18, 44, 48–51]). The form of the index depends upon the assumption of the factors limiting growth. Soil water availability is often the determining factor in crop production in all ecosystems and the application has ranged from determination of irrigation water requirements or potential impacts on production caused by water deficits. Daccache et al. [49] incorporated soil water variability to evaluate the need for irrigation for potato (*Solanum tuberosum* L.) production in England and Wales. Their index was based on the potential soil moisture deficit (PSMD) index defined as:

$$PSMD_i = PSMD_{i-1} + ET_i - P_i \tag{1}$$

where $\mathrm{PSMD_i}$ is the value in month i and $\mathrm{PSMD_{i-1}}$ is the value for the previous month, $\mathrm{ET_i}$ is the reference ET for the current month calculated with the Penman-Monteith equation formulated by Allen et al. [52], and $\mathrm{P_i}$ the precipitation in the current month. They found increased variation in precipitation decreased potato production in an area currently suited for production, unless supplemental water was provide through irrigation. This type of analyses could be utilized to determine the need for supplemental irrigation to ensure crop production.

Another form of this type of framework was developed by Moeletsi and Walker [51] to quantify climate risk for corn production in South Africa. They based their index, Poone AgroClimatic Suitability Index (PACSI), on three climatic parameters; onset of rains, frost risk, and drought risk utilized a weighed distribution of climate parameters as

$$PASCI = O\,x\,0.3 + FF\,x\,0.3\,x\,WRSI\,x\,0.4 \tag{2}$$

where O is the probability planting conditions are met, FF is the probability of a frost-free growing period, and the water requirements satisfaction index (WRSI). These indices require sufficient data over a long period of record to develop the probability of the different indices to develop reliable probability assessments [46]. An aspect of this index is the assessment of drought risk which is a complex interaction by soil water holding capacity and any change in the soil affecting water availability (Eq. 2).

Precipitation effects on crop productivity are defined by the occurrence of the water deficits in the soil profile which fail to meet the evaporative demand. Agroclimatic indices for arid and semiarid regions are often based on precipitation amounts adequate to exceed the ET rate at the time of planting in order to ensure crop establishment [18, 47–49, 51]. Moeletsi and Walker [51] evaluated soil water dynamics based on the WRSI to determine the potential to meet crop water requirements at any phenological stage as

$$WR_i = PET_i \, x \, k_{ci} \tag{3}$$

where WR_i is the water requirements for a decadal period during growing season, PET_i is the potential ET during this decadal period, and k_{ci} the crop coefficient for this corresponding phenological period. For any decadal period during the growing season, the soil water balance can be used to estimate plant available water (WA_i) as

$$WA_i = Prec_i - SW_{i-1} \tag{4}$$

and $Prec_i$ is the precipitation in a given decadal period and SW_{i-1} is the profile soil water content for the previous decadal period. Soil water holding capacity (WHC) becomes a critical component of this method because available SW is a function of WHC. They computed the WRSI as

$$WRSI_i = WRSI_{i-1} - \frac{WD_i}{\sum_{i=1}^{end} WR} \tag{5}$$

with WD_i the water deficit for decadal period i, defined as

$$WD_i = WR_i - Prec_i - SW_{i-1} \; when \; WR_i > Prec_i + SW_{i-1} \tag{6}$$

Or

$$WD_i = 0 \; when \; WR_i = Prec_i + SW_{i-1} \tag{7}$$

In this process soil water in the profile is quantified as

$$SW_i = Prec_i + SW_{i-1} - WR_i \tag{8}$$

$$SW_i = WHC \; when \; SW_i = WHC \tag{9}$$

$$SW_i = 0 \; when \; SW_i = 0 \tag{10}$$

Using this methodology, Moeletsi and Walker [51] were able to evaluate the suitability for maize production for various planting dates with a correlation of 0.8 between the PACSI and grain yields.

Precipitation is changing in intensity and frequency, and directly affect WA_i (Eq. 3). Precipitation patterns are projected to increase in annual totals, with decreasing summer precipitation amounts over the US [1, 53]. If we link these precipitation patterns with the PACSI (Eq. 2), then corn production could become more variable among years because of soil water availability.

Utilization of agroclimatic indices as a tool for the assessment of climate impacts on corn production areas will provide a quantitative view of shifts in production areas but potential risks to production within areas where corn is currently produced. The continued development of these tools will benefit corn production because we can evaluate the potential role of management and genetic resources on increasing yield stability over time.

6. Simulation models to quantify climate effects

Simulation models have been extensively used to estimate the impact of a changing climate on productivity. In 2014, Challinor et al. [27] summarized 1700 published reports using simulation models and the number of papers has increased rapidly since that time. Simulation models provide the capability of assessing the potential impacts of the change in temperature and precipitation under a given CO_2 regime and often models using the different emission scenarios to determine the expected temperature and precipitation parameters which are then placed into crop simulation models [54, 55]. It has been found that an ensemble of crop models provides a more rigorous approach to estimating crop responses to climate. This is being conducted under the Agricultural Model Implementation and Improvement Project (AgMIP) framework as described by Rosenzweig et al. [56]. Bassu et al. [57] used this framework to compare 23 different corn models and found temperature decreased yield by approximately -0.5 Mg $ha^{-1}{}^{\circ}C^{-1}$ while doubling the CO_2 from 360 to 720 μmol mol^{-1} increased yield by 7.5% across all models and sites. They concluded that temperature increases would be the dominant factor affecting corn yields. Zhao et al. [58] summarized a number of published results and found for each 1°C increase, corn yields decreased by 7.4%. Jin et al. [59] used the Agricultural Production Systems sIMulator (APSIM) model to evaluate the effect of different CO_2 scenarios (RCP4.5 and RCP8.5) for corn production in the US and found drought will be the largest factor affecting production. However, they stated that combined impacts of temperature and water stress need to be evaluated in breeding programs and adaptation strategies [59]. Earlier, Jin et al. [60] evaluated the algorithms in 16 different corn models and concluded that heat and drought stress was best simulated when models used event-based heat and water stress descriptions, accounted for nighttime temperature stresses, and evaluated the interactions of multiple stresses. Crop models allow for an assessment of the role of genetics and management on productivity for a range of present and future environmental conditions. Hatfield and Walthall [31] utilized this concept as the G x E x M (genetics × environment × management) framework to determine how these interactions would need to be understood to provide food security for the future population growth.

There have been efforts to combine observations with crop simulation models to evaluate changes in yield and yield stability. Leng [61] found yield variability across the US Corn Belt has decreased from 1980 to 2010 with climatic variability the major factor affected variability among years and regions. He found that statistical models explained more of the yield variation than crop simulation models. Bhattarai et al. [62] used the Environmental Policy Integrated Climate (EPIC) model with the combined results for eight general circulation models to show that under low and medium carbon scenarios, corn yields during the period 2080–2099 increased compared to the 2015–2034 period, while under the high carbon scenario yields during these same periods decreased. Lychuk et al. [63]) also used EPIC for the southeastern United States and found in the near-term corn yields increased, but from 2066 to 2070 yields decreased 5–13% because of the increased temperature stress. Huang et al. [64] combined field experiments with crop simulation models to evaluate the potential effect of different growing season length corn hybrids and found the longer growing season hybrid did not yield as high as the medium length hybrid. These results suggest that efforts be placed in evaluating the efficiency of plant growth relative to the changes in temperature and the accumulation of growing degree days.

The Global Agro-ecological zones model (GAEZ) categorizes areas suitable for crop production by climate, soil, terrain, management, and the specific growth limitations of crops, among others [65, 66]. One essential concept of GAEZ climate module is the temperature growing period (LGP_t), where air temperature is used as a proxy to estimate days of the growing period with optimal, sub-optimal, and no suitable crop production conditions for a specific crop. The growing period L is defined as the number of days with average daily temperature > 5°C (i.e., LGP_{t5}). The corn-specific LGP_t's are summarized in **Table 1**. For example, assume a temperate corn cultivar for grain production with a total growing period between 90 and 180 days. During this period average daily air temperature shall not decrease below 5°C, and the number of days with daily average air temperature between 10 and 15°C shall be below ⅕ of the total growing period to reach optimum growing conditions. In addition to air temperature, the length of the growing period is further limited by the moisture regime, defined as actual ET ≤ 0.5 * reference ET.

The GAEZ model also estimates potential yield of a specific crop in a specific agro-ecological zone, and applies constraint factors, such as heat or water stress, to calculate actual yield and yield gap. For example, periods of potential water stress occur when actual ET is below the total water requirement of a crop, maximum ET, and the difference between both cannot be compensated by precipitation, plant available water, or irrigation. Maximum ET is calculated as reference ET multiplied by crop coefficient k_c. Maximum ET is crop specific and changes during crop development by applying crop-development specific k_c values (**Figure 6**). The derived water stress data is then used to calculate yield constraining factors. The GAEZ model

Cultivars	Tropics lowland	Tropics highland	Subtropics-temperate	Subtropics-temperate
Crop	Grain	Grain	Grain	Silage
Growing period L (LGP_{t5}) (days)	90–120	120–300	90–180	105–180
Sub-optimum conditions	$LGP_{t < 10} = 0$	$LGP_{t > 25} = 0$	$LGP_{t < 5} = 0$	$LGP_{t > 30} = 0$
	$LGP_{t10–15} < 0.167*L$	$LGP_{t < 5} = 0$	$LGP_{t10–15} < 0.250*L$	$LGP_{t < 5} = 0$
		$LGP_{t10–15} < 0.500*L$		$LGP_{t10–15} < 0.667*L$
		$LGP_{t20–25} < 0.333*L$		$LGP_{t25–30} < 0.500*L$
Optimum conditions	$LGP_{t < 15} = 0$	$LGP_{t > 25} = 0$	$LGP_{t < 5} = 0$	$LGP_{t > 30} = 0$
		$LGP_{t < 5} = 0$	$LGP_{t10–15} < 0.200*L$	$LGP_{t < 5} = 0$
		$LGP_{t10–15} < 0.500*L$		$LGP_{t10–15} < 0.500*L$
		$LGP_{t20–25} < 0.333*L$		$LGP_{t25–30} < 0.333*L$

Adapted and simplified from [66]

Table 1. Corn growing period L (LGP_{t5}), optimum, and sub-optimum conditions of tropical lowland, tropical highland, and subtropical and temperature cultivars for grain production, as well as subtropical and temperate cultivars for silage production.

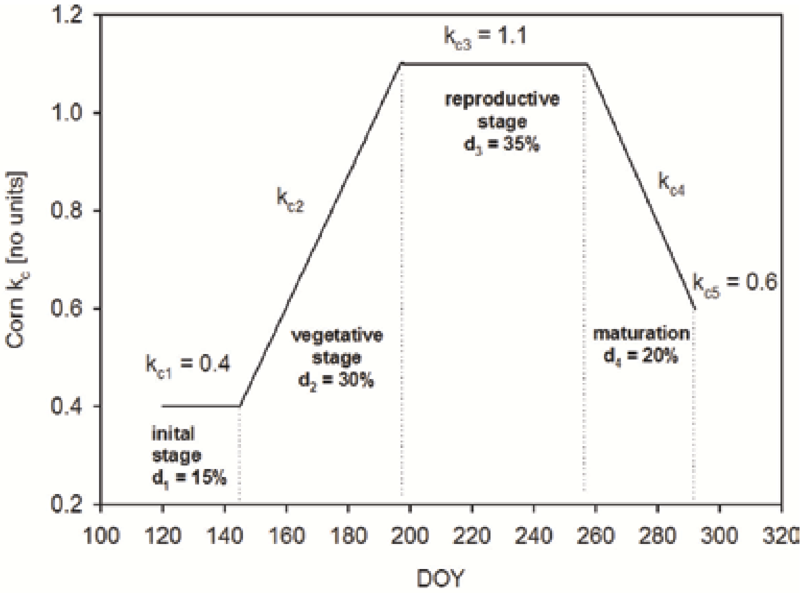


Figure 6. Crop development specific k_c values for corn: k_{c1}, k_{c2}, k_{c3}, and k_{c4} applies for the initial (d_1), vegetative (d_2), reproductive (d_3), and maturation (d_4) development period, respectively. Crop coefficient k_{c5} applies to the end of the growing period. Corn k_{c2} and k_{c4} data are linearly interpolated between k_{c1}, k_{c3}, and k_{c5}. The four corn development stages make up 15, 30, 35, and 20% of the total growing period. Data, equations, and redrawn graph according to IIASA/FAO [66]. In this example, total growing period (day of planting until harvest) was 173 days, for two corn fields nearby Ames, IA, USA from 2006 to 2017.

also determines which production areas are threatened by climatic changes by applying different climatic scenarios. Using this approach, Teixeira et al. [67] estimated that 5 Mha of cropland suitable for corn production are at risk due to climate change induced heat stress, and that yield declines are expected especially in the Northern hemisphere between 40 and 60°N latitudes.

One of the large challenges and opportunities for simulation models will be to incorporate the expected changes in insect and disease populations affecting corn production and link this with the production models. Integration of these two aspects into a single framework will allow for a more complete assessment of the corn production system being experienced by producers.

7. Conclusions

Climate impacts on corn production due to the changing temperature and precipitation regimes in the corn growing areas. The largest impact of these changes will be at the local scale where within season weather induced by the change in climate will become more noticeable. Increasing temperatures will increase the rate of phenological development during the vegetative and reproductive stages; however, the most negative effects will be exposure to high temperatures during the pollination and grain-filling stages. The largest impact on corn production will remain linked to the availability of soil water through precipitation and variation in precipitation during the grain-filling period will have the most detrimental impact on corn production. To overcome the effects of climate change there will be shifts in areas where corn is produced; however, these shifts may not be into areas with the capacity of the soil to support high production or have large variation in yield among years due to the variation in within season weather [33]. What will be critical is to increase our understanding of the G × E × M interactions as suggested by Hatfield and Walthall [31] in order to reduce the risk in production from a changing climate. What will be critical will be to use our current knowledge base (i.e. genetic resources (G) and management techniques (M)) to determine the viability of potential adaptation strategies to overcome climate changes (E). Combining experimental studies with crop simulation models will advance our understanding of the complex interactions occurring between the biological system and the physical environment and guide us toward viable adaptation practices with the potential to offset the negative impacts of climate change.

Author details

Jerry L. Hatfield* and Christian Dold

*Address all correspondence to: jerry.hatfield@ars.usda.gov

USDA-ARS National Laboratory for Agriculture and the Environment, Ames, Iowa, USA

References

[1] Collins M, Knutti R, Arblaster J, Dufresne J-L, Fichefet T, Friedlingstein P, Gao X, Gutowski WJ, Johns T, Krinner G, Shongwe M, Tebaldi C, Weaver AJ, Wehner M. Long-term climate change: Projections, commitments and irreversibility. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, editors. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2013

[2] Trenberth KE. Changes in precipitation with climate change. Climate Research. 2011;**47**: 123-138

[3] Hatfield JL, Boote KJ, Kimball BA, Ziska LH, Izaurralde RC, Ort D, Thomson AM, Wolfe DW. Climate impacts on agriculture: Implications for crop production. Agronomy Journal. 2011;**103**:351-370

[4] Leakey ADB, Uribelarrea M, Ainsworth EA, Naidu SL, Rogers A, Ort DR, Long SP. Photosynthesis, productivity, and yield of maize are not affected by open-air elevation of CO_2 concentration in the absence of drought. Plant Physiology. 2006;**140**:779-790

[5] Abendroth LJ, Elmore RW, Boyer MJ, Marlay SK. Corn growth and development. PMR 1009. Ames, Iowa: Iowa State University Extension; 2011

[6] Badu-Apraku B, Hunter RB, Tollenaar M. Effect of temperature during grain filling on whole plant and grain yield in maize (*Zea mays* L.). Canadian Journal of Plant Science. 1983;**63**:357-363

[7] Kiniry JR, Bonhomme R. Predicting maize phenology. In: Hodges T, editor. Predicting Crop Phenology. Boca Raton, FL: CRC Press; 1991. pp. 115-131

[8] Muchow RC, Sinclair TR, Bennett JM. Temperature and solar-radiation effects on potential maize yield across locations. Agronomy Journal. 1990;**82**:338-343

[9] Dupuis L, Dumas C. Influence of temperature stress on in vitro fertilization and heat shock protein synthesis in maize (*Zea mays* L.) reproductive systems. Plant Physiology. 1990;**94**:665-670

[10] Herrero MP, Johnson RR. High temperature stress and pollen viability in maize. Crop Science. 1980;**20**:796-800

[11] Fonseca AE, Westgate ME. Relationship between desiccation and viability of maize pollen. Field Crops Research. 2005;**94**:114-125

[12] Tebabldi C, Hayhoe K, Arblaster JM, Meehl GE. Going to the extremes; An intercomparison of model simulated historical and future changes in extreme events. Climatic Change. 2006;**79**:185-211

[13] Kumudini S, Andrade FH, Boote KJ, Brown GA, Dzotsi KA, Edmeades GO, Gocken T, Goodwin M, Halter AL, Hammer GL, Hatfield JL, Jones JW, Kemanian AR, Kim S-H, Kiniry J, Lizaso JI, Nendel C, Nielsen RL, Parent B, Stöckle CO, Tardieu F, Thomison PR, Timlin DJ, Vyn TJ, Wallach D, Yang HS, Tollenaar M. Predicting maize Phenology: Intercomparison of functions for developmental response to temperature. *Agronomy Journal*. 2014;**106**:2087-2097

[14] Gilmore EC, Rogers JS. Heat units as a method of measuring maturity in corn. Agronomy Journal. 1958;**50**:611-615. DOI: 10.2134/agronj1958.000219 62005000100014x

[15] Brown DM, Bootsma A. Crop Heat Units for Corn and Other Warm Season Crops in Ontario. Ministry of Agriculture and Food. ON, Canada: Guelph; 1993

[16] Stewart DW, Dwyer LM, Carrigan LL. Phenological temperature response of maize. Agronomy Journal. 1998;**90**:73-79. DOI: 10.2134/agronj1998.00021962009000010014x

[17] Wilson DR, Muchow RC, Murgatroyd CJ. Model analysis of temperature and solar radiation limitations to maize potential productivity in a cool climate. Field Crops Research. 1995;**43**:1-18. DOI: 10.1016/0378-4290(95)00037-Q

[18] Neild RE, Richman NH. Agroclimatic normals for maize. Agricultural Meteorology. 1981; **24**:83-95

[19] Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow V, Dimes JP, Silburn M, Wang E, Brown S, Bristow KL, Asseng S, Chapman S, McCown RL, Freebairn DM, Smith CJ. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy. 2003;**18**:267-288

[20] Hatfield JL. Increased temperatures have dramatic effects on growth and grain yield of three maize hybrids. Agricultural Environment Letters. 2016;**1**:150006. DOI: 10.2134/ael2015.10.0006

[21] Hatfield JL, Prueger JH. Temperature extremes: Effects on plant growth and development. Weather and Climate Extremes. 2015;**10**:4-10

[22] Schlenker W, Roberts MJ. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academy of Sciences of the United States of America. 2009;**106**:15594-15598

[23] Ordóñeza RA, Savina R, Cossania CM, Slafera GA. Yield response to heat stress as affected by nitrogen availability in maize. Field Crops Research. 2015;**183**:184-203

[24] Lizaso JI, Ruiz-Ramos M, Rodríguez L, Gabaldon-Leal C, Oliveira JA, Lorite IJ, Sánchez D, García E, Rodríguez A. Impact of high temperatures in maize: Phenology and yield components. Field Crops Research. 2018;**216**:129-140. DOI: https://doi.org/10.1016/j.fcr.2017.11.013

[25] Lobell DB, Field CB. Global scale climate-crop yield relationships and the impacts of recent warming. Environment Research Letters. 2007;**2**:1-7

[26] Mishra V, Cherkauer KA. Retrospective droughts in the crop growing season: Implications to corn and soybean yield in the Midwestern United States. Agricultural and Forest Meteorology. 2010;**150**:1030-1045

[27] Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N. A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change. 2014;**4**:287-291. DOI: 10.1038/NCLIMATE2153

[28] Boyer JS. Plant productivity and environment. Science. 1982;**218**:443-448

[29] Wang R, Bowling LC, Cherkauer KA. Estimation of the effects of climate variability on crop yield in the Midwest USA. Agricultural and Forest Meteorology. 2016;**216**:141-156

[30] Semenov MA, Stratonovitch P, Alghabari F, Gooding MJ. Adapting wheat in Europe for climate change. Journal of Cereal Science. 2014;**59**:245-256

[31] Hatfield JL, Walthall CL. Meeting global food needs: Realizing the potential via genetics x environment x management interactions. Agronomy Journal. 2015;**107**:1251-1226

[32] Hatfield JL, Sauer TJ, Cruse RM. Soil: The forgotten piece in the water, food, energy nexus. Advances in Agronomy. 2017;**143**:1-46. http://ds.doi.org/10.1016/bs.agron.2017.02.001

[33] Egli DB, Hatfield JL. Yield gaps and yield relationships in central U.S. maize production systems. Agronomy Journal. 2014;**106**:2248-2256

[34] Licker R, Johnston M, Foley JA, Barford C, Kucharik CJ, Monfreda C, Ramankutty N. Mind the gap: How do climate and agricultural management explain the 'yield gap' of croplands around the world? Global Ecology and Biogeography. 2010;**19**:769-782

[35] van Bussel LGJP, Grassini J, Van Wart J, Wolf L, Claessens H, Yang H, Boogaard H, de Groot H, Saito K, Cassman KG, van Ittersum Mk. From field to atlas: Upscaling of location-specific yield gap estimates. Field Crops Research. 2015;**177**:98-108

[36] Evans LT, Fischer RA. Yield potential: Its definition, measurement, and significance. Crop Science. 1999;**39**:1544-1551

[37] Hatfield JL. Radiation use efficiency: Evaluation of cropping and management systems. Agronomy Journal. 2014;**106**:1820-1827

[38] Cassman KG, Doberman A, Walters DT, Yang H. Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment Resource. 2003;**28**:315-358

[39] Lobell DB, Cassman KG, Field CB. Crop yield gaps: Their importance, magnitudes, and causes. Annual Review of Environmental Research. 2009;**34**:179-204

[40] Sinclair TR, Ruffy TW. Nitrogen and water resources commonly limit crop yield increases, not necessarily plant genetics. Global Food Security. 2012;**1**:94-98

[41] Fischer T, Byerlee D, Edmeades G. Crop Yields and Global Food Security: Will Yield Increase Continue to Feed the World? ACIAR Monograph 158. Australian Centre for International Agricultural Research. Australia: Canberra; 2014. 634 p

[42] Hatfield JL, Wright-Morton L, Hall B. Vulnerability of grain crops and croplands in the Midwest to climatic variability and adaptation strategies. Climatic Change. 2018;**146**:263-275. DOI: 10.1007/s10584-017-1997-x

[43] Green TR, Kipka H, David O, McMaster GS. Where is the US Corn Belt, and how is it changing. Science of the Total Environment. 2018;**618**:1613-1618. https://doi.org/10.1016/j.scitotenv.2017.09.325

[44] van Wart J, van Bussel LGJ, Wolf J, Licker R Grassini P, Nelson A, Boogaard H, Gerber J, Mueller NID, Claessens L, van Ittersum M K, Cassman KG. Use of agro-climatic zones to upscale simulated crop yield potential. Field Crops Research. 2013;**143**:44-55

[45] Zomer RJ, Trabucco A, Bossio DA, Verchot LV. Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. Agriculture, Ecosystems and Environment. 2008;**126**:67-80

[46] Siddons PA, Jones RJA, Hollis JM, Hallett SM, Huyghe C, Day JM, Scott T, Milford GFJ. The use of a land suitability model to predict where autumn-sown determinate genotypes

of the white lupin (*Lupinus albus*) might be grown in England and Wales. Journal of Agricultural Science, Cambridge. 1994;**123**:199-205

[47] Holzkämper A, Calanca P, Fuhrer J. Identifying climatic limitations to grain maize yield potentials using a suitability evaluation approach. Agricultural and Forest Meteorology. 2013;**168**:149-159

[48] Araya A, Keesstra SD, Stroosnijder L. A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. Agricultural and Forest Meteorology. 2010;**150**: 1057-1064

[49] Daccache A, Keay C, Jones RJA, Weatherhead EK, Stalham MA, Knox JW. Climate change and land suitability for potato production in England and Wales: Impacts and adaptation. The Journal of Agricultural Science. 2012;**150**:161-177

[50] Simane B, Struik PC. Agroclimatic analysis: A tool for planning sustainable durum wheat (*Triticum turgidum* var. durum) production in Ethiopia. Agriculture Ecosystems and Environment. 2003;**47**:31-46

[51] Moeletsi ME, Walker S. Simple agroclimatic index to delineate suitable growing areas for rainfed maize production in the free State Province of South Africa. Agricultural and Forest Meteorology. 2012;**162-163**:63-70

[52] Allen RG, Smith M, Perrier A, Pereira LS. An update for the definition of reference evapotranspiration. ICID Bulletin. 1994;**43**:1-34

[53] Walsh, J., Wuebbles D, Hayhoe K, Kossin J, Kunkel K, Stephens G, Thorne P, Vose R, Wehner M, Willis J, Anderson D, Doney S, Feely R, Hennon P, Kharin V, Knutson T, Landerer F, Lenton T, Kennedy J, Somerville R. Ch. 2: Our Changing Climate. Melillo JM, Richmond TC, Yohe GW, editors. Climate Change Impacts in the United States: The Third National Climate Assessment, U.S. Global Change Research Program, 19–67. 2014. DOI: 10.7930/J0KW5CXT

[54] Tubiello F, Ewert F. Simulating the effects of elevated CO_2 on crops: Approaches and applications for climate change. European Journal of Agronomy. 2002;**18**:57-74

[55] White JW, Hoogenboom G, Kimball BA, Wall GW. Methodologies for simulating impact of climate change on crop production. Field Crops Research. 2011;**124**:357-368

[56] Rosenzweig C, Jones JW, Hatfield JL, Ruane AC, Boote KJ, Thorburn P, Antle JM, Nelson GC, Porter C, Janssen S, Asseng S, Basso B, Ewert F, Wallach D, Baigorria G, Winter JM. The agricultural model Intercomparison and improvement project (AgMIP): Protocols and pilot studies. *Agric*. Forest Meteorology. 2012;**170**:166-182. http://dx.doi.org/10.1016/j.agrformet.2012.09.011

[57] Bassu S, Brisson N, Durnad J-L, Boote K, Lizaso J, Jones JW, Rosenzweig C, Ruane AC, Adam M, Baron C, Basso B, Biernath C, Boogaard H, Conijn S, Corbells M, Deryng D, De Sanctis D, Gayler S, Grassini P, Hatfield J, Hoek S, Izaurralde C, Jongschapp R, Kemanian AR, Kersebaum KC, Kim S, Kumar NS, Makowski D, Meuller C, Nendel C, Priesack E,

Pravia MV, Shcherbak FSI, Tao F, Teixeira E, Timlin D, Waha K. How do various maize models vary in their responses to climate change factors? Global Change Biology. 2014;**20**: 2301-2320. DOI: 10.1111/gcb.12520

[58] Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y, Huang M, Yao Y, Bassu AS, Ciais P, Durand J-L, Elliott J, Ewert F, Janssens IA, Li T, Lin E, Liu Q, Martre P, Mű̈ller C, Peng S, Peñuelas J, Ruane AC, Wallach D, Wang T, Wu D, Liu L, Zhu Y, Asseng S. Temperature increase reduces global yields of major crops in four independent estimates. PNAS. 2017; **114**:9326-9331. DOI: 10.1073/pnas.1701762114

[59] Jin Z, Zhaung Q, Wang J, Archontoulis SV, Zobel Z, Kotamarthi VR. The combined and separate impacts of climate extremes on the current and future US rainfed maize and soybean production under elevated CO_2. Global Change Biology. 2017;**23**:2687-2704. DOI: 10.1111/gcb.13617

[60] Jin Z, Zhuang Q, Tan Z, Dukes JS, Zheng B, Melillo JM. Do maize models capture the impacts of heat and drought stress on yield? Using algorithm ensembles to identify successful approaches. Global Change Biology. 2016;**22**:3112-3126. DOI: 10.1111/gcb.13376

[61] Leng G. Recent changes in county-level corn yield variability in the United States from observations and crop models. Science of the Total Environment. 2017;**607-608**:683-690. http://dx.doi.org/10.1016/j.scitotenv.2017.07.017

[62] Bhattarai MD, Secchi S, Schoof J. Projecting corn and soybeans yields under climate change in a Corn Belt watershed. Agricultural Systems. 2017;**152**:90-99. http://dx.doi.org/10.1016/j.agsy.2016.12.013

[63] Lychuk TE, Hill RL, Izaurralde RC, Momen B, Thomson AM. Evaluation of climate change impacts and effectiveness of adaptation options on crop yield in the southeastern United States. Field Crops Research. **214**:228-238. http://dx.doi.org/10.1016/j.fcr.2017.09.020

[64] Huang S, Lv L, Zhu J, Li Y, Tao H, Wang P. Extending growing period is limited to offsetting negative effects of climate changes on maize yield in the North China plain. Field Crops Research. 2018;**215**:66-73. http://dx.doi.org/10.1016/j.fcr.2017.09.015

[65] Fischer G, Van Velthuizen H, Shah M, Nachtergaele FO. Global Agro-Ecological Assessment for Agriculture in the 21st Century: Methodology and Results; 2002

[66] IIASA/FAO. Global Agro-ecological Zones (GAEZ v3. 0), IIASA, Laxenburg, Austria and FAO, Rome, Italy; 2012

[67] Teixeira EI, Fischer G, van Velthuizen H, Walter C, Ewert F. Global hot-spots of heat stress on agricultural crops due to climate change. Agricultural and Forest Meteorology. 2013; **170**:206-215. DOI: https://doi.org/10.1016/j.agrformet.2011.09.002

Chapter 7

GIS-Based Assessment of Smallholder Farmers' Perception of Climate Change Impacts and Their Adaptation Strategies for Maize Production in Anambra State, Nigeria

John Agbo Ogbodo, Samuel E. Anarah and
Sani Mashi Abubakar

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79009

Abstract

The production of *Zea mays* (otherwise called maize or corn), which is an important staple food crop in Nigeria, is limited by the impacts of climate change; thus, posing food insecurity in the country. The primary purpose of this study is to assess the perception of smallholders' maize farmers on climate variability; and, their climate change adaptations practices in Anambra State, Nigeria. A multi-stage sampling technique and structure questionnaires were applied to this study. Collected data were analyzed using both descriptive/ inferential statistics, together with a simple technique of geographic information system (GIS). The results show that, approximately 57.2% of climate variability negatively impacts on maize production in the study area. Basically flooding ($\overline{x}$ = 2.02 ± 1.166), erratic rainfall ($\overline{x}$ = 2.02 ± 0.816), and decrease in crop yield by strange pests and diseases ($\overline{x}$ = 1.59 ± 0.896) affect maize production. The well-informed farmers practice some climate change adaptations techniques such as: planting of grasses to prevent erosion, and, use of improved maize seeds to withstand environmental stress. In conclusion, the lower the standard deviation values, the more knowledgeable the farmers were about issues of climate variability and on climate change adaptations practices; and, vice-versa.

Keywords: smallholder maize farmers, climate change perception, adaptation strategies, GIS, Nigeria

1. Background information

Zea mays, popularly known as maize or corn, and, sometimes called Indian corn or mealies [1]; is one of the important Nigeria's household grains that contributes to food security. Food security is of high importance on the Nigeria's national agenda, taken into account the increasing demand for food for its increasing population [1, 2]. The importance of corn in Nigeria can be underlined in two ways: (a) its economic value to the national treasury, and, (b) the large number of smallholder-farmers that cultivate the crop at subsistence level [3]. According to [2], Nigeria was the tenth largest producer of maize in the world, and the largest maize producer in Africa. It is estimated that 70% of farmers are smallholders, and this number accounts for 90% of the total farm outputs [4]. Maize crop started as a subsistence crop in Nigeria and has gradually risen to a commercial crop on which many agro-based industries depend on, as raw materials [3]. In 2016, maize production for Nigeria was 10.4 million tonnes. Though Nigeria maize production fluctuated substantially in recent years, its yield was projected to increase to a maximum of 10.4 million tonnes in 2016 [1].

As a Nigerian staple food, corn is being utilized in making household diets, for industrial processing as a raw material, and for animal feed formulation [5]. Processed maize product: *tuwo—masara (Hausa), fufu (Yoruba), nri-oka (Igbo), uwe-nyumbakpa (Igede) or semo (common English branded name)*, is one of the food products that can be obtained from maize utilization in Southeast, Nigeria [6]. It is essentially a food gel or dumpling which is stiff, has a yield value and can be molded into shapes. Other food products that are obtained from maize grain include the following Nigerian native names: ogi, eko or agidi, egbo, elekute, aadun, abari and guguru (i.e. popcorn) [7]. This important cereal crop is widely cultivated within the rainforest and the derived Savannah zones of Nigeria [4, 8]. Improved varieties have been developed for high yield production in the country [9]. About 60% of maize in Nigeria is from high rain-forest zones [10]; and many varieties of maize were developed and available for cultivation in Nigeria [11]. However, maize production is greatly limited by the impacts of climate change [12].

Climate change is the most serious contemporary environmental threat facing humankind [13–16]; because, many aspects of planet Earth are changing mainly due to anthropogenic (human-induced) activities. The foregoing scenario thereby raises climate change issues for sustainable maize production [2, 12, 17–19] in countries that are susceptible to climate change impacts. IPCC (Intergovernmental Panel on Climate Change) in 2007 defined climate change as: "a change in the state of the climate which can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It further refers to any change in climate over time, whether due to natural variability or as a result of human activity" [20]. In addition, IPCC expressed that, Africa seems to be the most vulnerable continent to future climate change impacts [21–23]. Justly, climate change is already a reality for millions of Africa's smallholder farmers, especially, maize producers [24, 25]. Despite that, maize plays fundamental roles to national food security in Africa [12]; its production is thus, highly dependent on climatic variables [13, 14]. Therefore, concerns have been widely expressed, over the years by agronomists, research institutions, governmental agencies at both local and international fora, on the need to tackle the impacts of climate variability on maize yield [16, 26–28]. Climatic factors and are among environmental conditions that affect the productivity of many varieties of maize crops [29, 30]. Worse -still, many smallholder farmers are resource constrained, therefore, their demands for certain improved seeds vary as much as agro-climatic conditions do [24, 31, 32]. However, the formal seed sector has made some success in raising adoption of various improved maize varieties such as stress-tolerant varieties, early and extra-early varieties, or N_2-efficient varieties [29].

2. Related past research on climate variability and adaptation to climate change by smallholder maize farmers

This above expressed scenarios have motivated several past research works on climate variability on maize production over the past decade [12, 13, 33, 34]. Specifically, [33] identified climate variability as a global environmental challenge that is likely to have a serious effect on natural and human systems, economies and infrastructures. However, the nature of these biophysical effects and the human responses to these changes are complex and uncertain as the changes keep manifesting in different forms on a yearly basis. Climate change has already exhibited strong negative impacts on food security in many African countries such as: Eritrea [35]; Ethiopia [36]; Kenya [12, 37]; South Africa [38]; Nigeria [39]; etcetera.

Consequently, past studies have indicated substantial diversity in the awareness level of Nigerian maize farmers in regard to climate change adaption techniques [3, 10]. Adaptation to climate variability is defined as an adjustment in natural or human systems to actual or expected climatic stimuli or their effects, which moderates harm and exploit beneficial opportunities [40, 41]. Climate change adaptation depends on: demand for improved seeds for maize, category of techniques adopted to curtail climate variability, time of planting, among others [4]. Planting time is an essential component of maize crop management, especially in the South-eastern part of Nigeria [8]. Yields decline with lateness of planting after an optimum time, usually the start of the rains [17]. Response of maize varieties to climate variability is dependent upon planting time. Optimum planting in each of the major agro-ecological zones of Nigeria falls within the following ranges [42]: Forest zone—Mid April—second week in May; forest—Savannah transition—third week in April—third week in May; South Guinea Savannah comes up during the last week in April to the third week in May. These planting dates coincide with the period that flooding occurs with the riverine communities of the study area. Re-occurring flood is an impact of climate that strongly manifests in South-eastern Nigeria; thereby decreasing maize production in flood prone zones [43].

Furthermore, some other previous long-term climate change studies have established a nexus between the effects of carbon dioxide concentrations in the atmosphere, and the mean global temperature [13, 44]. In addition, the studies by [43, 45] opined that, global warming has influenced agricultural productivity negatively in parts of Sub-Saharan Africa, mostly in Nigeria, and had thus resulted in decline of food production. Numerous climate variability effects are outcomes of human activities bothering on industrialization, agricultural expansion, deforestation, bush burning, use of inorganic fertilizers, intensive livestock farming system and storage of wastes in landfills [46]. Landfill for example, releases lots of greenhouse gases to the environment thereby increasing the scourge of global- warming on humans and their crops [16]. Literature asserts that non-adaptation of climate smart strategies *vis-à-vis* lack of awareness creation about climate variability in communities, could aggravate a poor Nigerian economy at a percentage loss of between 2% and 11% GDP, by year 2020 [47]. The foregoing assertion could further worsen, to a record low of 12–50% by year 2050 [1, 48]. Such a negative trend can compromise the attainment of the purported Sustainable Development related Goals [27, 49] in Nigeria.

Nevertheless, the magnitude to which maize yield drastically reduced in last two consecutive years in Nigeria, creates the need for researchers to examine existing knowledge gaps on smallholder maize farmers' perception climate change variability in South-eastern Nigeria; as a remedy to forestalling future low maize productivity in the country.

3. Statement of the problem

Nigeria's ecological conditions and cultural diversities put the country at an advantage for production of a wide range of food products [25]. However, the Climate Change Vulnerability Index 2014 classified Nigeria's vulnerability as extreme and ranked the country as number six [6] most vulnerable country to climate change [39, 48]. This extreme vulnerability has negative implications for agricultural production and food security, especially in South-eastern Nigeria.

The awareness of farmers to adopting improved seed varieties as a panacea for climate change adaptation, has been relatively widely studied in Nigeria [3, 4, 9, 11, 13, 42, 50]. However, most previous climate change research measured the level of change in decades (long term) without considering the short term effects and adaptations [40]. The above illustrations also apply to Nigerian South-eastern states including Anambra State [6].

In a nutshell, smallholder maize farmers with a deep understanding of the specific environmental factors that determine or limit the growth of their crops, would have better capabilities to significantly increase their crop yields by making through rightful choices and using of novelty approaches of climate smart agriculture. Therefore, understudying the relative influence of farmers' awareness toward curbing severe climate change impacts on their maize plant growth and yield, is very crucial.

The pervasive role of Geospatial technology in solving agricultural problems has widely been established. Therefore, Geographical Information System (GIS) is a type of Geospatial technology that provides the means to collect and use geographic data to assist in support of food production and food security. GIS is a system for capturing, storing, analyzing and managing data and associated attributes, which are spatially referenced to the Earth [51].

Therefore, the overall objective of this present study is to fill the knowledge gap between the perception of smallholders' maize farmers on climate variability and their use of climate change adaptation approaches in relation to GIS, toward contributing to sustainable food security in Anambra State, South-eastern Nigeria.

4. Research location

Located in South-eastern Nigeria, Anambra state lies between Latitude 6° 45′ and 5° 44′ N and Longitudes 6° 36′ and 7° 20°E [38]. The climate is humid with mean average rainfall of 2010 mm and average temperature of 87°C (**Figure 1**). It has a weak soil that is easily eroded [38]. The climate here is tropical. The average annual temperature is 27.0°C. The rainfall here averages 1828 mm. The driest month is December, with 7 mm of rain. Most precipitation falls in September, with an average of 306 mm (**Figure 2**).

The state is divided into four agro-ecological zones (AEZ): Aguata, Awka, Anambra and Onitsha. The sites for this present study are shown in **Figure 3**. There is a difference of 299 mm of precipitation between the driest and wettest months. The average temperatures vary during the year by 3.8°C. The state occupies a land area of approximately 4887 km^2 and a population of 4,182,032 people based on the 2006 census figures. According to the Nigeria's National Population Commission figures of 2006, the population distribution is 2,174,641 million males and 2,007,391 million females. Anambra state is bounded to the north by Kogi state, to the south by Imo and Abia state, to the east by Enugu state and to the west by Delta state.

In 2006, maize production index for Anambra state was put at 69,1000 metric tonnes [48]. However, the state has in recent years, been substantially experiencing fluctuations in maize production at a decline rate of 23.28%. The decrease in maize yield in this Southern Nigeria, can be attributed to: (a) climate change related flooding [9, 25]; that re-occurs almost every year; and (b) non-adaptation of climate-smart measures by smallholder maize farmers [52, 53]. However, climate change adaption measures for maize, which is one of the most important grain crops, is less studied in Anambra State [6]. Another knowledge gap scenario is that, there is a limited

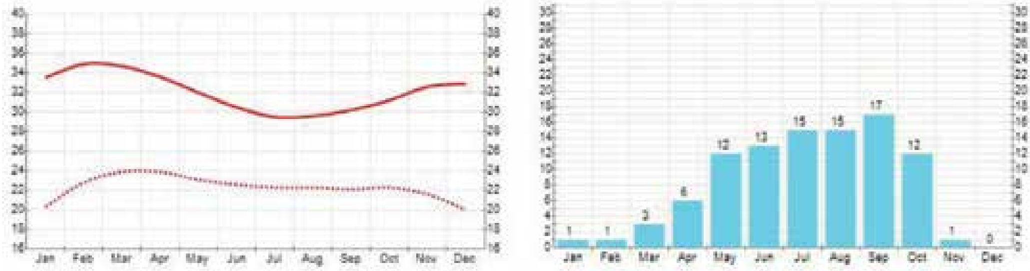
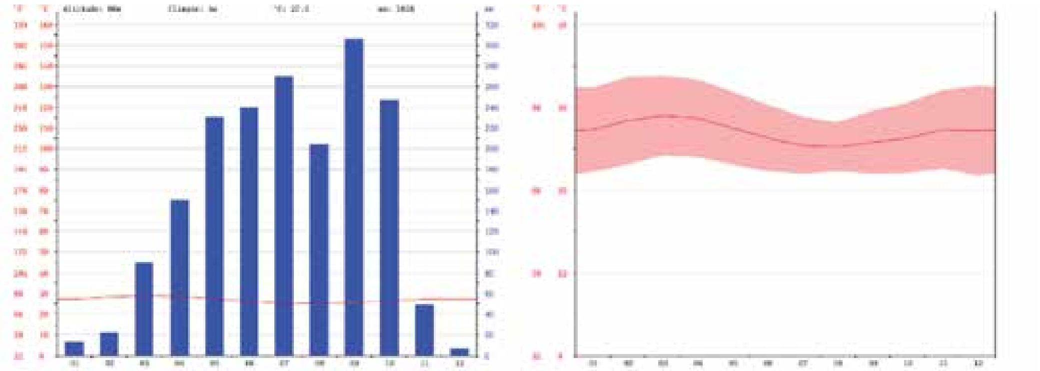


Figure 1. Average temperature per month (left) and average days with precipitation per month (right). Source: adopted from https://www.yr.no/place/Nigeria/Anambra/Anambra_State/statistics.html.



	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	27.3	28.4	29	28.7	27.5	26.3	25.4	25.2	25.8	26.3	27.3	27.2
Min. Temperature (°C)	22.2	23.1	24.2	24	23.1	22.3	22	22.3	22	22.1	22.6	21.8
Max. Temperature (°C)	32.4	33.7	33.8	33.4	31.9	30.3	28.9	28.2	29.6	30.6	32.1	32.6
Avg. Temperature (°F)	81.1	83.1	84.2	83.7	81.5	79.3	77.7	77.4	78.4	79.3	81.1	81.0
Min. Temperature (°F)	72.0	73.6	75.6	75.2	73.6	72.1	71.6	72.1	71.6	71.8	72.7	71.2
Max. Temperature (°F)	90.3	92.7	92.8	92.1	89.4	86.5	84.0	82.8	85.3	87.1	89.8	90.7
Precipitation / Rainfall (mm)	13	22	89	160	231	240	270	204	306	247	49	7

Figure 2. Climograph (left) and temperature graph (right and down) of Anambra state. Source https://en.climate-data.org/location/46675/#temperature-graph.

empirical evidence as to what extent climate variability is perceived by the smallholders maize farmers in Anambra state. These scenarios create the pertinent need to researching the assessment of smallholders maize farmers' perception on climate variability and its emerging consequences on their livelihoods in Anambra State of Nigeria.

5. Research methods

Survey design was adopted in carrying out the study. [54] describes survey research as the one in which a group of people or item is studied by collecting and analyzing data from only a few people or items considered to be representative of the entire group. **Population of the study:** Anambra state is made up of 2270 smallholder maize farmers (Anambra State Agricultural

Figure 3. Map of Anambra state showing the four sampled study sites of Akwa North, Idemili, Orumba North and Oyi 1 local government areas (L.G.A.).

Development Programme, which formed the sample frame). The distribution is as follows; Anambra-520, Aguata-680, Awka-620, Onitsha-450. **Sampling Techniques and sample size:** A multi-stage sampling method was used in selecting the sample units for the study. Anambra state is made up of four agricultural zones, namely, Anambra, Aguata, Awka and Onitsha. One extension block was randomly selected from each of the four agricultural zones to avoid bias; Awka north, Orumba north, Oyi 1 and Idemili to give a total of four blocks. Secondly, two circles were randomly selected from each of the four blocks again to give equal coverage, the selected circles were Amansi and Awba ofe nmiri from Awka north, Ufuma and Ajali from Orumba north, Nteje and Umunya from Oyi 1 and Nkpor and Obosi from Idemili north, thereby giving a total of eight circles. In the fourth stage, two sub-circles were randomly selected from each of the circles, the selected sub-circles were Ore, Egbe agu, Umu eze and Enugu agu from Amansi and Awba ofe nmiri, Umu onyiba, Umu ogem, Umu abiama and Umu ereh from Ufuma and Ajali, Umuefi, Achalla, Umuebo and Amaezike from Nteje and Umunya, Akuzor, Nbuba, Ire and Umu ota from Nkpor and Obosi, thereby given a total of sixteen sub- circles. The last stage involved random selection of eight farmers contact from each sub-circles. In all, a total of 128 farmers (respondents) were chosen from a list comprising of 2270 small scale maize farmers provided by Anambra ADP which formed the sampling size.

Reliability of Instrument: Reliability of the questionnaire was tested using cromlech alpha method which is 0.82%.

5.1. Method of data collection

Primary data were collected with well validated open and close ended questionnaire by the researcher. Questionnaire construction was based on the objectives of this study.

5.2. GIS technique

The aim of the GIS technology applied in this present study is provide maps of climate variability, degree of climate change adaptation and level of acceptability among the samples sites. The input data were from outcome of the questionnaire approach and GPS coordinates.

5.3. Data analysis

Descriptive statistics such as mean, frequency distribution and percentage were made to visualize and analyze the distribution of field data using box plots. Ordinal regression model statistic was also applied to the study.

5.4. Model specification

1. To get the mean score using three-point Likert scale

High extent = 3, Moderate extent = 2, Low extent =1.

Strongly aware = 3, Aware = 2, Not aware = 1.

Mean score = $\frac{3+2+1}{3}$ = 2.0

2. Mean estimation

Each of the total responses from all the respondents is calculated to get their individual mean response. The code of each of the responses is multiplied, and thereafter added to get the mean response thus:

For high extent (3), assuming total response to be 90: (90/128)*3 = 2.109.

For moderate extent (2), assuming total response to be 22: (22/128)*2 = 0.344.

For low extent (1), assuming total response to be 16: (16/128)*1 = 0.125.

Total mean score = 2.578 (thus, decision rule for this is high extent).

3. Equation for multiple linear regressions

$$Y_0 = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_p X_{pi} + e_i \quad (1)$$

Explicit.

where β_0 = the intercept, β_1 = slope (regression coefficient), Y_0 = dependent variable, e_i = standard error, X = independent variable, $p \geq 2$.

Where X_1 = age (years), X_2 = sex, X_3 = house hold size (No), X_4 = educational level (no of years), X_5 = farming years (No), X_6 = farming size (No), X_7 = labor source (Manday), X_8 = membership organization (No), X_9 = average income (₦), X_{10} = average yield (kg).

6. Findings and interpretations

6.1. Activities that contribute to climate variability

The various activities of the small scale maize farmers that contribute to climate variability are shown in **Table 1**.

Result in **Table 1**, reveals that the majority of the small scale maize farmers (88.28%) indicated that bush burning contribute to climate variability while (82.03%), (60.16%), (56.25%) and (50.78%) indicated that intensive agricultural land use, use of inorganic fertilizers, use of fossil fuels and deforestation as factors that contribute to climate variability. The implication of this finding is that many of the farming activities in the area contribute to climate change. This finding agrees with the study of Oladipo [41], who noted that most agricultural activities are the major factors of climate variability.

6.2. Level of awareness of climate variability

The result of mean responses of the level of awareness of climate variability by small scale maize farmers is shown in **Table 2**.

The result here, reveals that the smallholder maize farmers were significantly aware of the following climate variability in the study area: decreased rainfall days ($\overline{X}$ = 2.05; SD = 0.914), early onset of rainfall and early cessation ($\overline{X}$ = 2.08; SD = 0.929), late onset of rainfall and early cessation ($\overline{X}$ = 2.02; SD = 0.816), shorter than normal rainfall ($\overline{X}$ = 2.14; SD = 1.132), low

Farmers' activities	Frequency* (n = 128)	Percentage (%)
Burning of bush	113	88.28
Intensive agricultural land use	105	82.03
Use of inorganic fertilizers	77	60.16
Use of fossil fuels (fuel, kerosene, etc.)	72	56.25
Deforestation	65	50.78
Use of herbicides	54	42.19
Use of pesticides	55	42.97
Improper disposal of farm wastes	46	35.94

*Multiple response.
Source: Field survey, 2017.

Table 1. Percentage response of farmers according to the activities that contribute to climate variability.

S/N	Climate variability	$\overline{X}$	SD	Decision
1.	Decreased rainfall days	2.05	0.914	S
2.	Early onset of rainfall and early cessation	2.08	0.929	S
3.	Late onset of rainfall and early cessation	2.02	0.816	S
4.	Shorter than normal rainfall	2.14	1.132	S
5.	Low intensity rainfall	2.02	0.872	S
6.	Flash flooding	2.02	1.166	S
7.	Unusual patterns of precipitation	2.02	0.904	S
8.	High sunshine intensity	2.01	0.886	S
9.	Increase in earth surface temperature	1.50	0.627	NS
10.	Longer hours of sunshine	1.95	1.173	NS
11.	Short-lived Hamattan	1.48	0.869	NS
12.	Increase in crop yield	1.04	1.193	NS
13.	Decrease in crop yield	1.39	0.896	NS
14.	Loss in soil fertility	1.55	0.954	NS
15.	Increased erosion	1.50	0.854	NS
16.	Erratic/unusual rain	1.55	1.175	NS
17.	Early onset of rain and late cessation	1.03	1.131	NS
18.	Late onset of rain and late cessation	1.46	0.904	NS
19.	Delay in the onset of rainfall	1.56	1.194	NS
20.	Above normal rainfall	1.53	0.893	NS
21.	Below normal rainfall	1.40	0.964	NS
22.	Longer than normal rainfall	1.41	0.918	NS
23.	Longer period of dry spell	1.82	1.141	NS
24.	High intensity rainfall	1.52	0.947	NS
25.	Increase in rainfall	1.59	1.157	NS
26.	Erratic/torrential rainfall	1.48	0.930	NS
27.	Increase rainfall days	1.26	1.170	NS
28.	Rainstorms	1.62	0.896	NS
29.	Coastal flooding	1.48	0.957	NS
30.	Gustiness	1.09	1.191	NS
31.	Erosion/flooding	1.61	0.796	NS
32.	Rivers and stream overflowing their banks	1.41	0.910	NS
33.	Constant waves	1.98	1.153	NS
34.	Unusual flooding	1.53	1.170	NS
35.	Wet spells	1.24	0.867	NS
36.	Land slides	1.08	1.201	NS

S/N	Climate variability	$\overline{x}$	SD	Decision
37.	Increased in frequency of flooding	1.55	1.160	NS
38.	Low sunshine intensity	1.23	0.846	NS
39.	Early onset and early cessation of Hamattan	1.09	1.193	NS
40.	Late onset and late cessation of Hamattan	1.38	0.887	NS
41.	Early onset and late cessation of Hamattan	1.20	0.861	NS
42.	Late onset and early cessation of Hamattan	1.91	1.184	NS
43.	Typhoon wind	1.11	1.205	NS
44.	Erratic wind	1.69	1.092	NS
45.	High wind speed	1.88	1.136	NS
46.	Low wind speed	1.48	0.913	NS
47.	Frequency of cloudiness	1.05	1.179	NS
48.	Frequency of clement weather	1.03	1.048	NS
49.	Constant fog	1.08	1.188	NS
50.	Constant drought	1.01	1.187	NS
51.	Rising temperature	1.52	0.905	NS
52.	Presence of frost	1.14	1.202	NS
53.	Presence of hailstones	1.11	1.199	NS
54.	Constant waves	1.08	1.164	NS
55.	High humidity	1.39	0.889	NS
56.	Low humidity	1.73	1.008	NS
57.	Presence of unfamiliar diseases	1.95	1.149	NS
58.	Presence of unfamiliar pests	1.57	0.986	NS
59.	High incidence of pests	1.56	0.970	NS
60.	High incidence of diseases	1.41	0.910	NS

Source: Field Survey, 2017.

$\overline{x}$ = mean; SD = standard deviation; mean ≥ 2 = significant; mean ≤ 2 = not significant.

Table 2. Mean responses of the level of awareness of climate variability by small scale maize farmers.

intensity rainfall ($\overline{x}$ = 2.02; SD = 0.872), flash flooding ($\overline{x}$ = 2.02; SD = 1.166), unusual patterns of precipitation ($\overline{x}$ = 2.02; SD = 0.904) and high sunshine intensity ($\overline{x}$ = 2.0; SD = 0.886). The farmers indicated that they were aware of the following climate variability: erratic/unusual rainfall with ($\overline{x}$ = 1.55; SD = 0.914), longer period of dry spell ($\overline{x}$ = 1.82; SD = 1.132), unusual flooding ($\overline{x}$ = 1.53; SD = 0.904), longer hour of sunshine ($\overline{x}$ = 1.95; SD = 1.173), decrease in crop yield ($\overline{x}$ = 1.59; SD = 0.896), loss in soil fertility ($\overline{x}$ = 1.55; SD = 0.954), increased erosion ($\overline{x}$ = 1.50; SD = 0.854) and rainstorms ($\overline{x}$ = 1.62; SD = 0.896). They also indicated awareness of erosion/flooding ($\overline{x}$ = 1.61; SD = 0.796), presence of unfamiliar diseases ($\overline{x}$ = 1.95; SD = 1.149), presence of unfamiliar pest ($\overline{x}$ = 1.57; SD = 0.986), high incidence of pests ($\overline{x}$ = 1.56; SD = 0.970).

However, they were not aware of the following climate variability: short-lived Hamattan ($\bar{x}$ = 1.48; SD = 0.869), presence of frost ($\bar{x}$ = 1.14; SD = 1.202), low wind speed ($\bar{x}$ = 1.48; SD = 0.913). The standard deviations show the means variability. By implication, the lower the standard deviation the more the respondents are aware of the climate variability; the higher the standard deviation the lesser the respondents are aware of climate variability. These findings were in line with the result from trend analysis on such climate change variables conducted by the studies of Nwaiwu [55], which show that climate change effect is disastrous to agricultural production and requires mitigation. Also, it supports the findings of FAO [17] that there has been spatial increase in climatic variables from 1905 to 2010, and this is expected to continue over time.

6.3. Effects of climate variability on maize production

The ordinal regression on the effects of climate variability on maize production in Anambra State is shown in **Table 3**.

The R-square value of 0.572 explains about 57.2% of the level of climate variability affecting maize production in the study area. The chi-square value of 78.688 with the p-value less than 0.05 shows that the model prediction is good. Maize production is affected by increased rainfall (0.003), decreased rainfall days (0.004), increased rainfall days (0.002), erratic/unusual rainfall (0.002), increased earth surface temperature (0.042), decreased crop yield (0.004), loss in soil fertility (0.001), early rainfall and cessation (0.004), late rainfall and early cassation (0.000), erosion/flooding (0.002) and presence of unfamiliar diseases because they have significant coefficients ($p < 0.05$). This means maize production is affected by climate variability in Anambra State. This research finding justifies why, between 2015 and 2017, there was some worrying fluctuations regarding corn production as against its supply and demand trend in Nigeria (**Table 4**). Consequently, it is hereby expected that the Anambra state maize production index could further be constrained mainly by lack of climate smart improve measures that can contribute to reversing the current national export capacities at an average of minus-forty-percent (−40%) for Nigeria (**Table 4**) as against import of the maize commodity. Worse-still, the lack of government financial support to smallholder maize farmers and insecurity resulting from incessant herdsmen killings of farmers are expected to reduce maize production in the study area.

A high percentage of smallholder maize farmers in Anambra State do recycle their own maize seed from crops from their harvest and only a fraction of farmers purchase these seeds from other sources.

Detail results of the mean responses of the level of use of indigenous and improved adaptation strategies by small scale maize farmers in Anambra State are shown in **Tables 5** and **6**.

Table 5 shows that, planting of cover crops ($\bar{x}$ = 2.96; SD = 1.30) is largely adopted by the farmers to mitigate climate change impacts. Also, mixed farming ($\bar{x}$ = 2.59; SD = 1.25), change in tillage methods ($\bar{x}$ = 2.62; SD = 1.25), diversification from non-farming to farming activities ($\bar{x}$ = 2.70; SD = 1.31), use of organic/farmyard/mulch material ($\bar{x}$ = 2.80; SD = 1.19) were used by maize farmers as indigenous adaptation strategies. On the other hand, mixed

Climate variability	Coefficient	Standard error	Wald	df	Sig.	Cox & Snell (R^2)	Chi-square (goodness-of-fit)
Increased rainfall	0.044	0.369	0.014	1	**0.003**	0.572	78.688*
Erratic/unusual rain	1.017	0.411	0.002	1	**0.002**		
Delay rainfall onset	0.476	0.492	0.938	1	0.333		
Longer dry season period	0.041	0.45	0.008	1	0.928		
Increased rainfall days	0.184	0.424	0.188	1	**0.002**		
Decreased rainfall days	0.038	0.422	0.008	1	**0.004**		
Unusual flooding	0.338	0.445	0.575	1	0.448		
Increased flooding freq	0.829	0.441	3.542	1	0.060		
Increased earth surface temp	1.429	0.703	4.130	1	**0.042**		
Longer sunshine hours	0.463	0.486	0.906	1	0.341		
Short-lived Harmattan	0.403	0.585	0.474	1	0.491		
Increased crop yield	0.397	0.609	0.425	1	0.514		
Decreased crop yield	1.105	0.388	8.105	1	**0.004**		
Loss of soil fertility	1.166	0.482	0.118	1	**0.001**		
Increased erosion	0.263	0.443	0.352	1	0.553		
Early rainfall and early cessation	1.108	0.424	0.065	1	**0.004**		
Early rainfall and late cessation	0.105	0.409	0.066	1	0.798		
Late rainfall and late cessation	0.493	0.537	0.846	1	0.358		
Late rainfall and early cessation	1.225	0.453	0.248	1	**0.000**		
Above normal rainfall	0.157	0.476	0.109	1	0.741		
Below normal rainfall	0.332	0.509	0.425	1	0.514		
Longer than normal rainfall	0.149	0.428	0.121	1	0.728		
Shorter than norm rain	0.186	0.581	0.102	1	0.749		
High rainfall intensity	0.5	0.427	1.368	1	0.242		
How rainfall intensity	0.007	0.360	0.000	1	0.985		
Erratic/torrential rain	0.533	0.490	1.181	1	0.277		
Flash flooding	0.636	0.501	1.612	1	0.204		
Rainstorms	0.323	0.569	0.322	1	0.57		
Coastal flooding	0.534	0.476	1.257	1	0.262		
Gustiness	−0.250	0.434	0.333	1	0.564		
Erosion/flooding	2.230	4.017	0.308	1	**0.002**		
Rivers/streams Overflow their banks	0.381	0.600	0.402	1	0.526		
Constant waves	0.240	0.390	0.378	1	0.538		
Unusual precipitate pattern	0.322	0.453	0.504	1	0.478		
Wet spells	0.146	0.440	0.11	1	0.741		

Climate variability	Coefficient	Standard error	Wald	df	Sig.	Cox & Snell (R^2)	Chi-square (goodness-of-fit)
Landslides	0.283	0.358	0.624	1	0.43		
High sun intensity	0.205	0.443	0.214	1	0.644		
Low sun intensity	0.352	0.386	0.832	1	0.362		
Early onset of Harmattan and early cessation	0.393	0.481	0.667	1	0.414		
Late onset of Harmattan late and cessation	0.253	0.460	0.303	1	0.582		
Early onset of Harmattan and late cessation	0.095	0.375	0.065	1	0.799		
Late onset of Harmattan and early cessation	0.114	0.395	0.084	1	0.772		
Typhoon wind	0.275	0.472	0.339	1	0.561		
Erratic wind	0.371	0.345	1.156	1	0.282		
High wind speed	0.208	0.374	0.310	1	0.578		
Low wind speed	0.391	0.509	0.590	1	0.442		
Freq cloudiness	0.451	0.399	1.278	1	0.258		
Freq clement weather	0.379	0.503	0.566	1	0.452		
Constant fog	0.445	0.601	0.549	1	0.459		
Constant drought	0.012	0.372	0.001	1	0.975		
Rising temp	0.345	0.454	0.577	1	0.447		
Presence of frost	0.495	0.557	0.790	1	0.374		
Presence of hailstones	0.022	0.398	0.003	1	0.956		
Constant waves	0.010	0.392	0.001	1	0.979		
High humidity	0.121	0.552	0.048	1	0.827		
Low humidity	0.316	0.561	0.317	1	0.573		
Presence of unfamiliar diseases	1.145	0.525	0.076	1	**0.021**		
Presence of unfamiliar pests	0.294	0.368	0.639	1	0.424		
High incidence of pests	0.197	0.46	0.184	1	0.668		
High incidence of diseases	0.013	0.433	0.001	1	0.976		

Source: Field survey, 2017.

Table 3. Ordinal regression of the climate variability affecting maize production.

cropping ($\overline{x}$ = 2.05; SD = 1.30) and changing planting dates ($\overline{x}$ = 2.06; SD = 1.15) were moderately used by maize farmers as indigenous adaptation strategies while change in fallow period ($\overline{x}$ = 1.60; SD = 1.23) was used to a low extent by small scale maize farmers in Anambra State. This finding is in agreement with Okali [56], who found that the use of mulching materials (**Figure 4**) could prevent excessive soil moisture loss, and improve soil

Corn market begin year in Nigeria	**2015/2016**		**2016/2017**		**2017/2018**		**Percentage (%) difference**
	Oct 2015		**Oct 2016**		**Oct 2017**		**2016–2017**
	USDA	**Other source**	**USDA**	**Other source**	**USDA**	**Other source**	**Other source, only**
Harvested area	3800	3800	4000	4000	0	3800	5.13
Beginning stocks	361	361	161	161	0	161	0.00
Production	7000	7000	7200	7200	0	6900	4.26
MY imports	300	300	300	300	0	200	40.00
TY imports	300	300	300	300	0	200	40.00
TY imports (USA)	98	0	0	0	0	0	0.00
Total supply	7661	7661	7661	7661	0	7261	5.37
MY Exports	200	200	200	200	0	300	−**40.00**
TY Exports	200	200	200	200	0	300	−**40.00**
Feed and Residual	1800	1800	1800	1800	0	1800	0
FSI consumption	5500	5500	5500	5500	0	5000	9.52
Total demand	7300	7300	7300	7300	0	6800	7.09
Ending stocks	161	161	161	161	0	161	0
1000 (Ha), 1000 (MT)							

Source: Adapted from [53].

Table 4. Observable trend on corn production, supply and demand in Nigeria, 2015–2017.

S/N	**Items**	$\overline{x}$	**SD**	**Decision**
1.	Mixed cropping	2.05	1.297	S
2.	Mixed farming	2.59	1.245	S
3.	Changing planting dates	2.06	1.155	S
4.	Changing tillage methods	2.62	1.255	S
5.	Diversification from farming to non-farming activities	2.70	1.312	S
6.	Planting of cover crops	2.96	1.376	S
7.	Use fertilizers (organic/farmyard/mulch materials)	2.79	1.186	S
8.	Change in fallow period	1.60	1.231	NS

Source: Field survey, 2017.
$\overline{x}$ = mean; SD = standard deviation; mean ≥ 2 = significant; mean ≤ 2 = not significant.

Table 5. Mean responses of level of indigenous adaptation strategies used by small scale maize farmers.

S/N	Items	$\overline{x}$	SD	Decision
1.	Improved crop variety	2.93	1.112	S
2.	Climate predictions	1.56	1.048	NS
3.	Precision agriculture	1.50	1.089	NS
4.	Drought resistant varieties	2.53	1.065	S
5.	Drought tolerant varieties	2.60	1.056	S
6.	Resistant to temperature stresses varieties	2.16	1.114	S
7.	High yield water sensitive varieties	2.06	1.978	S
8.	Mixed crop-livestock farming system	2.14	1.070	S
9.	Crop diversification	2.14	1.055	S
10.	Changing harvesting date	2.03	1.059	S
11.	Rain making	2.06	1.121	S

Source: Field Survey, 2017.
$\overline{x}$ = mean; SD = standard deviation; mean ≥ 2 = significant; mean ≤ 2 = not significant.

Table 6. Mean responses of the level of improved adaptation strategies used by small scale maize farmers.

Figure 4. Cross section of mulched maize farms available in the study area (photo credit: Mr. Samuel Anarah).

aeration and moisture holding capacity of the soil. Types of grasses usually used for mulching purposes in the study area include: spear grass (*Heteropogon contortus*), and guinea grass (*Panicum maximum*). [57] observed that growing of varieties of crops on the same plot of land is an appropriate adaptation strategy for farmers because it helps to avoid complete crop failure as different crops may be affected differently by climate variability and may also require different soil nutrients.

Figure 5. The type of vertiva grass (red circled) that is planted for controlling erosion on farm farms in Anambra State.

Consequently, some smallholder maize farmers plant vetiver grass (*Chrysopogon zizanioides)* in (**Figure 5**) to control erosion menace on their maize farms.

Table 6 reveals that to a low extent precision agriculture ($\overline{x}$ = 1.50; SD = 1.11), climate predictions ($\overline{x}$ = 1.56; SD = 1.05), were used by maize farmers as improved adaptation strategies. Improved crop variety ($\overline{x}$ = 2.93; SD = 1.11), drought resistant varieties ($\overline{x}$ = 2.53; SD = 1.07) and drought tolerant varieties ($\overline{x}$ = 2.60; SD = 1.06), were used by maize farmers in high extent as improved adaptation strategies while resistant to temperature stresses varieties ($\overline{x}$ = 2.16; SD = 1.11), high yield water sensitive varieties ($\overline{x}$ = 2.06; SD = 1.10), mixed-crop-livestock farming system ($\overline{x}$ =2.14; SD =1.07), crop diversification ($\overline{x}$ = 2.14; SD =1.06), changing in harvesting date ($\overline{x}$=2.03; SD =1.06) and rain making ($\overline{x}$ = 2.06; SD =1.12) were moderately used by maize farmers as improved adaptation strategies to climate variability. This finding concurs with the work of [57], who concluded that farmers can adapt to climate changes through improved adaptation strategies relevant to them.

Sources of information	Frequency* (n = 128)	Percentage (%)
Fellow farmers	99	77.34
Radio set	67	52.34
Extension agents	79	61.72
Television set (NiMET)	62	48.44
Internet/social media	26	20.31

Source: Field Survey, 2017. NiMET = Nigerian Metrological Agency weather forecast.

Table 7. Percentage response of sources of information on climate variability by maize farmers in Anambra State.

Socioeconomic variables	Coefficient	Standard error	Sig.	R^2	p-Value
Age	0.278	0.126	**0.028**	0.176	0.048
Sex	−0.226	0.242	0.351		
Marital status	0.154	0.170	0.363		
Household size	0.370	0.152	**0.015**		
Education level	0.199	0.154	0.195		
Farming years	0.428	0.183	**0.019**		
Farm size	0.624	0.123	**0.046**		
Labor source	0.021	0.163	**0.037**		
Membership organization	0.330	0.239	0.167		
Average income	0.334	0.226	0.164		
Average yield	0.233	0.233	0.143		

Table 8. Multiple linear regressions of the socio-economic characteristics and production level of small scale maize farmers.

6.4. Sources of information on climate variability

The percentage response of sources of information among small scale farmers on climate variability in Anambra State is shown in **Table 6**.

Result from **Table 7** reveals that majority (77.34%) of the maize farmers source their information from fellow farmers, (61.72%) from extension agents, few (52.34%) from radio set, very few (48.44%) source from television set while (20.31%) source their information from the internet/social media. The implication is that farmers that belong to agricultural groups are more likely to have access to farm information on climate variability adaptation strategies than those who do not belong to any. This finding is similar to that of [36, 57] whose studies showed that adequate information flow channel and extension contact with registered farmers have a positive relationship with the adoption of agricultural strategies since extension agents transfer modern agricultural technologies to farmers to help counteract the negative impact of climate change.

Table 8 shows multiple linear regressions of the socio-economic characteristics of small scale maize farmers and their production level. The R-square value of 0.176 indicates that the socio-economic variables explained 17.6% variability of maize production. Of all the socio-economic variables, age (0.028), household size (0.015), farming years (0.019), farm size (0.046) and labor source (0.037) have significant coefficients ($p < 0.05$). The coefficient value of 0.278 for age indicates that a unit increase in age increases level of maize production by 0.278 kg. The coefficient value of 0.370 for household size indicates that increase in household size increases level of maize production by 0.370 kg; that of farming years which is 0.428 indicates that increase in farming experience increases level of maize production by 0.428 kg; that of farm size which is 0.624 indicates that increase in farm size increases level of maize production by 0.624 kg while that of labor source which is 0.021 indicates that increase in labor source increases the level of maize production by 0.021 kg. The p-value at 0.048, indicate that there is a significant relationship between socio-economic characteristics and production level by the small scale maize farmers in the study area. This further means that as the age, household size, farming years, farm size and labor source of small scale maize farmers in Anambra State increase, their propensity to produce maize also increases. This finding is in agreement with the study of [41] who noted that household size and farm size increases farmers' food production.

7. Conclusion

Better understanding and perception of climate variability and adaptions to climate change impacts in Anambra State, Nigeria, is crucial for increasing farmers adoption of improved maize seed varieties and practicing of climate-smart maize production. The ultimate objective of this study was to assess the smallholder maize farmers' perception on climate variability and their use of climate change adaptation approaches in Anambra state.

The results of this study show that, approximately 57.2% of climate variability negatively impacts on maize production in the study area. Basically flooding ($\overline{x}$ = 2.02 ± 1.166), erratic rainfall ($\overline{x}$ = 2.02 ± 0.816), and decrease in crop yield by strange pests and diseases ($\overline{x}$ = 1.59 ± 0.896) were identified as climate change effects on maize production. The smallholder maize farmers are significantly aware of the consequences of climate variability on their maize farms, reason for some of them, practicing climate change adaptations. 88.28% of the smallholder maize farmers perceived bush burning as a major contributor to climate variability in the study area. Whereas, other identified climate change drivers include: intensive agricultural land use (82.03%), use of inorganic fertilizers (60.16%), use of fossil fuels (56.25%) and deforestation (50.78%). Finally, from the statistical analysis in this study, we conclude that, the lower the standard deviation values, the more knowledgeable the farmers are about climate variability and on practice of climate change adaptations; and, vice-versa.

Therefore, an integrated efforts to mobilize funding resource for further research on climate change mitigation and adaptions in the forest zone of Nigeria and for practical works at the local level, are hereby recommended.

Author details

John Agbo Ogbodo[1,2]*, Samuel E. Anarah[3] and Sani Mashi Abubakar[4]

*Address all correspondence to: jaogbodo@yahoo.com

1 Department of Forestry and Wildlife, Faculty of Agriculture, Nnamdi Azikiwe University Awka, Anambra State, Nigeria

2 Sustainable TransEnvironment International Foundation—STEi Foundation www.steifoundation.org, Nigeria

3 Department of Agricultural Economics and Extension, Faculty of Agriculture, Nnamdi Azikiwe University Awka, Anambra State, Nigeria

4 Nigerian Meteorological Agency (NiMET), Bill Clinton Drive, Nnamdi Azikiwe International Airport, Abuja, Nigeria

References

[1] Knoema. Nigeria-Maize Production Quantity. 2018. Available from: https://knoema.com/atlas/Nigeria/topics/Agriculture/Crops-Production-Quantity-tonnes/Maize-production [Accessed: May 3, 2018]

[2] IPCC-Inter-governmental Panel on Climate Change. Contribution of Working Group II to the Fourth Assessment Report of the IPCC Summary for Policy Makers. Geneva, Switzerland: Cambridge University Press; 2007. pp. 1-3

[3] Iken JE, Amusa NA. Maize Research and Production in Nigeria. Ibadan, Nigeria: Institute of Agricultural Research and Training (IAR & T), Obafemi Awolowo University; 2014. pp. 302-307

[4] Manyong VM, Kling J, Makinde K, Ajala S, Aenkir A. Impact of IITA-Improved Germplasm on Maize Production in West and Central Africa. Ibadan, Nigeria: International Institute of Tropical Agriculture (IITA); 2000

[5] Kent NL, Evers AD. Technology of Cereals: An Introduction for Students of Food Science and Agriculture. Oxford: Elsevier; 1994

[6] Bolade MK, Adeyemi IA, Ogunsua AO. Studies on the traditional methods of production of maize tuwo (a Nigerian non-fermented maize dumpling). African Journal of Food, Agriculture, Nutrition and Development. 2009;**9**(7):24. ISSN: 1684-5374

[7] Okoruwa AE. Utilization and Processing of Maize. IITA Research Guide No. 35. Ibadan: IITA; 1997

[8] Obi IU. Maize: Its Agronomy, Diseases, Pests and Food Values. Enugu: Optimal Computer Solutions Limited; 1991. 208 p

[9] Daniel IO, Adetumbi JA. Maize seed supply systems and implications for seed sector development in Southwestern Nigeria. Journal of Sustainable Agriculture. 2006;**28**(2): 25-40

[10] IITA. International Institute for Tropical Agriculture. Growing in Nigeria. Commercial Crop Production Guide Series. Information and Communication Support for Agricultural Growth in Nigeria. Moor Plantation, Ibadan: USAID; 2012. pp. 1-8

[11] Lawal BO, Saka JO, Oyegbami A, Akintayo IO. Adoption and performance assessment of improved maize varieties among smallholder farmers in Southwest Nigeria. Journal of Agricultural & Food Information. 2005;**6**(1):35-47

[12] Shuaibu SM, Ogbodo JA, Wasige EJ, Sani Mashi A. Assessing the impact of agricultural drought on maize prices in Kenya with the approach of the SPOT-VEGETATION NDVI remote sensing. Future of Food: Journal on Food, Agriculture and Society. 2016; **4**(3):8-18

[13] Apata TG, Samuel KD, Adeola AO. Analysis of climate change perception and adaptation among arable food cassava-based crop farmers in South Western Nigeria. Contributed Paper prepared for presentation at the International Association of Agricultural Economists' Conference, Beijing, China, August 16-22, 2009. p. 209

[14] Brussel SEC. Adapting to climate changes: The challenge for European agriculture and rural areas. Commission of the European Communities. Commission Working Staff Working Document Accompanying the White Paper No. 147 Building Nigeria's Response to Climate Change. 2009. pp. 3-5

[15] Mejia D. Maize: Postharvest operations. In: Mejia D, Parrucci E, editors. Postharvest Compendium. Rome: FAO; 2006. Available from:: http://www.fao.org/inpho/ [Accessed: Dec 10, 2005]

[16] World Health Organization (WHO). World Health Report 2002: Reducing Risks, Promoting Healthy Life. Geneva: WHO; 2002. pp. 7-9

[17] FAOSTAT. Food and Agricultural Organisation of the United Nation. FAOSTAT. 2015. Available from: http://faostat fao.org/site/567/default.aspx [Accessed: Aug 20, 2015]

[18] Hassan R, Nhemachena C. Determinants of African farmers' strategies for adapting to climate changes: Multinomial choice analysis. African Journal of Agricultural and Resource Economics. 2008;**2**(1):85-104

[19] Khanal RC. Climate change and organic agriculture. The Journal of Agriculture and Environment. 2009;**10**:100-110

[20] IPCC—Intergovernmental Panel on Climate Change. Climate change 2007: Synthesis report. Intergovernmental Panel on Climate Change. 2007:23-73

[21] Onumadu FN. Approval of environmental benefits of adaptation of agro forestry practices by small-scale farmers in Katsina State of Nigeria. Journal of food and Fibre Production. 2009;**2**(1):423-428

[22] Boko M, Niang I, Nyong A, Vogel C, Githeko A. Africa, climate change 2007: Impacts, adaptation and vulnerability. In: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom: Cambridge University Press; 2007. pp. 433-467

[23] Case M. Climate Change Impacts on East Africa: A Review of the Scientific Literature. Switzerland: WWF–World Wide Fund For Nature, Gland; 2006. p. 12

[24] Stinge LC, Stave J, Chan KS, Ciannelli L, Pretorelli N, Glantz M, et al. The effect of climate variation on agro-pastoral production in Africa. Proceedings of the National Academy of Sciences of the United States of America. 2006;**103**:3049-3053

[25] Ogbodo JA, Tembe ET, Peter JG. Assessing the Issues and Prospects of Sustainable Forestry in Nigeria. 2017. Available from: https://www.researchgate.net/publication/314239587_Assessing_the_issues_and_prospects_of_sustainable_forestry_in_Nigeria

[26] Ogbo AI, Onyedinma AC. Climate change adaptation in Nigeria: Problems and prospects Sacha. Journal of Environmental Studies. 2012;**2**(1):130-145

[27] Ohajianya DO, Echetama JA, Offodile PO, Osuagwu CO, Henri-Ukoha A, Okereke E, et al. Allocative efficiency among maize farmers in Imo state Nigeria. Report and Opinion. 2010;**2**(12):139-147

[28] World Bank. Agriculture for development policy brief: Adaptation and mitigation of climate change in agriculture. World Development Report. The International Bank for Reconstruction and Development/The World Bank 2008. 2008. pp. 3-5

[29] Olakojo SA, Akinlosotu TA. Comparative study of storage methods of maize grains in southwestern Nigeria. African Journal of Biotechnology. 2004;**3**(7):362-365

[30] Oyekale AS. Climatic variability and its impacts on agricultural income and households' welfare in southern and northern Nigeria. Electronic Journal of Environmental, Agricultural and Food Chemistry. 2009;**8**(1):13-34

[31] Coumou D, Robinson A, Rahmstorf S. Global increase in record-breaking monthlymean temperatures. Climatic Change. 2013;**118**(3–4):771-782

[32] Skinner M, Smith WB, Holly Dolan A, Bradshaw B, Bryant CR. Adaptation Options to Climate Change in Canadian Agriculture: An Inventory and Typology Report. Guelph, Ontario: Department of Geography, University of Guelph; 2001. pp. 1-3

[33] Knowler D, Bradshaw B. Farmers adoption of conservation agriculture: A review and synthesis of recent research. Food Policy. 2007;**32**(1):212-228

[34] Ohajianya DO, Osuji MN. Climate change, adaptation measures and the determinants among food crops farmers in South East Nigeria. In: Paper presented at the 86th Average Conference of the Agricultural Economics Society Warwick University, April 16–18, 2012. pp. 34-37

[35] Araya B, Adjaye JA. Adoption for farm level soil conservation practices in Eritrea. Indian Journal of Agricultural Economics. 2001;**56**:239-252

[36] Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M. Analysis of the determinants of farmers' choice of adaptation methods and perceptions of climate change in the Nile basin of Ethiopia. IFPRI Research Brief 15–9. Washington, D.C. USA: IFPRI; 2008

[37] Ayuya OA, Lagat JK, Mironga JM. Factors influencing potential acceptance and adoption of clean development mechanism projects: Case of carbon trade tree project among small scale farmers in Njoro District, Kenya. Resource Journal Environmental Earth Science. 2011;**3**(3):275-285

[38] Gbetibouo GA. Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa. IFPRI Discussion Paper No. 00849 [cited May 3] 2009. pp. 23-27

[39] Nzeh EC, Eboh OR. Technological Challenges of Climate Change Adaptation in Nigeria: Insights from Enugu State. Enugu: African Technology Policy Studies Network Publication; 2010. pp. 24-28

[40] Odjugo PAO. Regional evidence of climate change in Nigeria. Journal of Geography and Regional Planning. 2010;**3**(6):7-9

[41] Oladipo E. Towards Enhancing the Adaptive Capacity of Nigeria: A Review of the Country's State of Preparedness for Climate Change Adaptation. Ilorin Nigeria: Heinrich Böll Foundation; 2010. pp. 23-25

[42] Adenola OA, Akinwumi JA. Maize production constraints in Nigeria. Maize Improvement, Production and Utilization in Nigeria. Maize Association of Nigeria. 1993. pp. 223-232

[43] Anyadike RNC. Climate Change and Sustainable Development in Nigeria: Conceptual and Empirical Issues, Lecture Series. Enugu: African Institute for Applied Economics; 2009. pp. 12-28

[44] Yohe GW, Lasco RD, Ahmad QK, Arnell NW, Cohen SJ, Hope C, et al. Perspectives on climate change and sustainability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press; 2007. pp. 811-841

[45] Magadza CHD. Climate change impacts and human settlements in Africa: Prospects for adaptation. Environmental Monitoring and Assessment. 2000;**61**(1):193-205

[46] Kurukulasuriya P, Mendelsohn R. A Ricardian analysis of the impact of climate change on African cropland. CEEPA Discussion Paper No. 8. Centre for Environmental Economics and Policy in Africa, University of Pretoria. 2006

[47] Nzeadibe TC, Egbule CL, Chukwuone NA, Agu VC. Climate change awareness and adaptation in the Niger Delta region of Nigeria. In: African Technology Policy Studies Network (ATPS) Working Paper Series. Nairobi: ATPS; 2011. pp. 7-13

[48] Knoema. Anambra-Production of Maize, 1000 metric tons. 2018. Available from: https://knoema.com/atlas/Nigeria/Anambra/Production-of-Maize [Accessed: May 3, 2018]

[49] FAO—Food and Agriculture Organization. Two Essays on Climate Change and Agriculture. A Developing Country Perspective. Rome, Italy: Food and Agriculture Organization (FAO). 2000. pp. 25-29

[50] Nhemachena C, Hassan R. Micro-Level Analysis of Farmers Adaption to Climate Change in Southern Africa. Southern Africa: International Food Policy Research Institute (IFPRI). 2007. pp. 56-59. Discussion Paper 714

[51] GISGeography.com. What is geographic information systems (GIS)? 2018. Available from: https://gisgeography.com/what-gis-geographic-information-systems/ [Accessed May 12, 2018]

[52] Ozor N. Understanding climate change; implications for Nigerian agriculture, policy and extension. In: Paper presented at the National Conference on Climate Change and the Nigerian Environment, Organized by the Department of Geography, University of Nigeria Nsukka, 29 June–2 July. 2009. pp. 23-28

[53] USDA—United States Department of Agriculture. Nigeria: Grain and Feed Annual. 2017. Available from: https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Lagos_Nigeria_4-12-2018.pdf [Accessed: Apr 25, 2018]

[54] Greene WH. Econometric Analysis. 5th ed. New Jersey: Prentice Hall; 2003. pp. 3-6

[55] Nwaiwu IU. Effects of climate change on labour use efficiency and sustainable Food Crop Production Systems in Southeast Nigeria [unpublished Ph.D thesis submitted to the Postgraduate School]. Owerri: Federal University of Technology; 2014. pp. 32-56

[56] Okali D. Climate Change and Nigeria: A Guide for Policy Makers. Nigerian Environmental Study Action Team (NEST). 2004. pp. 20-25

[57] Nwajiuba CU. Adaptation to Climate Change: Challenges and Opportunities, Lecture Series. Owerri, Nigeria: Department of Agricultural Economics, Imo State University; 2010. pp. 34-45

Edited by Amanullah and Shah Fahad

Corn or maize (*Zea mays* L.) plays an important role in global food security. The many uses of corn make it a central commodity and a great influence on prices. Because of its worldwide distribution and relatively lower price, corn has a wider range of uses. It is used directly for human consumption, in industrially processed foods, as livestock feed, and in industrial nonfood products such as starches, acids, and alcohols. Recently, there has been interest in using maize for the production of ethanol as a substitute for petroleum-based fuels. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Climate change, however, is a growing concern among corn growers worldwide. Scientists estimate that corn production will need to be increased by 15% per unit area between 2017 and 2037. To increase corn yields, advanced and new production technology needs to be developed and distributed among corn growers. The advanced technology to boost corn yields and counteract climate change is important for food security for the growing global population. Nutritionally, maize seeds contain 60–68% starch and 7–15% protein. Maize oil is widely used as a cooking medium and for manufacturing hydrogenated oil. The oil has the quality of reducing cholesterol in the human blood similar to sunflower oil. Corn flour is used as a thickening agent in the preparation of many edibles such as soups, sauces, and custard powder. Integrated nutrients management improves corn growth, leaf area index and light interception, dry matter accumulation and distribution, grain and fodder quality, yield components, grain and biomass yields, harvest index, and shelling percentage, and reduces the problem of food insecurity.

Published in London, UK

IntechOpen

ISBN 978-1-83881-767-1